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Formerly Utilized MED/AEC Sites Remedial Action 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

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Final Report

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PREFACE

This series of reports results from a program initiated in 1974 by the Atomic Energy Commission (AEC) for determination of the condition of sites formerly utilized by the Manhattan Engineer District (MED) and the AEC for work involving the handling of radioactive materials. Since the early 1940s, the control of over 100 sites that were no longer required for nuclear programs has been returned to private industry or the public for unrestricted use. A search of MED and AEC records indicated that for some of these sites, documentation was insufficient to determine whether or not the decontamination work done at the time nuclear activities ceased is adequate by current guidelines.

This report contains data and information on the resurvey effort and the effect of residual contamination as a result of nuclear weapons development programs conducted in this area. The report documents the present radiological conditions within the realm of today's sophisticated instrumentation and the impact on any future area development.

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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

ABSTRACT

Current radiological conditions were evaluated for the site of a former radioactive liquid waste treatment plant and the interconnected canyons that received both treated and untreated effluents between 1944 and 1951. The liquid radioactive wastes were generated by research with nuclear materials at Los Alamos, New Mexico, for the World War II Manhattan Engineer District atomic bomb project and subsequently by work conducted for the Atomic Energy Commission. After decommissioning of the treatment plant and decontamination of the site and part of one canyon, ownership of some of the land in question was transferred to Los Alamos County by the Federal Government in 1967. Some residual radioactivity attributable to the effluents remained and is found on soils and sediments at the former plant site and in the channels of the canyons. The study considered all relevant information including historical records, environmental data extending back to the 1940s, and new data acquired by special field sampling and measurements. Potential exposures to radiation were evaluated for conditions of current and possible future land uses. Maximum estimated doses were about 12% of radiation protection standards, and most were less than 2%. Detailed data and interpretations are given in extensive appendixes.

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1. SUMMARY

This evaluation of current radiological conditions at the site of a former radioactive liquid waste treatment plant and the interconnected canyons that received both treated and untreated effluents is based on extensive field measurements and sampling followed by interpretation of the resulting data. The study was completed as part of the Formerly Utilized Sites Remedial Action Program (FUSRAP) sponsored by the U.S. Department of Energy (DOE).

Liquid radioactive wastes were generated by research with nuclear materials at Los Alamos, New Mexico, for the World War II Manhattan Engineer District (MED) atomic bomb project starting in 1943 and subsequently by work conducted for the Atomic Energy Commission (AEC). Untreated effluents were discharged into Acid Canyon from 1944 until 1951. A treatment plant was constructed on the rim of Acid Canyon and discharged treated effluents from 1951 until 1964.

Following decommissioning of the plant and decontamination of the site and part of Acid Canyon, ownership of the property was transferred to Los Alamos County by the Federal Government in 1967.

Acid Canyon is a small branch of Pueblo Canyon, which, in turn, joins Lower Los Alamos Canyon. Acid Canyon and part of Pueblo Canyon are currently controlled by the County of Los Alamos. The Federal Government has an easement across the county land generally following the course of the normally dry channel from the discharge point at the head of Acid Canyon for collecting samples and maintaining test wells. The remainder of Pueblo Canyon and a small part of Lower Los Alamos Canyon are currently controlled by the DOE. Most of Lower Los Alamos Canyon, down to the point where it joins the Rio Grande, is controlled by the San Ildefonso Indian Pueblo. Some residual radioactivity attributable to the effluents is found on soils and sediments in the channels of each of these canyons. Intermittent runoff events transport and redistribute the sediments periodically.

The study considered all available relevant information. Records provided the history of the treatment plant and data on types and amounts of contaminants discharged. Environmental monitoring and hydrogeologic studies, some extending back to the mid-1940s, were reviewed for information on trends and patterns. Data from these and special radioecology research studies were compiled to provide points of comparison and a basis for planning the acquisition of new data. Most of the new data consisted of multiple analyses of several hundred sediment and soil samples from the affected areas. Field measurements included documentation of radiation conditions and surveys to assure no significant areas of contamination had been overlooked.

The findings, based on interpretation of the data, are expressed in this summary as potential maximum increments of risk to individuals exposed to the conditions. Specifically, individual risks of cancer from exposure to radiation were calculated from factors recommended by the International Commission on Radiological Protection (ICRP). Potential exposures to radiation for various possible mechanisms were generally calculated as 50-year dose commitments resulting from 1-year exposures to account for cumulative doses from those radioactive materials retained in the body for varying periods after the initial exposure. Exposure to radiation from natural background results in exactly the same kinds of risks. The ICRP risk estimating factors were applied to natural background radiation to provide one context for judging the significance of other risks. People living in Los Alamos County incur an estimated incremental risk of cancer mortality of 8 chances in 10 000, or a probability of 8×10^{-4}, from a 50-year exposure to the natural radiation background. The natural radiation background dose, about 150 mrem each year, includes contributions from cosmic radiation, natural terrestrial radioactivity, and natural radioactivity incorporated in the body. A larger perspective is that the overall U.S. population lifetime risk of mortality from cancers induced by all causes is currently about 2 chances in 10, or a probability of 0.2.

The maximum likely incremental risks from all mechanisms of potential exposure in the areas having residual radioactivity attributable to liquid effluent disposal range from about 6 chances in 1 000 000 (6×10^{-6}) down to 1 chance in 10 000 000 000 (1×10^{-10}) under current conditions of land use as summarized in Table I. The mechanisms include direct exposure to penetrating radiation and inhalation of resuspended dust.

Current land use includes occasional recreational use of Acid and Pueblo Canyons. In Lower Los Alamos Canyon, uses include commuter traffic on State Road 4, several households, a commercial sand and gravel operation (not involving any contaminated sediments), and some cattle grazing.

Table I gives the incremental risks of cancer mortality, bone cancer, and lung cancer, along with the 50-year dose commitments from which they were calculated. All of the dose commitment values are considered overstated to some degree because assumptions used in their derivation

were made to maximize estimates of potential effects. All of the dose commitments are small fractions of those permitted above natural background and medical exposure by the DOE Radiation Protection Standards (RPS). The highest one, from the unlikely circumstance of a full year occupancy of a small portion of the former waste treatment plant site, is about 12% of the RPS. All of the others are less than 2% of the RPS.

Measurements of conditions over many years in the Los Alamos County community and residential areas adjacent to the canyons have documented the absence of any doses in those locations attributable to the residual radioactivity from liquid effluent disposal. Measurements of food pathways (fish in Cochiti Lake on the Rio Grande and foodcrops irrigated with the water) show that no measurable doses are attributable to the transport of contaminated sediments from Los Alamos Canyon into the Rio Grande. Theoretical analysis shows two pathways could result in doses to a limited number of individuals (see Table I). One is the uptake of some contamination through an abrasion wound caused by rocks in the vicinity of the untreated waste outfall location. The other is the consumption of meat from a beef steer grazed in Lower Los Alamos Canyon. The potential risks from these pathways are in the same range as estimated for the other mechanisms.

Possible future changes in land use could result in other types of exposures. Pueblo Canyon has been discussed as a potential area for residential development to ease housing pressures in Los Alamos County. Most of the land amenable to development is in Lower Pueblo Canyon, now under DOE control. Were the area developed, the overall risks would be those already evaluated for external exposure and inhalation of resuspended dust in Lower Pueblo Canyon (see Table I). The potential for chronic exposure over many years from residential occupancy was also evaluated by an alternate approach. Calculated doses after 70 years continuous exposure to the resuspended dust were no more than about 1.3% of the proposed Environmental Protection Agency (EPA) guidance on dose limits for persons exposed to transuranium elements in the general environment. Potential exposures for hypothetical home gardeners and construction workers in Lower Pueblo Canyon (see Table I) were the highest estimated (1.5 and 6% of RPS) with maximum incremental bone cancer risks of about 1 and 5 chances in 10 000 000, respectively (1.2×10^{-7} and 4.5×10^{-7}). Potential exposure to a construction worker at the County-owned site of the former waste treatment plant could result in risks of about the same size.

Another context for judging the significance of these risks associated with exposure to radiation, whether from natural background or other sources, is a comparison with risks from other activities or hazards encountered in routine experience. Table II presents a sampling of risks for activities that may result in early mortality and annual risks of death from accidents or natural phenomena. Because not all of the risks are directly comparable, the values for mortality risks shown in Table I overlap the range of values for risks shown in Table II. The largest incremental risks from the exposure to the residual contamination are about the same size as the incremental risk of a 1000-mile automobile trip; most are smaller than the annual risk of death from lightning.

Some highlights of the occurrence and distribution of radioactivity on the sediments and soils affected by the liquid effluents may be useful in evaluating future management alternatives and describing possible future changes from natural hydrologic processes. Transuranium elements (plutonium and americium) are present in all affected areas at levels with statistical significance above those normally observed as background in Northern New Mexico from worldwide fallout. The highest concentrations occur in areas of limited extent at the County-owned site of the former waste treatment plant (affected area about 3500 m^2, to depths of about 2 m) and a natural drainage course that carried the untreated effluent (affected area about 500 m^2, to depths of about 1/2 m). Within the canyons most contaminated material is near-surface (less than 1/2 m). The largest average concentrations and about 16% of the total inventory occur in County-owned Acid Canyon (affected area about 1750 m^2). Intermediate average concentrations and about 12% of the inventory occur in County-owned Middle Pueblo Canyon (affected area

about 50 000 m^2). Similar concentrations, but about 67% of the inventory, occur in DOE-controlled Lower Pueblo Canyon (affected area about 200 000 m^2). The lowest average concentrations, and about 6% of the inventory, occur in Lower Los Alamos Canyon on San Ildefonso Indian Pueblo land (affected area about 260 000 m^2). Other radioactive contaminants including fission products are present at low but statistically significant levels above background in some, but not all, areas. Their major contribution to estimated risks is from external penetrating radiation that would be experienced only in the immediate vicinity of the contamination, e.g., the channels and banks.

Some differences in future conditions will result from radioactive decay processes. The estimated total doses from transuranics will change by no more than about 4% in 70 years, the approximate time required for maximum ingrowth of one daughter product (^{241}Am). The estimated doses from fission products will decline to about 1/5 of present values in the same time period. The fission products are largely responsible for the estimated external doses (see Table I) in Lower Los Alamos Canyon, Acid Canyon, and at the treatment plant site.

Major future runoff events in Pueblo Canyon could result in movement of the large proportion of the transuranic inventory, now accumulated in the broad channel of Lower Pueblo Canyon, further downstream and into Lower Los Alamos Canyon. Should such major movement occur, the estimated potential risks and doses now calculated for bone and lung in Lower Pueblo Canyon would be applicable as upper limits for Lower Los Alamos Canyon. The concentrations in Lower Los Alamos Canyon would be increased by factors of as much as 10, which would be no more than the levels presently occurring in Lower Pueblo Canyon, with the resultant changes in risk noted. During the year of such an event, it is possible that the average concentration of plutonium on suspended sediments in the Rio Grande in White Rock Canyon down to Cochiti Dam (about 20 km downstream from the junction with Los Alamos Canyon) would be higher than that typically observed in the river due to worldwide fallout. The maximum levels would be about the same as the concentration considered by the EPA to be average for soils throughout the U.S.

A number of other factors besides the radiological risks described here will have to be considered for evaluation of any future management alternatives including possible development. For example, in Lower Pueblo Canyon there is habitat for an endangered species (Peregrine Falcon), a large archeological site, and much of the apparently developable land is considered in a flood plain.

TABLE I

MAXIMUM LIKELY INCREMENTS OF RISK BASED ON EXPOSURE ATTRIBUTABLE TO RESIDUAL CONTAMINATION IN ACID, PUEBLO, AND LOWER LOS ALAMOS CANYONS[a]

	Incremental Risk (Increased Probability Based on 50-Year Dose Commitment)[c]			Incremental Dose Commitment (mrem in 50 Years from Given Exposure)			
				External	Internal Exposure		
Location[b]/Exposure	Overall Cancer Mortality	Bone Cancer	Lung Cancer	Whole Body	Whole Body	Bone	Lung
1-year Occupancy							
Acid Canyon	9.7×10^{-7}	1.1×10^{-8}	2.2×10^{-9}	9.6	0.053	2.1	0.11
Middle Pueblo Canyon	1.2×10^{-8}	3.6×10^{-9}	7.6×10^{-10}	0.1	0.018	0.73	0.038
Lower Pueblo Canyon	3.3×10^{-8}	5×10^{-9}	1.6×10^{-9}	0.3	0.027	1.0	0.08
Lower Los Alamos Canyon	1.8×10^{-7}	5×10^{-10}	1.2×10^{-9}	1.8	0.003	0.10	0.06
Treatment Plant Site	6.0×10^{-6}	---	---	60	---	---	---
Other Mechanisms Currently Possible							
Uptake through abrasion wound on rocks with highest contamination near Treatment Plant Site	---	2.8×10^{-8}	---	---	---	5.6	---
Consumption of Liver from Steer Grazed in Lower Los Alamos Canyon	1.0×10^{-10}	2×10^{-11}	---	---	<0.001	0.001	---

TABLE I (cont)

MAXIMUM LIKELY INCREMENTS OF RISK BASED ON EXPOSURE ATTRIBUTABLE TO RESIDUAL CONTAMINATION IN ACID, PUEBLO, AND LOWER LOS ALAMOS CANYONS[a]

	Incremental Risk (Increased Probability Based on 50-Year Dose Commitment)[c]			Incremental Dose Commitment (mrem in 50 Years from Given Exposure)			
					Internal Exposure		
Location[b]/Exposure	Overall Cancer Mortality	Bone Cancer	Lung Cancer	External Whole Body	Whole Body	Bone	Lung
Possible with Hypothetical Development							
Construction Worker:							
Lower Pueblo Canyon	---	4.5×10^{-7}	1.2×10^{-7}	---	---	89	6.2
Treatment Plant Site	---	4.1×10^{-7}	1.1×10^{-7}	---	---	82	5.6
Inhalation of Dust by Home Gardener in Lower Pueblo Canyon	---	1.2×10^{-7}	3.2×10^{-8}	---	---	23	1.6
Consumption of Produce by Home Gardener in Lower Pueblo Canyon	---	2.0×10^{-9}	---	---	---	0.4	---
Natural Background in Los Alamos County							
1-year occupancy	1.6×10^{-5}	---	---	134	24	---	---
50-year occupancy	8×10^{-4}	---	---	6700	1200	---	---

[a]All calculations based on current (~1978) conditions.
[b]Locations are described in more detail in Chapter 3 and shown in Fig. 14.
[c]Probabilities are expressed in exponential notation; they can be converted to expressions of chance by taking the numerical value in front of the multiplication sign (×) as "chances" and writing a one (1) followed by the number of zeros given in the exponent. For example, 9.7×10^{-7} becomes 9.7 chances in 10 000 000.

TABLE II

RISK COMPARISON DATA

Individual Increased Chance of Death Caused by Selected Activities[a]

Activity	Increase in Chance of Death
Smoking 1 pack of cigarettes (cancer, heart disease)	1.5×10^{-5}
Drinking 1/2 liter of wine (cirrhosis of the liver)	1×10^{-6}
Chest x-ray in good hospital (cancer)	1×10^{-6}
Travelling 10 miles by bicycle (accident)	1×10^{-6}
Travelling 1000 miles by car (accident)	3×10^{-6}
Travelling 3000 miles by jet (accident, cancer)	3.5×10^{-6}
Eating 10 tablespoons of peanut butter (liver cancer)	2×10^{-7}
Eating 10 charcoal broiled steaks (cancer)	1×10^{-7}

U.S. Average Individual Risk of Death in One Year Due to Selected Causes[b]

Cause	Annual Risk of Death
Motor Vehicle Accident	2.5×10^{-4}
Accidental Fall	1×10^{-4}
Fires	4×10^{-5}
Drowning	3×10^{-5}
Air Travel	1×10^{-5}
Electrocution	6×10^{-6}
Lightning	5×10^{-7}
Tornadoes	4×10^{-7}

U.S. Population Lifetime Cancer Risk[c]

Contracting Cancer from All Causes	0.25
Mortality from Cancer	0.20

[a]Adapted from Ref. 26.
[b]Adapted from Ref. 27.
[c]Ref. 28.

2. INTRODUCTION AND BACKGROUND

Early in 1976 the Energy Research and Development Administration (ERDA) identified Pueblo Canyon and the site of a former radioactive liquid waste treatment plant in Los Alamos as locations once used in, or affected by, operations of the U.S. Army Manhattan Engineer District (MED) or by early operations of the U.S. Atomic Energy Commission (AEC). The areas were subsequently resurveyed in 1976-77 for residual contamination as part of the Formerly Utilized Sites Remedial Action Program (FUSRAP) under the auspices of ERDA and its successor agency, the Department of Energy (DOE).

The land areas of interest for this survey of radiological conditions included the interconnected canyon channels, which received both untreated and treated liquid effluents containing radioactivity, and the mesa top site at the edge of one canyon where the radioactive liquid waste treatment plant and outfalls were located. The canyon systems start with a small branch of Pueblo Canyon known as Acid Canyon where the radioactive liquid waste from MED/AEC operations at Los Alamos were discharged between late 1943 or early 1944 and June 1964. The treatment plant site was located on the rim of Acid Canyon. Pueblo Canyon joins Los Alamos Canyon, which, in turn, joins the Rio Grande. All of these were evaluated for residual contamination.

The radioactive liquid waste treatment plant was decommissioned in late 1966 and decontamination work in Acid Canyon continued into 1967. By June 1967 the treatment plant site and Acid Canyon were deemed sufficiently free of contamination to be released from AEC control without restriction. The treatment plant site, Acid Canyon, and a portion of Pueblo Canyon were transferred to Los Alamos County by quitclaim deed on July 1, 1967. Radiation surveys conducted during the period of use and after decommissioning and decontamination indicated there were some low level residual contaminants especially in the channels. These have been monitored over the years as part of the routine environmental surveillance programs conducted by the Los Alamos National Laboratory. The purpose of this survey was, therefore, to document in greater detail and assess current radiological conditions in the affected areas, using modern instrumentation and analytical methods as a basis for determining whether any corrective measures would be desirable in light of present knowledge and environmental concerns.

I. GENERAL SITE DESCRIPTION

Los Alamos is located in northcentral New Mexico, about 100 km NNE of Albuquerque and 40 km NW of Santa Fe by air (Fig. 1). The Los Alamos National Laboratory and adjacent community areas of the Los Alamos Townsite and the White Rock areas are situated on the Pajarito Plateau. The Plateau consists of a series of mesas separated by canyons eroded by intermittent streams that trend eastward from altitudes of about 2400 m on the flank of the Jemez Mountains to about 1800 m at the eastern margin where it terminates above the Rio Grande valley (see Figs. 2, 3, and 4). The mesas and canyons in the Los Alamos area are generally formed from the Bandelier Tuff composed of ashfall and ashflow pumice and rhyolite tuff that form the surface of the Pajarito Plateau. The tuff ranges from nonwelded to welded and is in excess of 300 m thick in the western part of the plateau and thins to about 80 m thick at White Rock Canyon of the Rio Grande. It was deposited as a result of a major eruption of a volcano in the Jemez Mountains to the west about 1.1-1.4 million years ago.

The tuffs lap onto the older volcanics of the Tschicoma Formation, which form the Jemez Mountains along the western edge of the plateau. They are underlain by the fanglomerate of the

Puye Formation in the central and eastern edge along the Rio Grande. The Chino Mesa basalts interfinger with the fanglomerate along the river. These formations overlie the siltstone/sandstone Tesuque Formation, which extends across the Rio Grande valley and is in excess of 1000 m thick.

Pueblo Canyon heads on the flanks of the Sierra de los Valles and is cut into the surface of the Pajarito Plateau. At the junction with Acid Canyon, Pueblo Canyon is about 100 m deep and increases to about 150 m near the DOE boundary (Figs. 2 and 3). The canyon walls are formed by the Bandelier Tuff and consist of steep slopes and cliffs. As the result of different solar exposure, the north-facing canyon wall contains considerably more vegetation than the south-facing wall.

The channel in Acid and Pueblo Canyons is underlain by the Bandelier Tuff down to a point near the DOE boundary (Fig. 3). Further east the channel is underlain by the Puye Conglomerate.

Lower Los Alamos Canyon, below the junction with Pueblo, continues to widen toward the Rio Grande. The canyon walls rise 100 to 150 m above the canyon floor, broken by Bayo and Guaje Canyons, side canyons extending to the north. The north canyon walls are formed by the Puye Conglomerate and Tesuque Formation; the south walls have a cap of basalt over the Puye Conglomerate (Fig. 3).

The stream channel in Lower Los Alamos Canyon near the mouth of Pueblo Canyon is underlain by a short reach of basalt. The basalts have restricted the downcutting of the channel to the west forming a break (falls) of about 15 m in the channel. Further eastward the channel is underlain by the siltstone and sandstones of the Tesuque Formation.

There is no natural perennial flow of surface water in the canyon segments of interest in this study. Runoff from heavy snowmelt or heavy thunderstorms may reach the Rio Grande several times a year. Effluents from the two County-operated sanitary sewage plants are released into Pueblo Canyon (at one point upstream from the Acid Canyon confluence and at another point downstream a bit east of the point where the channel crosses the DOE boundary, Fig. 3) that result in perennial flows for varying distances downstream of their respective outfalls.

Ground water occurs in three modes in the Los Alamos area: (1) water in the shallow alluvium in the canyons, (2) perched water in the Puye Formation and the basalts, and (3) the deep main aquifer.

Intermittent stream flows in the canyons of the Plateau have deposited alluvium that ranges in thickness from less than 1 m to as much as 30 m. The alluvium is quite permeable in contrast to the underlying volcanic tuff and sediments. The intermittent runoff and effluents in the canyons infiltrate the alluvium until downward movement is impeded by the less permeable tuff and volcanic sediments. This results in a shallow alluvial ground-water body that moves downgradient in the alluvium. As water in the alluvium moves downgradient, it is depleted by evapotranspiration and movement into underlying volcanics.

A small body of perched water in the top of the Puye Formation beneath the midreach of Pueblo Canyon is recharged by water infiltrating from the shallow alluvium. The perched water also occurs in the basaltic rocks near the junction of Pueblo and Los Alamos Canyons.

The main aquifer lies at much greater depths and is separated from the alluvium and perched aquifers in Pueblo Canyon by 112 to 192 m of unsaturated tuff and volcanic sediments. The water supply for Los Alamos is drawn from this deep aquifer, which is principally in the Tesuque Formation beneath the central and western parts of the Plateau. The major recharge area to the main aquifer is in the intermountain basin of the Valles Caldera to the west (Fig. 2). There is no hydrologic connection between the shallow alluvial or perched water and the main aquifer. (See Appendix A for additional detail on geology and hydrology.)

II. OPERATIONS AND WASTE DISPOSAL

The radioactive liquid wastes resulted from work starting in 1943 as part of Project Y of the U.S. Army's secret Manhattan Engineer District to develop a nuclear fission weapon and carried on after 1947 under auspices of the AEC as the Los Alamos Scientific Laboratory. Los Alamos was selected in November 1942 as the site for Project Y. The War Department acquired the Los Alamos Ranch School with 54 buildings and about 14.6 km^2 of school and other private holdings. About 186 km^2 of additional land were acquired from other government agencies with the total land filling out essentially all of what is in the present-day Los Alamos County. The first construction contract was let in December 1942, and in January 1943 the University of California assumed responsibility for operating the Laboratory. The first technical facilities known as the Main Technical Area or TA-1 were constructed on about 0.16 km^2 near the existing Ranch School facilities around Ashley Pond and along part of the north rim of Los Alamos Canyon. Buildings, in which general laboratory or process chemistry and radiochemistry wastes were produced, were served by industrial waste lines known as acid sewers. Ultimately all such industrial wastes flowed into a main acid sewer that extended generally north to a discharge point at the edge of Acid Canyon (see Figs. 3, 4, and 5).

The untreated liquid wastes were discharged starting in late 1943 or early 1944 and continued through April 1951. These effluents contained a variety of radioactive isotopes from the research and processing operations associated with nuclear weapons development. No detailed analyses are available but it is known that radioactivity of interest included isotopes of strontium, cesium, uranium, plutonium, americium, and tritium. From some limited data, estimates have been made of the major isotopes released in the untreated effluents and are summarized in Table III (see Appendix A for additional discussion and references). The plutonium concentrations in these releases must have averaged about 1000 pCi/ℓ with maximum concentrations about 10 000 pCi/ℓ.

In 1948 a joint effort was started with the U.S. Public Health Service to develop a method for removing plutonium and other radionuclides from radioactive liquid waste. Bench scale experiments showed that conventional physico-chemical water treatment methods could be modified for treatment of radioactive waste. By June 1951 a treatment plant (identified as TA-45, see Figs. 3 and 5) had been designed, constructed, and began processing the radioactive and other laboratory wastes by a flocculation-sedimentation-filtration process (Ref. 1). Alpha activity was concentrated into the ferric hydroxide floc at high pH by the addition of calcium hydroxide, sodium carbonate, ferric sulfate, and a nonionic coagulant to the influent. Coarse floc was settled out in sedimentation tanks, collected for vacuum filtration, and placed in drums for burial in a solid radioactive waste disposal area within the present Los Alamos National Laboratory site. Finer floc was removed in sand or anthrafilt filters. The final effluent, containing about 1% of the influent plutonium concentration, was sampled prior to release into Acid Canyon (Refs. 2 and 3). The ^{239}Pu concentrations in the effluent ranged from about 20 to 150 pCi/ℓ during the plant's operation. Summary data on the radioactivity content of the released effluent are in Table III. Some representative operating data are presented in Tables IV and V. The plant typically removed 98 to 99% of the mass of plutonium in the influent. Thus, a total of about 0.34 grams of plutonium were released in treated effluent during the 14 years of the plant's operation compared to an estimated 1.9 grams released in untreated waste during the previous 8 years. These mass values and the others in Tables IV and V are informative in indicating the small physical quantity of plutonium that ended up in liquid waste streams during the early years of Los Alamos National Laboratory operation. Additional information on the chemical quality of the effluents is in Appendix A.

From startup until mid-1953, the TA-45 plant treated liquid wastes from only the original Main Technical Area, TA-1. Starting in June 1953, additional radioactive liquid wastes were piped to

TA-45 from the new laboratory complex (TA-3) south of Los Alamos Canyon, which included the Chemistry and Metallurgical Research building where plutonium research was conducted. In September 1953, liquid wastes from the Health Research Laboratory (TA-43) were added to the system. Initially the TA-3 waste was very dilute, and a practice was adopted of monitoring the levels to determine if treatment was required to maintain the 2-week effluent average from TA-45 below 330 disintegrations/min/ℓ (the level adopted from National Bureau of Standards Handbook 52, Ref. 4, as the administrative level for effluent release from TA-45). If treatment was not required to meet the criteria, the TA-3 waste was discharged untreated to Acid Canyon. By December 1953, only about 30% of the TA-3 waste was released untreated. In 1958, liquid wastes from a new radiochemistry facility (TA-48) were added to the line coming from TA-3. The wastes from this facility included primarily fission products and are reflected in the higher gross beta and gamma content of the TA-45 effluents shown in Table III for 1960-1963.

In July 1963, the wastes from TA-3 and TA-48 were redirected to a new Central Waste Treatment Plant (TA-50) located south of Los Alamos Canyon within the present Los Alamos National Laboratory site. The liquid wastes from TA-43 were redirected to the sanitary sewer because only small quantities of very low concentration wastes were generated by that time. Subsequently, only liquid wastes from TA-1 were processed at TA-45 until it ceased operation near the end of May 1964. Some untreated low level liquid wastes containing some fission products from decommissioning of Sigma Building at TA-1 were released until June 1964. After this time no further effluents were released into Acid Canyon.

Other releases have been or continue to be made into Pueblo and Los Alamos Canyons that have some bearing on the interpretation and assessment of the measurements of residual contamination in these canyons. Nonradioactive effluents include those released into Pueblo Canyon from three sanitary waste treatment plants, two of which continue in operation under the management of Los Alamos County. Radioactive effluents are those from the radioactive liquid waste treatment plant still serving TA-21 on the Los Alamos National Laboratory site (see Figs. 3 and 4). Effluents from this plant are released into DP Canyon, a small tributary to Los Alamos Canyon. This treatment plant started operations in June 1952 to serve the old plutonium processing facility that is now undergoing decontamination for conversion to other uses. The cumulative discharges from that waste treatment plant are summarized in Table VI. The plant may treat wastes from new operations at TA-21 in the future, but levels of plutonium and americium are expected to decline. Some residuals from these treated effluents are carried into and down Los Alamos Canyon. Additional information on these effluents and their residuals is presented in Appendix A of this report.

III. DECONTAMINATION AND DECOMMISSIONING

Decontamination and decommissioning of the TA-45 liquid waste treatment plant began in October 1966. All contaminated equipment, plumbing, and removable fixtures were taken to solid radioactive waste burial areas still located within the current Los Alamos National Laboratory site. The structures for the waste treatment plant (TA-45-2) and the vehicle decontamination facility (TA-45-1) were demolished and all debris removed to the disposal areas (see Figs. 6 and 7). Buried waste lines, manholes, and a significant amount of contaminated soil in the vicinity of the decontamination structure were dug out and the debris transported to the solid radioactive waste disposal area. A total of about 516 dump truck loads of debris were removed during these operations. During the same time decontamination of portions of Acid Canyon was accomplished. Contaminated tuff was removed from the cliff face where the effluent had flowed. Men using jackhammers and axes were suspended over the cliff edge on ropes with safety harnesses to

remove contaminated rock (see Figs. 8, 9, 10, and 11). The debris was loaded into dump trucks at the bottom of the cliff. Some contaminated rock, soil, and sediment were also removed from the canyon floor. A total of about 94 dump truck loads of debris were removed from Acid Canyon. The operation was suspended in January 1967 because of cold weather. In the spring of 1967 some additional decontamination was accomplished including other portions of buried waste lines in the TA-45 area and more contaminated rock and the flow-measuring weir from Acid Canyon. By July 1967 the TA-45 site and Acid Canyon were considered sufficiently free of contamination to allow unrestricted access and remove signs designating it as a contaminated area (Refs. 5, 6, and 7). Remaining contamination at that time was documented to be less than 500 counts/minute of alpha activity (as measured by a portable air proportional alpha detector) in some generally inaccessible spots and not considered to constitute any health hazard (Ref. 8).

IV. LAND OWNERSHIP AND USES

After initial acquisition or transfer of control of lands to the War Department in the early 1940s and then to the AEC in 1947, a number of other changes in ownership or control have occurred leading to the present land ownership pattern as it affects the surveyed area. In 1949, the New Mexico State Legislature created the County of Los Alamos encompassing all of the AEC-controlled lands. In 1961 administrative control of about 15.9 km^2 of Federal land in Santa Fe County known as the Otowi Section was transferred to the AEC from Bandelier National Monument. The portion of Pueblo Canyon between the Los Alamos County line and the confluence with Los Alamos Canyon is included in this area (see Figs. 12 and 13).

Pursuant to the Community Disposal Act, the AEC transferred ownership of substantial portions of the townsite to the County of Los Alamos by quitclaim deed on July 1, 1967. This transfer included the former TA-45 site, Acid Canyon, and the portion of Pueblo Canyon encompassing the channel from Acid Canyon eastward to a point about 1190 m west of the Los Alamos-Santa Fe County line. This transfer was subject to the reservation of an easement for continued access to and maintenance of sampling locations and test wells in and adjacent to the channel in Acid and Pueblo Canyons. The easement follows line segments connecting sampling locations, starting about where the untreated waste outfall was located, and includes 50 ft (15.2 m) on either side of the center line except in the vicinity of test wells 2 and 2A where it is an additional 90 ft (27.4 m) wide on the south side for a distance of about 460 ft (140.2 m) (Ref. 9).

From the point about 1190 m west of the County line to the County line, the Pueblo Canyon channel traverses the Pueblo Canyon Tract, which is under DOE control (see Figs. 12 and 13). This tract, containing an abandoned emergency landing strip, was declared excess property in 1972 and turned over to the General Services Administration for disposal. It was offered for sale in 1973 but was subsequently withdrawn and returned to control of the AEC, partly because of the unique opportunities it offered for radioecology studies of low levels of plutonium in a natural environment.

At the Los Alamos-Santa Fe County line, the channel crosses into the DOE-controlled Otowi Section. The channel joins Los Alamos Canyon just east of the junction of State Road 4 and Loop 4. From this point the Los Alamos Canyon channel continues eastward, roughly paralleling the southern boundary of the Otowi Section. The Los Alamos Canyon channel leaves DOE-controlled property at the eastern boundary of the Otowi Section. From that point to its confluence with the Rio Grande, the Los Alamos Canyon channel is on lands of the San Ildefonso Pueblo Indian Reservation (see Fig. 12). In this section there are several households and a commercial sand and gravel operation at Totavi and two households at Otowi.

Present uses of the canyon areas on County and DOE lands are exclusively recreational. Picnicking, trail riding (horses and motorcycles), hiking, firearms practice, woodcutting, and pinon nut gathering are examples of typical activities. Two unexcavated Indian ruins, known as Big Otowi and Little Otowi, are located within the Otowi Section and are in the process of being nominated by DOE as a National Historic Landmark site. Part of this same area is considered the principal habitat for a nesting pair of Peregrine Falcons, an endangered species.

Future land uses include both a continuation of present uses and the possibility of some residential and associated light commercial development. The most desirable area for development would include portions of the DOE-controlled lands in Pueblo Canyon and some of the adjacent County lands extending a limited distance to the west. Further west the terrain on the County lands becomes progressively less suitable for construction; however, there are currently no zoning restrictions that would preclude development (Fig. 13).

V. PREVIOUS MONITORING AND SPECIAL STUDIES

Data have been collected since 1945 on the presence of radioactivity in the environment as a result of liquid waste disposal operations at Los Alamos. From 1949 to 1971, the U.S. Geological Survey (USGS), Water Resource Division, studied the effects of the release of industrial effluents on the water quality and geohydrology of the area. Environmental monitoring staff at Los Alamos National Laboratory continued routine surveillance and appropriate special studies. Since 1970 a series of annual reports documenting and interpreting the environmental data have been published by Los Alamos National Laboratory. A number of special research programs have addressed the radioecological aspects of liquid waste disposal areas at Los Alamos. Data from all of these sources relevant to the canyon areas of interest in this study were compiled to provide a historical perspective and basis for planning additional sampling and interpretation. Appendix A of this report includes the compilation of available data and results of special studies for the period 1945 through 1975. Additional information and data became available or were published subsequent to that compilation; they were utilized as appropriate and are referenced in other parts of this report or other appendices.

The general patterns of spatial distribution of radioactivity and the general trends over time shown by previous work are consistent with the results obtained from this study. Most of the residual radioactivity is attached to bank soils or more stable inactive channel sediments. The concentrations are highest near the release points and generally decrease with distance. However, because the major flow events in the canyons of interest are intermittent, redistribution of the sediments and erosion or deposition processes are discontinuous and highly variable over both space and time. Thus it is important to keep in mind the dynamic nature of the hydrologic system when making comparisons with historic data or when projecting possible future changes. Concentrations of radionuclides on sediments at a particular location often vary considerably, either up or down, from one sampling period to the next, depending on the number and size of runoff events occurring in the intervening period. The quantities of residual contamination carried by sediments during runoff vary remarkably from one event to the next, depending on the volume and length of the runoff.

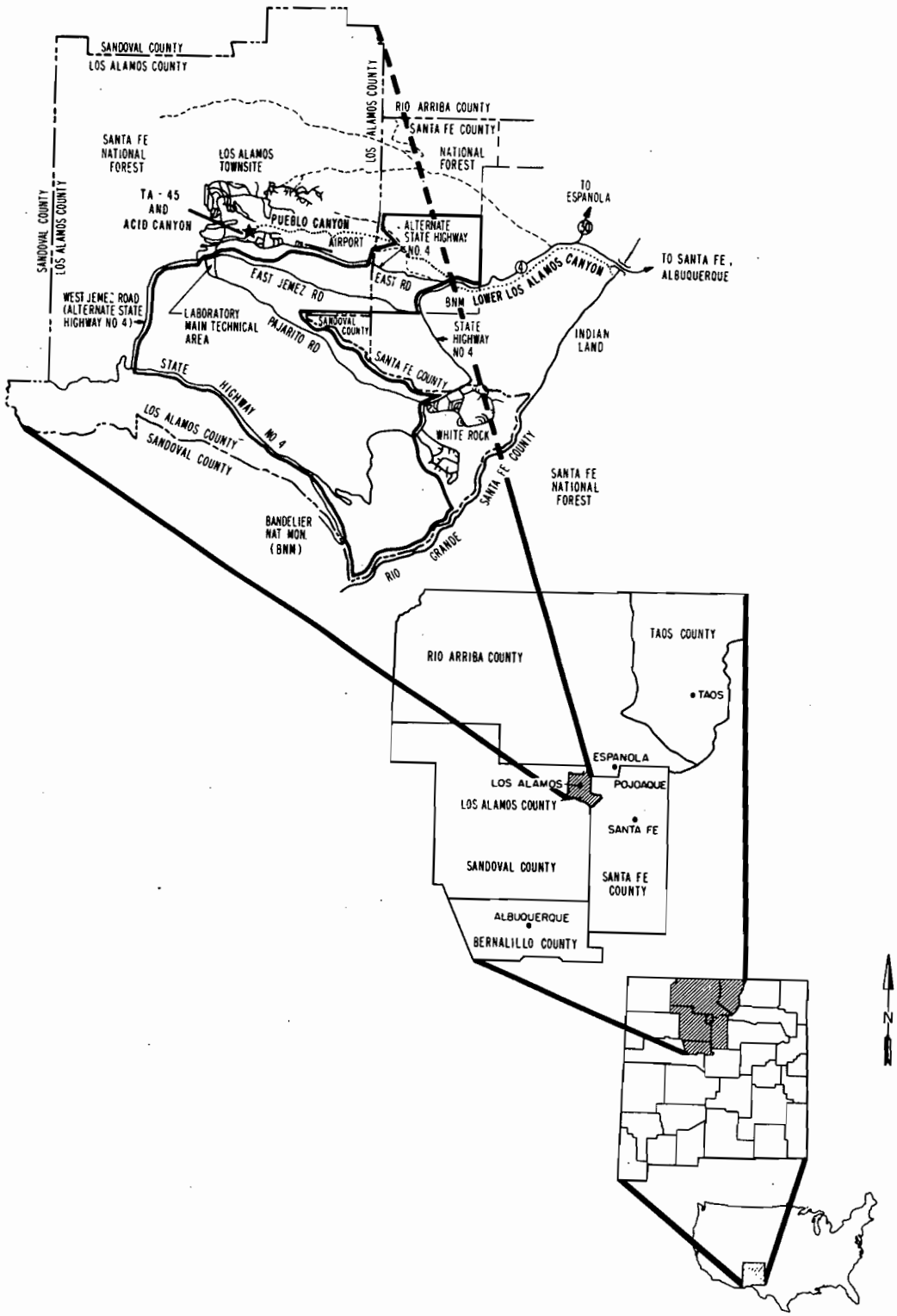

Fig. 1.
Regional location of study area.

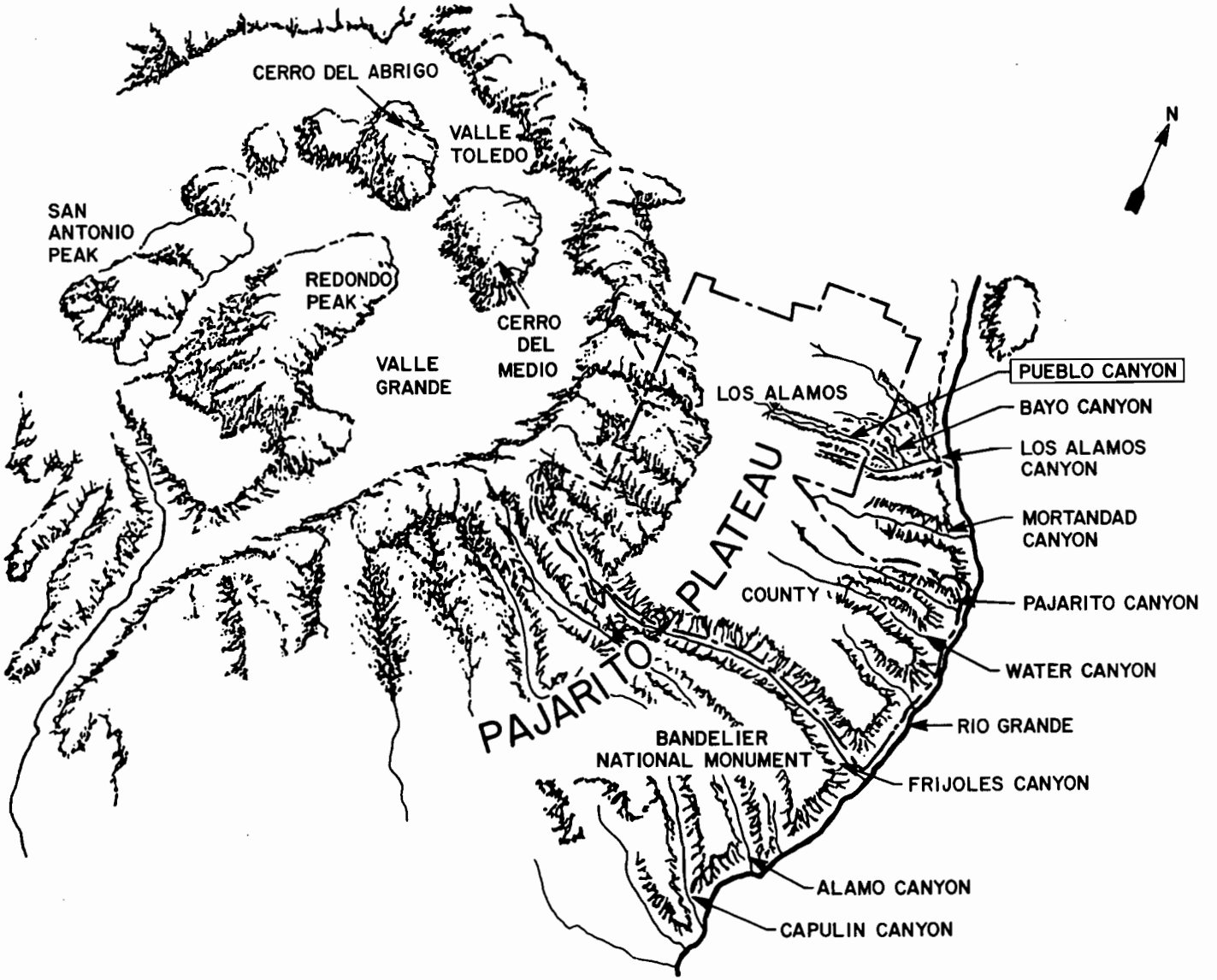

Fig. 2.
Physiographic setting of Los Alamos County.

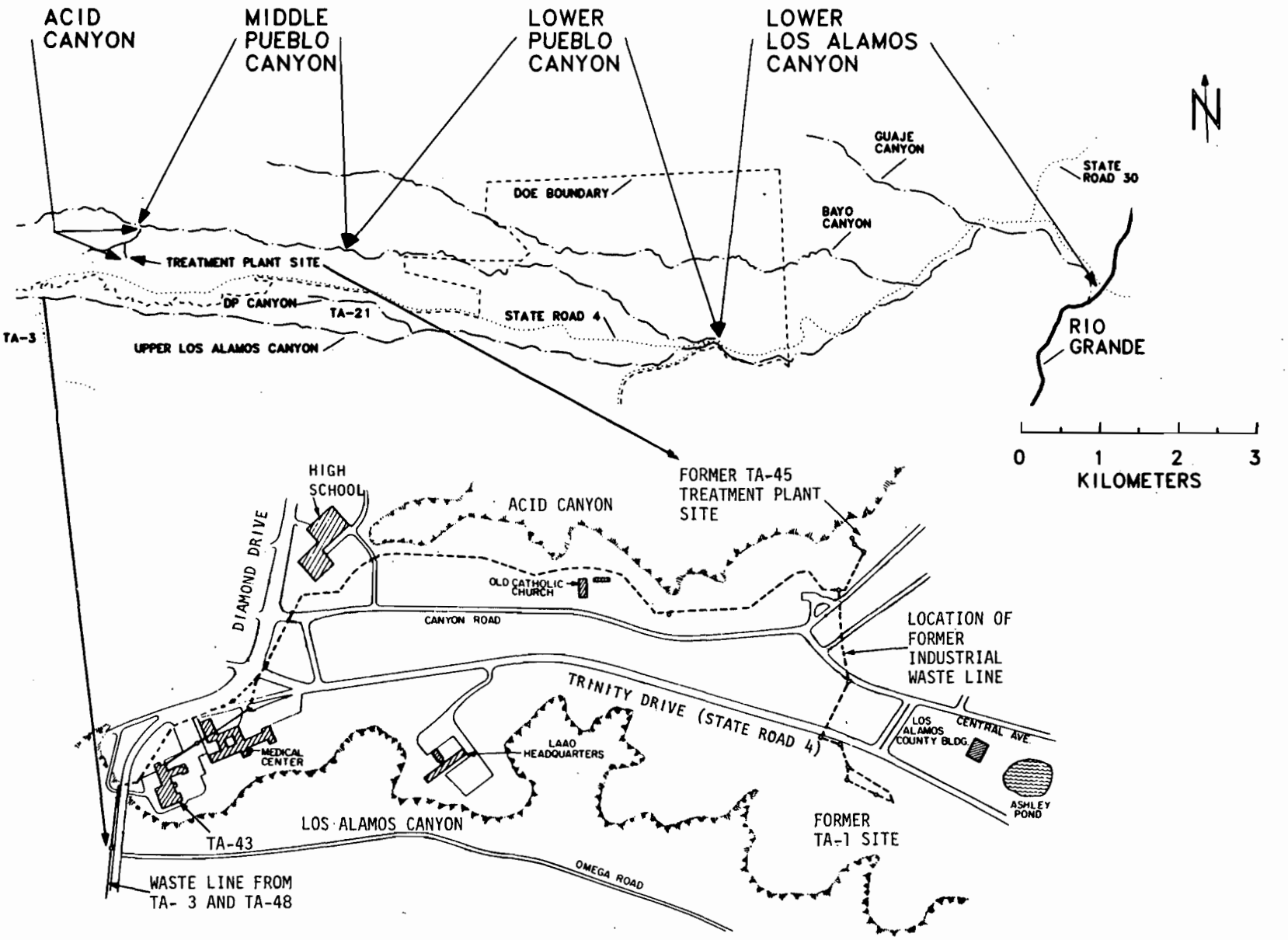

Fig. 3.

Former liquid waste handling facilities and relation to effluent receiving canyons.

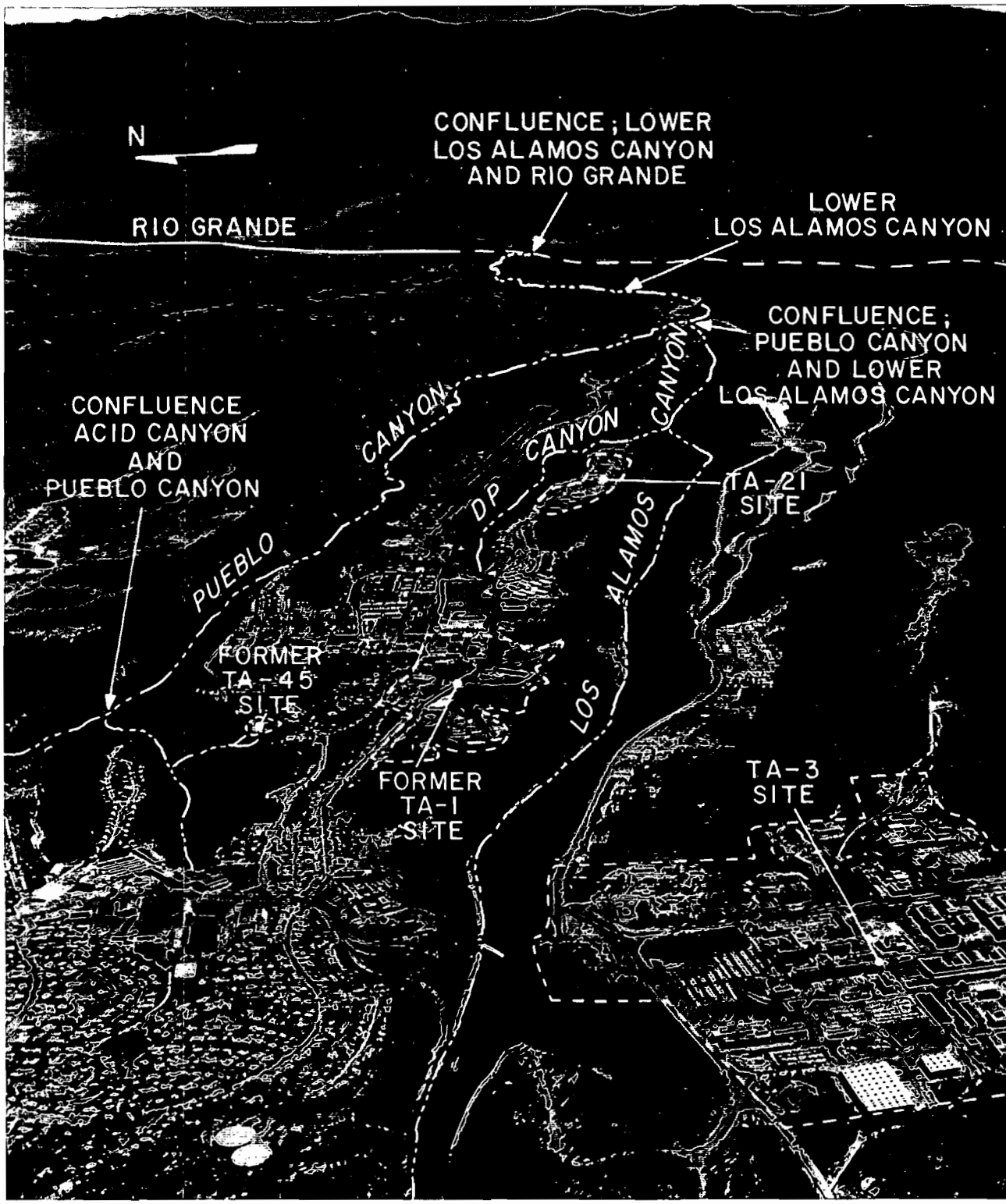

Fig. 4.
Aerial view of Los Alamos and study area looking east.

Fig. 5.
Liquid waste treatment plant (TA-45).

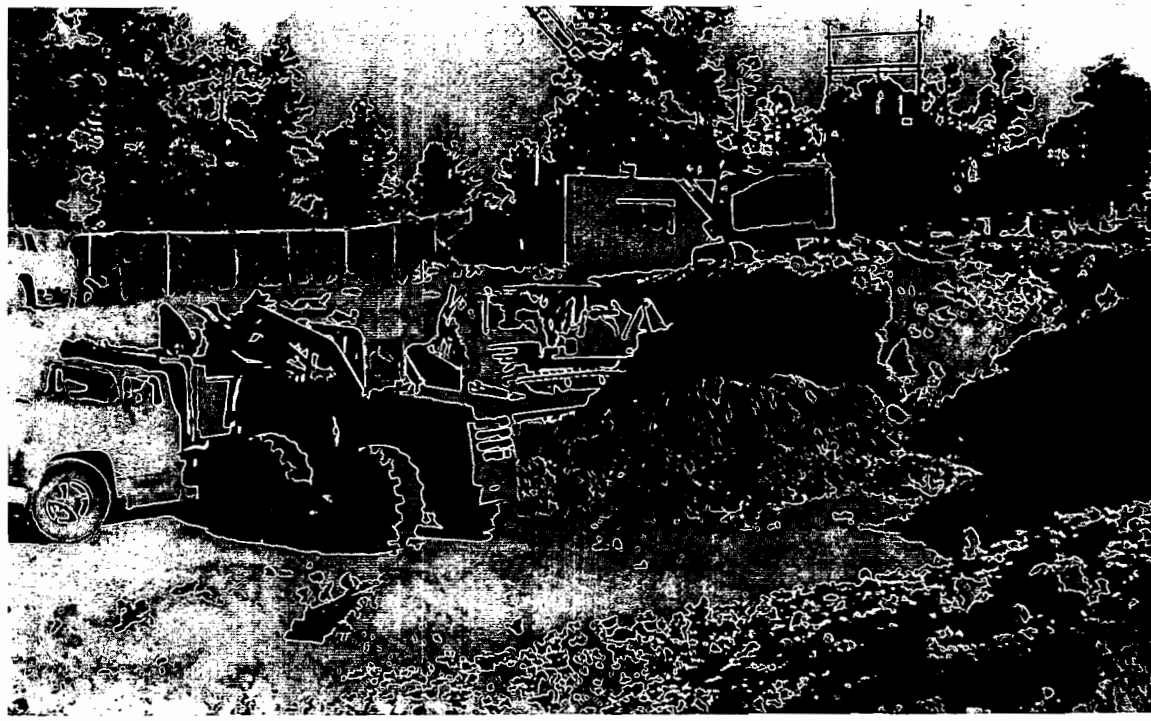

Fig. 6.
Demolition and decontamination of liquid waste treatment plant.

Fig. 7.
Site of former liquid waste treatment plant as restored.

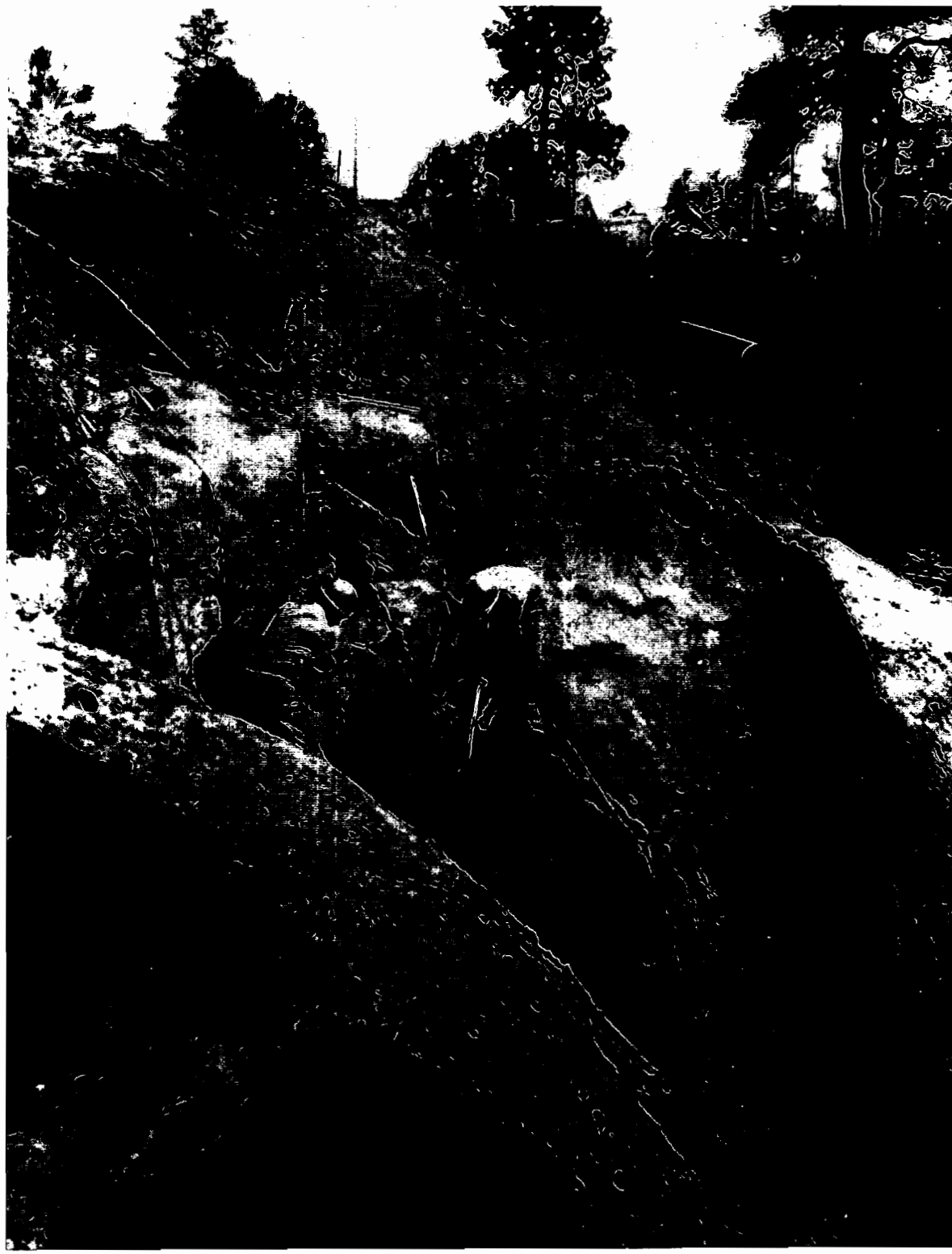

Fig. 8.
Decontamination near discharge point of main effluent line.

Fig. 9.
Decontamination of cliff face below discharge of main effluent line.

Fig. 10.
Cliff face below main effluent line in 1977 during instrumental survey of areas previously decontaminated.

Fig. 11.
Untreated waste line discharge point.

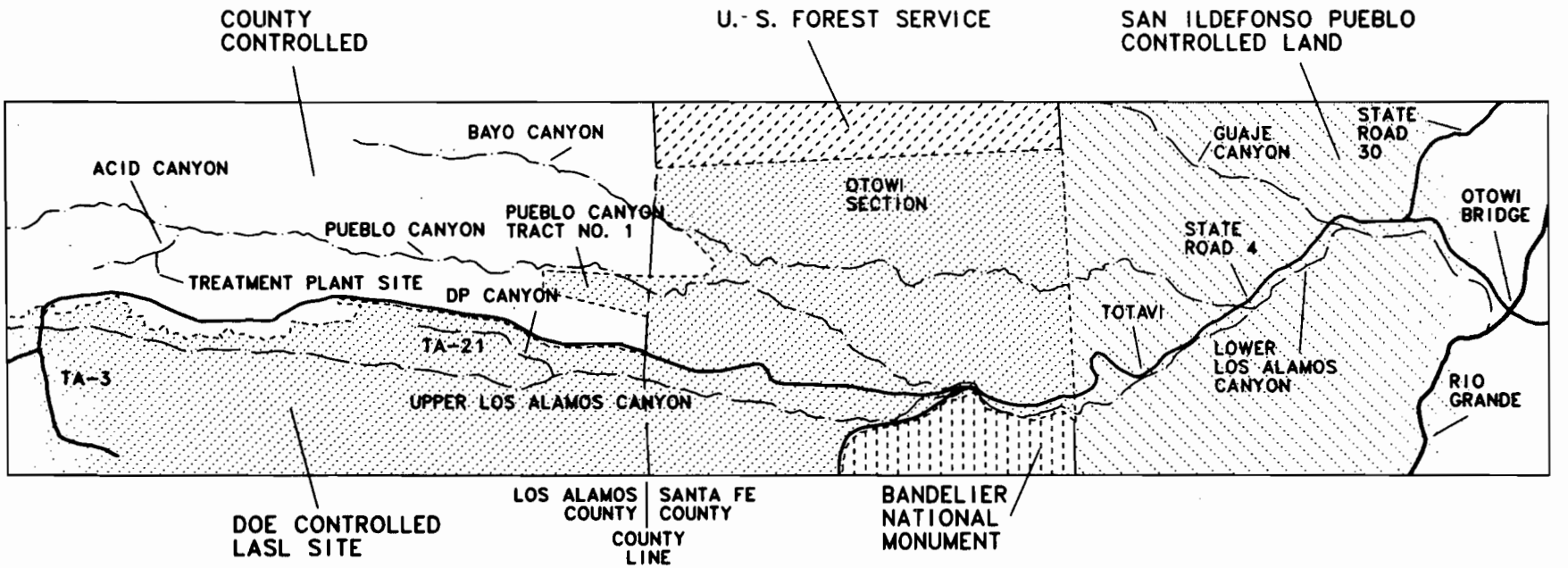

Fig. 12.
Land ownership or management in study area.

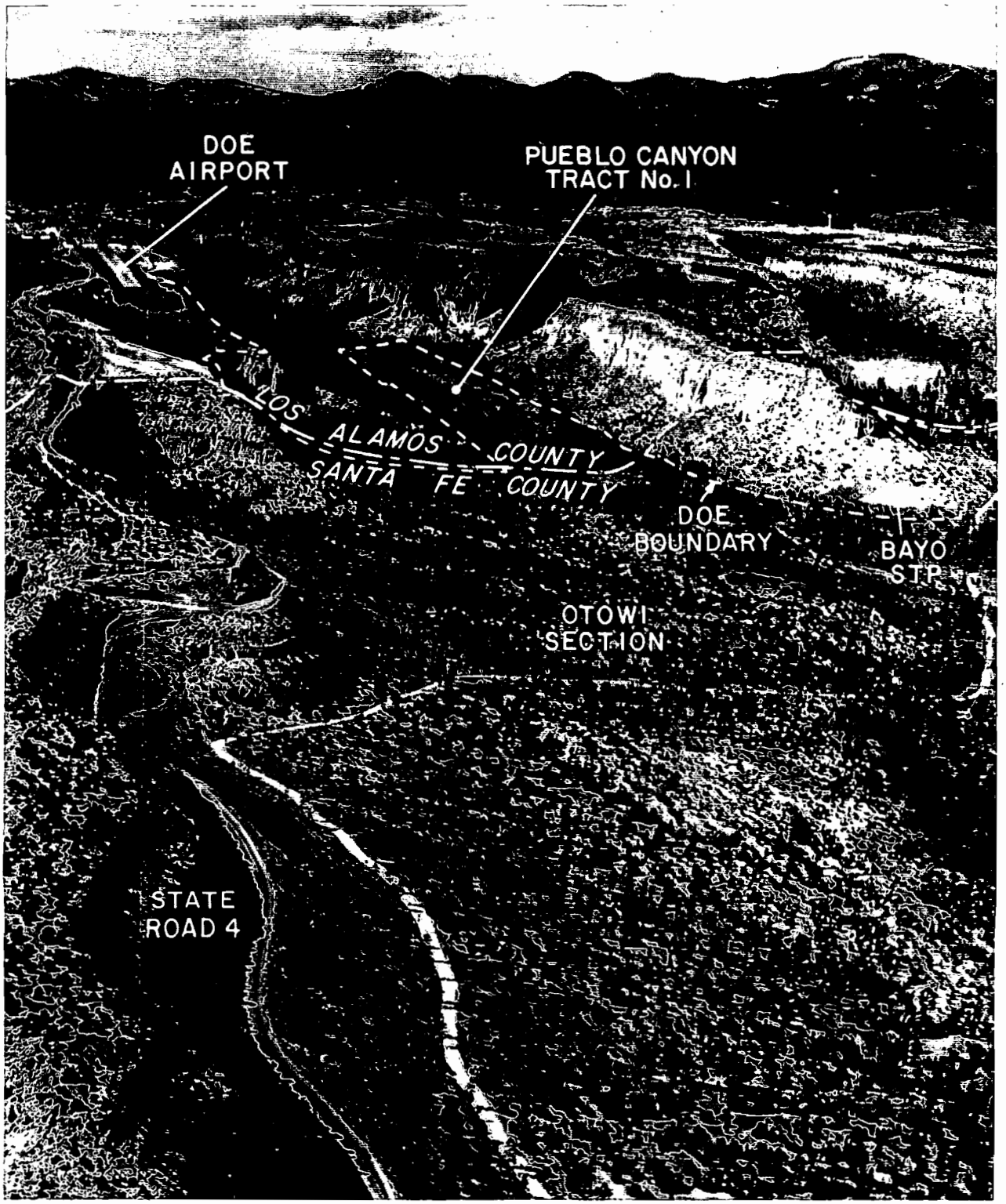

Fig. 13.
Aerial view of Lower Pueblo Canyon looking west with approximate location of DOE boundary and Santa Fe-Los Alamos County line.

TABLE III

RADIOACTIVITY CONTENT OF EFFLUENTS RELEASED TO ACID CANYON[a]

	Untreated Effluents, 1943 through April 1951			
	Isotope (curies)			
	^{3}H[c]	^{89}Sr	^{90}Sr	Pu[b]
Estimated Total Releases	18.25	0.25	0.094	0.15
Activity Decayed to Dec. 1977[e]	3.4	0	0.046	0.15

	Treated Effluents, April 1951 through June 1964			
	Isotope (curies)			
Annual Release	^{3}H[c]	Unidentified Gross α	Unidentified Gross β & γ	Pu[b]
1951	3	0.0024		0.0013
1952	3	0.0041		0.0011
1953	3	0.0038		0.0012
1954	3	0.0044		0.0022
1955	3	0.0041		0.0022
1956	3	0.0060		0.0011
1957	3	0.0087		0.0009
1958	3	0.0038		0.0009
1959	3	0.0018		0.0012
1960	3	0.0035	1.251	0.0026
1961	3	0.0093	0.505	0.0053
1962	3	0.0074	1.222	0.0039
1963	3	0.0072	0.804	0.0030
1964	1.2	0.0001	0.0001	0.00004
Total Release	40.2	0.0666	3.78	0.0269
Activity Decayed to Dec. 1977[e]	13.1	[d]	[d]	0.0269

[a]Measured and estimated data as compiled for and summarized in the U.S. DOE Onsite Discharge Information System (ODIS).

[b]Total plutonium, predominately ^{239}Pu, but includes small amounts of other isotopes. Reported in ODIS as ^{239}Pu.

[c]All tritium values estimated.

[d]No estimate of decayed value made because data on isotopic mixtures are not available. The gross α is assumed to be predominantly plutonium and uranium; therefore, little decay would have occurred. If the gross β and γ is assumed to be largely ^{90}Sr and ^{137}Cs, then decayed value would be about 70% of total released.

[e]Decay based on year of release and appropriate half-life.

TABLE IV

OPERATING DATA, TA-45
DECEMBER 1953

	Av Day	Min Day	Max Day
Flow to plant (1000 ℓ/day)	89.0[a]	63.2	154.4
Total treated (1000 ℓ/day)	110.5[a]	51.9	135.1
Influent gross alpha (1000 dis/min-ℓ)	2.2	0.2	14.6
Influent Pu (1000 dis/min-ℓ)	2.2	0.2	14.6
Influent (mg Pu/day)	1.5	0.1	9.9
Effluent gross alpha (dis/min-ℓ)	174	0	1892
Effluent Pu (dis/min-ℓ)	38	0	124
Influent Na (Mg/ℓ)	42	30	51
Influent Ca (mg/ℓ)	12	11	14
Influent F (mg/ℓ)	3	2	4
Influent NO_3-N (mg/ℓ)	64	8	140
Influent pH	7.8	3.4	8.4

[a]Average flows to the plant are less than the amount treated because fluids are added in the treatment process.

TABLE V

WASTE CHARACTERISTICS (RADIOACTIVITY)
1954-1963

Year	TA 3/43/48 Flow (10^6 Liters)	TA 1/3/43/48 Gross Alpha (1000 dis/min-ℓ) Monthly Average	Monthly Maximum	Monthly Minimum	Pu (mg)
1954	12.7	9.8	20.8	2.5	2604
1955	13.6	4.8	8.8	2.0	1032
1956	14.3	4.2	7.4	1.2	794
1957	17.0	7.2	21.0	3.4	1429
1958	16.9	9.4	17.5	3.6	1567
1959	26.7[a]	14.2	26.0	7.0	3577
1960	41.1[b]	13.3	71.6	9.2	5296
1961	52.9	9.8	31.4	10.8	5686
1962	64.1	7.4	26.4	7.8	4906
1963	29.7[c]	14.7	19.6	11.4	2142

[a]Transfer of operations from TA-1 to TA-3 resulted in a marked decrease in flow from TA-1 and increase from TA-3 for July and following. For December, TA-1 was 340 000 ℓ and further recording of separate TA-1/TA-3 influent flows was discontinued.

[b]For 1960 and beyond, the flow indicated is a total of that from TA-1, TA-3, TA-43, and TA-48.

[c]After June 27, 1963, all TA-3 and TA-48 waste was pumped to TA-50. This figure is a total of the TA-1, TA-3, TA-43, and TA-48 waste to TA-45 from Jan. 1 to June 27, 1963. Activity figures are also confined to the first 6 months of the year.

TABLE VI

RADIOACTIVITY CONTENT OF TREATED EFFLUENTS RELEASED TO DP CANYON FROM TA-21
June 1952 through December 1977

Isotope	Decay Corrected Cumulative Activity[a] (curies)
^{3}H	36.033
$^{89,90}Sr$	0.047
^{137}Cs	0.018
^{235}U	<0.001
^{238}Pu	0.001
^{239}Pu	0.032
^{241}Am	0.001
Unidentified Gross alpha	0.015
Unidentified Gross beta and gamma	0.551

[a]Measured data as compiled for and summarized in the US DOE Onsite Discharge Information System (ODIS).

3. METHODS AND APPROACH

This study was designed to provide a basis for estimating potential exposures under conditions of current land use, during hypothetical construction and occupancy as a residential area, and under possible natural hydrologic influences in the future. The sampling and measurement scheme attempted to account for previous use history as an industrial waste treatment, discharge, and receiving area as guided by data from previous investigations.

The area surveyed included (1) the location of the former liquid waste treatment plant (TA-45), (2) an adjacent untreated waste discharge location (used prior to TA-45 operation), and (3) the natural drainage that received wastes from both (1) and (2). The untreated waste discharge point and TA-45 were located on the mesa top above the south fork of Acid Canyon. The natural drainage system included Acid Canyon, Pueblo Canyon from Acid Canyon to Lower Los Alamos Canyon, and Lower Los Alamos Canyon from Pueblo Canyon to the Rio Grande (see Fig. 14). The survey area was divided into strata and substrata, which might be expected to show differing degrees of waste contamination based on historic use and differences in geological features. Results from previous work were used whenever possible to supplement current survey results. These data and information on nonradioactive waste constituents are presented in Appendices A and E.

The survey design was directed at obtaining the best estimate of the ranges of concentrations, distribution, and approximate inventory of the residual contamination within limits of available resources. The strategy was to:

- Incorporate the data from previous radiological studies where possible,
- Survey the areas with portable instruments (including the phoswich, which is particularly sensitive to uranium, plutonium and americium) to minimize any chance of omitting locations of high concentrations,
- Sample selected locations that gave a positive response to the portable instrument survey (0-5-cm depth),
- Sample channels and banks along randomly selected transects (0-25 cm depth),
- Supplement channel transects with surface samples (0-5 cm depth) scooped from accumulating features across the channel and composited into one sample,
- Sample in and adjacent to former structure locations that would have a potential for contamination in the soil (0-900 cm depth),
- Sample points on a rectangular grid around the treatment plant (0-240 cm depth), and
- Analyze selected samples, especially those containing exceptional alpha or beta activity, for specific isotopes.

Sample results from this strategy are biased toward overestimating the mean concentrations of radionuclides because they emphasize locations of known or suspected contamination. On the other hand, the results provide more confidence for establishing an upper bound of concentrations in each stratum. Sample means for each stratum were used for radiological dose evaluations, but it must be kept in mind that the basis for sample selection is biased to overestimate the population mean. Consequently, radiological dose evaluations calculated from the sample means are overestimated.

The exact sampling locations were selected by combinations of theoretical planning prior to field work and judgment exercised in the field to allow for special conditions. The portions of the Los Alamos and Pueblo Canyon channels of interest in this study were divided into 100-m intervals. The locations for most of the channel transects were picked by randomly selecting one of the positions out of every set of five intervals (500 m). In general, the transect included sampling positions in the active and inactive channel and one on each bank. Active channel refers to the

narrowest, deepest part of the normally dry canyon bottom, which carries flow from most smaller runoff events. Inactive channel refers to the broader portion of the channel that is inundated only during larger runoff events, is basically sand and gravel with no developed soil, and has relatively sparse vegetation. Bank refers to the higher sides adjacent to the channel that are rarely wet by flow and have a relatively stable soil with moderate vegetation.

Some transects in the lower reaches of Pueblo Canyon and Lower Los Alamos Canyon were very wide so additional samples were taken in the channel. Some transects crossed depleting or accumulating features such as the outside curve of a meander or a sand bar. Such features warranted additional samples. All samples from transects were cores taken to a depth of 20-25 cm. Supplementary samples were taken between planned transects where field observation of local conditions suggested possible unusual mechanisms of accumulation or where the historical record suggested a need for clarification. These samples were taken with scoops to a depth of about 5 cm. Sample collection and preparation methodology is presented in detail in Appendix C. Special intensive sites used in previous years for radioecology studies were omitted from initial sample site selections. However, some confirmatory sampling was performed at those sites.

The sampling locations in Lower Los Alamos Canyon from Pueblo Canyon to the Rio Grande were initially grouped into three contiguous strata (reaches) for anticipated statistical analysis. Preliminary evaluation of the data showed no reason to maintain a distinction and all results for these strata were combined. Similarly, sampling locations in Pueblo Canyon were initially grouped in three strata, but two strata were combined as Lower Pueblo Canyon and the third identified as Upper Pueblo Canyon for evaluation purposes. The general locations of the evaluation groupings are shown in Fig. 14. (All sampling locations are indicated on maps in Appendix E, Figs. E-1 through E-5.)

Acid Canyon (see Fig. 14) was sampled by two distinct schemes. Samples taken at the head of the canyon, nearest the point of the effluent discharges, were located by positive response of portable survey meters. These samples were generally surface samples taken to a depth of 5 cm. Additional samples taken in the stream channel were located for confirmation and supplementation of the relatively large number of samples taken in previous years for specific radioecology studies. These samples were cores taken to maximum depth of 25 cm. (Detailed sampling locations are shown on a map in Appendix E, Fig. E-2.)

The former site of TA-45 included the location of the untreated waste discharge point, the vehicle decontamination facility, and the liquid waste treatment plant. Because of the different uses, four substrata were designated with different sampling schemes used in each (see Fig. 14). One substratum encompassed the untreated waste discharge point and the drainage leading into Acid Canyon. Sampling locations were determined either by positive survey meter response or to document conditions adjacent to the alignment of the former untreated waste line. Most samples were surface samples to a depth of about 5 cm with a few cores to 25 cm depth.

The alignments of the former waste line leading to the treatment plant and the two former effluent discharge lines were the second substratum. Sampling in these locations was accomplished by digging trenches perpendicular to and across the former alignments with a backhoe. Surface samples were scooped from the cross trenches near the bottom of the original trench as indicated by differences in soil/rock texture generally at depths of about 120 cm. The sampling cross-trenches were dug at about 6.1-m intervals or at bends in the original alignment or former locations of manholes.

The area including the former location of the vehicle decontamination facility and its drainage into Acid Canyon was the third substratum. This area was surveyed with portable detection equipment and some surface samples to a depth of 5 cm collected at locations of positive instrument response.

The former location of the treatment plant and its general vicinity constituted the fourth substratum. Because varying depths of fill were placed in this area following the decontamination and decommissioning in the 1960s, samples in this area were collected by auger drilling. Inside the perimeter of the building at the location of holding and settling tanks, sumps, and near corners, auger samples extended down to and sometimes below bedrock beneath former foundation levels at depths ranging from about 120 to 900 cm below the present grade. Similar samples were also collected at the locations of related adjacent structures such as manholes. Outside the perimeter of the building location, auger samples were collected at points on a regular grid to depths of about 240 cm.

A separate survey using portable instrumentation was undertaken for the cliff face extending from the TA-45 site down into the head of Acid Canyon at locations where effluents flowed over the rock. The portable instruments were carried by personnel descending the steep cliff using mountaineering techniques. A total of 11 vertical lines were surveyed, 8 of them on the cliff face that had been extensively decontaminated by chipping, and one each along the flow courses for the untreated waste outfall, the drainage for the vehicle decontamination facility, and the smaller 6-inch outfall line from the treatment plant. (The detailed locations are depicted on a map in Appendix E, Fig. E-8.)

Prior to undertaking field work, specific permission to carry out the surveying and sampling was obtained from the County of Los Alamos to cover areas not included in the easement and from the San Ildefonso Pueblo to cover the portion of Los Alamos Canyon extending across their lands (Refs. 10 and 11). The Los Alamos National Laboratory Engineering Department surveyed the former locations of structures at the TA-45 site and set out a series of reference points extending down Pueblo and Los Alamos Canyons for use in identifying the sampling locations.

After collection, the soil and sediment samples were analyzed for gross activity and specific isotopes according to several selection schemes. All samples were analyzed instrumentally at Los Alamos National Laboratory for gross-alpha and gross-beta activity by ZnS and plastic scintillator detectors, respectively. Subsets of the samples were determined by random choice (to provide unbiased estimates) or by special selection (such as for confirmation of contaminant or to provide a basis for correlation with gross activity analyses). These subsets were submitted for various radiochemical analyses. The largest number of radiochemical analyses were performed for ^{238}Pu and ^{239}Pu,* followed closely by total uranium, then ^{90}Sr, ^{137}Cs, ^{232}Th, ^{226}Ra, ^{241}Pu, and ^{241}Am. Most radiochemical analyses were performed by an independent commercial laboratory under contract to Los Alamos National Laboratory. Some radiochemical analyses were performed by the Environmental Surveillance Group at Los Alamos National Laboratory. Additional detail on the analytical methods and quality control is included in Appendix B.

Table VII summarizes the soil sampling plan and analyses grouped by the five principal strata. Execution of the survey resulted in additional samples and analyses to verify or clarify preliminary results. Results are summarized in Chapter 4, and detailed results are compiled in Appendix D.

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*Note: The designation ^{239}Pu is used in this report to signify the sum of ^{239}Pu and ^{240}Pu, which are not separately distinguishable by normal alpha spectroscopy because their alpha particles have nearly the same energies.

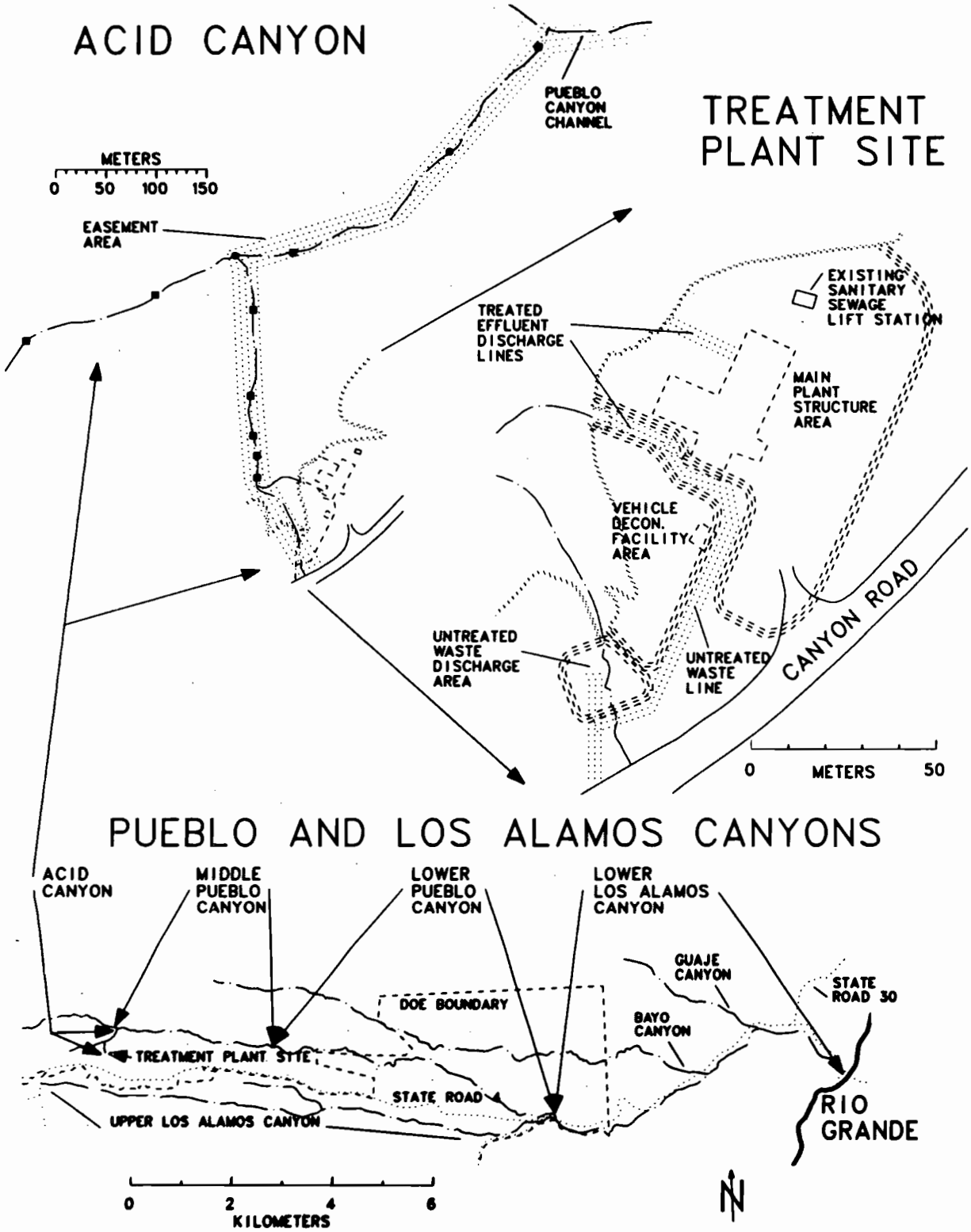

Fig. 14.
Relationships and general locations of sampling areas.

TABLE VII

RESURVEY SAMPLING AND ANALYSIS SUMMARY

Strata	Sample Type	No. of Locations	Analysis Type	Comment
Treatment Plant Site	surface	15	gross α, β	positive survey meter response and pattern around untreated discharge
		12	radiochemical	positive gross α, β result; positive survey meter response; expected contamination
	core (0-25 cm)	22	gross α, β	rectangular gridpoints, H_4
		11	radiochemical	positive gross α, β result; expected contamination
	trench (0-120 cm)	24	gross α, β	6.1-m increments of acid waste alignment
		12	radiochemical	positive gross α, β result; positive survey meter response; expected contamination
	auger (60-900 cm)	111	gross α, β	potential structural leakage
		26	radiochemical	positive gross α, β result; potential contamination
Acid Canyon	surface (0-5 cm)	12	gross α, β	positive survey meter response
		5	radiochemical	positive gross α result
	core (0-25 cm)	6	gross α, β	positive, survey meter response, potential contamination
		3	radiochemical	clarification
Pueblo and Los Alamos Canyons	surface (0-5 cm)	26	gross α, β	unusual accumulation or depletion feature
		2	radiochemical	positive gross α result
	core (0-25 cm)	148	gross α, β	transect points; background clarification
		91	radiochemical	positive gross α, β result; background; clarification; random selection

4. RESULTS

The data collected for this special study, as well as information collected from other studies and routine environmental monitoring in the vicinity of Los Alamos, were analyzed in various ways to describe the radiological conditions of areas related to the former waste treatment plant and effluent receiving canyons. This section summarizes the data on the occurrence and distribution of radiation and radioactivity and discusses the natural physical processes such as hydrologic transport and resuspension that redistribute the radioactivity. The following section, Dose Evaluation and Interpretation, summarizes the analysis of potential effects and risk estimates. Technical details of the analysis are presented in Appendix E. Readers desiring more information on concepts of radioactivity, radiation, and dose interpretation may be helped by Appendix F, Evaluation of Radiation Exposures. Sections 4 and 5 are organized according to the logic of the evaluation proceeding from the basic data on concentrations of radioactivity in environmental media, through analysis of transport processes to derive estimates of doses to humans and finally interpretations of the significance of those estimates. The evaluation of potential doses and their significance is probably the most useful decision information. Some other comparisons with natural background and concentration standards have been included to provide perspective throughout the discussion.

I. RADIOACTIVITY IN SOILS AND SEDIMENTS

A. Concentrations

The many samples of soils and sediments collected and analyzed for radioactivity contributed considerable detail and further confidence of understanding to the basic patterns known previously (Appendix A).

The basic pattern of the distribution of ^{239}Pu* on sediments and soils is displayed in Fig. 15. Quantitative data summaries are also presented in Table VIII. The most important features of the pattern include the following.

- The highest concentrations are associated with the untreated waste outfall (Treatment Plant Site Surface, see Figs. 15 and 16).
- Some subsurface contamination is present in the immediate area of the former waste treatment plant location and along part of the alignment of the location of the former industrial waste line (Treatment Plant Site Subsurface, see Figs. 15 and 16).
- Plutonium is present at above background levels in all the channels and banks from the discharge points in Acid Canyon, through Middle and Lower Pueblo Canyon, and in Lower Los Alamos Canyon (see Figs. 14 and 15).
- The concentrations in the channels and banks generally decline with increasing distance from the discharge points (see Fig. 15).
- The banks have higher concentrations than channels in given intervals as would be expected from the intermittent stream character that scours the channels more frequently than the banks (see Fig. 15).

Note: The designation ^{239}Pu is used in this report to signify the sum of ^{239}Pu and ^{240}Pu, which are not separately distinguishable by normal alpha spectroscopy because their alpha particles have nearly the same energies.

A number of other facts are important to understanding the overall pattern of occurrence and distribution of radioactivity in the affected areas. These include the size of the areas, the isotopes other than ^{239}Pu present, and the variability of the data collected.

The affected area in the vicinity of the former waste treatment plant site having subsurface contamination (see Fig. 16 and Table VIII) is generally within a rectangular area about 55 m by 60 m and within about 2 m depth from the surface. Another smaller area along the alignment of the former waste line is about 40 m by 3 m and within about 1.5 m depth from the surface.

The highest concentrations of surface (depths to about 30 cm) contamination in the vicinity of the Treatment Plant Site are adjacent to the natural drainage channel that received the untreated effluent (see Fig. 16). This area is about 30 m long and no more than 5 m wide. Within this area the maximum concentrations occur within a band of elevated activity about 30-75 cm wide along the channel and are in spots having dimensions on the order of 15 cm as determined by portable instruments. Additional but considerably lower surface activity was primarily associated with the natural drainage area leading from the former vehicle decontamination facility location toward the canyon edge. This area is roughly 10 m by 30 m.

Within the canyon segments the affected areas have widths averaging between about 2.3 and 35 m and have a total length of about 17.5 km (see Table VIII). Throughout the canyons the activity is largely confined to depths of about 30 cm.

Transuranic radioactive isotopes present in the contamination in addition to ^{239}Pu included ^{238}Pu, ^{241}Pu, and ^{241}Am. They were accounted for in the evaluation by using ratios of their activities to the activity of ^{239}Pu as shown in Table IX. A single set of ratios for current conditions was assumed for all study areas to simplify presentation of the results. The values were based on radiochemical analyses performed on a subset of the samples analyzed for ^{239}Pu and judgment of other factors including variability of analyses and worldwide fallout. Future condition ratios were calculated from the current condition ratios to account for the decay of ^{238}Pu and ^{241}Pu and the ingrowth of ^{241}Am. This use of a single set of ratios for all areas means the estimates of contributions from ^{241}Pu and ^{241}Am in Acid Canyon are probably overstated by factors of as much as 5 to 10 compared to the rest of the areas.

Other radioactive isotopes found to be present at concentrations with statistical significance above background in at least some areas include ^{90}Sr, ^{137}Cs, and uranium. Data for these constituents are summarized in Table VIII. The values given are the statistically significant increment above regional background values. Where there was no significant increment (significance level $\alpha = 0.05$) the entry in the Table is "N.S."

Because a large number of samples were collected and analyzed, it must be kept in mind that the physical areas involved and the complex natural processes involved in the dispersion of the contaminants from the discharge points make representative sampling extremely difficult. This is reflected clearly in the standard deviations of the concentrations presented in Table VIII. In most cases the standard deviations are about the same value as the mean. The consequence of this is that all subsequent analyses of information based on the concentrations have a large uncertainty and can generally be considered to be accurate only within a factor of about 2. Most of the results have been rounded to two significant figures to maintain reasonable consistency in the presentation, but even this probably implies more precision than is warranted. Within the ranges of uncertainties discussed, and considering the fact that runoff events do redistribute contaminated sediments within the channels, measurements made during this study are compatible with values obtained during previous special and monitoring studies (see Appendix E, Sec. I.B.).

The standard deviations of the concentration data are given in Table VIII to indicate the large variability in the values. Because of the large variability, the mathematical standard deviation could be misinterpreted to mean that some of the actual concentrations were negative, an obvious physical impossibility. The standard deviations in such cases should be interpreted to indicate

that the majority of the individual concentrations were between zero and the mean plus the standard deviation. The standard deviation value associated with each of the concentration means can also be used to represent the upper limit of a one-sided confidence interval on the mean with a confidence level of at least 95%.

Some preliminary evaluations of the data were performed utilizing geometric means because the physical processes such as hydrologic transport have often been found to be well described by some type of extreme value distribution. These evaluations gave means that were often about one-third the arithmetic means but had much larger standard deviations. The concentration data sets were too small to permit a clear choice between arithmetic and geometric mean representations. Accordingly, the arithmetic means were utilized for subsequent analyses of potential effects because they are simpler, are less likely to understate effects, and are the preferred statistical estimators for inventory calculations (see Appendix E, Sec. I.B).

For inventory calculations, the standard errors of the means of both concentrations and channel widths were used to estimate confidence intervals of the computed inventories.

B. Estimated Inventory

Estimates of the amount of ^{239}Pu present in the affected canyon segments were calculated for two purposes. They provide a basis for making qualitative predictions of future redistribution by hydrologic transport of sediments, and they provide a basis for evaluating the plausibility of this analysis in accounting for the estimated releases into the canyons.

The ^{239}Pu inventories were estimated as the product of the average concentrations in the channels and banks of each segment and the estimated mass of affected sediments and soils derived from average measured physical dimensions and density. These estimates are depicted graphically in Fig. 17. The quantitative estimates are summarized in Table VIII. Two major features of the pattern are evident.

- Most of the plutonium is associated with the banks and inactive channels, as would be expected because the intermittent streamflow inundates the higher ground less frequently than the active channel.
- The largest proportion, about 67%, of the plutonium is found in Lower Pueblo Canyon, as would be expected from the wider, flatter channel that reduces flowrates and leads to deposition of suspended sediments.

The total estimated inventory, based on arithmetic means, is about 630 ± 300 mCi (approximate 95% confidence interval), or 7.9 ± 3.8 grams. This is about 3 times the total of estimated and measured releases into Acid Canyon and the still-onsite DP Canyon as discussed in Sec. 1, Introduction and Background (see also Tables III and VI). This is considered reasonable agreement given the uncertainties discussed above. It is also plausible, considering interpretations of runoff data (see Appendix A, Sec. VII) that suggest relatively little plutonium has been transported into the Rio Grande and interpretations of data from other studies (see Appendix E, Sec. I.B.5) that suggest at least 75% (or 24 mCi) of the releases from DP Canyon have been transported into Lower Los Alamos Canyon. A further indication of the plausibility is reflected in the estimate of total inventory based on geometric means (see Appendix E, Sec. I.3), about 250 mCi or 3.1 grams, which is well within the uncertainty of the arithmetic estimate and corresponds very well with the estimates of releases. The estimate from geometric means showed nearly the same percentage distribution of plutonium between the segments and between channels and banks within segments. These estimates are also compatible with previous studies that made inventory estimates for the channel sediments only, as presented in Appendix A.

One detail of the inventory distribution (not shown in the summary graph or table) may be important to consideration of possible future sediment transport. The inventory estimated to be present in the inactive channel in Lower Pueblo Canyon (see Fig. 17) is dominated by the estimate for the interval between about 1.5 and 3 km upstream (west) from the confluence with Lower Los Alamos Canyon (see Appendix E, Sec. I.B.4). The inactive channel there is broad, giving a large estimated mass of contaminated sediments and soils. This led to a large inventory estimate even with concentration averages of about 3-10 pCi/g. About 80% of the Lower Pueblo Canyon inactive channel inventory is represented by this estimate or about 40% of the total estimated inventory for all segments.

No quantitative inventory estimate was made for the Treatment Plant Site because of the extremely spotty nature of the contamination and the small volume of potentially affected material in comparison with the canyon areas.

C. Transport and Redistribution

The basic inference in terms of future redistribution of plutonium and other contaminants associated with the sediments is that there is a likelihood of transport into Lower Los Alamos Canyon and ultimately into the Rio Grande. The amount and timing of such transport cannot be predicted in any quantitative fashion, largely because of the uncertainty in predicting the spatial and temporal distribution of hydrologic events. Transport over the last 35 years has obviously moved a major portion of the contamination from Acid Canyon downstream to Lower Pueblo Canyon. Runoff events have moved a small portion of the contaminated sediments from Pueblo into Lower Los Alamos Canyon where they have been mixed with other contaminated sediments from Upper Los Alamos Canyon. Runoff in Los Alamos Canyon has carried some contaminated sediments into the Rio Grande, estimated from data for recent years (see Appendix A, Sec. VII) to be on the order of 1 mCi (0.01 gram) of ^{239}Pu per year. On an average basis, this much input would increase the average concentration of ^{239}Pu by about 0.0005 pCi/g on sediments in the Rio Grande in White Rock Canyon down to Cochiti Dam, which is about 30 km downstream. This concentration increment is about 10% of the average measured on sediments in Northern New Mexico beyond the influence of Los Alamos National Laboratory operations, and less than either the measured variability or the detection limits for such samples. Transport in Lower Los Alamos Canyon is likely to continue in this general pattern for some time with some input from periodic runoff in Pueblo Canyon, and expected declining input from Upper Los Alamos Canyon as operational discharges into DP Canyon will be eliminated through planned improvements to the Los Alamos National Laboratory waste treatment system. The major, and unpredictable, future changes would occur as a result of major flooding events in Pueblo Canyon, which could transport a large portion of contaminated sediments into Lower Los Alamos Canyon. Essentially no data exist on flow rates experienced in Pueblo Canyon during the last 35 years to relate to theoretical estimates of potential maximum flow rates with various probabilities of occurrence (return periods) derived in Appendix A. The qualitative judgment based on data for Los Alamos Canyon is that none of the larger potential events have occurred. Los Alamos Canyon maximum flows correspond to theoretical flows with return periods of about 10 years or probability 0.1 in any given year. The best qualitative prediction to be made is that major precipitation events could probably result in flows able to transport a large proportion of the sediments in Lower Pueblo Canyon on downstream into Lower Los Alamos Canyon. The probability of such an event is low in any given year, but over sufficiently long intervals, e.g. 50-100 years, there is the likelihood of at least one such event.

Transport of the radioactivity on sediments is also possible by dissolution in water. Considerable information has been collected on radioactivity in the surface and ground water associated with Acid, Pueblo, and Los Alamos Canyons for many years as part of the environmental monitoring programs at Los Alamos National Laboratory. This information is compiled in Appendix A. For purposes of this interpretive summary, only a few important conclusions are directly relevant.

Transport of radioactivity in solution during snowmelt or rainstorm runoff events is of little consequence in terms of redistributing significant proportions of the radioactivity. Measurements have shown that generally about 1 to 10% of the total activity transported is in solution with the bulk being transported as suspended or bed load sediments. There is some possibility of livestock in Lower Los Alamos Canyon or wildlife drinking runoff water or effluent from the County-operated sewage treatment plant in Pueblo Canyon that has dissolved radioactivity. The levels observed have been generally less than 0.1 pCi/ℓ with maxima on the order of 1 pCi/ℓ. These values are all less than 0.02% of the DOE Uncontrolled Area Concentration Guide (5000 pCi/ℓ) and less than 7% of the EPA gross alpha Maximum Contaminant Level (15 pCi/ℓ) for drinking water (see Table X). Dose estimates for the livestock food pathway are considered in the next section. The surface flows from runoff or sewage plant effluent are not, as far as can be determined, used by humans.

Water from the effluents or natural runoff surface flows infiltrates the shallow channel alluvium in the canyons. The quality of this water in Pueblo Canyon has been affected by the discharge of industrial and sanitary sewage effluents over the years (see Appendix A). Most of the observable changes have been due to nonradioactive chemicals such as nitrates and fluorides. One surface discharge of this alluvial water occurs at Hamilton Bend Spring, near the present County-operated Bayo Treatment Plant. Water from this small spring has been monitored routinely. In recent years traces of plutonium have been measured, but most samples have been at or below detection limits of about 0.03 pCi/ℓ. Tritium is measurable at above background levels, but the concentrations are less than 10% of the EPA limit for drinking water and a fraction of 1% of the DOE Uncontrolled Area Concentration Guides (see Table X). This is expected because tritium was released in the effluents and, as part of a water molecule, behaves just as normal water.

Water infiltrating from this alluvium recharges a small body of perched water under the midreach of Pueblo Canyon. Samples from a test well have shown the chemical quality to reflect the characteristics of the alluvial water. The only radioactivity measurable in these samples is tritium; plutonium has been consistently below the limits of detection (see Appendix A, Sec. VIII).

Perched water also occurs in the basaltic rocks underlying Pueblo Canyon near its confluence with Lower Los Alamos Canyon. This perched water, at depths of about 50 to 70 m, is recharged from the alluvial water in Lower Pueblo Canyon and Upper Los Alamos Canyon. Its quality has been monitored by samples from a test well and from the discharge of Basalt Spring in Los Alamos Canyon about 1 km below the confluence with Pueblo Canyon. Though nonradioactive chemical quality (e.g., concentrations of Cl and NO_3) has changed as would be expected from influence by industrial and sanitary sewage effluents, no radioactivity above detection limits has been observed (see Appendix A, Sec. VIII). None of these alluvial or perched ground water bodies are used for any domestic or agricultural application.

The main aquifer that provides the municipal and industrial supply for Los Alamos is located at much greater depth in the Tesuque and Puye formations beneath Acid and Pueblo Canyons. It is separated from the alluvial water by 180 to 300 m of dry, unsaturated tuff and volcanic sediments. It is separated from the perched water bodies by 112 to 192 m of unsaturated volcanic sediments. Thus there is no known hydrologic connection between the main aquifer and either the

shallow alluvial or perched aquifer. In Lower Los Alamos Canyon, where the channel cuts down into the Puye and Tesuque formations, the water in the main aquifer is under confined or artesian conditions that provide hydrologic isolation from surface or alluvial water. Analyses of water samples taken from the supply wells since they were drilled have shown no influence on either chemical or radiochemical quality in the main aquifer attributable to release of any effluents into Acid, Pueblo, or Los Alamos Canyons.

II. AIRBORNE RADIOACTIVITY

Radioactivity on soils and sediments can be redistributed in the environment by resuspension, whereby small particles of soil or dust are moved and become airborne through the action of wind or other mechanical forces. This raises the possibility of exposure to the radioactivity through inhalation. This potential mechanism, or pathway, was examined by analysis of actual measurements of airborne radioactivity in the vicinity of Los Alamos and by the application of a simple theoretical model to the data on radioactivity on the canyon sediment and soil.

A. Measurements

Continuous sampling for airborne radioactivity has been conducted routinely at Los Alamos National Laboratory as part of its environmental surveillance program. Data from several stations for the 5-year period 1974 through 1978 were examined to estimate the potential contribution from resuspension (see Appendix E, Sec. II). The stations selected included four on the mesa tops at various distances from Pueblo Canyon and other Los Alamos National Laboratory facilities, one near the midpoint of Lower Pueblo Canyon at the County-operated sewage treatment plant (see Fig. 13), and one located in Santa Fe, some 40 km to the southeast (see Fig. 1). Data from measurements made in New York City were also compiled as another indicator of worldwide fallout. The basic conclusions include the following.

- Measurements of annual average ^{239}Pu concentrations found in Pueblo Canyon showed the same temporal pattern as locations representative of only worldwide fallout.
- Some possible, but generally not statistically significant, differences in individual airborne plutonium concentration measurements during 6-8 week sampling periods during 1976-1977 at various locations in Los Alamos were apparently not related to proximity to Acid and Pueblo Canyons or to measurements of total airborne particulates.
- Measurements during one year (1976) of particularly low worldwide fallout levels permitted a good estimate of the long-term maximum potential contribution of resuspension to airborne concentrations of plutonium in Pueblo Canyon. This estimate (3 aCi/m^3) is about 0.005% of the appropriate DOE Concentration Guide or 0.3% of the proposed EPA derived air concentration limit (see Table X).

The most useful data of the 5 years analyzed came from 1976 when the annual averages of airborne concentrations of ^{239}Pu were about 20 to 25% of preceding or succeeding years. This enhances the sensitivity of any analysis looking for local effects because any such effects would be a much larger proportion of the total measurement. Two factors contributed to the unusually low year: (1) there was very little downmixing of worldwide fallout from the stratosphere into the troposphere that usually occurs in the late spring and (2) there had been no atmospheric nuclear tests since June 1974.

The data on ^{239}Pu concentrations measured during 1976 at the sewage treatment plant in Pueblo Canyon, in Santa Fe, and in New York are shown in Fig. 18. In general, all three locations display the same pattern throughout the year, in most cases not differing by as much as the measurement errors. The data from Santa Fe are assumed to represent fallout background for Northern New Mexico well beyond any potential influence of Los Alamos operations or resuspension from the canyon areas. During the first and seventh sampling periods shown (12/12/75-2/2/76 and 9/13/76-10/26/76), the airborne ^{239}Pu concentration in Pueblo Canyon was higher than at Santa Fe (significant for $\alpha = 0.1$ but not for $\alpha = 0.05$) by as much as 2.8 ± 2.8 aCi/m^3 (90% confidence interval). During the fifth sampling period (6/21/76-8/2/76) the measurement in Pueblo Canyon was significantly less than in Santa Fe ($\alpha = 0.05$). However, the monthly geometric mean total particulates as measured in the Los Alamos townsite were higher during months in the second, third, fourth, eighth, and ninth sampling periods shown, when no significant differences in plutinoum concentrations occurred. Thus, there are only marginal differences between airborne concentrations of ^{239}Pu in Pueblo Canyon and worldwide fallout levels measured elsewhere. There is no clear relation between airborne concentrations of ^{239}Pu and atmospheric dust loading. Evaluation of data from other air sampling locations in the Los Alamos townsite might be questioned because of a presumed greater potential for influence from airborne emissions from operating Los Alamos National Laboratory facilities. Some apparent differences in individual sampling periods may plausibly be related to spatial relationships, but there is no consistency in the pattern with time and the annual averages over several years show no consistent differences related to location (see Appendix E, Sec. II). Most important, additional data from many more sampling locations, as reported annually by the Los Alamos National Laboratory environmental monitoring program (e.g., Refs. 12, 13, 14, 15, and 16) have shown no statistically discernable effect on airborne ^{239}Pu concentrations outside the Los Alamos National Laboratory site.

The 1976 data are the soundest bases for an estimate of the maximum effect of resuspension of contaminated sediments and soils on the airborne concentrations of ^{239}Pu in Pueblo Canyon. In addition to the very low worldwide fallout, 1976 was somewhat drier than average (total precipitation about 76% of long-term average) and the annual geometric mean suspended airborne particulates were slightly higher than normal (37.6 μg/m^3 compared to 35 μg/m^3). These conditions would all be expected to maximize resuspension. The largest increment in ^{239}Pu concentration measured during the year was 2.8 aCi/m^3 in Pueblo Canyon compared to Santa Fe. This value, rounded to 3 aCi/m^3, was used in subsequent analysis as the upper bound on the average increment of ^{239}Pu airborne concentration that could be expected over a typical year.

The likely maximum short term concentration of airborne ^{239}Pu in Pueblo Canyon was based on one anomalous measurement that occurred during the last quarter of 1977 (see Appendix E, Sec. II). The value was 166 aCi/m^3, about 5 to 10 times greater than any other Los Alamos National Laboratory station measured during the same period, and was 2 to 3 times greater than measured during previous sampling periods in 1977. All stations measured higher concentrations in 1977 than in 1976 because there were fallout contributions from a spring mixing as well as from three atmospheric nuclear tests by the Peoples Republic of China, two of which took place late in 1976 and one in September of 1977 (see Appendix E, Table E-VIII). The spatial and temporal variation in measurements was much larger because of these inputs. A final interpretive factor is that the geometric mean airborne particulate concentration during the last quarter was lower than any previous quarter of the year, suggesting that contributions from resuspension would be minimized. Despite these contributing uncertainties, the value (rounded to 170 aCi/m^3) was taken as a likely maximum short term concentration of airborne ^{239}Pu that might be expected in Pueblo Canyon.

B. Theoretical Estimates

A theoretical model was applied as another approach to resuspension and as a means of estimating the contribution of resuspension in other parts of the canyon system where no direct measurements were available. The mass loading model was selected because of conceptual simplicity. Estimated airborne concentrations of radioactivity are calculated as the product of the mass concentration of particulates in the air and the activity concentration of radioactivity on the soil. Refinements were included to account for the observed higher concentrations on the smaller, more-resuspendable particles (enrichment factor), and for the small proportion of the contaminated area along the channels (area modification). Details of the assumptions and calculations are presented in Appendix E, Sec. III.C.1. The enrichment factor was calculated using actual data on activity fractions for different particle size increments from previous radioecology studies in the Los Alamos Canyons and the method described in Ref. 17. Soil and sediment concentrations were taken to be the arithmetic means for the various channel and bank components of the canyon segments with some adjustment to account for slightly higher concentrations occurring in the top 1-cm layer. The area modification was taken to be the ratio of the channel and bank area considered contaminated to the horizontal projection of the canyon area containing the segment. The annual geometric mean particulate mass loading observed in the Los Alamos townsite, 35 $\mu g/m^3$, was used as representative of the area.

Table XI presents the estimates of incremental airborne ^{239}Pu concentrations attributable to resuspension as calculated from both the actual measurements and the mass loading model. The range of annual average concentrations of ^{239}Pu measured in Santa Fe is included at the bottom of the table for comparative purposes. The other columns in the table give the relation of the estimated concentration increments and background to the DOE Concentration Guide (CG) and to the proposed EPA derived concentration limit. The DOE CG (60 000 aCi/m^3, see Table X) is that for ^{239}Pu in Uncontrolled Areas, i.e., accessible to the public, with continuous occupancy, and the lung is considered the critical organ. The EPA value (1000 aCi/m^3, see Table X) is given in its proposed Federal guidance as a derived air concentration that can reasonably be predicted to result in dose rates less than the guidance recommendations. The proposed EPA recommendations "... are for guidance on possible remedial actions for the protection of the public health in instances of presently existing contamination..." (Ref. 18). Most of the estimated annual increments are in the same range as worldwide fallout observed in recent years. The exception is the estimate for Acid Canyon, which is about 4.5 times the 5-year average for fallout. The estimated maximum short term value for Pueblo Canyon is about 10 times the 5-year average. The measurements in Lower Pueblo Canyon (Stratum DE) indicate that the theoretical estimates probably overstate the contribution of resuspension by as much as a factor of 10.

The activity ratios fromTable IX may be applied to these estimated ^{239}Pu concentrations to obtain estimates of other transuranics. As the proposed EPA derived limit applies to transuranic alpha activity, only the alpha portion of the ^{241}Pu activity should be counted. The total transuranic alpha airborne activity would thus be estimated as 1.13 times,or 13% more than the ^{239}Pu value for current conditions.

III. EXTERNAL PENETRATING RADIATION

Radioactivity on soils and sediments can contribute to radiation doses by the emission of gamma and x rays. The potential increments of such external radiation that could be attributed to the residual, above background contaminants were addressed in this study by measurements in the environment and by theoretical calculation.

Measurements were made during the first quarter of 1978 by thermoluminescent dosimeters (TLDs) placed at 20 locations in the vicinity of the treatment plant site and along the different canyon bottom segments (see Appendix E, Sec. III.A.). These measurements represented total doses without discrimination between the contribution from the contaminated soils or sediments and that from the natural cosmic and terrestrial sources. Accordingly, they can be compared to measurements made in areas representing only natural sources and to estimates of potential contaminant contributions. Such estimates are subject to considerable uncertainty because of the large temporal and spatial variation in natural background.

Natural background external penetrating radiation variations have been well documented in the Los Alamos area. Most of the variation is due to differences in the terrestrial component as the cosmic component is almost entirely determined by elevation above sea level. In the Los Alamos area the cosmic contribution is about 60 mrem/yr, or about 6.8 μrem/h. The terrestrial component, on the other hand, ranges from about 30 to 90 mrem/yr or about 3 to 10 μmrem/h, depending on time and location. The variety of geologic formations with different amounts of natural radioactive elements (principally potassium and the uranium and thorium chains) determines most of this range. Temporal differences largely associated with soil moisture and snow cover, which affect the accumulation of natural radon daughters, often amount to as much as ±25% from one quarter to the next at a given location. These geologic and temporal variations in the terrestrial component result in total quarterly dose measurements for the 12-station perimeter group of the Los Alamos National Laboratory routine monitoring program ranging from 9.4 μrem/h to 17.4 μrem/h between 1976 and 1978. These stations are located on the mesas in the townsite and other places adjacent to the Los Alamos National Laboratory boundary.

During the first quarter of 1978, the perimeter group measured an average of 12 μrem/h, slightly lower than the 4-year average of 13.4 μrem/h, as shown in Table XII. The TLD measurements in the four canyon areas averaged 12 to 19 μrem/h. The individual measurements contributing to the averages had 95% confidence intervals of ±10 to 17% with the implication that the accuracy of the means cannot be much better in spite of the small standard deviations of the means. There is no significant difference between the Lower Los Alamos or Lower Pueblo Canyon averages and the perimeter group average taken to represent typical background for the area. The apparent differences of 4 to 7 μrem/h for the Middle Pueblo Canyon and Acid Canyon are probably largely due to natural circumstances, different geological formations, and a much narrower, steeper canyon geometry resulting in a larger proportionate terrestrial dose than in the wider canyon segments or on mesa tops. At the site of the former waste treatment plant, the apparent difference is primarily due to measurements made in small areas in the vicinity of the untreated waste outfall and the vehicle decontamination facility where maximum levels of surface contamination were found (see Fig. 16).

Significant support for these conclusions comes from the theoretically calculated contributions to be expected from the average measured concentrations of radioactivity on the sediments and soils in different strata. Dose rates from above background concentrations were calculated for ^{137}Cs, ^{234}U, $^{238,239}Pu$ and ^{241}Pu, and ^{241}Am. The method assumed doses were from an infinite plane, with the radioactivity distributed vertically, and accounted for absorption and scattering in the soil (see Appendix E, Sec. III.B.). The estimated total contributions to doses from these isotopes are presented in Table XII. The estimated contributions in the canyons range from less than 0.01 μrem/h in Middle Pueblo Canyon to 1.1 μrem/h in Acid Canyon. These calculated values are compatible with and support the TLD measurements and interpretation of importance of variations from natural factors.

The highest estimates of dose contributions from contaminants on soil were based on measurements of concentrations in the small areas with the highest levels of radioactivity. In the vicinity

of the untreated waste outfall, the estimate of 50 μrem/h is due mainly to ^{241}Am and ^{137}Cs. The infinite plane assumption obviously overstates the estimate because the maximum concentrations occur in areas with dimensions on the order of tens of centimeters. Similarly, in the vicinity of the vehicle decontamination facility, where the maximum contamination occurs in areas of a few meters, the 40 μrem/h estimate is also overstated.

During the course of the field work, many measurements were made with portable instruments (see Appendix E, Sec. III.A.). The readings observed with these instruments were compatible with these interpretations and the TLD measurements. Because of different energy responses, the readings from such instruments cannot be directly interpreted as dose estimates (see Appendix B). The purpose of the instrumental surveys was to increase the confidence that no major areas of contamination had been overlooked.

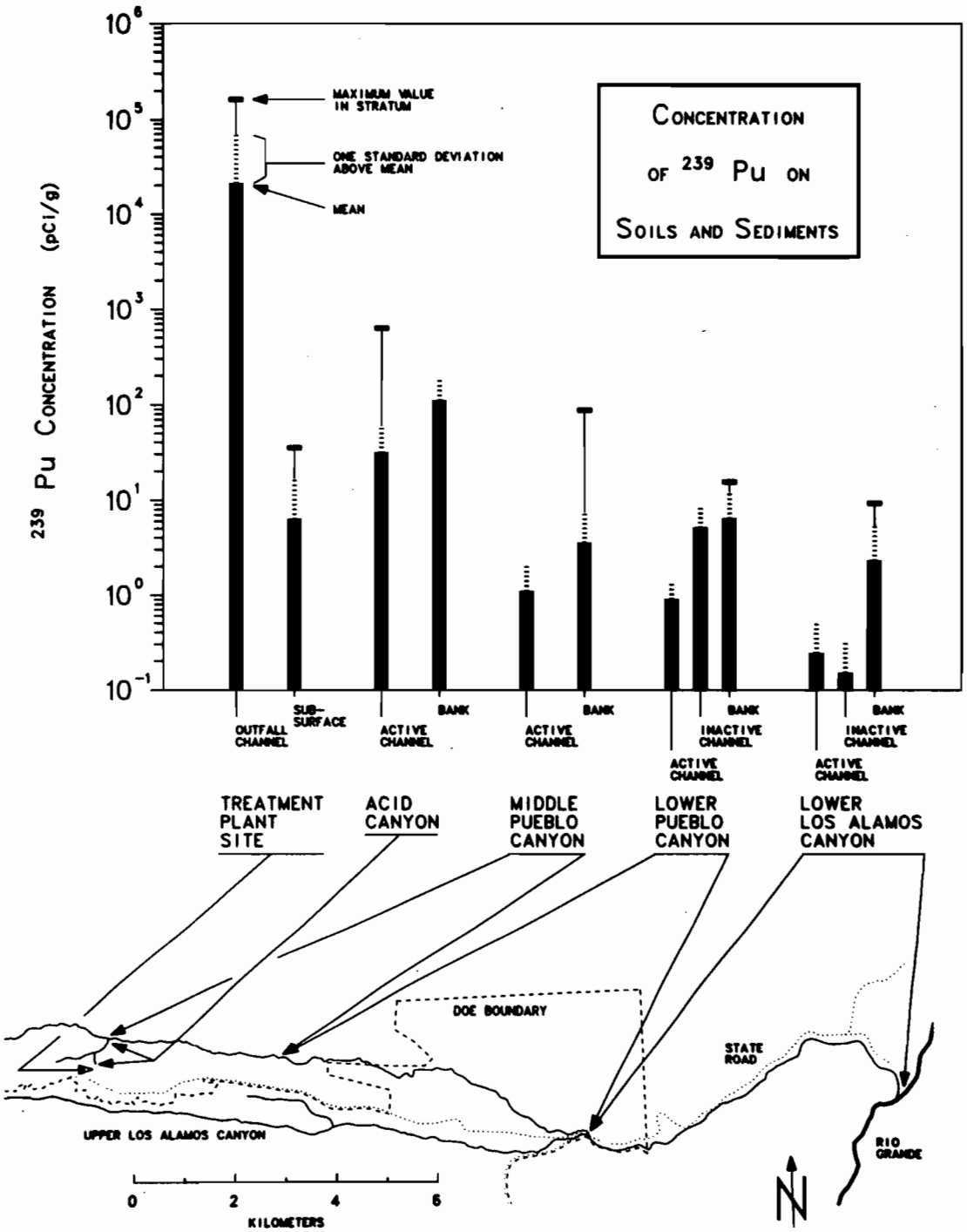

Fig. 15.
Concentration of ^{239}Pu on soils and sediments by location.

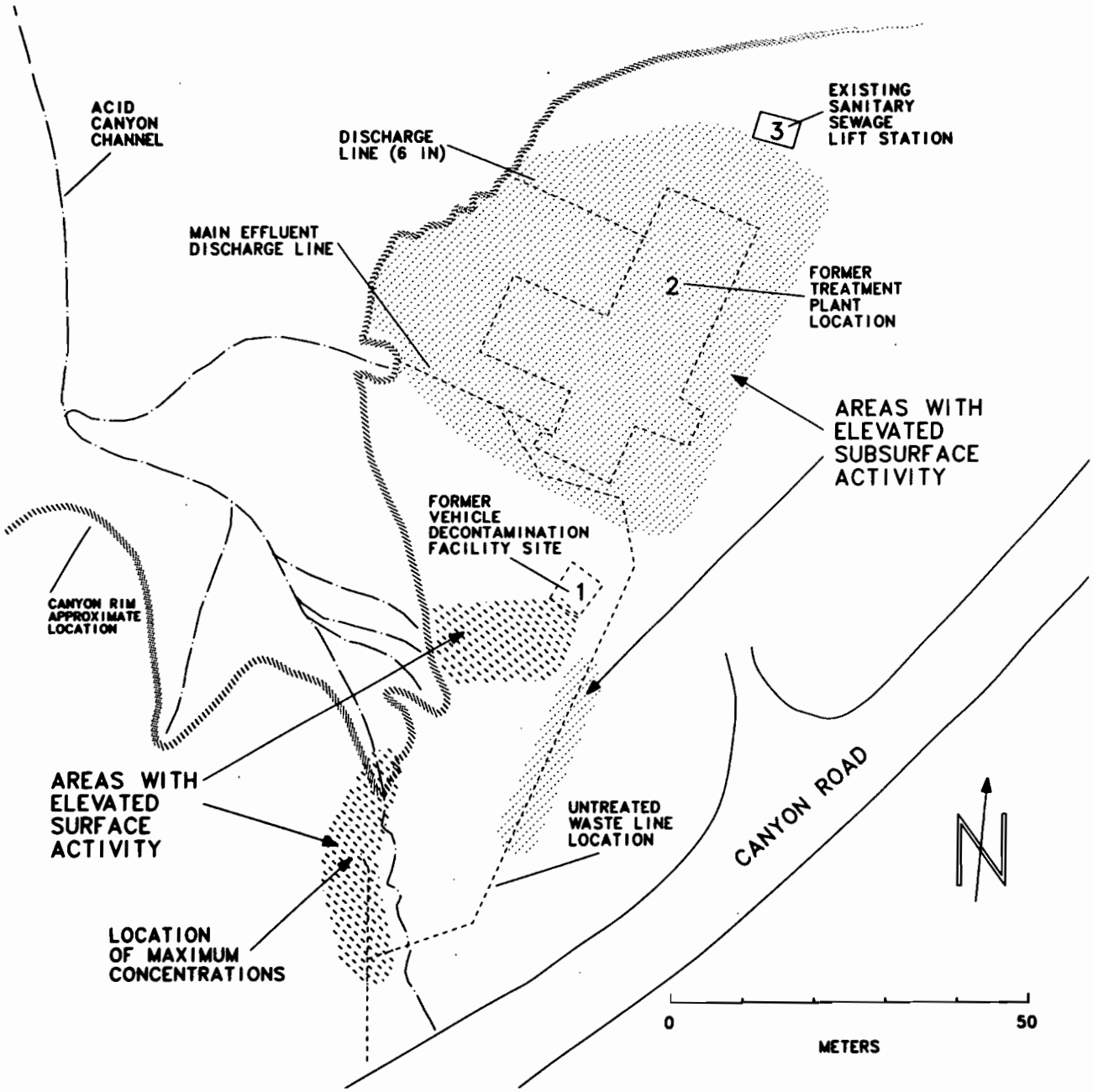

Fig. 16.
General locations of above background activity in vicinity of treatment plant site.

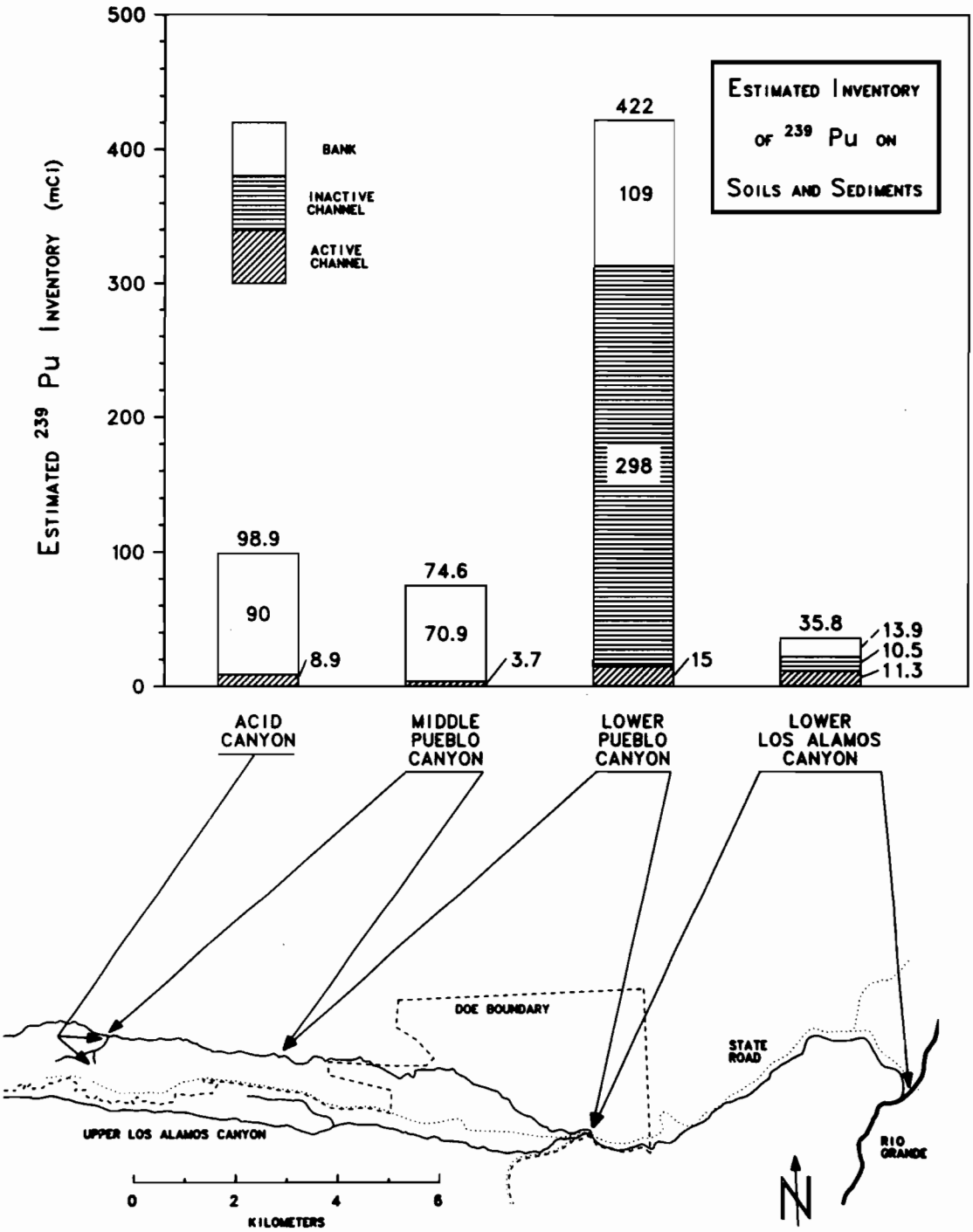

Fig. 17.
Estimated inventory of ^{239}Pu on soils and sediments by location.

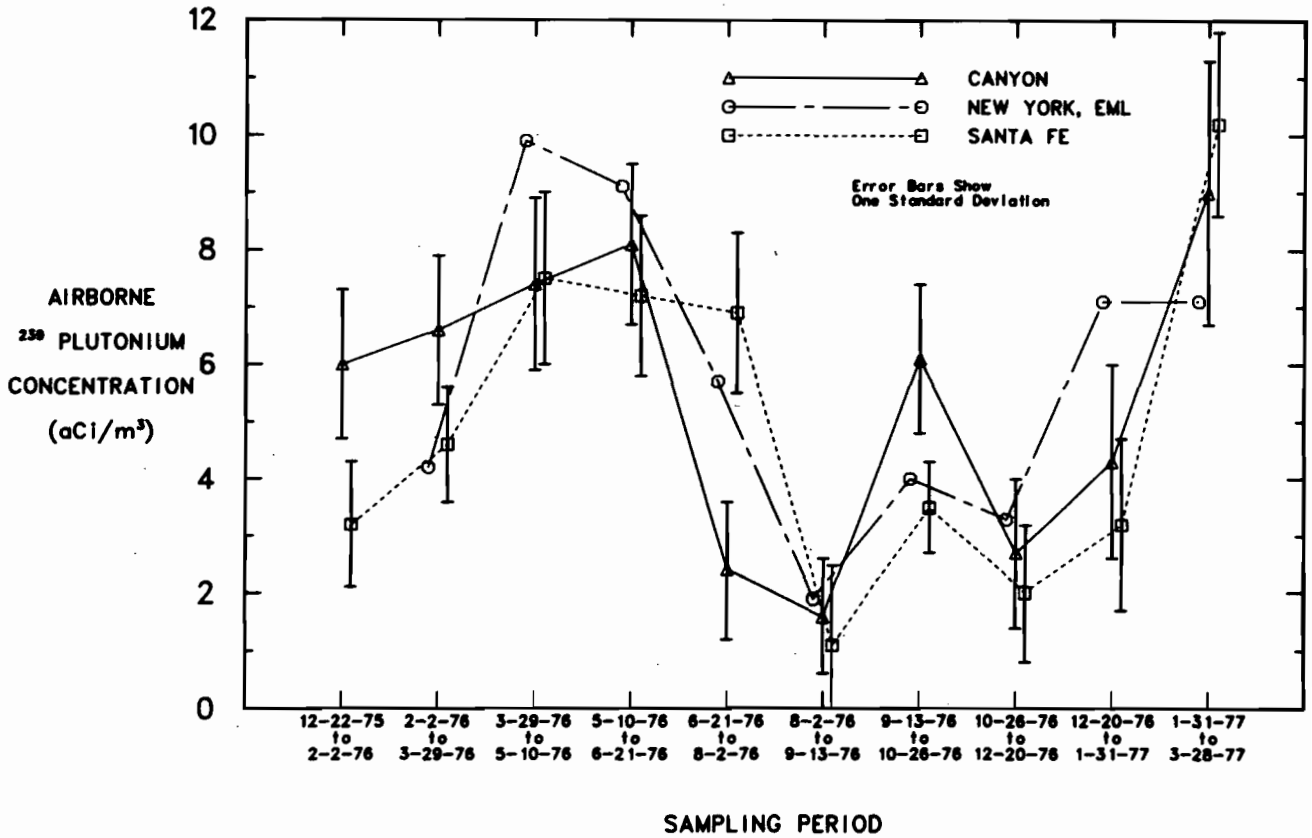

Fig. 18.
Concentrations of airborne ^{239}Pu at three locations during 1976-1977.

TABLE VIII

SUMMARY OF DATA

STRATUM:	Treatment Plant Site: Subsurface	Treatment Plant Site: Surface	Acid Canyon	Mid-Pueblo Canyon	Lower Pueblo Canyon	Lower Los Alamos Canyon	Northern New Mexico Background Concentrations
Radioactivity Concentrations ($\bar{x} \pm s$)[a]							
^{239}Plutonium (pCi/g)							0.008 ± 0.010
Maximum in Stratum	35	163 000	630	88	15.5	9.3	
Average in Active Channel	6.3 ± 10.6		31 ± 29	1.1 ± 1.1	0.9 ± 0.5	0.24 ± 0.26	
Average in Inactive Channel			---	---	5.1 ± 3.6	0.15 ± 0.18	
Average in Banks		21 000 ± 49 000	110 ± 75	3.5 ± 4.0	6.4 ± 5.8	2.3 ± 3.0	
Other Isotopes							
Concentration Increment Above Background							
^{90}Sr (pCi/g)	0.1 - 10 (Range)	0.5 - 230 (Range)	1.0 ± 1.4	N.S.[b]	N.S.	N.S.	0.25 ± 0.27
^{137}Cs (pCi/g)	0 - 3 (Range)	0.1 - 180 (Range)	1.9 ± 4	N.S.	N.S.	0.27 ± 0.18	0.32 ± 0.30
Uranium (μg/g)	1 - 36 (Range)	1 - 600 (Range)	1.3 ± 1	N.S.	1.1 ± 0.6	2.0 ± 0.6	1.8 ± 1.3
^{239}Plutonium Inventory Estimate							
Stratum Inventory (mCi, $x \pm 2s_{\bar{x}}$)[c]			98.9 ± 52	74.6 ± 83.4	422 ± 281	34.8 ± 19.9	
Percent of Total (%)			15.7	11.8	66.8	5.7	
Distribution in Stratum							
Active Channel (%)			9	5	4	32	
Inactive Channel (%)			---	---	70	29	
Bank (%)			91	95	26	39	
Physical Characteristics							
Channel Length (m)			750	3250	6050	7400	
Average Width (m)			2.3	15	33	35	
Area with Greater than Background Concentration (m²)	~3500	~500	~1750	~50 000	~200 000	~260 000	

[a]s denotes the standard deviation of the data population; in this particular table, the numerical value of $\bar{x} \pm s$ may be taken to represent the upper limit of the confidence interval on the mean with at least 95% confidence.

[b]N.S. means "no significant difference."

[c]$s_{\bar{x}}$ denotes the standard error of the calculated estimate; in this line $\bar{x} \pm 2s_{\bar{x}}$ may be taken as an approximate 95% confidence interval of the estimate.

TABLE IX

RELATIONSHIP OF ^{239}Pu AND OTHER TRANSURANIC CONCENTRATIONS

Activity Ratio	Values Used for Analysis: Current Condition (~1978)	Values Used for Analysis: Future Condition (~2050)
$^{238}Pu/^{239}Pu$	0.03	0.017
$^{241}Pu/^{239}Pu$[a]	1.5	0.045
$^{241}Am/^{239}Pu$	0.1	0.15

[a] ^{241}Pu is primarily a β-particle emitter; the activity ratios in the table are for total activity; α-activity is about 0.002% of the total.

TABLE X

STANDARDS AND GUIDES FOR RADIATION AND RADIOACTIVITY

DOE Radiation Protection Standards for External and Internal Exposures[a]

Individuals and Population Groups in Uncontrolled Areas

Type of Exposure	Annual Dose Equivalent or Dose Commitment[b]: Based on Dose to Individuals at Points of Maximum Probable Exposure	Annual Dose Equivalent or Dose Commitment[b]: Based on an Average Dose to a Suitable Sample of the Exposed Population
Whole body, gonads, or bone marrow	0.5 rem (or 500 mrem)	0.17 rem (or 170 mrem)
Other organs	1.5 rem (or 1500 mrem)	0.5 mrem (or 500 mrem)

DOE Concentration Guides for Radioactivity in Air and Water Above Natural Background in Uncontrolled Areas[c]

Isotope	Media	Concentration: In Units of Original Reference	Concentration: In Units Used in This Report
^{239}Pu	Water	5×10^{-6} μCi/mℓ	5000 pCi/ℓ
^{239}Pu	Air	6×10^{-14} μCi/mℓ	60 000 aCi/m^3
^{3}H	Water	3×10^{-3} μCi/mℓ	3 000 000 pCi/ℓ

EPA Maximum Contaminant Levels from Natural Interim Primary Drinking Water Regulations[d]

Isotope	Media	Concentration
^{3}H	Water	20 000 pCi/ℓ
Gross Alpha (including ^{226}Ra but excluding radon and uranium)	Water	15 pCi/ℓ

TABLE X (cont)

EPA Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment[e]

Maximum Annual Alpha Radiation Dose Rate as Result of Exposure to Transuranium Elements:

1 mrad/yr to pulmonary lung	(approximately 10 mrem/yr)
3 mrad/yr to bone	(approximately 150 mrem/yr)

Derived Air Concentration Reasonably Predicted to Result in Dose Rates Less Than the Guidance Recommendations:

In Units of Original Reference	In Units Used in This Report
1 fCi/m^3	1000 aCi/m^3

(for alpha emitting transuranium nuclides on an activity median aerodynamic particle diameter not to exceed 0.1 μm)

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[a]See Reference 29.

[b]To meet the above dose commitment standards, operations must be conducted in such a manner that it would be unlikely that an individual would assimilate in a critical organ, by inhalation, ingestion, or absorption, a quantity of a radionuclide(s) that would commit the individual to an organ dose exceeding the limits specified in the above table.

[c]See Reference 29.

[d]See Reference 30.

[e]See Reference 18.

TABLE XI

POTENTIAL CONTRIBUTIONS OF RESUSPENSION TO ^{239}Pu AIRBORNE RADIOACTIVITY

	^{239}Pu Concentration (aCi/m^3)	Percent of DOE Concentration Guide[a] (%)	Percent of Proposed EPA Derived Limit[a] (%)
Analysis of Measured Airborne ^{239}Pu Concentrations (Lower Pueblo Canyon)			
Likely Maximum Annual Increment from Resuspension	3	0.005	0.3
Likely Maximum Short-Term Increment from Resuspension	170	0.3	17
Theoretical Contributions of Resuspension to ^{239}Pu Airborne Concentrations			
Acid Canyon	71	0.1	7
Middle Pueblo Canyon	25	0.04	2.5
Lower Pueblo Canyon	36	0.06	3.6
Lower Los Alamos Canyon	2.9	0.005	0.3
Range of ^{239}Pu from Worldwide Fallout 1974-1978 at Santa Fe, NM			
Low (1976)	3.8	0.006	0.4
5-year average	16	0.03	1.6
High (1978)	24	0.04	2.4

[a]See Table X.

TABLE XII

EXTERNAL PENETRATING RADIATION
Measurements and Estimates of Contaminant Contributions
(μrem/h)

Location	Measurement by TLD First Quarter 1978	Theoretical Contribution from Above Background Contaminants
	{$\bar{x}$ ± 1 S.D. or range}	
Lower Los Alamos Canyon	12 ± 1	0.2[a]
Lower Pueblo Canyon	13 ± 1	<0.03
Middle Pueblo Canyon	16 ± 1	<0.01
Acid Canyon	19 ± 3	1.1[a]
TA-45 Site	19 ± 3	
Untreated Waste Outfall	16-18	50[b] (maximum)
Vehicle Decontamination Facility	22-26	40[a] (maximum)
LASL Surveillance Program Perimeter Group[c]		
First Quarter 1978	12 ± 1	
Four-Year Group Average	13.4 ± 1	
Range of Separate Station Values	9.4 - 17.4	

[a] ^{137}Cs main contributor.

[b] ^{241}Am and ^{137}Cs main contributors.

[c] Not affected by Los Alamos operations.

5. POTENTIAL DOSE EVALUATION AND INTERPRETATION

The significance of the data on concentrations of radioactivity on soils and sediments, radioactivity on airborne particulates, and external penetrating radiation may be evaluated in terms of the doses that can be received by people exposed to the conditions. The doses can be compared to natural background and appropriate standards or guides for one type of perspective. The doses can also be used to estimate risks or probabilities of health effects to an individual, providing another type of perspective more readily compared to other risks encountered. This section summarizes the analysis of potential doses and risk estimates. The detailed analysis is presented in Appendix E. Readers desiring more information on concepts of radioactivity, radiation, and dose interpretation may be helped by Appendix F, Evaluation of Radiation Exposures.

I. BASES OF DOSE ESTIMATES AND COMPARISONS

Doses were calculated for various pathways that could result in the inhalation or ingestion of radioactivity. The calculations were based on theoretical models or factors from standard references and health physics literature as detailed in Appendix E. The doses are expressed in fractions of rems, where a millirem (mrem) is 1/1000 of a rem, and a microrem (μrem) is 1/1 000 000 of a rem. They are generally expressed as dose rates, i.e. the radiation dose received in a particular time interval. The rem is a unit that permits direct comparison of doses from different sources, such as x rays, gamma rays, and alpha particles, by accounting for the differences in biological effects from the energy absorbed from different radiations and isotope distributions. These doses can be compared to the DOE Radiation Protection Standards shown in Table X, which are expressed as the permissible dose or dose commitment in addition to natural background radiation and medical exposures. First year doses represent the dose received during the first year that a given radioactive isotope is ingested or inhaled. Because most of the isotopes of concern in this study are retained in various organs in the body for more than a year, 50-year dose commitments were also calculated. The 50-year dose commitments represent the total dose that would be accumulated in the body or specific critical organs over a 50-year period from ingestion or inhalation during the first year. (Alternatively, the numerical values can also be interpreted to represent the annual dose rate during the 50th year given continuous exposure over all 50 years.) The 50-year commitments are always as large or larger than 1st year doses. In this summary, only the 50-year commitments are compared to the standards.

Conceptually, this is in agreement with the recommendations of the International Commission on Radiological Protection (ICRP) that in effect charge the entire dose commitment against the year in which exposure occurs for regulatory purposes (Ref. 19). The use of the 50-year dose commitment also permits making estimates of risk over a lifetime from the given exposure and simplifies comparisons between different exposure situations.

The dose commitments were calculated using published factors from references (Refs. 20 and 21) currently used in regulation. The dose models employed in the derivation of these factors are based primarily upon the 1959 report of Committee 2 of the ICRP as updated by ICRP reports 6 and 10. These factors were chosen partly to provide a consistency between the evaluations of different FUSRAP sites. Other methods of computing doses are available and are considered more up-to-date in terms of utilizing the current understanding of the behavior of radionuclides in the body (e.g., Refs. 19 and 22). Additionally, there are conceptually different approaches emphasizing the dose at the time of maximum dose rate following exposure as the basis for comparison with standards (e.g., Refs. 17, 23, and 24). This is significant for isotopes such as plutonium that accumulate in certain parts of the body and can lead to a constantly increasing dose rate under

conditions of chronic exposure. One such approach has been proposed by the EPA as guidance for Federal agencies (Ref. 18) in regard to plutonium and is used later as an alternative means of evaluating potential continuous occupancy of one canyon area. These other approaches do not yield dose estimates or comparisons with standards sufficiently different from the methods used in this report to make any significant difference in the conclusions drawn for the radionuclides of concern in this evaluation. For example, under conditions of chronic exposure to airborne ^{239}Pu, the radiation dose in the year of maximum dose rate (taken to be the 70th year) calculated by the methods of Healy (Ref. 24) or the EPA (Ref. 17) would give organ specific estimates ranging from about 1/4 (for bone) to 2.6 (for lung) times the values given in this report. These factors are about the same size as other uncertainties in the data (see Sec. 4.I.A) and smaller than some of the intentionally overestimated assumptions (see Sec. 4.II.B) incorporated in this evaluation. Thus there would be no significant changes in the relative ranking or order of magnitude of estimated doses and risks if other methodologies were used.

The estimates of radiological risks from doses, presented in Table I of the summary chapter, were based on the risk factors recommended by the ICRP (Ref. 25). Multiplying an estimated dose and the appropriate risk factor yields an estimate of the probability of injury to the individual as a result of that exposure. The risk factors used are

For uniform whole body dose	
Cancer mortality	1×10^{-4} per rem whole body
For specific organ doses	
Lung cancer	2×10^{-5} per rem to lung
Bone cancer	5×10^{-6} per rem to bone.

As an example, a whole body dose of 10 mrem/yr (1×10^{-2} rem/yr) would be estimated to add a risk of cancer mortality to the exposed individual of 1×10^{-6} per year of exposure, or 1 chance in 1 000 000 per year of exposure.

Such risk estimates must be placed in appropriate contexts to be useful as a decision-making tool. One comparison is with other types of risks encountered in normal life that may result in early mortality. Table II (in Sec. 1) of this report presented a range of selected examples of activities and risks that increase chances of death (from Refs. 26 and 27). A second useful comparison is an estimate of the risk that can be attributed to natural background radiation. Radiation from various natural external and internal sources results in exactly the same types of interactions with body tissues as those from so-called "man-made" radioactivity. Thus, the risks from a given dose are the same regardless of the source.

Natural background radiation for people in the Los Alamos area consists of the external penetrating dose from cosmic and terrestrial sources, cosmic neutron radiation, and self-irradiation from natural isotopes in the body. The several year average for external penetrating radiation measured by a group of 12 perimeter stations located mainly in the Los Alamos townsite is about 117 mrem/yr. Cosmic neutrons contribute about 17 mrem/yr, and average self-irradiation, largely from natural radioactive potassium (^{40}K), is about 24 mrem/yr. These give a combined dose of about 158 mrem/yr. Because of the variations in the terrestrial component with location and time of year, this value is probably valid to about ±25% for most of the Los Alamos population. For purposes of comparison we will use a rounded value of 150 mrem/yr as typical natural background in the area. This can be interpreted, using the ICRP risk factors, to represent a contribution to the risk of cancer mortality of 1.5×10^{-5} (15 chances in 1 000 000) for each year of exposure or a risk of 8×10^{-4} (8 chances in 10 000) in 50 years of exposure to natural background radiation. As perspective, estimates of the overall U.S. population lifetime risk of mortality from cancer induced by all causes are currently about 0.2 (2 chances in 10, Ref. 28).

II. POTENTIAL DOSES UNDER PRESENT CONDITIONS

Given present conditions of land use and the residual contamination in the affected areas, there are two basic groups (not mutually exclusive) of the public to be considered. One group is the normal residential and working population in Los Alamos County. Measurements of airborne radioactivity and external penetrating radiation over many years as part of the Los Alamos National Laboratory routine environmental monitoring program lead to the conclusion that this group is not receiving any increments of radiation exposure attributable to the residual contamination.

The second group includes those who occupy the canyon areas for varying periods of time. The occasional users—hikers, picknickers, horseback riders, and others—spend only a small fraction of any given year in the affected areas. The residents of Lower Los Alamos Canyon—several households living at Totavi and Otowi—on land controlled by the San Ildefonse Pueblo, spend a large fraction of any given year in that one portion of the affected area. Commuters and travelers on State Road 4 also occupy Lower Los Alamos Canyon for varying periods (see Fig. 12 for general locations).

The potential for exposure is dependent, more-or-less linearly, on the amount of time spent in one of the affected areas. For this summary no attempt was made to develop assumptions of the fractions of time spent by any given person or group in various areas. The maximum likely doses for continuous occupancy, throughout a year, are tabulated for each canyon segment in Table XIII. These estimates should overstate average annual doses by varying amounts even in the case of continuous occupancy because of the assumptions used for the analysis and interpretation of data, as detailed in Appendix E. To give two examples: (1) the calculated external penetrating radiation doses are based on the highest averages of soil concentrations in a given segment even though they persist over only small fractions of the total area and are close to the channels, and (2) actual measurements of airborne radioactivity concentrations in Lower Pueblo Canyon suggest that the theoretically estimated resuspension of contaminated soils probably overstates actual average levels by a factor of about 10.

In the four canyon areas (see Figs. 12 and 14), the calculated external penetrating radiation whole body dose for 1 year occupancy ranges from less than 0.1 mrem in Lower Pueblo Canyon to about 10 mrem in Acid Canyon (see Appendix E, Sec. III.B.). (Note that the external penetrating radiation dose is all received in the same year as the exposure occurs, but for risk estimation can also be considered to be the entire dose commitment from that exposure.) The calculated 50-year dose commitments from inhalation of resuspended dust during 1 year range from less than 0.001 to about 0.05 mrem to the whole body, from about 0.001 to about 2.1 mrem to bone, and from about 0.004 to about 0.11 mrem to lung (see Appendix E, Sec. III.C.1). None of these are more than about 2% of the appropriate DOE Radiation Protection Standards (see Table X, Ref. 29), and most are less than 0.5%. In the particular case of Lower Los Alamos Canyon where occupancy factors are likely to be highest, the range is from about 0.4% down to 0.004% of the standard. The maximum contribution to exposure potential in Lower Los Alamos Canyon is that estimated for external exposure, about 1.8 mrem/y, or about 1.1% of natural background.

Several other mechanisms of exposure that might affect a small number of individuals were also considered. The estimated doses from these pathways are also presented in Table XIII. At the site of the former treatment plant, there are some relatively small areas where external penetrating radiation is above background. The unlikely possibility of continuous occupancy of that location is estimated to result in annual exposure about 60 mrem above natural background (12% DOE RPS, see Table X; 40% of natural background). In the drainage from the location of the former untreated outfall, there is a possibility of uptake through an abrasion wound of some contamination from the rock surfaces with highest concentrations (see Appendix E, Sec. III.C.4.).

This is estimated to result in a 50-year dose commitment of about 5.6 mrem to bone (0.3% of DOE RPS, see Table X; 3.7% of natural background). Beef cattle are grazed in Lower Los Alamos Canyon at times (see Appendix E, Sec. III.C.2.). The likely maximum 50-year dose commitment from consumption of the entire liver from a steer grazed there during 2 years is no more than 0.001 mrem to bone or whole body (0.0002% of DOE RPS, see Table X; 0.0007% of natural background).

Actual measurements have confirmed the absence of any pathway doses attributable to potential incremental contributions of residual radioactivity concentrations above worldwide fallout in the Rio Grande (see Appendix E, Sec. III.C.3, and Ref. 30).

No doses were considered likely from the slight elevations of radioactivity measured in some of the shallow alluvial and perched groundwater beneath Pueblo and Upper Los Alamos Canyons because they are not now nor are they likely to be utilized. This ground water is limited in extent and is largely recharged by the effluents from the sanitary sewage treatment plants.

Water supply for the residences at Totavi (see Fig. 12) is taken from the Los Alamos Municipal system and, therefore, not subject to potential contamination.

One private household near Otowi Bridge (see Fig. 12) is on the south bank of Lower Los Alamos Canyon about 600 m east or upstream from the confluence with the Rio Grande. Its well draws water from the alluvium of Lower Los Alamos Canyon. Samples of water from the alluvium appearing as return flow at the mouth of Los Alamos Canyon show no adverse influence from recharge by runoff based on analyses of 10 chemical parameters and tritium (see Appendix A, Sec. III.B.3).

The second house near Otowi Bridge is on the east bank of the Rio Grande north or upstream from the confluence with Lower Los Alamos Canyon. Its well is drilled in the gravels at the edge of the Rio Grande and draws water recharged from the Rio Grande. Therefore, it should not be subject to any potential contamination from Lower Los Alamos Canyon.

The only potential dose resulting from contaminants carried by surface water runoff events was considered as part of the beef cattle pathway analysis. The intermittent runoff is normally quite muddy during peak flows and any signficant human consumption is unlikely.

III. POTENTIAL DOSES UNDER FUTURE CONDITIONS

Two types of changes could occur in the future that would change some potential exposures. The first is the possibility of new development of some of the areas. The second is the alteration of the current occurrence and distribution patterns of radioactivity by natural processes.

Development of part of Lower Pueblo Canyon has been considered as an option to reduce pressure on residential housing in Los Alamos County (see Fig. 13). Most of the land suitable for possible development is presently under DOE control; the balance is owned by the County. Potential doses to hypothetical future residents of Lower Pueblo Canyon would include those from external penetrating radiation and general resuspension exposure as discussed above and summarized in Table XIII. These doses are less than 0.2% of natural background (external penetrating radiation) or less than 0.1% of standards (50-year bone dose).

This scenario can also be evaluated as a chronic exposure situation. Assuming maximum chronic exposure from continuous occupancy over 70 years, the maximum annual dose rate from ^{239}Pu can be compared with the proposed EPA guidance (see Table X and Ref. 18) of maximum dose rates of 1 mrad/yr to lung and 3 mrad/yr to bone. (Note that these are different units that do not take into account different biological response but are simply absorbed energy.) Calculations

based on the maximum theoretical airborne ^{239}Pu concentration in Lower Pueblo Canyon (Appendix E, Table E-XV) and EPA derived doses in the 70th year of chronic exposure (Tables A3-2 and A3-3 of Ref. 17) gave estimates of 0.013 mrad/yr to lung (1.3% of the proposed EPA guidance) and 0.0046 mrad/yr to bone (0.15% of the proposed EPA guidance).

Additional pathways considered possible were inhalation of dust by construction workers during development and inhalation of dust and consumption of fresh produce by home gardeners. The estimates of maximum likely doses from these activities are summarized in Table XIII. Conservative assumptions of high breathing rates, extremely dusty conditions, and the highest average soil concentrations for the stratum should make these estimates overstated (see Appendix E, Sec. III.D.). Other considerations are that the construction worker dose would likely be a one-time occurrence, and there would likely be very few gardens with such high production. The maximum doses in the case of a construction worker are about 6% of standard (DOE RPS, see Table X) or 60% of natural background. The maximum doses in the case of the gardener are about 1.5% of standard (DOE RPS, see Table X) or 15% of natural background.

The passage of time will result in some changes in the occurrence and distribution of the residual radioactivity. Some isotopes will decrease in concentration because of radioactive decay, and some isotopes will increase as the result of ingrowth of radioactive daughter products. In the case of transuranics, both processes are involved. The net effect of the decay of ^{238}Pu and ^{241}Pu and the ingrowth of ^{241}Am are calculated and accounted for in terms of the effect on total dose rates due to transuranics inhaled on resuspended dust (see Appendix E, Sec. III.C.1.). The conclusion was that the differences in the future, at the time of maximum ingrowth of ^{241}Am (about 2050), would be at most 4% higher than for current conditions (whole body, 1st-year dose) and at most 4% lower (bone, 1st-year dose). These are much smaller differences than already implicit in the uncertainties of the calculations. In the case of the fission products, strontium and cesium, which have half-lives on the order of 30 years, the portions of the doses attributable to them will continuously decline by a factor of about 2 every 30 years. Concentrations of ^{137}Cs were largely responsible for the calculated external penetrating doses in Lower Los Alamos Canyon and in the vicinity of the former waste treatment plant site.

Redistribution of the sediments carrying residual radioactivity by hydrologic transport is a likely mechanism of change in the future. Moderate flows in Pueblo Canyon, such as associated with snowmelt runoff and thunderstorm peaking events of the magnitude that have evidently occurred in the last 10-20 years, would be expected to continue the patterns detailed in Appendix A. Basically these amount to transport of sediments carrying up to a few millicuries a year of ^{239}Pu from Lower Pueblo Canyon into Lower Los Alamos Canyon and something on the order of a millicurie of ^{239}Pu a year from Lower Los Alamos Canyon into the Rio Grande (see Fig. 14 for locations).

There are insufficient data available on sediment transport to justify a quantitative theoretical estimate of what might happen in a 50-100 year period. However, a qualitative analysis of an assumed large transport event is probably useful from a decision-making need to have an upper limit on potential effects. Assume that the entire inventory of ^{239}Pu and associated tranuranics now in the inactive channel of the eastern part Lower Pueblo Canyon (about 250 mCi ^{239}Pu) could be moved into Lower Los Alamos Canyon, and that about half of that could be carried on into the Rio Grande within a 1-year period (see Fig. 17). The concentrations on sediments that would be left in Lower Los Alamos Canyon would be on the order of 10 times the values now observed in Lower Los Alamos Canyon, but no more than presently occur in Lower Pueblo Canyon (see Table VIII and Fig. 15). The dose potential from future resuspension of such concentrations would be no more, and probably less, than the doses calculated for current conditions in Lower Pueblo Canyon (see Table XIII), which are much less than background, applicable standards, or the

proposed EPA guidance. The transport of about 125 mCi of ^{239}Pu into the Rio Grande during 1 year could raise the average concentration on suspended sediments to a level about 10 times that currently observed on bed sediments in the Rio Grande resulting from worldwide fallout. That level, perhaps 0.05 pCi/g, would be about the same as the 0.06 pCi/g considered by the EPA to be the national average for fallout ^{239}Pu on soils (Ref. 17). Thus, the effects during such an assumed maximum year event could result in a considerable change (factors of 10 to 100) from the current conditions, but those effects would be no larger than already considered for other locations in Pueblo and Los Alamos Canyons.

TABLE XIII

INCREMENTAL 50-YEAR DOSE COMMITMENTS
(mrem in 50 years from given exposure)

Location/Exposure	External Whole Body Increment Above Natural Background	Inhalation/Ingestion					
		Transuranics			Other		
		Whole Body	Bone	Lung	Whole Body	Bone	Lung
1-Year Occupancy							
Acid Canyon	9.64	0.052	2.1	0.110	<0.001	0.001	0.005
Middle Pueblo Canyon	0.09	0.018	0.73	0.038	---	---	---
Lower Pueblo Canyon	0.26	0.026	1.0	0.053	<0.001	0.005	0.027
Lower Los Alamos Canyon	1.75	0.002	0.085	0.004	<0.001	0.011	0.057
Treatment Plant Site	60	---	---	---	---	---	---
Other Mechanisms							
Consumption of liver from steer grazed in lower Los Alamos Canyon	---	<0.001	0.001	---	---	---	--
Uptake through abrasion wound on rocks with highest contamination near Treatment Plant Site	---	---	5.6	---	---	---	---
Inhalation of dust by construction worker in Lower Pueblo Canyon	0.002	---	88.4	4.72	---	0.28	1.50
at Treatment Plant Site	0.5	---	80.5	4.33	---	1.64	1.24
Inhalation of dust by home gardener	0.001	---	22.4	1.19	---	0.07	0.38
Consumption of produce by home gardener	---	---	0.039	---	---	0.37	---
Radiation Protection Standard	500	500	1500	1500	500	1500	1500

REFERENCES

1. U.S. Department of Energy, "Final Environmental Impact Statement, Los Alamos Scientific Laboratory Site, Los Alamos, New Mexico," U.S. DOE report DOE/EIS-0018 (December 1979).

2. U.S. Department of Energy, "Removal of a Contaminated Industrial Waste Line, Los Alamos, New Mexico," U.S. DOE, Assistant Secretary for Environment, Division of Environmental Control Technology, Formerly Utilized MED/AEC Sites Remedial Action Program, Report DOE/EV-0005/14, prepared by Environmental Surveillance Group, Health Research Division, Los Alamos National Laboratory (April 1979).

3. T. E. Hakonson, J. W. Nyhan, L. J. Johnson, and K. V. Bostick, "Ecological Investigation of Radioactive Materials in Waste Discharge Areas at Los Alamos," Los Alamos Scientific Laboratory report LA-5282-MS (May 1973).

4. National Bureau of Standards, "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water," NBS Handbook No. 52 (1953).

5. Los Alamos National Laboratory internal memoranda from Carl Buckland, H-1, to Charles A. Reynolds, ENG-4, "Acid Canyon Cleanup" (Aug. 11, 1966) and "Supplement to Aug. 11, 1966 Memorandum Acid Canyon Cleanup" (Nov. 8, 1966).

6. Los Alamos National Laboratory internal memorandum from Charles D. Blackwell, H-1, to Charles A. Reynolds, ENG-4, "Supplement to November 8, 1966 Memorandum Acid Canyon Cleanup" (June 21, 1967).

7. Los Alamos National Laboratory internal memorandum from Charles D. Blackwell, H-1, to Dean D. Meyer, H-1, "Removal of Structures and Cleanup of Radioactive Materials Within the TA-45 Area" (Jan. 11, 1967).

8. Los Alamos National Laboratory internal memorandum from Charles D. Blackwell, H-1, to S. E. Russo, ENG-3, "Final Clearance and Sign Removal from Pueblo Canyon and Acid Canyon" (July 11, 1967).

9. Los Alamos County, Document 10545, Book 1, Page 97, of the Records of Plat, Drawing No. Z-4226 (two sheets), "Pueblo Canyon Test Wells-Metes and Bounds Description of Access Easements," Office of the County Clerk of Los Alamos County (December 1, 1966).

10. Incorporated County of Los Alamos, New Mexico, letter from Neil G. Seeley, County Administrator, to Kenneth R. Braziel, Area Manager, U.S. Energy Research and Development Administration, Los Alamos (April 26, 1977).

11. Pueblo de San Ildefonso, letter from James R. Martinez, Governor, to Wayne C. Hanson, H-8, Los Alamos National Laboratory (March 9, 1977).

12. K. E. Apt and V. J. Lee, compilers, "Environmental Surveillance at Los Alamos During 1974," Los Alamos Scientific Laboratory report LA-5977-PR (May 1975).

13. K. E. Apt and V. J. Lee, compilers, "Environmental Surveillance at Los Alamos During 1975," Los Alamos Scientific Laboratory report LA-6321-MS (April 1976).

14. Environmental Studies Group, "Environmental Surveillance at Los Alamos During 1976," Los Alamos Scientific Laboratory report LA-6801-MS (April 1977).

15. Environmental Surveillance Group, "Environmental Surveillance at Los Alamos During 1977," Los Alamos Scientific Laboratory report LA-7263-MS (March 1978).

16. Environmental Surveillance Group, "Environmental Surveillance at Los Alamos During 1978," Los Alamos Scientific Laboratory report LA-7800-ENV (April 1979).

17. U.S. Environmental Protection Agency, "Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment," U.S. EPA Office of Radiation Programs report EPA 540/4-77-016 (September 1977).

18. U. S. Environmental Protection Agency, "Persons Exposed to Transuranium Elements in the Environment," Proposed Federal Radiation Protection Guidance on Dose Limits, in Federal Register Vol. **42**, No. 230, Wednesday, Nov. 30, 1977, pp. 60956-60959 (1977).

19. International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," Annals of the ICRP Vol. **2**, No. 3/4, ICRP Publication 30 (1979).

20. U.S. Energy Research and Development Administration, "A Guide for Environmental Radiological Surveillance at ERDA Installations," U.S. ERDA Division of Safety, Standards, and Compliance report ERDA 77-24 (March 1977).

21. G. R. Hoenes and J. K. Soldat, "Age-Specific Radiation Dose Commitment Factors for One-Year Chronic Intake," U.S. Nuclear Regulatory Commission document NUREG-0172 (November 1977).

22. International Commission on Radiological Protection, "Report of the Task Group on Reference Man," ICRP Publication 23, Pergamon Press, Inc., Elmsford, NY (1975).

23. J. W. Healy, "A Proposed Interim Standard for Plutonium in Soils," Los Alamos Scientific Laboratory report LA-5483-MS (January 1974).

24. J. W. Healy, "An Examination of the Pathways from Soil to Man for Plutonium," Los Alamos Scientific Laboratory report LA-6741-MS (April 1977).

25. International Commission on Radiological Protection, Annals of the ICRP, Vol. **1**, No. 3, ICRP Publication 26, Pergamon Press, New York (1977).

26. R. Wilson, "Analyzing the Daily Risks of Life," Technology Review, Massachusetts Institute of Technology, pp. 41-46 (February 1979).

27. U.S. Nuclear Regulatory Commission, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes," Docket No. PR-71,73 (40FR23768), Office of Standards Development, USNRC document NUREG-0170, Vol. 1 (December 1977).

28. U. S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants; Policy and Procedures for Identifying, Assessing, and Regulating Airborne Substances Posing a Risk of Cancer," proposed rulemaking 40 CFR Part 61, Federal Register, Vol. 44, No. 197, pp. 58642 f.f., Wednesday, Oct. 10, 1979.

29. U.S. Energy Research and Development Administration, ERDA Manual, Chapter 0524, "Standards for Radiation Protection," Appendix, Part III, "Individuals and Population Groups in Uncontrolled Areas," and Annex A, "Concentrations in Air and Water Above Natural Background" (March 30, 1977).

30. U.S. Environmental Protection Agency, "National Interim Primary Drinking Water Regulations," Sections 141.15 and 141.6, U.S. EPA, Office of Water Supply, Publication EPA-570/9-76-003 (1977).

ACRONYMS AND ABBREVIATIONS

AEC	Atomic Energy Commission
ALO	Albuquerque Operations Office
c	counts
cpm	counts per minute
CG	concentration guide
DOE	Department of Energy
dis	disintegrations
EML	Environmental Measurements Laboratory
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
FDA	Food and Drug Administration
FEIS	final environmental impact statement
FUSRAP	Formerly Utilized Sites Remedial Action
HPIC	high-pressure ionization chamber
HTO	tritiated water
ICRP	International Commission on Radiological Protection
LAAO	Los Alamos Area Office
MED	Manhattan Engineer District
NCRP	National Council on Radiation Protection and Measurements
NRC	Nuclear Regulatory Commission
ODIS	Onsite Discharge Information System
OSHA	Occupational Safety and Health Administration
QA	quality assurance
RCG	Radioactivity Concentration Guide
rem	roentgen equivalent man
RPS	Radiation Protection Standard
TA	technical area
TDS	total dissolved solids
TLD	thermoluminescent dosimeter
TRU	transuranic
TSS	total suspended solids
USGS	United States Geological Survey
TLD	thermoluminescent dosimeter
ZnS	zinc sulfide

α	alpha
β	beta
γ	gamma
s	standard deviation
$\bar{x}$	mean

UNITS

Abbreviation	Unit
c	count
aCi	attocurie (10^{-18} curies)
Ci	curie (unit of radioactivity)
cm	centimeter
cpm/ℓ	counts per min per liter
fCi	femtocurie (10^{-15} curies)
ft	foot
g	gram
h	hour
in	inch
keV	kiloelectron volt
kg	kilogram
km	kilometer
km^2	square kilometer
ℓ	liter
m	meter
m^3	cubic meter
mCi	millicurie (10^{-3} curies)
MeV	megaelectron volt
mg	milligram (10^{-3} grams)
min	minute
mℓ	milliliter (10^{-3} ℓ)
mm	millimeter (10^{-3} meter)
mrem	millirem (10^{-3} rem)
mS/m	milliSiemens/meter (1 mS/m = 10 μmho/cm)
MGD	million gallons per day
MT	megaton (10^6 tons)
μCi	microcurie (10^{-6} curies)
μg	microgram (10^{-6} grams)
μm	micrometer (10^{-6} meters)
nCi	nanocurie (10^{-9} curies)
pCi	picocurie (10^{-12} curies)
rad	62.5×10^6 MeV/g (unit of absorbed dose)
rem	roentgen equivalent man (unit of dose equivalence)
s	second
yr	year

GLOSSARY

alpha particle	A charged particle (identical to the helium nucleus) composed of two protons and two neutrons that is emitted during decay of certain radioactive atoms. Alpha particles are stopped by several centimeters of air or a sheet of paper.
beta particle	A charged particle (identical to the electron) that is emitted during decay of certain radioactive atoms. Most beta particles are stopped by 0.6 cm of aluminum or less.
CG (Concentration Guide)	The concentration of radioactivity in air or water that is determined to result in whole body or organ doses equal to ERDA's Radiation Protection Standards for external and internal exposures if the air is continuously inhaled or the water is the sole source of liquid nourishment throughout the year.
Curie	A special unit of radioactivity. One curie equals 3.70×10^{10} nuclear transformations per second (abbreviated Ci).
gamma radiation (or x radiation)	Short-wavelength electromagnetic radiation of nuclear origin that has no mass or charge. Because of its short wavelength, gamma radiation can cause ionization. Other electromagnetic radiation (microwaves, visible light, radio waves, etc.) has longer wavelengths (lower energy) and cannot cause ionization.
arithmetic mean	The average of n given numbers obtained by dividing their sum by n.
geometric mean	The average of n given numbers obtained as the nth root of their product.
gross alpha	The total amount of measured alpha activity.
gross beta	The total amount of measured beta activity.
rad	The unit of absorbed radiation dose. It applies to the fraction of energy deposited by ionizing radiation in a unit volume of material exposed. 1 Rad = 1×10^{-2} Joules per kilogram.

roentgen	The unit of radiation exposure (abbreviated R). It applies only to the amount of charge produced by x or gamma radiation in air. $1R = 2.58 \times 10^{-4}$ coulombs per kilogram.
rem	The unit of radiation dose equivalence that takes into account different effects on humans of various kinds of ionizing radiation and permits them to be expressed on a common basis.
RPS (Radiation Protection Standard)	DOE standards for external and internal exposure to radioactivity as defined in ERDA Manual Chapter 0524.
total uranium	Uranium having the isotopic content of uranium in nature (99.27% ^{238}U, 0.72% ^{235}U, 0.0057% ^{234}U).
tuff	Rock of compacted volcanic ash and dust.

APPENDIX A

GEOHYDROLOGY OF ACID-PUEBLO AND DP-LOS ALAMOS CANYONS 1945 - 1975

I. INTRODUCTION

The Los Alamos National Laboratory is located in northcentral New Mexico (Fig. A-1), about 100 km NNE of Albuquerque and 40 km NW of Santa Fe. Since 1943, Los Alamos National Laboratory has been engaged in the research and development of nuclear technology, within technical areas and facilities that cover some 111 km^2. Because of these operations, some of the Laboratory's industrial effluent is radioactively and chemically contaminated. Two canyon areas that received or continue to receive effluents are addressed in this compilation. Untreated effluents containing radionuclides, mainly plutonium, uranium, tritium, and fission products were released into Acid-Pueblo Canyon from 1943 through 1951. Acid-Pueblo Canyon is a tributary to Lower Los Alamos Canyon; Lower Los Alamos Canyon is, in turn, tributary to the Rio Grande. To reduce the amounts of radionuclides present in the effluent, a treatment plant (TA-45) began operation in 1951 and was operated until June 1964. At that time a new treatment plant (TA-50) was completed, which releases treated effluent into another canyon to the south, entirely within the confines of the Laboratory boundary. The amount of plutonium released into Acid-Pueblo Canyon from 1943 through 1964 was estimated at 170 mCi. Other radionuclides were also released during that period.

From 1945 to 1952, radioactive effluents from Technical Area 21 were released, untreated, into seepage pits near the edge of DP Canyon. The pits were used intermittently from 1952 to 1965. DP Canyon is a small tributary to Upper Los Alamos Canyon upstream from the junction with Pueblo Canyon. A treatment plant was installed in 1952 to treat the liquid wastes. A replacement plant (TA-21-257) was built in 1967 and continues operation to the present time. Various radionuclides in the effluents from the two plants were released into DP Canyon. The amount of plutonium released into DP Canyon from 1952 to 1975 was about 33 mCi.

Radionuclide monitoring of surface water and stream channel sediments in the canyons began in 1945. Observation holes and test wells drilled into the alluvium, perched aquifers, and the main aquifer between 1949 and 1970 complete the present monitoring network.

Briefly, the concentrations of radionuclides in water and sediments decreased as the treatment plants became operational. Radionuclide concentrations also generally decrease downgradient in the canyons from the effluent outfalls, because of adsorption of the radionuclides into sediments in the stream channels and transport and dispersion of sediments by storm runoff.

When the TA-45 plant was operational, the chemicals used to reduce the radionuclide content in the effluent strongly influenced the water quality in Acid Canyon. However, the chemical quality of surface and shallow alluvial water of Pueblo Canyon reflects the chemical quality of sanitary effluent released from the sanitary treatment plants. The chemical quality of surface water in DP Canyon, and shallow water in Los Alamos Canyon below the confluence with DP-Canyon, reflects the chemicals used in treatment processes at the TA-21-257 industrial plant.

The chemical quality of water from perched aquifers in the midreach of Pueblo Canyon and near the confluence of Pueblo and Los Alamos Canyons indicates recharge from the stream in Pueblo Canyon; however, there was no detectable contamination of these perched aquifers by radionuclides, except in the midreach of Pueblo Canyon where tritium was above background. The chemical quality of water from four test wells completed in the main aquifer below Pueblo and Los Alamos Canyons showed no significant change from 1951 through 1977 and reflects no detectable contamination by sanitary or industrial effluents.

The Los Alamos National Laboratory is located on the Pajarito Plateau, which forms an apron 8 to 16 km wide and 32 to 40 km long (Fig. A-1) around the eastern flanks of the Sierra de los Valles, the easternmost range of the Jemez Mountains. The surface of the plateau slopes west to east, from an elevation of 2290 m to 1930 m along the eastern edge, which terminates along the Puye Escarpment and White Rock Canyon. It is drained by southeast and eastward trending intermittent streams that have cut deep canyons into the surface.

The Rio Grande lies to the east of the plateau, dropping from an elevation of 1680 m at Otowi, at the mouth of Los Alamos Canyon, to about 1630 m at the junction with Frijoles Canyon. North of Otowi the Rio Grande lies in a broad valley; to the south it is confined in deep, narrow, White Rock Canyon.

The mountain peaks of the Sierra de los Valles rise to elevations of 3100 m through 3525 m. The crest of this north-south trending range forms a surface water divide, so that streams originating on its eastern slopes and the Pajarito Plateau flow directly into the Rio Grande.

The vegetation and climate change are commensurate with the elevational gradation westward from the Rio Grande to the crest of the Sierra de los Valles. The transition zones of overstory vegetation range from juniper and grasslands at lower elevations along the Rio Grande to fir, spruce, and subalpine grasslands at the higher elevations along the crest of the mountains. The average annual precipitation increases from about 23 cm along the Rio Grande to as much as 76 cm along the crest of the mountains. About 46 cm fall on the plateau. Approximately 2/3 of the precipitation falls in July and August during summer thunder showers. The average July temperature at the lower elevations is about 23°C, and on the plateau about 19°C, whereas average January temperatures are −6°C and −7°C, respectively. On the mountain crests, temperatures are even lower and snow stays on the peaks until late May or early June.

Geohydrology

The movement of surface and shallow ground water is the major transport mechanism for radionuclides and chemicals associated with the release of industrial and sanitary effluents. Intermittent streams in Acid-Pueblo and DP-Los Alamos Canyons have cut deep canyons into the rock units forming and underlying the Pajarito Plateau.

In general, canyons cut into the flanks of the mountains are in rocks of the Tschicoma Formation, whereas the canyons of the plateau are cut into and underlain by the Bandelier Tuff. Along the eastern edge of the plateau the channels are underlain by the Puye and Tesuque Formations. The basaltic rocks of Chino Mesa, in some areas, are interbedded with sediments of the Puye Formation. The Tesuque Formation forms the valley north of Otowi and is exposed in the lower canyon walls along the Rio Grande in White Rock and Lower Los Alamos Canyons (Fig. A-2).

The rock units, from oldest to youngest, are the Tesuque Formation, Puye Formation, and basaltic rock of Chino Mesa of the Santa Fe Group; the Tschicoma Formation and Bandelier Tuff of the volcanic rocks of the Jemez Mountains; and the alluvium and soil of recent age.[A1] Figure A-3 shows the generalized relation of stratigraphic units and structure in an east-west cross section from the Rio Grande across the plateau to the mountains.

The Tesuque Formation is a sequence of light colored sediments laid down as a coalescing alluvial fan and flood-plain deposits in the Rio Grande depression. The separate beds are composed of friable to moderately well cemented, light-pink-grey to light-brown siltstone and sandstone that contain lenses of conglomerate and clay.[A2]

The Puye Formation consists of two members. The lower member is a poorly consolidated, channel-fill deposit. The lower member of the Puye Formation overlies the Tesuque Formation along the Rio Grande and in Los Alamos and Guaje Canyons. It is a grey, poorly consolidated conglomerate, consisting of fragments of quartzite, schist, gneiss, and granite ranging in size from sand to boulders; well-sorted lenses of silt and sand are present sporadically. The upper fanglomerate members are composed of pebbles, cobbles, and boulders of rhyolite, latite, quartz latite, and pumice in a grey matrix of silt and sand. These rocks were derived from flows associated with the volcanic rocks of the Jemez Mountains. Sorting is poor, but tongues and lenses of well-sorted pumiceous siltstone and water-lain pumice are present with the fanglomerate.

The basaltic rocks of Chino Mesa originated from volcanic vents on the Cerros del Rio to the southeast of the Los Alamos area. The basalt flowed north and northwest into the Los Alamos area, interfingering with the Puye Formation. The basalts range in color from grey to black, and contain varying amounts of olivine, pyroxene, and plagioclase feldspar. Individual flows vary in thickness from a few meters to over 40 m. Sediments may occur between the individual flows. The basalt caps the mesa of Cerros del Rio and is exposed in the steep walls of White Rock Canyon (Fig. A-3).

Volcanic rocks of the Jemez Mountains, along the eastern flanks of the Sierra de los Valles and on the Pajarito Plateau, are of the Tschicoma Formation and the younger Bandelier Tuff.[A3] The Tschicoma Formation is composed of undifferentiated latite and quartz latite flows and pyroclastic rocks that are highly fractured and jointed; some intervals contain weathered zones and interflow breccia. These rocks form the core and flanks of the Sierra de los Valles (Fig. A-3). The Bandelier Tuff is composed chiefly of ashfall, ashflow tuff with some thin, water-lain sediments. The formation has been divided into three members: Guaje, Otowi, and Tshirege, from the oldest to the youngest. The Bandelier Tuff forms the upper part of the Pajarito Plateau.

The Guaje Member of the Bandelier Tuff is an ashfall pumice and water-laid pumiceous tuff that rests unconformably on older rocks. The base of the unit contains grey, lump-pumice fragments as much as 5 m in length. Rounded pebble-size fragments of light red rhyolite are present near the top. The Otowi Member of the Bandelier Tuff is a light-grey, nonwelded, pumiceous rhyolite tuff that weathers to a gentle slope. Quartz and sanidine crystals, glass shards, minor amounts of mafic minerals, and varying amounts of rhyolite, latite, and pumice fragments that are included in a fine-grained ash. The Otowi consists of a massive ashflow, with several beds of silt and water-laid pumice near the top. The Tshirege Member of the Bandelier Tuff is composed of a series of ashflows of rhyolite tuff. The Tshirege unconformably overlies the Otowi and forms the caprock of the narrow mesas of the Pajarito Plateau. The rhyolite tuff is composed of quartz sanidine crystals and crystal fragments, rock fragments of rhyolite, dacite, and pumice in an ash matrix that ranges from nonwelded to welded.

Alluvium, eroded from the Sierra de los Valles and the Pajarito Plateau, has been deposited in the canyons of the plateau. Near the heads of the canyons, bedrock is commonly exposed, but further down the canyons, alluvium may be 10 to 80 m wide and as much as 30 m thick. Alluvial deposits in the canyons heading on the flanks of the Sierra de los Valles contain cobbles and boulders, with accompanying clay, silt, sand, and gravel derived from the Tschicoma Formation and Bandelier Tuff. Deposits in the canyons heading on the Pajarito Plateau contain clay, silt, sand, and gravel derived from the Bandelier Tuff. Clayey soil, derived from weathering of the Bandelier Tuff, covers most of the fingerlike mesas of the Pajarito Plateau.

The most prominent structural feature of the Pajarito Plateau is the Pajarito Fault Zone, which trends northward along the western edge of the plateau (Fig. A-2). It is a part of the complex fault system that formed the Rio Grande depression.[A4] The depression extends from southern Colorado, through central New Mexico, into northern Mexico. The Pajarito Fault Zone consists of normal faults that are downthrown to the east and displace rocks of the Bandelier Tuff, Puye Formation, and Tschicoma Formation (Fig. A-3). The displacement, estimated from the fault scarp, is 120 to 150 m. north of Los Alamos and east of the Pajarito Fault Zone; two normal faults cut the Bandelier Tuff, the Puye Formation, and the Tschicoma Formation.[A5] These faults, downthrown to the west, form a depositional basin between them and the Pajarito Fault Zone. These faults extend into the mesa north of Pueblo Canyon (Fig. A-2). A north-trending depositional basin is formed in the Tesuque Formation beneath the central part of the Pajarito Plateau. The basin is filled with volcanic debris of the Puye Formation, overlain by the Bandelier Tuff. The bottom of the sediment-filled trough lies at a depth of about 1500 m below sea level. The eastern edge of the basin is formed by thick flows of basalt from Chino Mesa, 3 to 6 km west of the Rio Grande (Fig. A-3).

The Rio Grande, the master stream in northcentral New Mexico, flows southwestward along the eastern edge of the Pajarito Plateau (Fig. A-1). The Rio Grande receives all runoff from the flanks of the Sierra de los Valles and the Pajarito Plateau. The main drainage area is about 37×10^3 km^2 in southern Colorado and northern New Mexico. The surface water discharge of the Rio Grande is measured at the U.S. Geological Survey gauging station at Otowi. The average discharge for 71 years of record at the station is about 40 m^3/s. The stream carries considerable amounts of suspended sediments. The annual suspended sediment load, 1948 through 1975, has ranged from 6.48×10^8 to 6.86×10^9 kg with an annual average of 2.2×10^9 kg for the 28-yr period of record. The annual volume of flow for this period has ranged from 4.65×10^8 to 1.88×10^9 m^3 with an annual average of 1.03×10^9 m^3. The suspended sediment load is important in computing the effects of release of radionuclides and transport from industrial effluent areas into the Rio Grande.

Pueblo and Los Alamos Canyons head on the flanks of the Sierra de los Valles. Acid Canyon, which received industrial effluent, is tributary to Pueblo Canyon near the western edge of the plateau. DP Canyon, which still receives industrial effluents, is a tributary to Los Alamos Canyon near the center of the plateau (Fig. A-4). Los Alamos Canyon enters the Rio Grande at Otowi.

Perennial flow in the upper reach of Los Alamos Canyon on the flanks of the mountains is impounded at Los Alamos Reservoir. Surface flow in sections of Pueblo and Los Alamos Canyons occurs on the plateau with the release of industrial and sanitary effluents. As the effluents move downgradient, the surface flow is depleted by infiltration into the alluvium of the stream channels and by evapotranspiration. Thus the surface flow in the lower reaches of these canyons is intermittent and only during periods of heavy precipitation does surface flow reach the Rio Grande.

The storm runoff and industrial and sanitary effluents infiltrate from the stream channel to recharge small perennial bodies of ground water in the alluvium perched on underlying tuff or volcanic sediments.[A6] The volume of water in the alluvium of these stream-connected alluvial aquifers is largest during the spring from snowmelt and in the early summer from storm runoff. In the late summer, fall, winter, and early summer, the volume of water declines. As the water in the alluvium moves downgradient in the canyon, part infiltrates into the underlying tuff and volcanic sediments.

Water infiltrating from the alluvium recharges a small body of ground water perched in the Puye Formation in the midreach of Pueblo Canyon (Fig. A-5). The perched aquifer is of limited extent. Perched water also occurs in the basaltic rocks of Chino Mesa near the junction of Pueblo and Los Alamos Canyons (Fig. A-5). The perched aquifer is recharged from water in the alluvium to the west in Pueblo and Los Alamos Canyons; movement is eastward where a part is discharged

from basalts exposed in Lower Los Alamos Canyon. The Bandelier Tuff does not contain any perched ground water in the Acid-Pueblo and DP-Los Alamos Canyon area.

The main aquifer is at a depth of about 380 m beneath the western edge of the plateau, decreasing to a depth of about 180 m below the land surface at the confluence of Pueblo and Los Alamos Canyons.[A7] The main aquifer is separated from water in the alluvium by over 180 to 300 m of unsaturated tuff and volcanic sediments. The main aquifer is separated from perched aquifers in Pueblo Canyon by over 112 to 192 m of unsaturated volcanic sediments. Thus there is no hydrologic connection between the shallow alluvial and perched aquifers and the main aquifer.

The upper surface of the main aquifer, the only ground water body capable of water supply, rises westward from the Rio Grande in the Tesuque Formation into the lower part of the Puye Formation beneath the central part of the plateau (Fig. A-5). The aquifer extends into the rocks of the Tschicoma Formation beneath the western edge of the plateau.[A8] Movement of water in the aquifer is from the recharge area, deep canyons on the flanks of the mountains and Valles Caldera, eastward to the Rio Grande where a part is discharged to the river from seeps and springs.[A9] Transit time of water in the aquifer from recharge area to discharge area is unknown. Tritium age dating of water from the main aquifer beneath the plateau indicates the water has been in transit for greater than 50 yr. Aquifer tests on supply wells and test holes indicate movements ranging from 55 to 220 m/yr.

II. ENVIRONMENTAL MONITORING 1945-1947

Untreated industrial effluents containing radionuclides were released into Acid-Pueblo and Los Alamos Canyons and monitored during studies made in 1945, 1946, and 1947.[A10,A11] The initial study, made in September 1945, consisted of collection and analyses of surface water samples in Acid-Pueblo and Los Alamos Canyons. As a result of this study, an additional 26 stations were sampled in 1946 and 8 stations in 1947 (Fig. A-6).

The 1945 survey reported 9900 cpm/ℓ (counts per min per liter) of plutonium and 420 cpm/ℓ of polonium at Station 1 in Acid-Pueblo Canyon. Plutonium ranged from 42 to 7200 cpm/ℓ and polonium ranged from 1150 to 57 000 cpm/ℓ at Stations 9 to 11 in Los Alamos Canyon near TA-1. Plutonium was not detected at Station 12, polonium was 24 cpm/ℓ. At Station 14 in DP Canyon, plutonium was 6 cpm/ℓ and no polonium was detected. At Station 26, in Los Alamos Canyon near the Rio Grande, plutonium was 8 cpm/ℓ with no polonium reported.

In 1946 water or sediments were collected from 8 locations in Acid-Pueblo Canyon (Acid Canyon locations 1-4; Pueblo Canyon locations 5-8) and 18 stations in Los Alamos Canyon (above the confluence with Pueblo Canyon locations 9-18; below confluence locations 19 to 26). The samples were collected after a summer runoff event, and some of the water samples were reported to be collected from pools in the channel. The results are shown in Table A-I.

Polonium was reported at locations 12 through 17 in Los Alamos Canyon above the junction with Pueblo Canyon and at location 22 below the confluence—the latter reporting a trace amount of polonium. No polonium was detected in the 1946 samples from Acid-Pueblo Canyon. Plutonium was found in both canyons (Table A-I). The highest concentrations were 10 700 pCi/ℓ at location 3 in Pueblo Canyon and 3500 pCi/ℓ at location 12 in Los Alamos Canyon. Location 12 is located below the laundry (removed) at TA-21. The polonium and plutonium decreased downgradient toward the Rio Grande.

Sample collections were made at eight locations in May 1947. These samples were collected in Los Alamos Canyon from location 12 to the Rio Grande (Table A-I). Again, the samples were collected after a heavy rain and runoff. The polonium and plutonium concentrations were much lower in the May 1947 set of samples than in the July 1946 set.

In summary, the polonium and plutonium concentrations decreased downgradient in the canyons for all 3 yr sampling, as the untreated wastes were diluted with sanitary effluent, storm runoff, and by adsorption or ion-exchange of radionuclides with sediments in the stream channel. It is evident that radionuclides were transported to the Rio Grande in storm runoff at the time of these studies.

III. ENVIRONMENTAL MONITORING 1949-1975

From 1949 to 1971, the U. S. Geological Survey (USGS), Water Resource Division, studied the effect of release of industrial effluents on the environment and geohydrology of the area. The data collected by the USGS are summarized in a series of USGS reports covering the period 1949 through 1967.[A12-A22] Environmental data gathered subsequently by Los Alamos National Laboratory are summarized in a series of reports from 1970 through 1975.[A12-A22] Data from these USGS and Los Alamos National Laboratory reports and from three unpublished sources were used to compile the majority of this discussion section.[A23-A33] Additional data relating to individual studies are referenced accordingly.

The chemical quality of effluents, surface, and ground waters was determined by methods outlined in "Standard Methods for Analyses of Water and Waste Water," "Methods for Collection Analyses of Water Samples," and "Study and Interpretation of Chemical Characteristics of Natural Waters."[A34-A36] The annual average concentrations of sodium (Na), chloride (Cl), fluoride (F), nitrate (NO_3), total dissolved solids (TDS), and of pH of a number of samples are used in the tables to show trends in concentrations in the effluent disposal area and, over a period of time, at a single station. These specific ions and chemical characteristics were used because they readily reflect a change in water quality.

The radiochemical quality of effluents, surface, and ground water is presented in two parts covering the periods 1958 through 1967 and 1968 through 1975. Analyses during the period 1958 through 1967 were made for gross-beta activity, total plutonium, and total uranium. Limits of detection for gross-beta activity for this period (1958-1967) were 14 pCi/ℓ and for total uranium 0.5 μg/ℓ. The procedure for plutonium analyses was the Bismuth-Phosphate-Coprecipitation Method, which has a limit of detection of 0.5 pCi/ℓ.

During the period 1967 through 1975, analyses were made for gross alpha and beta, ^{238}Pu, ^{239}Pu, tritium, and total uranium. Procedures used for sample preparation and gross-alpha, -beta, and -gamma screening are outlined in "Radioassay Procedures for Environmental Samples."[A25] Specific alpha emitters were determined using an alpha spectrometer and internal tracers for recovery corrections. Purification and concentrations were performed by ion exchange and electrodeposition or by coprecipitation. Uranium was determined fluorometrically. Limits of detection for gross-alpha and -beta activity were 1 pCi/ℓ, for plutonium 0.05 pCi/ℓ, and for total uranium 0.4 μg/ℓ. The average concentration of a number of analyses for each sampling station was used in the tables of this report to show general trends in concentrations in the disposal area.

A. Acid-Pueblo Canyon

During the period 1951 through 1964, stream flow in Pueblo Canyon consisted of effluents from the Pueblo and Central Sanitary Sewage Treatment Plants and from the TA-45 industrial waste treatment plant near Acid Canyon. Rainfall and snowmelt occasionally added to the volume of flow.

From 1957 to 1964, the average discharge in Pueblo Canyon, just below the junction of Acid Canyon, was about 56 ℓ/s from September through April and about 14 ℓ/s from May through

August. Flow loss occurs downgradient as water moves into the alluvium and is lost to evapotranspiration. Near test well T-2 (downstream from the Central sanitary sewage plant), the average discharge was about 45 ℓ/s from September through April and 14 ℓ/s from May through August (Fig. A-4). The smaller stream flow between May and August reflects diversion of effluents released from the sanitary sewage treatment plants to use for irrigation and cooling water at the golf course and the power plant. Stream flow during summer usually ended near observation well PO-4A but, during the winter, extended to near Pueblo 3 or beyond (Fig. A-4). After the central plant was closed, effluents from the Pueblo plant extended stream flow to near PO-4A during the winter and terminated near T-2 during the summer.

In 1964 a new sewage treatment plant at Bayo Canyon began operation, and by 1966 the Central Treatment Plant was closed (Fig. A-4). This caused a shift in release of effluent toward the lower part of the canyon, with stream flow ending east of test well T-1. Only during storm runoff does flow extend into Los Alamos Canyon.

The stream flow decreases down the canyon as water moves into the alluvium. The alluvium is thin in the upper reaches of the canyon and thickens to about 18 m to the east. Slight losses of surface water were noted where the alluvium overlies the Tschicoma Formation (Fig. A-5) as the alluvium in this area is thin. The rocks of the formation are quite hard and resist down cutting of the stream channel. To the east the channel is underlain by the easily eroded and weathered Bandelier Tuff, and the alluvium thickens. Thus, storage capacities of the alluvium increase, and there is more loss of surface flow as it infiltrates into the alluvium. Surface water losses also occur because of evaporation and transpiration by plants and trees.

The surface water loss in the canyon is estimated at about 5 ℓ/s/km when the discharge at the confluence of Acid and Pueblo Canyons is about 60 ℓ/s. As discharge increases, these losses increase because of water taken into bank storage. This is later partly released as the discharge declines. Loss from bank storage also occurs from evapotranspiration, and some water is held as soil moisture.

1. Sanitary and Industrial Treatment. Sanitary sewage was treated and released at three plants in Pueblo Canyon between 1951 and 1975 (Fig. A-4). The oldest plant in operation is the Pueblo Plant, which was started in the mid 1940s and is still in operation. The yearly volume of sewage effluent released from the Pueblo Plant increased from 375×10^3 m^3 in 1956 to 875×10^3 m^3 in 1961 and was about 780×10^3 m^3 in 1970. From April through September about 90% of the effluent is pumped to the golf course for irrigation.

The Central Treatment Plant (Fig. A-4) was operated from the late 1940s to about 1966, when the effluent was switched to the Bayo Plant for treatment. The release from the plant ranged from 570×10^3 to 760×10^3 m^3 annually until 1954. Then part of the effluent was pumped to the power plant for use as cooling water, and the releases into Pueblo Canyon dropped, ranging from 75×10^3 m^3 to 150×10^3 m^3 per year until 1966.

The Bayo Plant began operation in 1963 (Fig. A-4). In 1966 the plant began treating sewage that had previously been processed at the Central Treatment Plant. The release in 1972 was about 900×10^3 m^3.

The industrial waste treatment plant at TA-45 was in operation from April 1951 through June 1964 (Fig. A-4). Plutonium, the major waste contaminant, was removed from liquid wastes by chemical treatment with ferric sulfate and lime, which forms a flocculent that precipitates to the bottom of tanks.[A37] The precipitate (ferric hydroxide) carries nearly all of the plutonium with it. The sludge was removed from the bottom of the tank, packaged, and buried in pits at a solid waste disposal site on the mesa to the south.

An annual average of $\approx 18 \times 10^3$ m^3 of untreated effluent was released into Acid Canyon between 1943 and 1951. The volume of released effluent increased from 2.2×10^4 m^3 in 1951 to a maximum of about 6.4×10^4 m^3 in 1962, then decreased to about 0.8×10^3 m^3 in 1964 as the new plant at TA-50 became operational. The wastes from the TA-45 plant were released into Acid Canyon in batches of 55 m^3 to 75 m^3, rather than by continuous flow. The effluents made up the bulk of the flow in Acid Canyon except for storm runoff.

The chemical quality of sanitary effluents from the Pueblo, Central (abandoned), and Bayo plants has shown no significant change over the years (Table A-II). The chlorides, fluorides, and nitrates are higher than found in naturally occurring waters. The chemical quality of these effluents, because of the large volumes released, dominates the quality of surface and ground water in the alluvium of Pueblo Canyon. Metal-ion analyses of sanitary effluent from the Pueblo and Bayo plants were made in 1971 and 1972 (Table A-III). Trace amounts of cadmium, beryllium, lead, and mercury were detected.

The chemical quality of industrial effluents released into Acid Canyon reflects the chemicals used to aid in removing radionuclides. The effluents are highly mineralized when compared to naturally occurring waters (Table A-IV). The high pH is the result of the treatment process to remove radionuclides. In general, the chemical concentrations vary with the changing quality of influents and the treatment process used.

Radiochemical analyses of sanitary effluents from the Pueblo and Bayo plants were made in 1971 and 1972. Only trace amounts of gross-alpha activity were present; however, the concentrations of gross-beta activity from the Bayo Plant were above normal (Table A-V). Plutonium, cesium, and tritium were below limits of detection. Total uranium ranged from 1.6 to 1.8 $\mu g/\ell$.

The volume of effluents and concentrations of radionuclides in effluents from the industrial treatment plant at TA-45 varied during the period 1951 through 1964. The volumes generally increased during the lifetime of the plant; however, the largest volume was released in 1962 (Table A-VI). During 1963, the plant at TA-50 came into being and the plant at TA-45 was phased out with the last batch of effluent released in 1964. The total amount of plutonium released into Acid Canyon was about 170 mCi (Table A-VI). The largest amount (an estimated 143 to 150 mCi) was released as raw effluents during the period 1943 to 1950, prior to construction of the treatment plant.[A38,A39] About 27 mCi of plutonium were released during the operation of the plant from 1951 through 1964.

The major objective of the plant was to reduce the plutonium; however, other radionuclides were released with the untreated and treated effluents. It is estimated that about 18 200 mCi of tritium, 250 mCi of ^{89}Sr, and 94 mCi of ^{90}Sr were released from 1945 to 1950. An additional 40 200 mCi of tritium, <1 mCi of ^{90}Sr, <1 mCi of ^{235}U, and 67 mCi of unidentified gross-alpha activity were released during the operation of the plant.[A39] However, because of decay the activity of tritium would have been about 18 500 mCi and ^{90}Sr about 48 mCi by December 1975. The release of raw effluents prior to 1951 and the release of treated effluents from 1951 through 1964 caused contamination of sediments, surface, and ground water in the alluvium in Pueblo and Los Alamos Canyons below the junction with Pueblo Canyon. Release of industrial effluents from the treatment plant at TA-21 also contributed contamination in Los Alamos Canyon below the junction with Pueblo Canyon. This is discussed in a subsequent section.

2. Surface Water. In 1954, surface water stations for monitoring the chemical and radiochemical quality of surface water were established at Acid Weir, Pueblo 1, Pueblo 2, and Pueblo 3 (Fig. A-4). From 1954 to 1963, the chemical quality of water from Acid Weir reflected the chemical quality of the effluent released from the TA-45 treatment plant (Table A-VII). The water was basic with high concentrations of sodium, fluorides, nitrates, and TDS. During the period 1965-1976, stream flow in the canyon consisted mainly of storm runoff, release of water

from the swimming pool at the high school, and runoff from lawn watering in the Los Alamos residential areas. There was a general decline in the fluorides and nitrates during this latter period. The chlorides and sodium remained high, possibly due to leaching and transport by runoff from a sand-salt mixture stored near the edge of the canyon. Runoff into the canyon is from paved areas in the community, thus TDS also remain high.

The chemical quality of water at Pueblo 1 reflects the chemical quality of sanitary effluent from the Pueblo Treatment Plant (Table A-VIII). There was little detectable effect on the chemical quality of water at Pueblo 1 by the effluent released from TA-45 because the sanitary effluent volume was much larger. The chemical quality of water at Pueblo 2 reflects the quality of combined release of sanitary effluent from the Pueblo and Central Plants from 1953 to 1964 and, after 1964, the release from Pueblo Plant only (Table A-IX). From 1957 through 1964, the quality of water at Pueblo 3 was generally affected by return flow from the alluvium at Hamilton Bend Spring and Otowi Seep. After 1964, the flow was mainly the release of sanitary effluent from the Bayo Plant (Table A-X). There was an increase in nitrates in the water after 1964. In 1971 and 1972, metal-ion analyses were made of water at Acid Weir, Pueblo 1, Pueblo 2, and Pueblo 3 (Table A-XI). Trace amounts of cadmium, lead, and mercury were reported.

The treated effluents were released directly into Acid Canyon. The radioactivity generally decreases downgradient in the canyon, from Acid Weir to Pueblo 3, because of dilution by sanitary effluents and adsorption of radionuclides with sediment particles. The highest plutonium concentrations reported in Acid Canyon occurred in 1956 and 1963 while the TA-45 treatment plant was operational (Table A-XII). The annual average ranged from 0.6 to 27 pCi/ℓ during the period 1952 to 1963; at Pueblo 1 the range was <0.5 to 4.9 pCi/ℓ; at Pueblo 2 the range was <0.5 to 2.7 pCi/ℓ; at Pueblo 3 the range was <0.5 to 0.4 pCi/ℓ.

Gross-beta activity from 1958 to 1963 showed the same general trend with activity decreasing downgradient in the canyon (Table A-XIII). The variation in concentrations of plutonium and gross-beta activity during this period reflects the changing conditions in the canyon while industrial effluents were released. These changes included variations in dilution, in adsorption, and in the volumes and nuclide concentrations of the effluents. The "slug" type of effluent release also caused the radiochemical quality to vary according to the time the sample was collected.

The radiochemical analyses of surface water in 1970 through 1975 showed that residual contamination from previous release of industrial effluents is presently subject to resuspension of radionuclides previously adsorbed or exchanged with ions in the sediments of the stream channel (Table A-XIV). The resuspension of gross-beta activity and plutonium is greater in Acid Canyon than in Pueblo Canyon, indicating that a large portion of the radionuclides from previous effluents were tied up in the alluvium or tuff of the stream channel. Generally, the concentrations of radionuclides decrease downgradient in the canyon. Tritium was detected in the surface flow at Acid Weir, but was below limits of detection in Pueblo Canyon.

3. Water in Alluvium. Stream flow infiltrating into the alluvium maintains small bodies of water perched on the underlying tuff and volcanic rocks and sediments of the Tschicoma and Puye Formations. A series of shallow observation holes were dug in Acid and Pueblo Canyons from 1952 to 1957 (Fig. A-4). To obtain samples of water moving through the alluvium, drive points and corrugated metal pipe were driven or dug 1 to 2 m into the alluvium. The observation holes in Acid Canyon were designated "AC" (AC-3, AC-4, AC-5), whereas the observation holes in Pueblo Canyon were designated as "PC" (PC-1 through 11). Collection of water samples (pumped or bailed from these holes) was dependent on stream flow for recharge. Therefore there were times when the stream was not flowing and the holes were dry. Storm runoff occasionally destroyed a hole, so that by 1964 most of this sampling network was gone.

In 1957, 16 test holes were drilled in the area of Hamilton Bend Spring for geologic and hydrologic information. Three of these test holes, PO-1A, PO-4A, and PO-4B, were completed into the alluvium and were used as part of the monitoring network until 1965. A fourth test hole, PO-3B, was completed in the Puye Formation (perched aquifers) and was also used as part of the monitoring network.

The chemical quality of water in the alluvium in Acid Canyon (AC-series holes) from 1954 through 1964 reflected the chemical quality of industrial effluents, whereas water in the alluvium in Pueblo Canyon (PC and PO series holes) reflected the quality of the sanitary sewage effluents. The Acid Canyon alluvial water varied markedly between sampling periods, but was always highly mineralized. In Pueblo Canyon, the quality of the alluvial water was somewhat better, having lower fluoride, nitrate, and TDS concentrations (Table A-XV).

The trends or significant changes in the chemical quality of the water in alluvium as the water moves downgradient are partly obscured by the dilution effect of snowmelt and storm runoff, changes in the volume of sanitary effluent released, slug-type release methods from the industrial waste treatment plant, and change in the quality of effluents released from both sewage and industrial plants. The chemical quality of water in Acid Canyon was unstable because of a pH of 9.6 or above. In Pueblo Canyon, the pH of the water in the alluvium decreased abruptly to an average of 7.5 or less (Table A-XV). During operation of the TA-45 industrial plant, the chemical quality of the water generally improved downgradient in the canyon. The quality of water was best during the winter and early spring, when stream flow was at a maximum because of snowmelt and increased release of sewage effluents, and poorest during the late spring and early summer, when sewage effluent release and storm runoff were at a minimum.

Hamilton Bend Spring was the only station retained to monitor the quality of water in the alluvium after 1965. The quality of water during the period 1970 to 1975 varied slightly, but was of the same general type that occurred during the period 1954 through 1965 (Table A-XVI). The only change was a slight increase in fluorides. In trace metal analyses made of water from Hamilton Bend Spring in 1971 (Table A-XVII), the concentrations of cadmium, lead, and mercury were slightly lower than found in surface water.

Water in the alluvium is recharged directly from stream flow. When compared to the analyses in Pueblo Canyon, the concentrations of plutonium and gross-beta activity from 1954 through 1963 were highest in Acid Canyon because of direct release of industrial effluents and lack of dilution by sanitary effluents (Tables A-XVIII and A-XIX). The highest concentrations of plutonium occurred in 1954 and generally decreased through 1964. Gross-beta activity from 1958 through 1965 indicated the same general trend. From 1970 through 1975, water from Hamilton Bend Spring contained only trace amounts of plutonium in samples for 1972 and 1973 (Table A-XX). Tritium above detection limits was reported only for 1972.

B. DP-Los Alamos Canyon

Los Alamos Canyon drainage area extends to the drainage divide on the flanks of the Sierra de los Valles and enters the Rio Grande to the east near Otowi. Major tributaries are Pueblo Canyon near the eastern edge of the plateau and DP Canyon near the center of the plateau (Fig. A-4). The alluvium in the canyon is thin in the upper reaches and thickens eastward to about 8 m near the eastern edge of the plateau. The alluvium is underlain by tuff in the western and central part of the canyon and conglomerate and basalt in the eastern part.

Perennial surface flow occurs in the upper reach on the flanks of the mountains, and part is impounded at Los Alamos Reservoir. Surface flow in the canyon across the plateau is intermittent. There is some release of water from the TA-41 cooling tower and sewage effluent from TA-2 and TA-41. During the summer, storm runoff in the canyon occasionally reaches the Rio Grande. The

sanitary sewage effluent, cooling tower blowdown, storm runoff, and inflow of water from the alluvium in DP Canyon recharge the water in the alluvium that is perched on the tuff in Los Alamos Canyon. As the water in the alluvium moves downgradient, some is lost to evapotranspiration, whereas the rest moves into the underlying tuff, conglomerate, and basalt. The major area of water loss from the alluvium occurs in the lower reach of the canyon on the plateau where the alluvium is underlain by conglomerate and basalt. Infiltration of water from the alluvium into the conglomerate and basalt replenishes the body perched in the basalt in Pueblo Canyon. The water from the perched zone discharges from the base of the basalts (Basalt Spring) in Los Alamos Canyon to the east (Fig. A-5).

DP Canyon heads on the plateau and has a small drainage area. The canyon is tributary to Los Alamos Canyon near the center of the plateau. The alluvium in the upper reach of the canyon is thin or nonexistent; however, in the lower reach of the canyon, the alluvium thickens rapidly to about 6 m at the junction with Los Alamos Canyon. The canyon is cut into and underlain by tuff. Treated sanitary effluent is released into the canyon from the plant at the eastern edge of TA-21 (Fig. A-4). The treated industrial waste effluent from TA-21-257 is released into the canyon at the northern edge of TA-21 (Fig. A-4). The stream flow in DP Canyon is intermittent, consisting of industrial and sanitary effluents and storm runoff. The industrial and sanitary effluents maintain an intermittent stream that infiltrates into the alluvium in the lower reach of DP Canyon. Only during storm runoff in DP Canyon does surface flow reach Los Alamos Canyon.

1. Sanitary and Industrial Treatment. Sewage effluent from TA-21 is treated at a sewage treatment plant near the eastern edge of the area prior to release into DP Canyon. The plant treats and releases about 30×10^3 m^3 of effluent per year into the canyon between sampling stations west of DPS-4 (Fig. A-4).

Industrial waste effluents were handled by three methods at TA-21 from 1945 through 1975. The first disposal of liquid waste was into seepage pits dug into the tuff near the head of the canyon. In 1952, a treatment plant was constructed and put into operation. This plant was replaced by a second plant in 1967.

The seepage pits in TA-21 are the oldest used for the disposal of liquid wastes at Los Alamos. Wastes from the processing of plutonium were released into pits from 1945 to 1952. The disposal area consists of four pits 38 m long, 5.5 m wide, and about 2 m deep. The pits are filled with approximately 1.2 m of sand, gravel, and boulders with berms extending around the individual pits. These pits remain on Los Alamos National Laboratory property.

The industrial waste treatment plant at Bldg 35 replaced disposal into the pit and was operated from 1952 to late 1967. The treatment plant was similar to that operated at TA-45.[A37] The treatment was virtually the same with plutonium and americium the major contaminants. Chemical wastes, such as hydrofluoric acid used in processing plutonium, were neutralized and discharged with other effluents from the plant into DP Canyon.

The sludge and wastes containing high concentrations of inert salts were packaged at the plant at Bldg 35 and buried in the solid disposal pits on the mesa. The plant had a somewhat smaller capacity than that at TA-45. After 1967, operations were transferred to a new plant at Bldg 257.

The new plant at Bldg 257 began operation in late 1967 and had a slightly greater capacity for treatment of effluents than the old plant at Bldg 35. The treatment of the liquid wastes was essentially the same with some modification of newer equipment such as pressure type filters rather than gravity flow and some changes in filter media.

In 1967 and 1969, samples of effluent from the sewage treatment plant, immediately below the effluent outfall, were collected for chemical analyses. The individual analyses varied slightly but

were in the same general range in the few analyses shown. The effluents contained chemical concentrations typical for sewage treatment plants. The effluents are similar to the Pueblo and Bayo Plants (Table A-XXI).

The chemical quality of effluent released from the industrial plant varied because of the changing quality of wastes received. In general, the effluents released into the canyon were highly mineralized as compared to naturally occurring water in the area. Table A-XXII shows one weekly composite collected during the first week of July for 1960 through 1975.

Radiochemical analyses were made of effluent from the sewage treatment plant. The samples were collected below the effluent outfall. Traces of americium were found in the samples collected August 5, 1969 and July 16, 1970. The presence of trace amounts of americium and plutonium may be because of contamination getting into the sewage collection system from laboratories at TA-21 (Table A-XXIII).

The volume of effluent from the industrial waste treatment plant has ranged from 4.5×10^3 to 16×10^3 m^3 annually (Table A-XXIV). The major waste treated contained plutonium. From 1952 through 1975, about 33.2 mCi of plutonium were released with the effluents into the canyon (Table A-XXIV). Prior to 1972, specific analyses were not performed to determine the isotope of plutonium. Since 1972, plant analyses indicate that about 80% of plutonium released has been ^{239}Pu and the remaining 20% has been ^{238}Pu. Radionuclides released with the effluent from 1951 through 1975 were estimated as ^{241}Am, 1 mCi; ^{137}Cs, 19 mCi; tritium, 60 000 mCi; ^{238}Pu, 1 mCi; ^{239}Pu, 32 mCi; ^{90}Sr, 6 mCi; ^{235}U, <1 mCi; unidentified gross-alpha activity, 15 mCi; and unidentified beta-gamma activity, 543 mCi.[39] The shorter-lived radionuclides would decay so that by December 1975 only 17 mCi of ^{137}Cs, 36 000 mCi of tritium, and 5 mCi of ^{90}Sr would remain. The others would be virtually unchanged.

2. Surface Water. Stream flow in DP Canyon is intermittent and is from the release of sewage and industrial effluents. The effluents maintain regular flow in various sections of the canyon; however, all effluents move into the alluvium in the lower reach of the canyon. The effluents do not reach Los Alamos Canyon as surface flow except when mixed with runoff from heavy precipitation. Normally, they move as groundwater in the alluvium. Because of the thin alluvium in the upper and middle reaches of DP canyon and the limited access in the lower reaches of DP Canyon, there are no observation holes in the alluvium (Fig. A-4).

The chemical quality of the surface water in DP Canyon reflects the quality of industrial and sewage effluents released from the treatment plants. In general, the quality of water improves as it moves downgradient in DP Canyon. There has been a general improvement in the quality of effluents released into DP Canyon as seen by a general decline of chemical constituents in surface water at DPS-1 (Table A-XXV). Select trace metal ion analyses were made of water from two stations, DPS-1 and DPS-4 in 1971 and 1972 (Table A- XXVI).

Radiochemical analyses of water from DPS-4 for the period 1961 through 1965 indicated the presence of gross-beta activity and some minor amounts of plutonium (Table A-XXVII). Analyses for the period 1967 through 1975 indicated a slight increase in the presence of radionuclides at stations DPS-1 and -4 (Table A-XXVIII). Most of the concentrations decreased downgradient in DP Canyon.

Surface water is perennial in Los Alamos Canyon above the reservoir. Chemical analyses indicate a TDS range of 70 to 147 mg/ℓ (Table A-XXIX). This is natural water not contaminated by industrial or sanitary effluents. Radiochemical analyses show low concentrations of naturally occurring gross-alpha and -beta activities, as well as total uranium (Table A-XXX). There was no detectable plutonium in water at the reservoir or in the intermittent snowmelt runoff below the reservoir. Tritium reported in water from the reservoir generally increased downgradient in the intermittent surface flow.

3. Water in Alluvium. Seven observation holes are used to monitor the chemical and radiochemical quality of water in alluvium of Upper Los Alamos Canyon. Observation hole LAO-C is in the western reach of the canyon (Fig. A-4) upstream of any discharge points. The TDS for the period 1970 through 1975 ranged from 166 mg/ℓ to 253 mg/ℓ. At LAO-1 downstream from the release of cooling water and sanitary effluents, the TDS range extends from 246 to 434 mg/ℓ (Table A-XXXI). Below the confluence with DP Canyon at LAO-2, the inflow of effluents as they move into the canyon is seen by increased concentrations of fluorides, nitrates, and TDS. The full effect of the effluent is seen at observation hole LAO-3. Downgradient from this observation hole there is a general decline of chemical concentrations. Metal ions analyzed in 1971 and 1972 show the same general trend exhibited with chemical analyses (Table A-XXXII).

In 1966 and 1967, radiochemical analyses of water in the alluvium indicated gross-beta activity in excess of that found in natural water. One analysis from LAO-2 indicated trace amounts of plutonium (Table A-XXXIII). The high gross-beta activity at LAO-1 is from reactor cooling water at TA-2. Analyses from 1970 through 1975 show some traces of plutonium at LAO-1 probably because of contamination remaining in the canyon from the operation of laboratories at TA-1 (Table A-XXXIV). There is an increase in gross-beta activity, plutonium, and tritium at LAO-2 as industrial effluents from DP Canyon recharge the water in alluvium. In general, the concentrations of radionuclides decrease downgradient because of adsorption of the nuclides in alluvial material and dilution of the effluent as it moves through the alluvium.

The quality of water in the alluvium in Lower Los Alamos Canyon near the confluence with the Rio Grande has been monitored by samples of return flow collected near the mouth of Lower Los Alamos Canyon. The return flow occurs infrequently and only after significant runoff results in recharge. The most recent sample was collected in April 1979. The analyses of 10 chemical parameters show that the water quality does not appear to be affected by the runoff or by the shallow alluvial water further upstream in Upper Los Alamos Canyon (see discussion in preceding paragraphs) or in Pueblo Canyon (see discussion in Sec. III.A.3 of this Appendix). Fluoride and nitrate analyses are particularly diagnostic because they are present in the effluents from the sanitary sewage treatment plants at levels above natural concentrations and do not exhibit abnormal levels in the return flow samples. The data for the analyses are as follows: Fluoride, 0.13 mg/ℓ; nitrate-nitrogen, less than 0.04 mg/ℓ; total dissolved solids, 271 mg/ℓ; silica, 59 mg/ℓ; calcium, 40 mg/ℓ; magnesium, 6 mg/ℓ; total hardness, 125 mg/ℓ; carbonate, 6 mg/ℓ; bicarbonate, 150 mg/ℓ; chloride, 13 mg/ℓ. Tritium in the sample was measured at less than 400 pCi/ℓ, which is typical for regional surface waters in northern New Mexico.

IV. RADIONUCLIDES IN SEDIMENTS

Sediments in the stream channels that receive industrial effluent strongly influence the radiochemical quality of the surface flow. The radionuclides are adsorbed or exchanged with ions in the alluvium, thus reducing the amount of radioactivity in the surface water and water in alluvium.[A40] Plutonium and cesium in the waste effluent are adsorbed or retained with the finer material in the channel alluvium. During the fall through spring, concentrations of radionuclides tend to build up at the point of effluent discharge in the channel. This buildup is then dispersed by transport during storm runoff, especially during heavy summer showers.[A40]

The fine particles in the alluvium in the channel have a greater affinity for the radionuclides; however, most of the activity is in the coarser alluvium as it is more abundant. This is indicated by particle size distribution of sediments. The finer sediments in the alluvium are carried out of the canyons with storm runoff as suspended sediments, whereas the larger materials are transported as channel material. The channel material lags behind, moving only short distances with each succeeding runoff event.

Stream channel material is referred to as sediments. The sediments were collected by a 7.6-cm-wide scoop across the main channel to a depth of about 3 cm. Suspended sediments are those classed as having a mean diameter less than 6 mm and generally remain in suspension in water for a period of time without contact with the bottom. These sediments were collected with a single-stage sampler, cumulative sampler, or a DH-48 sampler during floor or storm runoff. The procedures used for radiochemical analyses of channel sediments and suspended sediments are outlined in "Standard Analytical Procedures for Soil."[A41] Plutonium was analyzed, using an alpha spectrometer, after concentration and purification by ion-exchange chemistry with internal tracers added for recovery corrections.

Particle-size distribution was made using a Ro-Tap mechanical shaker and a series of different sized mesh screens. Distribution was made of sediments having a particle size diameter of less than 3.96 mm according to the Wentworth Grade Scale (Table A-XXXV). The particle-size distribution is expressed as percent by weight of the channel sediments.

A. Acid-Pueblo Canyon

The sediments in Acid-Pueblo Canyon result from chemical and mechanical weathering of acid volcanic rocks (Tschicoma and Puye Formations and Bandelier Tuff). The granules are composed principally of tuff, pumice, latite, and rhyolite rock fragments with minor amounts of quartz and sanidine crystals. The fractions of fine to coarse sand consist mainly of quartz and sanidine crystals and crystal fragments with minor amounts of rock fragments. The silt and clay fractions are composed mainly of clay minerals, montmorillonite, and illite.

From AC-5 to PC-7, the silt, clay, very fine, and fine sand size fraction of the channel sediments makes up less than 8% of the sediments in the canyon (Fig. A-4). From PC-7 to APSC, this size fraction increases to more than 13% as the channels change from tuff to volcanic sediments (Table A-XXXVI).

Samples of sediments collected from the stream channel between 1954 and 1961, when the industrial plant was in operation, were analyzed for gross-alpha and gross-beta activity (Table A-XXXVII). This activity increased in October 1958 because of an unintentional release of untreated effluents. Activity was considerably lower in Pueblo Canyon than in Acid Canyon. In general, the activity decreased with increased distance from the effluent outfall. There was no apparent buildup of radionuclides in the sediments in Acid Canyon. This was because of sediment transport by storm runoff, which moves the radionuclides attached to the sediments downstream and disperses them over a larger area. These radionuclides are also dispersed throughout the canyons by intermittent releases of industrial and sewage effluents.

A series of sediment samples were collected from Acid-Pueblo Canyon on November 24 and 25, 1965, and were analyzed for gross-alpha, -beta, and -gamma activity (Table A-XXXVIII). The gross-alpha activity decreased downgradient in the canyon, but there appears to be no pattern for the distribution of gross-beta and -gamma activity. A second set of samples was collected in 1970 (Table A-XXXVIII).[A42]

From 1971 through 1975, sediment samples were collected at various times at two stations in Pueblo Canyon. The stations are located at Pueblo 2 in the midreach of the canyon and Station APSC near State Road 4 above the confluence of Pueblo and Los Alamos Canyons (Fig. A-4). The ^{239}Pu concentrations were above worldwide fallout levels and show residual radioactivity from the release of effluents in the canyon prior to 1964 (Table A-XXXIX).

In 1972, sediment samples were collected in the canyon for a special radioecology study involving radiochemical analyses for plutonium and cesium.[A43,A44] The location of the sampling stations was based on a geometric progression of distances from the outfall. The sampling was made to a

depth of 30 cm. Plutonium 239 was the major plutonium isotope found in the sediments. Plutonium 239 and cesium have the highest concentration in Acid Canyon, 0 to 640 m. The trends included

(1) vertical mixing to 12.5 cm was stronger and more rapid than horizontal mixing;

(2) maximum total Pu concentration is associated with soil particles <53 μm; and

(3) even though the higher Pu concentrations are associated with the finer sediment, the larger Pu inventory will be with the larger sediments as they constitute the large volume of sediments. In general, the radionuclides decrease downgradient in the canyon (Table A-XL).

As part of this study, a second set of samples was collected in 1973 and analyzed for total plutonium.[A45] The samples were collected at intervals of 0 to 2.5, 2.5 to 7.5, 7.5 to 12.5 cm and between 12.5 and 30 cm in depth. (Table A-XLI). The vertical distribution of plutonium in individual cores varied, indicating no particular trends. The distribution of plutonium downgradient in the canyon also varied. The highest concentrations of plutonium reported were in the midreach of Pueblo Canyon at Station 2560m. The concentrations, ranging from 369 to 2250 pCi/g with depth, were not consistent with other data collected in this canyon. It may have represented an analytical error or, in fact, a point of accumulation of plutonium in the sediments, which were subsequently dispersed.

B. DP and Upper Los Alamos Canyons

Channel sediments in DP Canyon are derived from the Bandelier Tuff. Particle size distribution indicates that silt and clays make up less than 3% by weight of the samples analyzed (Table A-XLII). The sediments in Upper Los Alamos Canyon are derived from weathering of the Tschicoma Formation and Bandelier Tuff. Silt and clay make up about 1% by weight of analyses at LAO-C and LAO-1, whereas at LAO-3, the silt and clays make up about 12% by weight of the sample analyzed (Fig. A-4). The channel in Los Alamos Canyon is composed of gravels and sand with cobbles and boulders derived from the Tschicoma Formation. In DP Canyon the larger material is composed of tuff, which breaks down rapidly with transport during storm runoff.

Analyses of sediments from DP Canyon in 1967 and 1968 indicated a decreasing amount of plutonium downgradient from the effluent outfall (Table A-XLIII). This decrease in concentrations downgradient into Los Alamos Canyon was also shown by analyses of sediments in 1965 and 1970 (Table A- XLIII). Samples of alluvium from near LAO-3 have been analyzed from 1971 through 1975 (Table A-XLIV). The concentrations varied as the sediments were transported during summer runoff. There has not been a continual buildup of radioactivity in sediments near the effluent outfall because storm runoff during the summer has dispersed and carried the sediments and adsorbed radionuclides downgradient in DP into Los Alamos Canyon.

In 1972, sediment samples were collected in DP and Los Alamos Canyons for a special study.[A43] Sediments to a depth of 12.5 cm were analyzed for plutonium and cesium (Table A-XLV). The concentrations of both plutonium and cesium decrease downgradient in the canyon. Plutonium 239 was the major plutonium isotope found in the sediments.

A second set of sediment samples was collected in 1973.[A45] Analyses were made at intervals of 0 to 2.5, 2.5 to 7.5, and 7.5 to 12.5 cm in depth. Plutonium concentrations varied with depth (Table A-XLVI).

C. Lower Los Alamos Canyon

Los Alamos Canyon, at the junction with Pueblo Canyon, is cut into the basaltic rocks of Chino Mesa. About 1200 m east of the junction is a series of falls formed by the basalts at the eastern edge of the flow (Figs. 4 and 5). Eastward from the falls, the channel is underlain for a short distance by the Puye Formation and from there to the Rio Grande by the Tesuque Formation. The alluvium in the channel, underlain by basalts, is thin or nonexistent. The alluvium thickens and widens east of the falls. The alluvium in the channel is made up of rhyolites, latites, and dacites derived from the Tschicoma Formation, gravels from the Bandelier Tuff, volcanic sediments from the Puye Formation, and arkosic sediments from the Tesuque Formation. The thickness of the alluvium near the Rio Grande probably exceeds 20 m, and at the Rio Grande the channel widens to about 100 m where it has built a fan into the river. The main channel in this reach of the canyon braids into a number of smaller channels that confine the intermittent flow into a channel width of about 4 m. The channel material is made up of silt and clays to boulder-size debris. The silt, clay, and very fine and fine sand size fraction makes up greater than 10% by weight of the sediments, quite similar to the size distribution of sediments found in Lower Pueblo Canyon (Table A-XLVII). Observations from the four stations in Lower Los Alamos Canyon indicate no specific trend in the particle size distribution.

Samples were collected at infrequent intervals from 1968 through 1975 at seven stations in the lower reach of Los Alamos Canyon (Table A-XLVIII). Station LASC is located in Los Alamos Canyon above the junction with Pueblo. Station APSC is located in Pueblo Canyon above the junction with Los Alamos Canyon (Fig. A-4). The plutonium concentrations on sediments in Pueblo Canyon were higher than found in Los Alamos Canyon. The sediments in both canyons are subject to transport with storm runoff into the lower reach of Los Alamos Canyon.

The six stations in the lower reach of Los Alamos Canyon showed measurable amounts of ^{239}Pu. In general, the concentrations decrease downgradient in the canyon as the sediments are dispersed over and mixed with the larger volume of alluvial material in the channel. A major decrease in concentration occurs at Station LAS-7 (near the Rio Grande) showing the effect of dilution and distribution with intermittent runoff and associated transport of sediments from Guaje Canyon.

V. INVENTORY OF PLUTONIUM AND CESIUM IN SEDIMENTS

Inventories of plutonium and cesium remaining in the sediments were made for several periods where data were available.[A46-A47] These inventories consider only the active stream channel material and do not include any accumulation that may have occurred in stream bank material. The radiochemical data used were presented in the previous section.

Four sections of the channel in Acid-Pueblo Canyon were considered. They included the natural channel in Acid Canyon below the outfall at TA-45 to the confluence with Pueblo Canyon (0-480 m) and three sections in Pueblo Canyon to the confluence with Los Alamos Canyon (480 to 10 280 m) as shown in Fig. A-7. Two sections were used for the inventory in DP and Upper Los Alamos Canyons, 0-1800 m and 1800 to 6600 m, and two sections in Lower Los Alamos Canyon 0 to 4800 m and 4800 to 7200 m.

The physical characteristics of the channel (Table A-IL) in each section, along with average concentrations of plutonium and cesium, were used to compute the inventory of the radionuclides in each section. The inventories were calculated as the products of the average concentration of the radionuclide on sediments and the mass of sediment in the section as determined from the volume and specific gravity of the sediments.

An inventory and relative distribution of plutonium in four segments of Acid-Pueblo Canyon were estimated from sediment plutonium data and are presented in Table A-L. Calculations

based on 1970 samples indicated that about 18.1 mCi remained in the 10.3-km section of the stream channel downstream from the former waste outfall to the confluence with Los Alamos Canyon. In 1972, the calculated inventory was 11.6 mCi for the same sections of stream channel. The difference between the 1970 and 1972 inventories indicates an annual loss from the stream channel of about 2.2 mCi/year or roughly 13% of the inventory per year. The loss appears to have been largely from the upper reaches of the canyon, where the stream channel is narrow, precipitous, and easily scoured. The inventory of plutonium attached to sediment particles in the lower sections, 2.6 to 10.3 km, is apparently at steady state with annual gains equaling losses.

The ^{137}Cs sediment inventory for Acid-Pueblo Canyon was approximately 4.1 mCi in 1972 with about 3.1 mCi attributable to worldwide fallout background based on average pre-outfall concentrations of 0.38 pCi/g (Table A-LI). Few sediment samples from this canyon contained above-background levels of ^{137}Cs. Thus, the amount of ^{137}Cs released to the canyons was either small or it has since been transported downstream by storm runoff.

Estimated inventories of plutonium on channel sediments in two sections of DP-Upper Los Alamos Canyon are presented in Table A-L. The plutonium inventories in May and August 1968 reflect the storm runoff transport phenomenon. The inventory in May shows the buildup of plutonium during the fall-winter-spring months, and the August inventory represents the residual after the summer rainfall season. The plutonium losses from the section of Los Alamos Canyon between the confluence with DP Canyon to the DOE boundary apparently equaled gains, as the inventory remained relatively constant. The inventory estimate in February 1970 was 5.8 mCi. About 3.7 mCi remained in October 1972. The inventory estimates for all 3 years indicate that year-to-year losses approximately equal gains, even though 1 year's losses may occur within a short time. The net loss of plutonium from May 1968 to February 1970 was about 1.25 mCi/year, based on inventory and current release from the plant. The net loss from February 1970 to October 1972 was 1.8 mCi/year, which was based on inventory and current releases. The average of the two relative loss rates was about 1.5 mCi/m or about 23% of the inventory in the sediments and releases during the year. A simple mathematical model predicts that background levels of Pu ($\approx$0.01 pCi/g) in the active channel would be achieved about 10 years after termination of effluent releases at current rates. The estimated inventory of ^{137}Cs on sediments in DP and Upper Los Alamos Canyons was about 154 mCi in 1972. About 84% was within 1.8 km of the outfall in DP Canyon (Table A-LI). The 154 mCi of ^{137}Cs is high when compared to the amount of ^{137}Cs reported released; however, only since 1973 has the effluent had specific analyses for ^{137}Cs. During 1973 to 1975 the amount released has ranged from 1.1 to 4.3 mCi annually. The amounts released in years previous to 1973 were probably greater since the plant at TA-21 has been steadily receiving less radioactivity for the past few years.

The inventory estimates and relative distribution of plutonium on active channel sediments in Lower Los Alamos Canyon 1968 and 1970 are presented in Table A-L. The 1968 data reflect summer storm transport with 2.3 mCi present in May and decreasing to about 1 mCi in August. The inventory in February 1970 was 3.1 mCi. The estimated average annual plutonium loss because of sediment transport in this lower reach is about 53% per year based on the inventory data and input of about 2 mCi/yr from Pueblo Canyon and about 0.5 mCi/yr from Upper Los Alamos Canyon.

Cesium-137 in channel sediments in Lower Los Alamos Canyon was 10.2 mCi in 1972 (Table A-LI). The total ^{137}Cs inventory for the Acid-Pueblo-DP-Los Alamos Canyon system, including Lower Los Alamos Canyon, was about 168 mCi. About 92% was in the DP-Upper Los Alamos Canyon, with less than 3% in Acid-Pueblo Canyon, and about 6% in Lower Los Alamos Canyon.

VI. FLOOD FREQUENCY AND MAXIMUM DISCHARGE

The major transport of radionuclides released from industrial treatment plants into the canyons is by storm runoff. The runoff occurs from precipitation from summer thunderstorms or spring snowmelt. Data are not available from surface water gauging stations for estimating flood frequency and maximum discharge from the summer storms in the canyons. Therefore, an indirect method developed by Scott was used, which relates flood frequencies and discharges to the physical and climatic characteristics of the drainage basin.[A48]

The peak discharges for floods with 2, 5, 10, 25, and 50 yr recurrence intervals were determined for Upper Los Alamos and Acid-Pueblo Canyons using Scott's nomographs and appropriate climatic data for the flood frequency or "recurrence interval." This is a way of expressing probabilities, i.e., the probability of the occurrence of a 10-yr flood in any given year is 1 in 10 or 0.1; the probability of a 50-yr flood in any given year is 1 in 50, or 0.02. The combined drainage area of Acid-Pueblo Canyon is about 22.3 km^2. The estimated maximum discharges for various flood frequencies range from 3.1 m^3/s for 2-yr intervals to 21 m^3/s for 50-yr intervals (Table A-LII).

Los Alamos Canyon has a drainage area of about 27.5 km^2 upstream of the confluence with Pueblo Canyon. The estimated maximum discharges for various flood frequencies range from 3.0 m^3/s for a 2-yr interval to 20 m^3/s for a 50-yr interval (Table A-LII). The maximum discharge recorded in the canyon at the gauging stations near test well T-3 was about 10 m^3/s for 1967 through 1975. This is comparable to the computed flood frequency for a 10-year period of 11 m^3/s.

The theoretical data indicate that the probable maximum discharges of Acid-Pueblo, DP, and Upper Los Alamos Canyons are of the same general magnitude at the confluence. Runoff in Lower Los Alamos Canyon can be greater than the combined flow of these upper canyons because of inflow from other tributary canyons.

Guaje Canyon has a larger drainage area than Acid-Pueblo and Los Alamos Canyons combined and its maximum discharge would be equal to or greater than the discharge from Acid-Pueblo and Los Alamos Canyons.

VII. TRANSPORT OF RADIONUCLIDES IN STORM RUNOFF

The major transport mechanism of radionuclides in the canyons receiving industrial effluents is by storm runoff.[A49,A50] The radionuclides are transported in solution, suspended sediments, and bed sediments. In the summers of 1967 and 1968, a study was attempted to determine the volume of runoff, the suspended sediment load, and the amount of radioactivity carried out of DP Canyon into Upper Los Alamos Canyon by summer runoff. Precipitation during the summer resulted in 23 runoff events that carried about 88 000 kg of suspended sediments out of the canyon in about 36 800 m^3 of water. About 74 μCi of gross-alpha emitters and about 40 000 μCi of gross-beta emitters were carried out of the canyon with the runoff. About 31 000 μCi of ^{90}Sr left the canyon in solution, as did traces of ^{238}Pu, ^{239}Pu, and ^{241}Am.[A48]

The runoff events in the summers of 1967 and 1968 were sampled using cumulative samplers installed in the walls of a gauging station at DPS-4 in Lower DP Canyon. The samples were collected during the initial 5 min of flow when it reached a depth of 15 cm above the base of the control section. The samples were analyzed for chemical constituents, all of which were higher than normal and are attributed to the drainage area, including streets and parking lots in the community area (Table A-LIII). The presence of radionuclides in solution is attributed to the release of industrial effluents into Upper DP Canyon and transport during storm runoff. Activity is resuspended from the sediments that had previously adsorbed radionuclides from liquid waste effluents. During the summer of 1968, a series of samples were collected at intervals throughout runoff events, using a DH-48 suspended sediment sampler at the gauging stations at the mouth of

DP Canyon and in Los Alamos Canyon above the junction with DP Canyon. Discharge and suspended sediment concentrations were determined during these events. The gross-alpha and gross-beta activities in solution and suspended sediment samples were measured by laboratory analyses.

On July 30 and 31, 1968, samples were collected at DPS-4 during runoff events in DP Canyon (Table A-LIV). A set of samples was collected at DPS-4 and in Los Alamos Canyon on August 6, 1968 (Table A- LV).

The measurements on July 30 at DPS-4 were made over a 2-h 30-min period. The mean discharge was about 900 ℓ/s. The total discharge during the period was 11.4×10^3 m³, which carried out about 3.4×10^{-5} Ci of gross-alpha activity and 1.6×10^{-2} Ci of gross-beta activity in solution. The mean suspended sediment concentration was about 11 000 mg/ℓ with total suspended sediment load of 1.2×10^5 kg for the period. The suspended sediment carried out about 4.0×10^{-4} Ci of gross-alpha activity and 1.3×10^{-1} Ci of gross-beta activity.

The measurements on July 31 at DPS-4 were made over a 2-h 30-min period. The mean discharge was about 1050 ℓ/s. The total discharge for the period was 9.4×10^3 m³, which carried out about 7.1×10^{-5} Ci of gross alpha activity and 1.0×10^{-2} Ci of gross-beta activity in solution. The mean suspended sediment load for the period was about 21 000 mg/ℓ with a total load of 1.9×10^5 kg for the period. The suspended sediments carried out about 4.3×10^{-3} Ci of gross-alpha activity and 8.0×10^{-2} Ci of gross-beta activity.

The measurements on August 6 at DPS-4 were made over a 70-min period. The mean discharge was about 315 ℓ/s. The total discharge for the period was about 1.3×10^3 m³, which carried out about 9.6×10^{-6} Ci of gross-alpha activity and 2.6×10^{-3} Ci of gross-beta activity in solution. The mean suspended sediment concentration was about 7200 mg/ℓ for a total load of 9.9×10^6 kg. The suspended sediments carried out about 1.3×10^{-4} Ci of gross-alpha activity and 3.9×10^{-3} Ci of gross-beta activity.

The August 6 measurements in Los Alamos Canyon were above the confluence with DP Canyon and thus reflect discharge from a noneffluent discharge area. The flow was measured over a 2-h period. The mean discharge was 1090 ℓ/s. The total discharge for the period was 7.8×10^3 m³, which carried out about 2.3×10^{-5} Ci of gross-alpha activity and 1.1×10^{-4} Ci of gross-beta activity in solution. The mean suspended sediment discharge was about 8700 mg/ℓ with a total load of 6.8×10^3 kg for the period. The suspended sediments carried about 2.7×10^{-4} Ci of gross-alpha activity and 3.4×10^{-4} Ci of gross-beta activity.

In comparing the amounts of activity carried past the stations during runoff events, it becomes quite evident that larger amounts of both gross-alpha and gross-beta activity are transported with the suspended sediments. The amount of gross-beta activity transported in DP Canyon both in solution and suspended sediments is much greater than gross alpha, whereas in Los Alamos Canyon above the confluence with DP Canyon, the amounts are nearly equal. These intermittent runoff events during the summer are one of the major transport modes from the canyons that receive industrial effluents.

Two seepage runs were made during the recession of a late summer storm runoff in September 1975. The discharge was estimated at the stations, and the plutonium in solution and in suspended sediments was determined (Table A-LVI). The bulk of the runoff during these two events was from Acid-Pueblo Canyon. The suspended sediment concentration ranged from 3500 to 5000 mg/ℓ at Station APSC and from 200 to 600 mg/ℓ at LASC. The sediment concentration varied downgradient in the September 4 event and decreased downgradient during the September 12 event. The concentration of plutonium was greater in suspended sediments than in solution. During the event on September 6, the crest (peak discharge) of the event occurred between LAS-3 and LAS-4. The crest of the flow on September 12 had reached the Rio Grande and the flow in the canyon was in recession. The samples collected during the recession had contained larger plutonium concentrations in solution and suspended sediment than the event on September 4

before the crest reached the Rio Grande. The ratio of plutonium concentration in solution to the concentration in suspended sediments also became greater during the recession. It appears, from the amount of limited data, that during the recession of a runoff event, the transport of plutonium may be greater with larger concentrations of plutonium in solution and suspended sediments than during the initial part of the runoff. The transport data at individual stations illustrate the variations in discharge, suspended sediment, and plutonium concentrations that occur during a single runoff event (Tables A-LIV through A-LVII).

The transport of radionuclides in spring snowmelt was studied during the spring of 1973. It was estimated from the runoff volume (425×10^3 m^3) that about 30 μCi of the plutonium in solution and 290 μCi of the plutonium in suspended sediments were discharged into Lower Los Alamos Canyon. The runoff also scoured out and transported 2880×10^3 kg of bed sediments, which contained about 1094 μCi of plutonium, into the lower reach of Los Alamos Canyon.

A second study of the transport of plutonium by snowmelt was made during the spring of 1975. This study extended to the Rio Grande. Los Alamos Canyon has a large drainage area on the flanks of the mountains at a higher elevation than Pueblo Canyon. The volume of runoff at Station LASC was 302×10^3 m^3. During the same event the inflow into the lower canyon at APSC was only 3.4×10^3 m^3. The volume of runoff decreased downgradient to the Rio Grande because of infiltration into the thick section of unsaturated alluvium in the lower part of the canyon. About 26×10^3 m^3 of runoff from this event reached the Rio Grande (Table A-LVII). The concentration of plutonium in suspended sediment was about 20 times greater than the concentration in solution. In general, the plutonium in solution increased downgradient in the canyon. The suspended sediment concentrations also increased downgradient in the canyon, accompanied by an increase in the amount of plutonium transported past each station.

Los Alamos Canyon at Station LASC contributed 81 μCi of plutonium because of the large volume of flow. In Pueblo Canyon, APSC contributed 11 μCi with less than 1% of the flow at Station LASC (Table A-LVII). The total transport through Los Alamos Canyon reaching the Rio Grande measured in solution and suspended sediments was 321 μCi. As an approximation, it is estimated that the amount of activity carried on bed sediments would also have been about 300 μCi for a total estimated transport into the Rio Grande of about 600 μCi.

The data from these few studies are inadequate to make statistically sound projections of the amount of transport of radioactivity through the canyon systems and into the Rio Grande. However, in conjunction with other data on sediment transport, some approximations of expected ranges can be made.

Extrapolating the measurements of sediment transport made in the upper part of Los Alamos Canyon during the 1973 spring runoff suggests that about 2.5 mCi may have been transported into the Rio Grande. The 1973 spring runoff was probably substantially higher than average, but there is simply no historic record of discharge from Los Alamos Canyon to provide any statistics.

The summer thunderstorm runoff event measurements in September of 1975 indicate that the smaller event carried about 0.5 μCi in solution and suspended sediments with an estimated equal amount on bed sediments or a total of about 1 μCi into the Rio Grande. Extrapolation of available data for the larger event suggests that as much as about 40 μCi may have been transported into the Rio Grande.

Thus it is likely that the typical annual amount of plutonium transported by runoff into the Rio Grande is on the order of 1 mCi. This is a rough estimate based on limited data. The actual amount in any given year would range widely depending largely on climatology. There are some years when moisture is so low that no flow reaches the Rio Grande from Pubelo and Los Alamos Canyons. In other years both snowmelt and thunderstorm runoff reach the Rio Grande for varying periods.

Assuming that 1 mCi/yr is distributed in the average annual suspended sediment load of 2.2 $\times 10^9$ kg in the Rio Grande at Otowi gives an average concentration of 0.0005 pCi/g or about 10% of the concentration typically measured in sediments from regional surface waters in Northern New Mexico.[A27-A30] This estimated value is less than observed variability in measurements of plutonium on sediments from the Rio Grande downstream from the confluence with Los Alamos Canyon and less than the measurement errors at such low levels. It is not possible to distinguish expected increments of plutonium attributable to transport out of Pueblo and Los Alamos Canyons from the variation in concentration of worldwide fallout plutonium on sediments in the Rio Grande.

VIII. PERCHED WATER IN PUYE FORMATION AND BASALTIC ROCKS OF CHINO MESA

Perched water in the Puye Formation occurs in the midreach of Pueblo Canyon. Test Well T-2A, drilled to a depth of 40.5 m in 1947, penetrates the alluvium, the Bandelier Tuff, and is completed in the Puye Formation (Fig. A-5). Aquifer tests indicate the perched aquifer is of limited extent. The changes in water levels over a period of time indicate the aquifer is hydrologically connected to recharged stream flow and water in the alluvium.

Water samples were collected from test well T-2A from 1951 through 1965 (Table A-LVIII). The quality of the water has changed over the years, reflecting the quality of water in the stream. The most noticeable increases have been in chlorides, nitrates, and TDS. Radiochemical analyses from 1958 through 1965 indicate no detectable radioactivity (Table A-LIX). No samples were collected between 1965 and 1978 because of pump failure. Samples collected in 1978 contained no detectable Pu; however, tritium was above normal background at 18.9×10^{-6} μCi/mℓ. This is consistent with chemical quality of data indicating recharge from the stream because tritiated water moves with ordinary.

Perched water in the basaltic rocks of Chino Mesa occurs in test well T-1A in Lower Pueblo Canyon and Basalt Spring, to the east in Lower Los Alamos Canyon (Fig. A-5). Recharge to the aquifer that is perched in basalt occurs in Pueblo Canyon in the area between Observation Hole PO-3B and Otowi Seep and in Los Alamos Canyon west of State Road 4. The surface flow in the recharge reach of Pueblo Canyon is mainly effluent from the Bayo Sewage Treatment Plant. The movement of water is eastward and part is discharged through Basalt Spring. This discharge ranges from 0.9 to 2.1 ℓ/s, according to the volume of recharge entering the aquifer. Based on water-level response to stream flow, it is estimated that recharge from Observation Hole PO-3B to the Otowi Seep area takes 1 to 2 months to reach T-1A and another 2 to 3 months to reach Basalt Spring.

Water samples were collected from Observation Hole PO-3B from 1957 to 1975. The observation hole is completed at a depth of 18 m in the Puye Formation. The water has shown a general increased in sodium, chlorides, fluorides, nitrates, and TDS (Table A-LX). This chemical quality is similar to the alluvial and stream water, which is the source of recharge to the aquifer.

Perched water was encountered at a depth of 53 to 68 m in the basaltic rocks of Chino Mesa at Test Well T-1A. The well is equipped with a pump and samples have been collected from 1951 through 1975 for chemical analyses (Table A-LXI). The water quality is similar to that found in the stream between Hamilton Bend Spring and Pueblo 3.

The chemical quality of Basalt Spring water has been monitored since 1951 (Table A-LXII). It is similar to water in Test Well T-1A, although the concentrations are a little lower. This is probably because of changes in quality that occur in transit in the aquifer.

Trace metal analyses were run on water from Test Well T-1A and Basalt Spring (Table A-LXIII). Trace amounts of cadmium and lead were reported. The high lead concentrations (470 $\mu g/\ell$) at T-1A in particulates is probably from the pump column or the lead packer that connects the screen to the casing at the bottom of the well.

The plutonium concentration in water samples from Observation Hole PO-3B, from 1957 through 1964, were below detection limits (<0.5 pCi/ℓ). Gross beta was reported in March 1958, 1270 pCi/ℓ; May 1958, 189 pCi/ℓ; and by June 1958, <14 pCi/ℓ. The gross beta in the remainder of the analyses, from 1957 through 1964, was below detection limits (<14 pCi/ℓ). Radiochemical analyses for 1970 through 1975 indicate some high concentrations of gross beta and tritium, as well as traces of plutonium from 1972 through 1975 (Table A-LXIV). However, these analyses are probably not representative of the water in the aquifer, as the well was inadvertently flushed with a contaminated pump. Little, if any, ^{238}Pu was released into the canyon during the period 1945 through 1964.

Radiochemical analyses of water from Test Well T-1A for the period 1958 through 1964 reported plutonium, gross beta, and total uranium below limits of detection (< 0.5 pCi/ℓ, <14 pCi/ℓ, and 0.5 $\mu g/\ell$, respectively). Radioactivity in samples collected from 1968 through 1975 was essentially the same, below limits of detection (Table A-LXIV).

From 1957 through 1965, plutonium and gross-beta activity in water from Basalt Spring was below limits of detection (Table A-LXIV). Total uranium varied slightly, ranging from <0.5 to 2.0 $\mu g/\ell$. Radionuclides in water collected from 1967 through 1975 were below limits of detection (Table A-LXIV).

IX. MAIN AQUIFER

Test Well T-1, completed in 1950, penetrated the top of the main aquifer at a depth of 180 m (Fig. A-4). The well was equipped with a pump from 1952 through 1960; since that time, water samples have been collected with a bailer. From 1952 through 1970, the chemical quality of water has shown no significant change (Table A-LXV).

Test Well T-2, completed in 1949, penetrated the top of the main aquifer at a depth of 232 m. From 1950 through 1974, the well was equipped with a pump. From 1951 through 1974, the water has shown a slight increase in sodium. Total dissolved solids have varied slightly (Table A-LXVI), and the other ions have remained about the same.

Test Well T-3, completed in 1949, penetrated the top of the main aquifer at a depth of 229 m. From 1950 through 1975, the well, located in Los Alamos Canyon, was equipped with a pump (Fig. A-4). The chemical quality has shown no change over the period of record (Table A-LXVII).

Test Well T-4 was completed into the main aquifer at a depth of 256 m. The well is located near the site of the industrial treatment plant, TA-45 (Fig. A-4). Sampling was infrequent; however, chemical quality shows no significant change during the period 1952 through 1965 (Table A-LXVIII).

In 1971, trace metal analyses were made of water from test wells T-2 and T-3. The results showed slight amounts of lead in solution and in particulates (Table A-LXIX). Radiochemical analyses of water from test wells completed in the main aquifer indicated no contamination as a result of the release of industrial effluents into Acid-Pueblo or DP and Upper Los Alamos Canyons (Table A-LXX).

X. RADIONUCLIDES IN VEGETATION AND RODENTS

A preliminary study described the vegetation and small mammal communities and composition, distribution and biomass along with air temperature, humidity, and precipitation as a function of elevation in Acid-Pueblo, DP, and Los Alamos Canyons. The dominant overstory vegetation in the upper reach of Acid-Pueblo and DP Canyons is ponderosa pine and fir, whereas in the middle and lower reaches of Pueblo Canyon and Upper Los Alamos Canyon, the growth is ponderosa pine, piñon, and juniper. Juniper, saltbrush, sagebrush, rabbitbrush, and Apache plume were found in Lower Los Alamos Canyon near the Rio Grande. The dominant forbs and grasses in Acid-Pueblo and DP-Upper Los Alamos Canyons are bluegrass, dandelions, and sorghum. Bromegrass, mullein, and snakeweed are dominant in Lower Los Alamos Canyon near the Rio Grande.[A51]

Plutonium and cesium concentrations in vegetation were determined from 0 to 640 m in Acid Canyon and from 640 to 10 280 m in Pueblo Canyon (Fig. A-7). The vegetation data are grouped into two categories, control data and discharge reach. The average sediment concentrations of radionuclides is also shown (Table A-LXXI). These limited data indicate uptake of radionuclides is highest in the upper section (0 to 640 m) of Acid-Pueblo Canyon where the highest concentration of radionuclides occurs in the sediments. Grasses in the lower reach of the canyon (640 to 10 280 m) show some trace amounts of plutonium and cesium.[A43]

Similarly, plutonium and cesium in vegetation were determined from 0 to 20 m below the effluent outfall in DP Canyon and 20 to 10 280 m in DP and Los Alamos Canyons (Table A-LXXI). The highest concentration in grass occurs immediately below the outfall in the 0 to 20 m reach, whereas there is some indication of uptake in the lower reach studied (20 to 10 280 m). In general, the concentration of uptake varies, decreasing downgradient in both canyons, and is related to radionuclide concentration in the sediments.

The small mammal communities in Acid-Pueblo and Los Alamos Canyons have been described in a biotic survey of the area.[A51] Plutonium and cesium data from rodents have been collected in Acid Canyon and DP Canyon near effluent outfalls (Fig. A-4). The results are compared to a control area (Table A-LXXII). The highest mean plutonium concentration occurred in the pelts of the rodents. Little, if any, plutonium was found in the lungs, liver, or carcasses of rodents. Cesium concentrations in the carcasses were only slightly elevated when compared to the control area analyses. It appears that the rodents in the outfall area have picked up contaminated particles of the fine sediments in their pelts.[A43] The uptake and transport of radionuclides by vegetation and rodents is minor when compared to concentrations found in sediments of the canyons receiving industrial effluents.

XI. RADIATION SURVEY OF PUEBLO CANYON, LAND PARCEL C

In 1972 a radiation survey was made of the canyon bottom in the midreach of Pueblo Canyon to determine the impact of Los Alamos National Laboratory activity.[A52] This was part of an overall survey conducted north of Pueblo Canyon. The area surveyed included the floor of the canyon south of the stream between PC-7 and PC-8 and had an area of about 0.38 km^2. Analyses were made for a number of different radionuclides in soil, and vegetation was compared to a background area in Northern New Mexico (Table A-LXXIII). Tritium in vegetation was slightly elevated above the regional background. The remaining radionuclides analyzed in soil and vegetation were similar to regional background concentrations.

XII. SUMMARY

Acid-Pueblo Canyon now receives effluent from two community sewage treatment plants but did receive industrial effluents containing radionuclides from 1943 through 1964. The release of sewage effluents maintains a base flow in a part of the canyon and recharges the water in the alluvium, a small body of perched water in the Puye Formation in the midreach of the canyon, and a second body of perched water in the basaltic rocks of Chino Mesa in the lower part of the canyon. The chemical quality of water in the stream, aquifers in alluvium, perched water in the volcanic sediments, and basalts is dominated by the quality of sewage effluents released. The intermittent release of industrial effluents during the period the treatment plant was in operation elevated, for short periods of time, the chemical concentrations of sewage effluents in the canyon. The industrial effluents contained some mixed fission products, but the major radionuclide was plutonium. In general, these concentrations decreased downgradient in the canyon from the effluent outfall.

DP-Los Alamos Canyon receives effluent from two sewage treatment plants (one near TA-21 and the other near TA-41) and an industrial waste treatment plant that processes radioactive influents. The volume of sewage and industrial effluents released into DP and Los Alamos Canyons is low. They rapidly infiltrate into the alluvium. The stream flow in Los Alamos Canyon is impounded by a dam on the flanks of the mountain to the west of the plateau. Stream flow is intermittent in the canyons of the plateau. The major volumes of stream flow occur during the summer from heavy showers; however, a heavy snow pack can produce runoff for 1 to 2 months during the late spring. The chemical quality of water in the short reaches below the plants is reflected in the similar quality of water in the alluvium. This is quite evident as the industrial and sewage effluent from DP Canyon moves into the midreach of Los Alamos Canyon. As in Pueblo Canyon, the chemical and radiochemical quality of the water improves downgradient in the canyon.

Four test wells completed into the main aquifer exhibited no change in chemical quality nor any trace of radionuclides that can be attributed to the release of industrial or sanitary effluents into Acid-Pueblo or DP-Los Alamos Canyons.

The bulk of radionuclides released with the industrial effluents becomes bound either by adsorption or ion-exchange with fine particles in the alluvium of the stream channels, thus the concentration in solution decreases downgradient in the canyon. The accumulation of radioactivity in sediments near the effluent outfalls is flushed and dispersed down the canyon by storm runoff. Estimated inventories of plutonium in channel sediments in Acid-Pueblo and DP-Los Alamos Canyons indicate transport to the Rio Grande. The largest amounts of plutonium and cesium in sediments occurs in DP Canyon. The radionuclides and associated sediments are subject to transport by storm runoff. Only trace amounts of plutonium and cesium are found in vegetation and rodents in the immediate effluent release areas. Compared to the concentrations in the sediments, the uptake and transport of these radionuclides by vegetation and rodents is minor.

REFERENCES

A1. R. L. Griggs, "Geology and Ground-Water Resources of the Los Alamos Area, New Mexico," U.S. Geol. Survey Water-Supply Paper 1753 (1964).

A2. Zane Spiegel and Brewster Baldwin, "Geology and Water Resources of the Santa Fe Area, New Mexico," U.S. Geol. Survey Water-Supply Paper (1963).

A3. R. A. Bailey, R. S. Smith, and C. S. Ross, "Stratigraphic Nomenclature of the Volcanic Rocks in the Jemez Mountains, New Mexico," U. S. Geol. Survey Bull. 1274-P (1969).

A4. V. C. Kelley, "The Rio Grande Depression from Taos to Santa Fe," New Mexico Geol. Soc. Seventh Field Conf., Southeastern Sange de Cristo Mountains, New Mexico (1956).

A5. A. J. Budding and W. D. Purtymun, "Seismicity of the Los Alamos Area Based on Geologic Data," Los Alamos Scientific Laboratory report LA-6278-MS (1976).

A6. J. H. Abrahams, E. H. Baltz, and W. D. Purtymun, "Movement of Perched Ground Water in Alluvium Near Los Alamos, New Mexico," U.S. Geol. Survey Prof. Paper 450-B (1962).

A7. C. V. Theis and C. S. Conover, "Pumping Tests in the Los Alamos Canyon Well Field Near Los Alamos, New Mexico," U.S. Geol. Survey Water-Supply Paper 1619-I (1962).

A8. R. L. Cushman, "An Evaluation of Aquifer and Well Characteristics of Municipal Well Fields in Los Alamos and Guaje Canyons Near Los Alamos, New Mexico," U.S. Geol. Survey Water-Supply Paper 1809-D (1965).

A9. W. D. Purtymun and Steven Johansen, "General Geohydrology of the Pajarito Plateau," New Mexico Geol. Soc. Twenty-Fifth Field Conf., Ghost Ranch Central-Northern New Mexico (1974).

A10. E. R. Jette, "Report of Radioassay Tests Run on Sewer Water Samples and on Water and Soil Samples Taken from Los Alamos and Pueblo Canyons," Los Alamos Scientific Laboratory report LA-516-MS (1946).

A11. J. F. Tribby and W. H. Kingsley, "Survey of Los Alamos and Pueblo Canyons for Radioactive Contamination in May 1947," Los Alamos Scientific Laboratory report LA-516A-MS (1947).

A12. J. H. Abrahams, "Geologic and Hydrologic Environment of Radioactive Waste-Disposal Sites at Los Alamos, New Mexico," U.S. Geol. Survey Admin. Rept. (1962).

A13. J. E. Weir, Jr., J. H. Abrahams, Jr., J. R. Waldon, and W. D. Purtymun, "The Hydrology and Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, 1949-1955," U.S. Geol. Survey Admin. Rept (1963).

A14. J. H. Abrahams, "Hydrology and the Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, January 1956 through June 1957," U.S. Geol. Survey Admin Rept. (1966).

A15. J. H. Abrahams and W. D. Purtymun, "The Hydrology and Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1957 through June 1961," U.S. Geol. Survey Admin. Rept. (1966).

A16. W. D. Purtymun, J. H. Abrahams, and J. R. Arrett, "Hydrology of Waste Disposal Systems at Los Alamos, New Mexico, 1949 through 1961," U.S. Geol. Survey unpublished report.

A17. W. D. Purtymun, "The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1961 through June 1962," U.S. Geol. Survey Admin. Rept. (1966).

A18. W. D. Purtymun, "The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1962 through June 1963," U.S. Geol. Survey Admin. Rept. (1966).

A19. W. D. Purtymun, "The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1963 through June 1964," U.S. Geol. Survey Admin. Rept. (1966).

A20. W. D. Purtymun and E. A. Enyart, "The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1964 through June 1965," U.S. Geol. Survey Admin. Rept. (1966).

A21. W. D. Purtymun and J. L. Kunkler, "The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1965 through June 1966," U.S. Geol. Survey Admin. Rept. (1967).

A22. W. D. Purtymun and J. L. Kunkler, "The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1966 through June 1967," U.S. Geol. Survey Admin. Rept. (1969).

A23. W. R. Kennedy, "Los Alamos Environmental Monitoring Program," Los Alamos Scientific Laboratory report LA-3639-MS (1970).

A24. W. R. Kennedy, W. D. Purtymun, and H. F. Schulte, "Los Alamos Environmental Monitoring Program, July through December 1970," Los Alamos Scientific Laboratory report LA-4672-MS (1971).

A25. J. E. Herceg, compiler, "Environmental Monitoring in the Vicinity of the Los Alamos Scientific Laboratory, January through June 1971," Los Alamos Scientific Laboratory report LA-4871-MS (1972).

A26. J. E. Herceg, compiler, "Environmental Monitoring in the Vicinity of the Los Alamos Scientific Laboratory, July through December 1971," Los Alamos Scientific Laboratory report LA-4970 (1972).

A27. J. E. Herceg, compiler, "Environmental Monitoring in the Vicinity of the Los Alamos Scientific Laboratory, Calendar Year 1972," Los Alamos Scientific Laboratory report LA-5184 (1973).

A28. K. J. Schiager and K. E. Apt, compilers, "Environmental Surveillance at Los Alamos During 1973," Los Alamos Scientific Laboratory report LA-5586 (1974).

A29. K. E. Apt and V. J. Lee, compilers, "Environmental Surveillance at Los Alamos During 1974," Los Alamos Scientific Laboratory report LA-5977-PR (1975).

A30. K. E. Apt and V. J. Lee, compilers, "Environmental Surveillance at Los Alamos During 1975," Los Alamos Scientific Laboratory report LA-6321-MS (1976).

A31. Group H-7, "Chemical and Radiochemical Quality of Surface and Ground Water from 1952 Through 1967 Compiled by Source," Los Alamos National Laboratory, group records, 1967.

A32. Group H-6, "Radiochemical Analyses—Results for Water Samples, 1958 Through 1970, Los Alamos National Laboratory, group records, 1970.

A33. U.S. Geological Survey, "Chemical Quality of Surface and Ground Water," Los Alamos National Laboratory, data cards on file in Group H-8, 1961.

A34. American Public Health Assoc., American Water Works Assoc., and Water Pollution Control Federation, *Standard Methods for the Examiination of Water and Wastewater*, (American Public Health Assoc., 1790 Broadway, New York, NY 10019, Vol. 12, 1965).

A35. F. H. Rainwater and L. L. Thatcher, "Methods for Collection and Analyses of Water Samples," U.S. Geol. Survey Water-Supply Paper 1454 (1960).

A36. J. D. Hem, "Study and Interpretation of the Chemical Characteristics of Natural Water," U.S. Geol. Survey Water-Supply Paper 1473 (1959).

A37. C. W. Christenson, "Radioactive Waste Disposal Practice at Los Alamos," First Session on Ind. Radioactive Waste Disposal, Hearings before Spec. Sub. Comm. on Radiation, V. 1, Eighty-sixth Cong., U.S. Govt Printing Office (1959).

A38. T. E. Hakonson, J. W. Nyhan, L. J. Johnson, and K. V. Bostick, "Ecological Investigation of Radioactive Materials in Waste Discharge Areas at Los Alamos for the Period July 1, 1972 through March 31, 1973," Los Alamos Scientific Laboratory report LA-5282-MS (1972).

A39. U.S. Energy Research and Development Administration, U.S. ERDA Onsite Discharge Information System, "Radionuclide Decay Report for Los Alamos Scientific Laboratory CY-75," computer-generated tabulation prepared for ERDA by EG&G, Idaho, Inc. (1976).

A40. W. D. Purtymun, G. L. Johnson, and E. C. John, "Distribution of Radioactivity in Alluvium of a Disposal Area at Los Alamos, New Mexico," U.S. Geol. Survey Prof. Paper 550-D (1966).

A41. P. E. Trujillo, Jr., "Standard Analytical Procedures for Soil," Los Alamos National Laboratory, unpublished report (1970).

A42. W. D. Purtymun, "Plutonium in Stream Channel Alluvium in the Los Alamos Area, New Mexico," Los Alamos Scientific Laboratory report LA-4561 (1971).

A43. T. E. Hakonson and K. V. Bostick, "Cesium-137 and Plutonium in Liquid Discharge Areas at Los Alamos," Ecology Soc. of Am. Spec. Pub. No. 1 (1975).

A44. J. W. Nyhan, F. R. Miera, Jr., and R. J. Peters, "Distribution of Plutonium in Soil Particle Size Fractions of Liquid Effluent-Receiving Areas at Los Alamos," Jour. of Environmental Quality, Vol. 5, No. 1 (1976).

A45. J. W. Nyhan, F. R. Miera, Jr., and R. J. Peters, "The Distribution of Plutonium and Cesium in Alluvial Soils of the Los Alamos Environs," Ecology Soc. of Am. Spec. Pub. No. 1 (1975).

A46. W. D. Purtymun, "Inventory and Movement of Plutonium in Acid-Pueblo, DP-Los Alamos, and Mortandad Canyons," Los Alamos National Laboratory, unpublished data, H-8-424, November 14, 1974.

A47. W. D. Purtymun and T. E. Hakonson, "Inventory and Movement of Plutonium in Acid-Pueblo, DP-Los Alamos, and Mortandad Canyons," Los Alamos National Laboratory, unpublished data, H-8-74-430, December 3, 1974.

A48. A. G. Scott, "Preliminary Flood-Frequency Relations and Summary of Maximum Discharges in New Mexico," U.S. Geol. Survey Open-file Report (1971).

A49. William D. Purtymun, "Storm Runoff and Transport of Radionuclides in DP Canyon, Los Alamos County, New Mexico," Los Alamos Scientific Laboratory report LA-5744 (1974).

A50. T. E. Hakonson, J. W. Nyhan, and W. D. Purtymun, "Accumulation and Transport of Soil Plutonium in Liquid Waste Discharge Areas at Los Alamos," in Transuranium Nuclides in the Environment, IAEA-SM-99/99 (1976).

A51. F. R. Miera, Jr., K. V. Bostick, T. E. Hakonson, and J. W. Nyhan, "Biotic Survey of Los Alamos Radioactive Liquid-Effluent Receiving Areas," Los Alamos Scientific Laboratory report LA-6503-MS (1977).

A52. L. J. Johnson, "Los Alamos Land Areas Environmental Radiation Survey 1972," Los Alamos Scientific Laboratory report LA-5097-MS (1972).

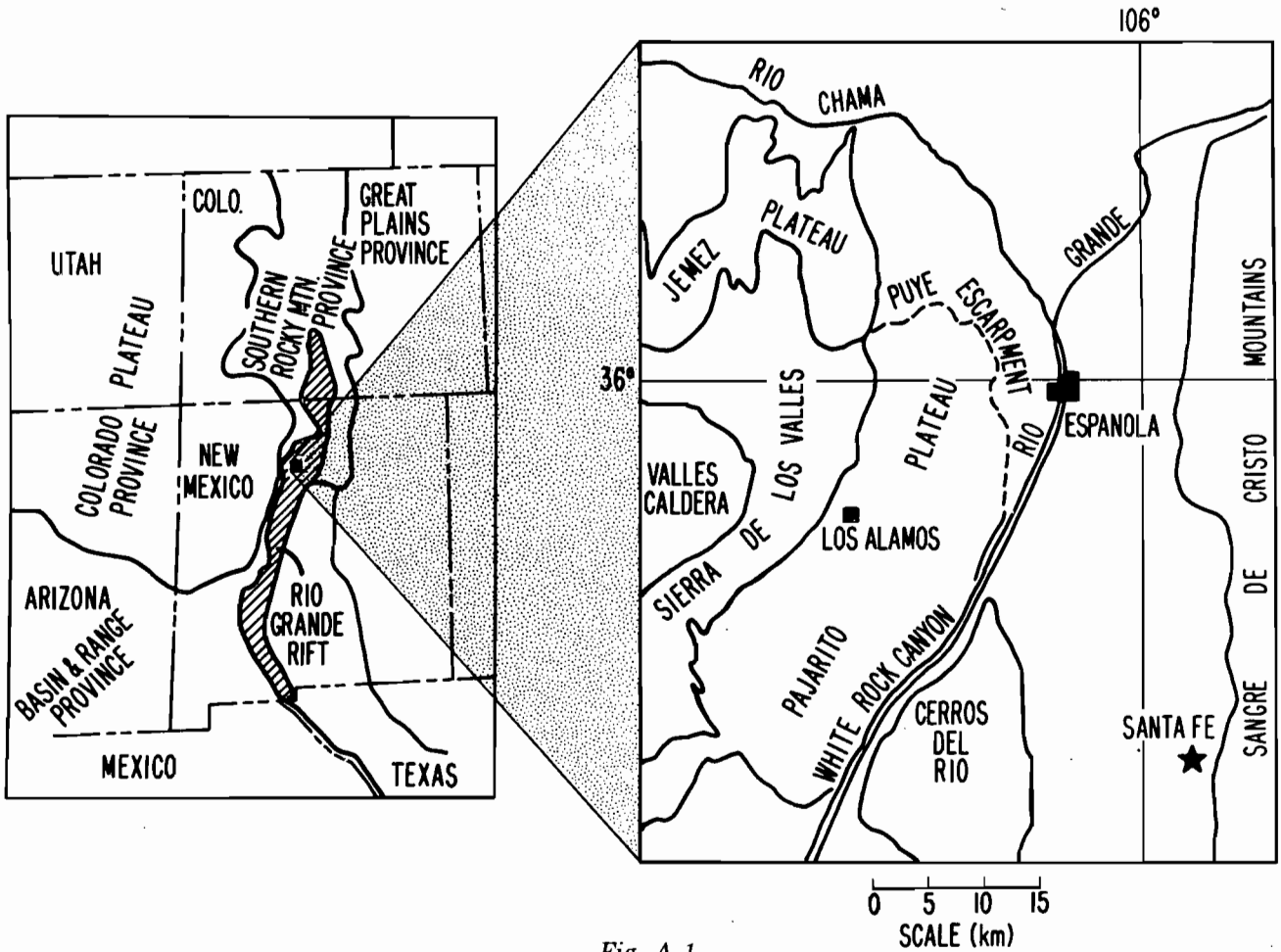

Fig. A-1.
Physiographic features in the Los Alamos area, northcentral New Mexico.

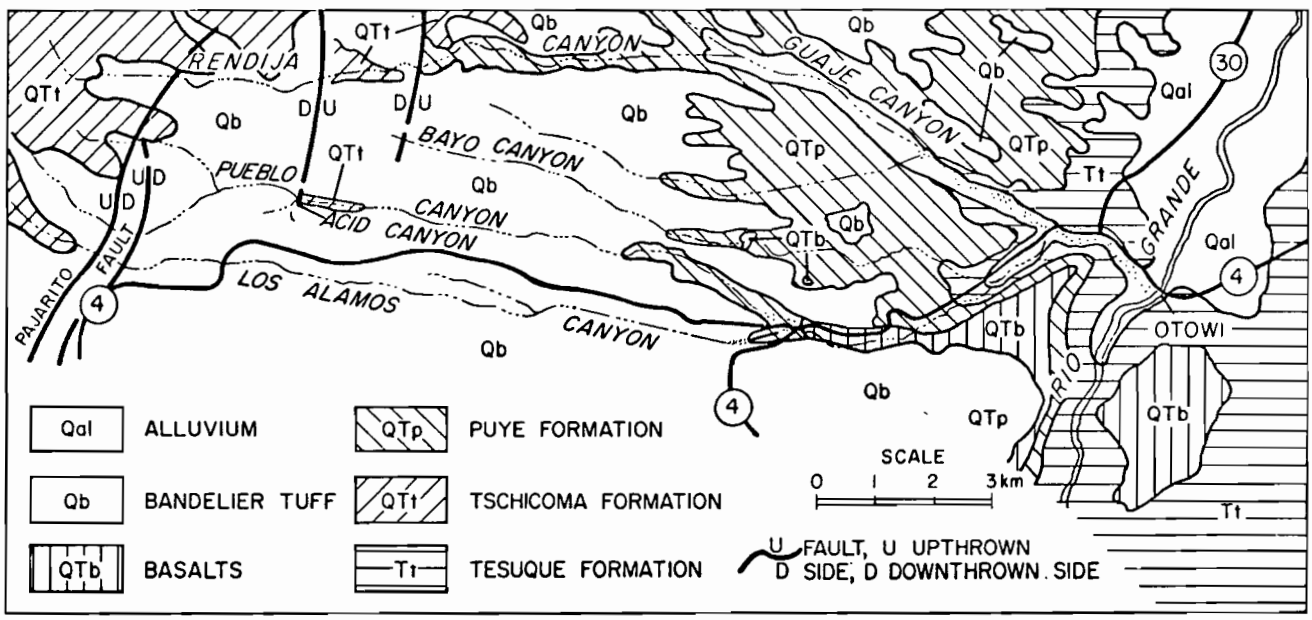

Fig. A-2.
Geologic map of a part of the Pajarito Plateau in the Los Alamos area.

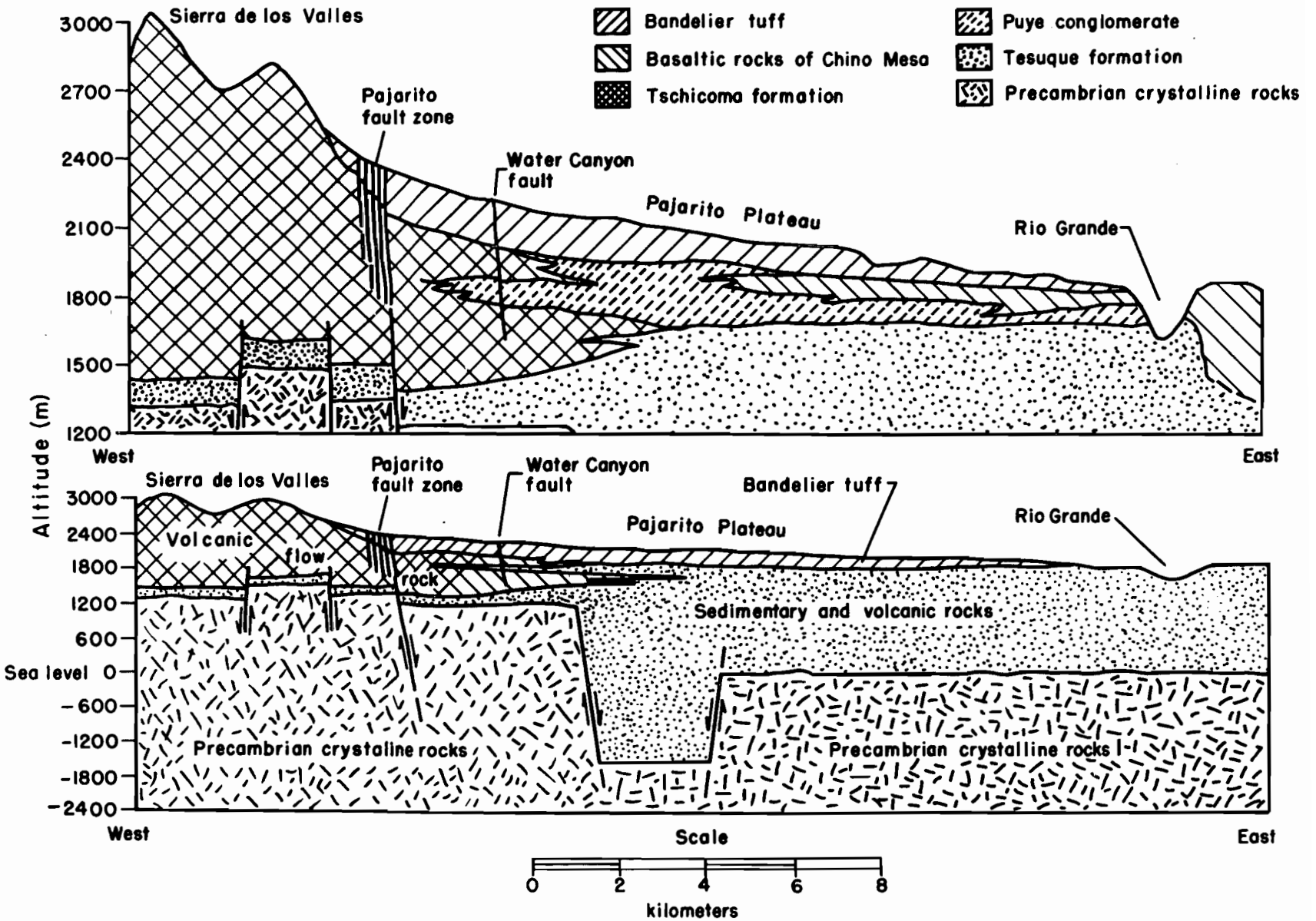

Fig. A-3.

Generalized stratigraphic and structural sections east-west through the Pajarito Plateau.

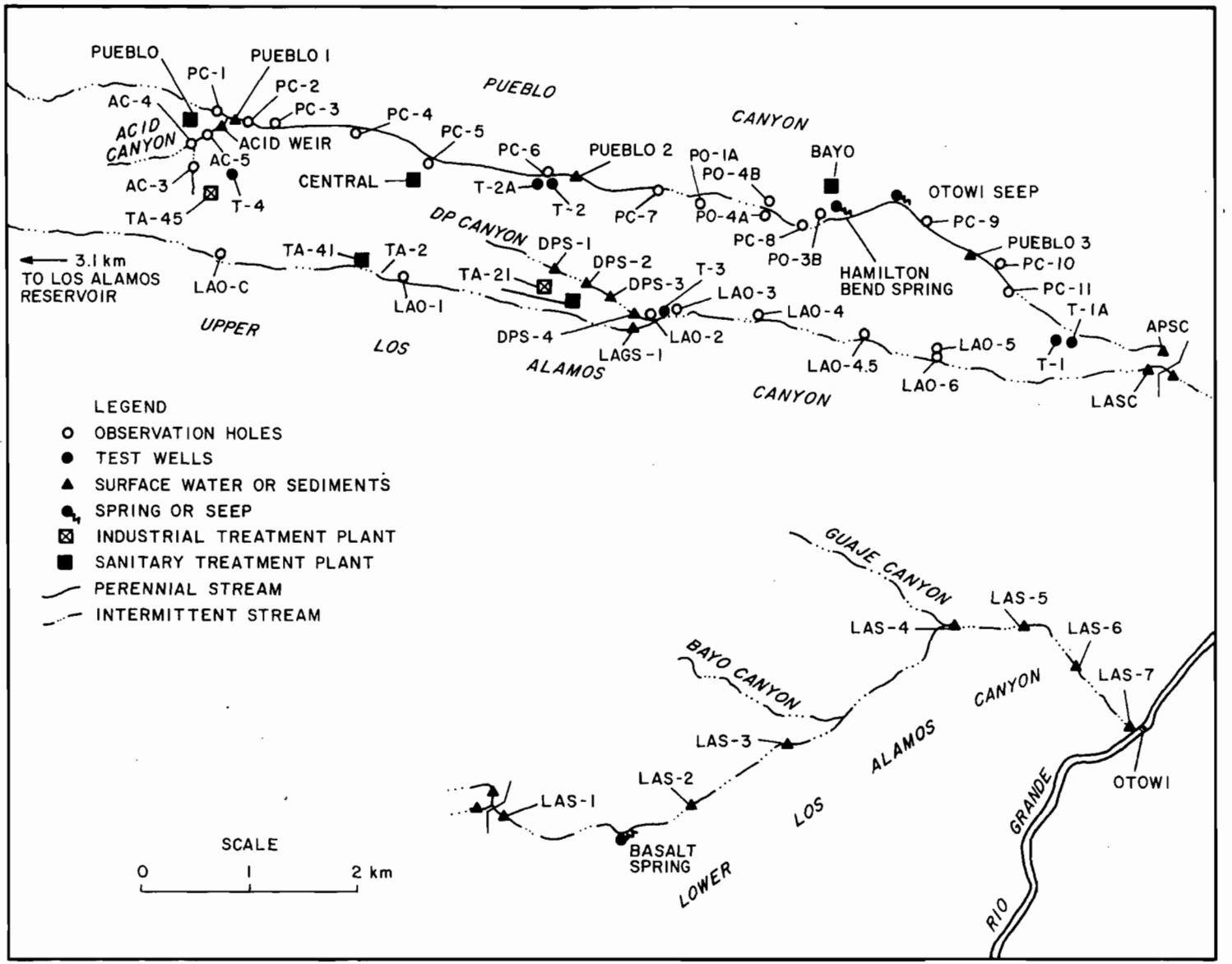

Fig. A-4.
Monitoring net in Acid-Pueblo and DP-Los Alamos Canyons, 1949-1975.

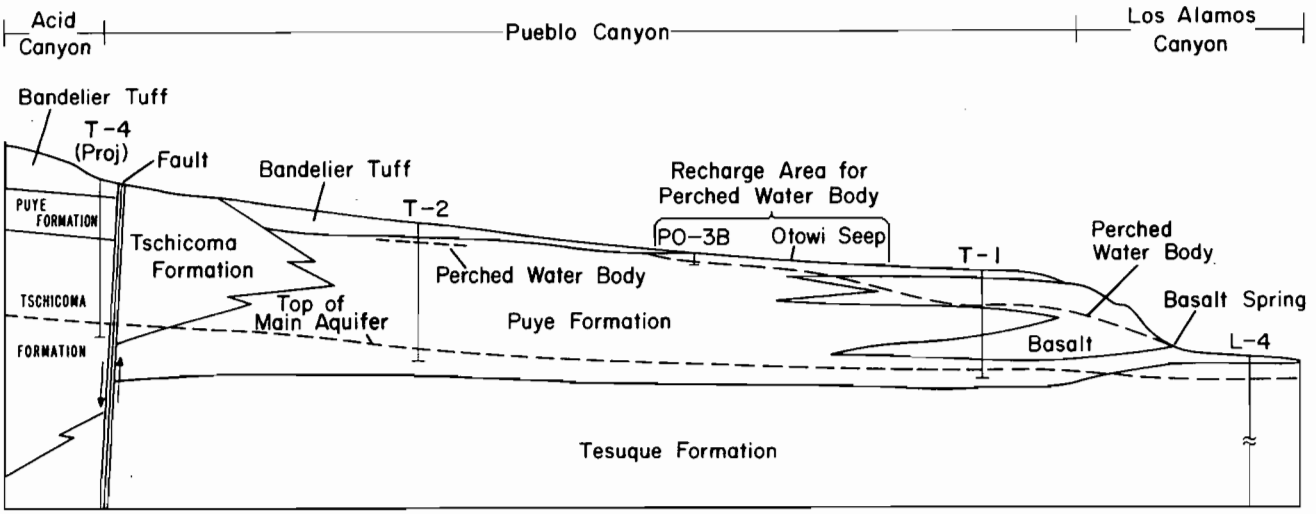

Fig. A-5.
Stratigraphic section of Pueblo and part of Lower Los Alamos Canyons, showing hydrologic characteristics.

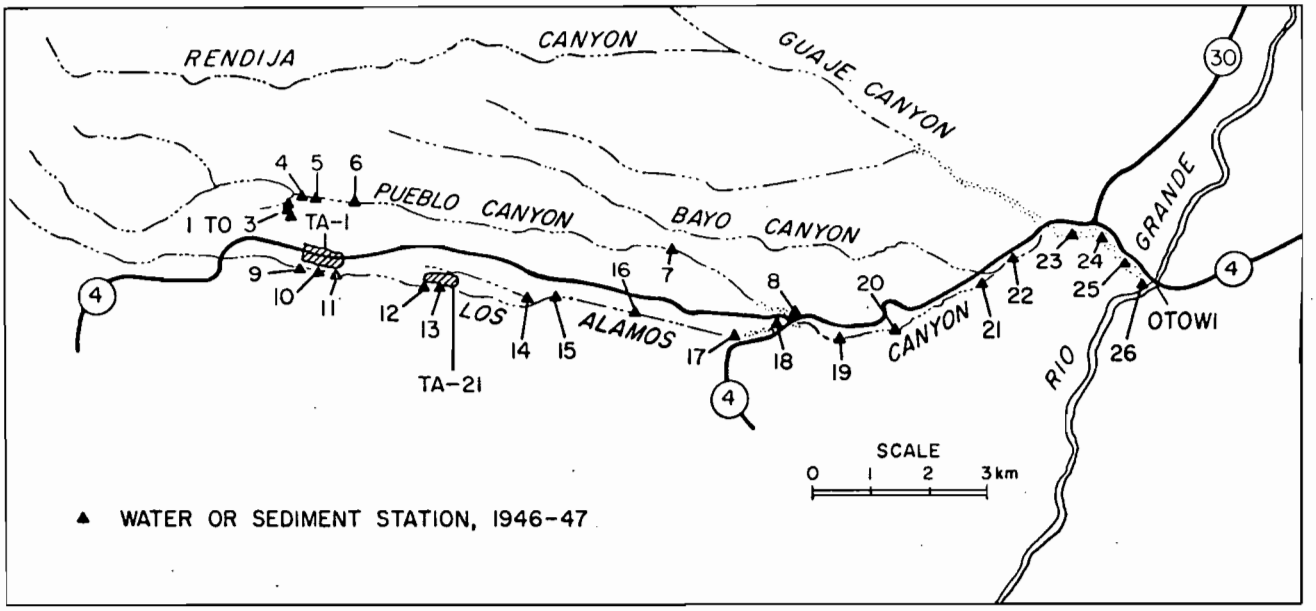

Fig. A-6.
Surface water and sediment station in Acid-Pueblo and Los Alamos Canyons, 1945-1947.

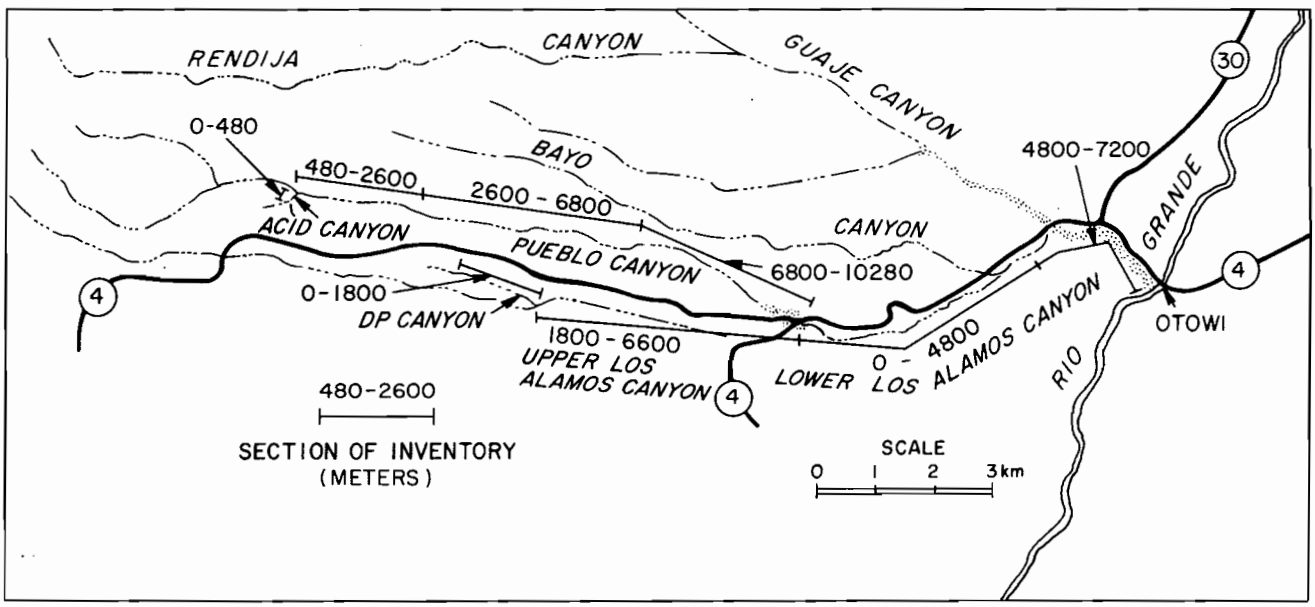

Fig. A-7.
Sections in Acid-Pueblo and DP-Los Alamos Canyons used for plutonium and cesium inventories.

TABLE A-I

POLONIUM AND PLUTONIUM IN SURFACE WATER AND SEDIMENTS, 1946 AND 1947
(analyses in pCi/ℓ, except as noted)

	July 1946		May 1947	
Location[a]	Po	Pu	Po	Pu
1	ND	45	---	---
2	ND	45	---	---
3	ND	10 700	---	---
4	ND	2300	---	---
5	ND	1400	---	---
6	ND	ND	---	---
7	ND	ND	---	---
8	ND	910	---	---
9	ND	ND	---	---
10	ND	230	---	---
11	ND	340	---	---
12	4800	3500	---	---
13	3600	4100	6	790
14	390	160	---	---
15	110	170	---	---
16	23	100	4	140
17	0.32[b]	1.7[b]	8	140
18	ND	175	6	20
19	ND	230	---	---
20	ND	680	---	---
21	ND	450	---	---
22	0.09	3.8	---	---
23	ND	38	---	---
24	ND	48	ND	ND
25	ND	ND	ND	ND
26	ND	ND	ND	ND

ND - None Detected.
[a]For location see Fig. A-6.
[b]Sediment sample, pCi/g.

TABLE A-II

CHEMICAL QUALITY OF SANITARY EFFLUENTS
(average of a number of analyses in mg/ℓ, except as noted)

	Pueblo				Central		Bayo	
	1952	1961	1971	1972	1952	1961	1971	1972
No. of Analyses	1	1	2	4	1	1	2	4
Ca	---	---	26	14	---	---	13	14
Mg	---	---	3	6	---	---	2	5
Na	---	94	88	76	---	114	89	78
CO_3	---	0	0	0	---	0	0	0
HCO_3	176	121	120	140	210	158	160	118
PO_4	---	35	---	---	---	22	---	---
Cl	32	34	36	31	30	46	30	55
F	1.6	1.6	0.8	0.7	1.6	2.6	1.5	1.2
NO_3	40	30	66	26	35	43	31	57
TDS	350	400	420	403	370	400	374	408
pH[a]	---	7.0	7.2	7.2	---	7.1	7.2	7.3

[a]No units.

TABLE A-III

METAL-ION ANALYSES OF SANITARY EFFLUENTS
1971 AND 1972
(average of a number of analyses in μg/ℓ)

	Pueblo	Bayo
In Solution		
Cadmium	1.3	0.91
Beryllium	0.29	1.4
Lead	<1.0	3.8
Mercury	0.5	<0.02
Particulates		
Cadmium	0.48	0.30
Beryllium	<0.25	<0.25
Lead	6.5	4.7
Mercury	0.34	0.05

TABLE A-IV

CHEMICAL QUALITY OF INDUSTRIAL EFFLUENT
(analyses in mg/ℓ, except as noted)

	Ca	Mg	Na	CO_3	HCO_3	Cl	F	N[a]	Hard	Cond[b]	pH[c]
1952	14	3	46	38	132	54	5	24	46	---	---
1953	74	49	162	3	46	290	2	130	390	---	---
1954	116	60	35	68	140	57	10	178	537	---	9.1
1955	96	---	87	289	314	18	4	10	240	---	11.5
1956	55	0	105	---	284	9	4	24	88	1200	11.4
1957	15	38	57	138	280	9	14	2	195	1380	11.2
1958	10	16	680	336	599	229	80	200	90	600	11.0
1959	80	5	78	162	193	1	3	12	219	630	11.8
1960	82	5	118	467	530	83	10	3	225	795	11.6
1961	28	1	87	100	140	48	7	7	70	650	11.0
1962	76	2	102	154	201	61	2	4	200	1110	10.9
1963	27	1	99	82	151	24	2	1	68	640	10.8
1964	4	1	69	60	130	10	2	1	10	450	10.5

Weekly composite, one analysis from each year of plant record.

[a]N × 4.4 = NO_3.
[b]μmho/cm.
[c]No units.

TABLE A-V

RADIOCHEMICAL ANALYSES OF SANITARY EFFLUENTS 1971 AND 1972

(average of a number of analyses in pCi/ℓ, except as noted)

	Pueblo	Bayo
Gross Alpha	1	2
Gross Beta	9	30
^{238}Pu	<0.05	0.05
^{239}Pu	<0.05	0.05
^{137}Cs	<350	<350
^{3}H	<1000	<1000
Total U[a]	1.6	1.8

[a] μg/ℓ.

TABLE A-VI

VOLUME OF INDUSTRIAL EFFLUENTS AND AMOUNT OF PLUTONIUM RELEASED INTO ACID-PUEBLO CANYON

Year	Volume of Effluents (m^3)	Total Plutonium (mCi)
1943-1951	113 000	143
1951	22 080	1.3
1952	28 540	1.1
1953	27 610	1.2
1954	38 910	2.2
1955	39 910	2.2
1956	39 720	1.0
1957	43 310	0.9
1958	40 580	0.9
1959	46 110	1.2
1960	40 870	2.6
1961	52 850	5.2
1962	64 110	3.9
1963	30 880	3.0
1964	891	0.04
Total		170

TABLE A-VII

CHEMICAL QUALITY OF SURFACE WATER AT ACID WEIR

(average of a number of analyses in mg/ℓ, except as noted)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS	pH[a]
1953	9	---	29	4.1	157	435	---
1954	10	---	37	5.2	242	545	---
1955	6	---	36	5.2	304	640	---
1956	10	---	32	5.7	50	583	8.6
1957	3	72	23	3.8	36	345	7.9
1958	6	66	25	5.1	23	350	8.1
1959	3	87	45	4.0	26	400	8.3
1960	1	85	44	3.9	16	335	8.6
1961	1	78	29	2.0	29	420	8.5
1962	2	94	39	2.2	26	400	9.4
1963	2	72	24	2.0	13	356	8.3
1965	1	38	14	1.7	4	246	7.6
1970	2	98	165	1.7	4	437	7.7
1971	1	41	52	0.9	4	276	7.1
1972	2	86	73	1.9	4	305	7.4
1973	2	68	41	0.9	5	326	7.4
1974	2	80	89	0.8	7	316	7.4
1975	2	59	50	0.7	26	324	7.7

[a]No units.

TABLE A-VIII

CHEMICAL QUALITY OF SURFACE WATER AT PUEBLO 1
(average of a number of analyses in mg/ℓ, except as noted)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS	pH[a]
1953	9	---	31	2.2	61	350	---
1954	11	---	30	2.4	77	360	---
1955	6	---	32	3.3	153	470	---
1956	8	---	35	2.5	14	445	8.0
1957	6	65	24	2.3	38	275	7.5
1958	12	56	24	1.6	30	280	7.5
1959	5	62	26	1.4	35	320	7.4
1961	1	45	16	1.0	22	340	7.7
1962	2	70	28	1.6	53	403	6.9
1963	2	60	33	2.0	35	348	7.2
1970	2	80	40	1.4	44	374	7.0
1971	1	82	28	1.0	57	376	7.0
1972	2	75	41	3.3	53	416	7.1
1973	2	75	33	6.0	16	430	7.3
1974	2	78	45	1.0	32	426	7.6
1975	2	61	39	0.7	42	362	7.3

[a]No units.

TABLE A-IX

CHEMICAL QUALITY OF SURFACE WATER AT PUEBLO 2
(average of a number of analyses in mg/ℓ, except as noted)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS	pH[a]
1953	8	---	32	1.2	42	305	---
1954	9	---	32	1.2	60	310	---
1955	2	---	34	2.5	64	360	---
1956	9	---	34	2.4	26	494	8.2
1957	4	63	27	2.3	25	280	7.6
1958	12	64	27	1.7	24	265	7.8
1959	5	72	31	1.5	35	325	7.3
1961	1	38	12	1.0	13	294	7.8
1962	1	61	25	1.2	30	325	7.2
1963	3	71	30	1.5	40	398	7.5
1964	2	84	31	2.0	40	390	7.5
1970	2	81	44	1.3	22	402	7.5
1971	1	72	28	0.6	26	330	7.3
1972	2	73	39	3.3	31	363	7.7
1973	2	59	36	4.8	18	344	7.6
1974	2	86	44	1.0	22	387	7.5
1975	2	64	38	0.6	36	225	7.2

[a]No units.

TABLE A-X

CHEMICAL QUALITY OF SURFACE WATER AT PUEBLO 3
(average of a number of analyses in mg/ℓ, except as noted)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS	pH[a]
1957	1	48	18	2.0	20	210	7.9
1958	7	51	22	1.4	22	215	7.6
1959	5	71	32	1.6	20	310	7.4
1961	2	59	17	0.7	18	465	7.7
1963	1	65	28	2.0	9	362	7.5
1964	2	115	47	2.0	22	455	7.8
1970	2	84	22	1.0	61	376	7.0
1971	1	74	26	1.2	66	416	6.9
1972	2	76	39	3.3	44	385	7.3
1973	2	78	35	5.7	66	453	7.1
1974	2	92	54	1.1	31	434	7.5
1975	2	72	36	0.8	48	380	7.2

[a]No units.

TABLE A-XI

METAL-ION ANALYSES OF SURFACE WATER 1971 AND 1972
(average of a number of analyses in μg/ℓ)

	Acid Weir	Pueblo 1	Pueblo 2	Pueblo 3
In Solution				
Cadmium	3.3	3.7	3.9	3.2
Beryllium	<0.25	<0.25	<0.25	<0.25
Lead	3.0	2.0	3.0	5.2
Mercury	<0.02	0.05	<0.02	0.14
Particulates				
Cadmium	0.35	7.0	<0.25	0.75
Beryllium	<0.25	<0.25	<0.25	<0.25
Lead	0.16	7.1	2.8	11.1
Mercury	0.11	0.34	0.06	0.14

TABLE A-XII

PLUTONIUM IN SURFACE WATER
1952 THROUGH 1965
(average of a number of analyses in pCi/ℓ)

Year	Acid Weir	Pueblo 1	Pueblo 2	Pueblo 3
1952	2.8	1.8	---	---
1953	---	---	---	---
1954	---	---	---	---
1955	3.2	4.0	---	---
1956	27	4.9	2.3	4.0
1957	3.6	1.4	2.3	---
1958	4.2	0.6	<0.5	0.7
1959	4.5	<0.5	<0.5	<0.5
1960	0.6	---	---	<0.5
1961	1.3	<0.5	<0.5	<0.5
1962	2.0	<0.5	2.7	---
1963	7.6	<0.5	1.0	<0.5
1964	---	---	<0.5	<0.5
1965	<0.5	---	---	---

TABLE A-XIII

GROSS-BETA ACTIVITY IN SURFACE WATER
1958 THROUGH 1965
(average of a number of analyses in pCi/ℓ)

Year	Acid Weir	Pueblo 1	Pueblo 2	Pueblo 3
1958	694	75	55	326
1959	285	447	<14	<14
1960	245	---	---	27
1961	225	<14	<14	52
1962	110	<14	18	---
1963	78	<14	22	17
1964	---	---	20	22
1965	<14	---	---	---

TABLE A-XIV

RADIOCHEMICAL QUALITY OF SURFACE WATER
1970 THROUGH 1975
(average of a number of analyses in pCi/ℓ, except as noted)

Station	Year	No. of Analyses	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu	^{137}Cs	^{3}H	Total U[a]
Acid Weir	1970	2	2	225	<0.05	0.27	---	3000	0.6
	1971	1	6	52	0.18	7.9	<300	1600	2.3
	1972	2	2	132	<0.05	0.42	<300	1200	1.7
	1973	2	5	86	<0.05	0.20	<300	1400	<0.4
	1974	4	3	140	<0.05	1.4	<100	1000	1.2
	1975	3	2	61	<0.05	<0.05	---	2300	1.3
Pueblo 1	1970	2	<1	21	<0.05	<0.05	---	<500	0.8
	1971	1	<1	16	0.07	0.08	<300	<500	<0.4
	1972	2	<1	8	0.11	0.09	<350	<500	1.4
	1973	2	<1	21	0.09	0.33	<300	3000	<0.4
	1974	4	2	24	<0.05	<0.05	<100	<500	0.8
	1975	3	1	11	<0.05	<0.05	---	1500	---
Pueblo 2	1970	2	<1	20	<0.05	0.06	---	<500	0.8
	1971	1	<1	9	0.07	1.02	<300	<500	0.4
	1972	2	1	14	<0.05	0.11	<350	<500	1.4
	1973	2	1	14	0.10	0.70	<300	<500	<0.4
	1974	4	2	17	<0.05	0.12	<100	<500	0.7
	1975	3	1	17	<0.05	0.34	---	<500	0.8
Pueblo 3	1970	2	<1	11	<0.05	<0.05	---	<500	0.7
	1971	1	1	6	0.06	<0.05	350	<500	<0.4
	1972	2	<1	20	0.05	0.08	<350	<500	1.6
	1973	2	<1	14	0.05	0.21	<300	<500	<0.4
	1974	4	1	17	0.10	<0.05	<100	<500	0.6
	1975	3	1	19	0.10	<0.05	---	<500	2.3

[a] μg/ℓ.

TABLE A-XV

CHEMICAL QUALITY OF WATER FROM THE ALLUVIUM 1954 THROUGH 1964

(average of a number of analyses in mg/ℓ, except as noted)

Station	No. of Analyses	Cl	F	NO_3	TDS	pH[a]
AC-3	25	30	3.4	38	481	10.4
AC-4	29	38	4.4	35	765	10.0
AC-5	8	26	3.0	65	553	9.6
PC-1	24	27	1.8	22	300	7.5
PC-2	31	28	2.2	28	542	7.4
PC-3	29	27	2.3	33	430	7.5
PC-4	23	30	1.9	40	432	7.3
PC-5	9	32	1.8	42	315	7.3
PC-6	37	25	1.3	12	373	7.4
PC-7	21	30	1.6	28	338	7.4
PC-8	16	29	1.1	36	275	7.4
PC-9	25	29	1.2	16	430	7.4
PC-10	30	27	1.4	19	379	7.3
PC-11	13	29	1.5	28	361	7.2
PO-1A	9	27	1.2	7	327	7.4
PO-4A	15	25	1.7	23	318	7.1
PO-4B	10	28	0.9	10	330	7.2
Hamilton Bend Spring	31	30	0.8	18	336	7.5
Otowi Seep	4	33	1.6	2	275	7.5

[a] No units.

TABLE A-XVI

CHEMICAL QUALITY OF WATER FROM THE ALLUVIUM FROM HAMILTON BEND SPRINGS 1970 THROUGH 1975

(average of a number of analyses in mg/ℓ, except as noted)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS	pH[a]
1970	2	74	37	3.3	13	476	7.2
1971	---	---	---	---	---	---	---
1972	2	69	40	1.7	18	370	7.6
1973	2	66	52	4.2	18	370	7.5
1974	2	72	51	3.9	16	374	7.4
1975	2	70	37	0.9	22	359	7.7

[a]No units.

TABLE A-XVII

METAL-ION ANALYSES OF WATER FROM THE ALLUVIUM, 1972

(analyses in μg/ℓ)

	Hamilton Bend Spring
In Solution	
Cadmium	0.18
Beryllium	<0.25
Lead	4.5
Mercury	<0.02
Particulate	
Cadmium	0.72
Beryllium	<0.25
Lead	4.8
Mercury	<0.02

TABLE A-XVIII

PLUTONIUM IN WATER FROM THE ALLUVIUM
1954 THROUGH 1965
(average of a number of analyses in pCi/ℓ)

Station	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
AC-3	828	468	---	---	5.3	2.9	<0.5	---	14.6	18.2	---	---
AC-4	342	34	---	---	1.9	42	4.0	1.3	---	---	---	---
AC-5	198	554	---	---	4.9	---	<0.5	---	---	---	---	---
PC-1	3.6	1.4	1.8	0.7	<0.5	<0.5	---	---	---	---	---	---
PC-2	21	6.3	5.8	1.8	<0.5	10.9	---	---	---	---	---	---
PC-3	6.3	2.7	1.8	0.9	1.3	<0.5	<0.5	<0.5	---	---	---	---
PC-4	7.7	3.2	5.8	0.9	0.5	<0.5	---	---	<0.5	<0.5	---	---
PC-5	6.8	---	---	---	0.5	0.5	---	---	---	---	---	---
PC-6	8.6	3.6	3.6	1.8	1.8	<0.5	<0.5	<0.5	<0.5	0.9	0.8	---
PC-7	14	5.8	3.2	1.8	<0.5	<0.5	---	---	---	---	---	---
PC-8	5.4	---	---	0.9	<0.5	<0.5	---	---	---	---	---	---
PC-9	8.6	---	3.2	2.7	0.7	<0.5	---	---	<0.5	<0.5	<0.5	---
PC-10	---	---	---	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
PC-11	---	---	---	---	---	<0.5	<0.5	2.7	<0.5	<0.5	0.9	<0.5
PO-1A	---	---	---	2.7	1.9	<0.5	<0.5	---	---	---	<0.5	---
PO-4A	---	---	---	1.5	<0.5	<0.5	<0.5	---	---	---	<0.5	<0.5
PO-4B	---	---	---	---	<0.5	<0.5	<0.5	---	---	---	---	<0.5
Hamilton Bend Spring	4.5	11.7	2.7	0.6	<0.5	<0.5	<0.5	0.5	<0.5	1.0	0.9	---
Otowi Seep	9.9	---	2.7	---	<0.5	<0.5	<0.5	---	3.8	<0.5	0.8	<0.5

TABLE A-XIX

GROSS-BETA ACTIVITY IN WATER FROM ALLUVIUM
1958 THROUGH 1965
(average of a number of analyses in pCi/ℓ)

Station	1958	1959	1960	1961	1962	1963	1964	1965
AC-3	788	347	1260	---	108	260	---	---
AC-4	810	621	165	198	---	---	---	---
AC-5	1080	---	---	---	---	---	---	---
PC-1	<14	<14	<14	---	---	---	---	---
PC-2	26	<14	---	---	---	---	---	---
PC-3	28	22	15	135	---	---	---	---
PC-4	337	<14	---	---	900	22	---	---
PC-5	<14	<14	---	---	---	---	---	---
PC-6	32	<14	16	90	<14	31	<14	---
PC-7	260	<14	---	---	---	---	---	---
PC-8	98	<14	---	---	---	---	---	---
PC-9	53	<14	---	---	<14	48	<14	---
PC-10	<14	<14	<14	48	17	31	<14	<14
PC-11	---	144	<14	<14	<14	16	57	<14
PO-1A	268	<14	---	---	---	---	18	---
PO-4A	69	<14	---	---	---	---	<14	<14
PO-4B	27	<14	---	---	---	---	---	<14
Hamilton Bend Spring	<14	<14	<14	<14	<14	<14	<14	<14
Otowi Seep	38	<14	<14	---	<14	87	<14	---

TABLE A-XX

RADIOCHEMICAL QUALITY OF WATER IN THE ALLUVIUM FROM HAMILTON BEND SPRING 1970 THROUGH 1975

(average of a number of analyses in pCi/ℓ except as noted)

	1970	1971	1972	1973	1974	1975
No. of Analyses	2	---	2	2	3	2
Gross Alpha	1	---	2	4	<1	1
Gross Beta	6	---	7	14	8	7
^{238}Pu	<0.05	---	0.05	0.16	<0.05	0.05
^{239}Pu	<0.05	---	0.07	0.05	<0.05	0.05
^{137}Cs	---	---	<350	<300	<300	---
^{3}H	1000	---	1400	<1000	800	<1000
Total U[a]	0.4	---	1.7	<0.4	<0.4	1.7

[a]μg/ℓ.

TABLE A-XXI

CHEMICAL QUALITY OF SANITARY EFFLUENTS FROM TA-21

(analyses in mg/ℓ, except as noted)

	12/67	5/69	8/69
Ca	20	16	16
Mg	12	4	7
Na	160	230	175
CO_3	0	0	0
HCO_3	280	394	190
Cl	35	50	35
F	3	2	4
NO_3	4	6	13
TDS	383	458	442
pH[a]	7.5	7.4	8.2

[a]No units.

TABLE A-XXII

CHEMICAL QUALITY OF INDUSTRIAL EFFLUENTS FROM TA-21

(analyses in mg/ℓ, except as noted)

Year	Ca	Mg	Na	CO_3	HCO_3	Cl	F	N[a]	Hard	Cond[b]	pH[c]
1960	4	2	532	314	478	370	60	67	16	1600	11.3
1961	1	1	485	560	626	405	140	25	7	4000	11.8
1962	2	<1	423	428	558	234	20	5	6	1860	11.4
1963	4	1	272	118	296	290	30	10	12	2000	10.9
1964	4	1	413	690	920	665	140	26	15	5600	12.1
1965	44	1	195	315	430	45	0.9	13	115	1880	11.7
1966	64	2	270	1740	2036	178	15	104	170	4400	12.0
1967	56	10	690	130	210	598	15	23	180	3200	11.4
1968	22	<1	280	37	212	72	11	45	54	900	9.8
1969	8	<1	340	300	505	40	44	34	20	2140	11.5
1970	26	29	270	300	420	113	7	11	185	2260	11.5
1971	8	2	490	260	910	55	20	48	30	2240	10.3
1972	16	4	680	110	790	90	13	195	60	2700	8.2
1973	36	4	410	0	990	25	26	35	110	2300	7.2
1974	12	4	960	110	510	80	7	410	50	3760	10.5
1975	2	<1	984	685	1070	70	3	357	14	4600	11.9

Weekly composite, one analysis from each year of plant record.

[a]$N \times 4.4 = NO_3$.
[b]μmho/cm.
[c]No units.

TABLE A-XXIII

RADIOCHEMICAL QUALITY OF SANITARY EFFLUENTS FROM TA-21
(analyses in pCi/ℓ, except as noted)

	12/67	5/69	8/69	2/70
Gross Alpha	3	3	2	3
Gross Beta	14	20	13	14
^{238}Pu	<0.05	<0.05	<0.05	0.16
^{239}Pu	<0.05	<0.05	<0.05	0.14
^{241}Am	---	---	0.07	0.08
^{3}H	<30 000	<30 000	<30 000	8000
Total U[a]	0.9	0.9	1.3	0.6

[a]μg/ℓ.

TABLE A-XXIV

VOLUME OF INDUSTRIAL EFFLUENT AND AMOUNT OF PLUTONIUM RELEASED INTO DP CANYON

Year	Volume of Effluents (m^3)	Total Plutonium (mCi)
1952	16 220	0.3
1953	14 400	1.1
1954	11 520	1.0
1955	9 436	0.9
1956	11 690	0.8
1957	16 170	1.0
1958	9 987	0.6
1959	9 138	0.8
1960	8 408	1.7
1961	9 251	5.4
1962	11 660	2.9
1963	12 150	2.2
1964	6 228	1.1
1965	9 594	1.0
1966	10 920	0.9
1967	11 341	2.4
1968	11 360	1.6
1969	13 290	1.6
1970	10 850	1.5
1971	9 839	0.7
1972	8 780	1.3
1973	5 440	0.9
1974	4 560	0.5
1975	5 750	1.0
Total		33.2

TABLE A-XXV

CHEMICAL QUALITY OF SURFACE WATER IN DP CANYON
(average of a number of analyses in mg/ℓ, except as noted)

Station	Year	No. of Analyses	Na	Cl	F	NO_3	TDS	pH[a]
DPS-1	1967	2	630	410	9.5	104	1740	9.7
	1968	3	670	215	23	381	1950	10.1
	1969	2	375	92	32	53	1100	10.7
	1970	5	241	140	6.0	118	878	9.6
	1971	4	233	76	4.7	62	893	9.3
	1972	3	206	137	2.5	88	932	7.9
	1973	3	180	46	8.9	198	1097	7.9
	1974	2	148	46	5.6	92	456	8.0
	1975	2	176	65	2.3	260	816	8.9
DPS-2	1967	1	290	75	8.0	140	669	8.5
	1968	2	250	65	9.4	101	746	9.4
	1969	2	282	103	12	26	716	9.8
	1970	2	188	85	13	48	714	9.1
	1971	1	68	88	3.7	35	642	8.2
DPS-3	1967	1	310	85	10	28	799	8.8
	1968	2	325	88	16	150	676	9.1
	1969	2	293	75	12	31	409	9.0
	1970	3	200	93	10	84	814	9.3
DPS-4	1962	2	143	134	15	40	771	7.4
	1963	2	132	113	13	41	742	7.5
	1964	3	109	106	5.6	57	734	7.8
	1965	2	110	109	15	40	656	7.8
	1966	---	---	---	---	---	---	---
	1967	2	253	103	7.7	145	757	7.9
	1968	2	200	85	6.2	---	607	8.1
	1969	2	198	60	5.0	35	390	8.0
	1970	4	103	45	11	18	464	8.5
	1971	4	113	47	5.0	36	531	7.8
	1972	3	214	58	4.1	30	493	8.0
	1973	4	115	75	4.2	34	540	7.8
	1974	2	96	45	2.7	32	247	7.7
	1975	2	107	47	2.9	295	479	7.6

[a]No units.

TABLE A-XXVI

METAL-ION ANALYSES OF SURFACE WATER IN DP CANYON 1971 AND 1972
(average of a number of analyses in μg/ℓ)

	DPS-1	DPS-4
In Solution		
Cadmium	6.9	3.6
Beryllium	0.30	<0.25
Lead	1.8	1.8
Mercury	0.09	<0.02
Particulates		
Cadmium	0.43	0.30
Beryllium	<0.25	<0.25
Lead	2.8	1.8
Mercury	<0.02	<0.2

TABLE A-XXVII

GROSS-BETA ACTIVITY AND PLUTONIUM IN SURFACE WATER AT DPS-4 1961 THROUGH 1965
(average of a number of analyses in pCi/ℓ)

Year	No. of Analyses	Gross Beta	Plutonium
1961	2	91	<0.5
1962	3	139	<0.5
1963	2	197	0.7
1964	3	71	0.9
1965	3	50	0.7

TABLE A-XXVIII

RADIOCHEMICAL QUALITY OF SURFACE WATER IN DP CANYON 1967 THROUGH 1975

(average of a number of analyses in pCi/ℓ, except as noted)

Station	Year	No. of Analyses	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu	^{241}Am	^{137}Cs	^{3}H	^{90}Sr	Total U[a]
DPS-1	1967	1	63	51 700	3.87	76.1	1.29	34 000	540 000	28 600	---
	1968	3	34	14 300	4.25	28.8	4.52	13 400	20 000	11 360	---
	1969	3	14	2 060	5.55	9.10	3.58	3 490	430 000	800	---
	1970	5	7	1 200	0.81	2.20	1.19	692	402 000	568	---
	1971	4	22	1 390	1.16	2.07	0.60	1 200	356 000	716	2.3
	1972	3	13	2 470	0.32	5.68	0.33	<350	396 100	---	7.1
	1973	3	12	460	2.91	10.1	---	260	310 000	---	0.1
	1974	4	10	670	0.17	0.27	---	48	11 000	---	3.1
	1975	3	25	500	0.27	0.57	---	12	19 000	---	6.9
DPS-2	1967	1	4	6 690	0.38	2.70	0.63	2 760	660 000	5 810	---
	1968	2	7	4 695	0.30	2.10	0.83	3 165	413 000	2 620	---
	1969	2	22	1 055	2.29	3.64	1.70	2 260	670 000	350	---
	1970	2	8	990	1.14	1.33	0.58	480	381 000	534	---
	1971	1	5	640	5.64	0.72	0.25	523	195 000	376	---
DPS-3	1967	1	5	290	0.21	0.77	---	310	927 000	2 260	---
	1968	2	6	1 525	0.43	2.63	1.42	1 445	549 000	3 180	---
	1969	2	19	940	3.05	4.23	1.00	530	140 000	500	---
	1970	2	24	945	1.40	1.09	0.62	395	459 000	453	---
DPS-4	1967	1	2	1 800	0.13	0.14	<0.05	<240	410 000	632	---
	1968	2	6	625	0.09	0.08	0.08	<240	476 000	435	---
	1969	4	2	418	0.44	0.52	0.35	<240	346 000	380	---
	1970	4	1	457	0.13	0.21	0.20	<240	162 000	233	---
	1971	4	3	370	0.11	0.13	0.08	<300	103 000	315	0.6
	1972	3	2	609	0.11	0.27	0.25	<350	172 000	---	3.3
	1973	4	2	215	0.04	0.11	---	<50	51 000	---	0.4
	1974	4	5	500	0.94	0.39	---	<50	23 000	---	0.9
	1975	2	3	---	0.02	<0.05	---	<50	46 000	---	1.3

[a] μg/ℓ.

TABLE A-XXIX

CHEMICAL QUALITY OF SURFACE WATER AT AND ABOVE LOS ALAMOS RESERVOIR
(analyses in mg/ℓ, except as noted)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS	pH[a]
1961[b]	1	3	1	0.1	0.2	70	7.4
1958[c]	1	3	1	0.4	0.3	80	7.1
1952	1	3	5	2.0	<0.1	---	8.0
1967	1	8	3	0.2	0.4	80	7.3
1969	1	6	2	<0.1	0.4	85	7.3
1971	1	7	<1	<0.1	0.4	110	7.1
1972	1	7	2	<0.1	0.4	98	7.0
1973	1	6	2	0.1	0.4	98	7.0
1974	1	5	2	0.2	0.4	114	7.2
1975	2	5	4	0.2	1.7	147	7.2

[a]No units.
[b]1.8 km above reservoir.
[c]0.3 km above reservoir.

TABLE A-XXX

RADIOCHEMICAL QUALITY OF SURFACE WATER IN LOS ALAMOS CANYON
(average of a number of analyses in pCi/ℓ, except as noted)

Station	Year	No. of Analyses	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu	^{137}Cs	^{3}H	Total U[a]
Los Alamos Res	1971	1	2	2	<0.05	<0.05	---	1000	<0.4
	1972	2	1	3	<0.05	<0.05	<300	---	4.6
	1973	1	<1	4	<0.05	<0.05	<50	500	<0.4
	1974	3	<1	5	<0.05	<0.05	<70	500	---
	1975	3	<1	4	<0.05	<0.05	<100	1350	0.6
Near LAO-1[b]	1969	3	<1	17	<0.05	<0.05	---	1000	0.7
Near LAS5-1[b]	1969	1	<1	4	<0.05	<0.05	---	---	1.5
Near LAO4.5[b]	1967	1.	<1	18	<0.05	<0.05	---	1600	1.1

[a]μg/ℓ.
[b]Intermittent surface flow.

TABLE A-XXXI

CHEMICAL QUALITY OF WATER IN ALLUVIUM FROM LOS ALAMOS CANYON

(average of a number of analyses in mg/ℓ, except as noted)

Station	Year	No. of Analyses	Na	Cl	F	NO_3	TDS	pH[a]
LAO-C	1970	1	28	21	1.0	4.4	166	7.5
	1971	2	37	46	0.2	0.4	249	7.5
	1972	4	53	74	0.4	2.4	253	7.5
	1973	3	26	31	0.2	0.9	207	7.4
	1974	2	38	36	0.2	0.9	217	7.6
	1975	2	36	46	0.2	3.9	213	7.5
LAO-1	1967	2	132	32	0.6	2.1	406	7.2
	1968	3	82	33	1.7	1.8	246	7.4
	1969	2	83	47	0.3	1.8	295	7.3
	1970	4	54	26	0.9	3.5	434	7.8
	1971	4	74	27	0.6	6.6	414	7.3
	1972	4	75	50	0.7	5.7	397	7.4
	1973	4	75	53	1.2	2.5	331	7.3
	1974	2	74	35	1.1	7.2	393	7.3
	1975	2	54	56	1.0	12.0	344	7.7
LAO-2	1967	1	180	73	7.0	7.5	594	7.3
	1968	3	94	39	8.1	9.6	334	7.6
	1969	2	37	37	5.0	7.9	369	7.6
	1970	3	96	44	6.3	20	479	7.7
	1971	2	91	33	5.6	18	431	7.5
	1972	3	97	55	4.4	24	472	7.5
	1973	3	69	65	2.3	7.6	419	7.4
	1974	1	105	50	3.9	20	370	7.4
	1975	2	77	92	3.6	18	476	8.2
LAO-3	1967	2	139	57	7.5	25	451	7.4
	1968	2	84	30	8.5	4.4	362	7.6
	1969	2	115	54	5.0	15	394	7.6
	1970	4	85	43	7.0	13	445	7.7
	1971	3	82	40	5.2	17	439	7.4
	1972	4	109	69	4.9	27	484	7.5
	1973	4	80	68	4.9	13	408	7.6
	1974	1	61	44	4.0	9.7	448	7.3
	1975	2	76	38	2.7	49	446	8.1
LAO-4	1967	2	100	36	0.6	7.0	294	7.3
	1968	3	66	31	1.5	1.8	285	7.5
	1969	2	65	35	2.3	0.9	217	7.5
	1970	1	57	40	2.0	18	284	7.1
LAO-4.5	1969	2	58	32	<0.1	0.9	277	7.6
	1970	5	38	32	0.5	1.3	265	7.2
	1971	3	36	30	<0.1	3.9	280	7.3
	1972	4	55	27	0.4	0.9	222	7.5
	1973	4	43	34	0.3	0.8	248	7.3
	1974	2	44	25	1.7	40	253	7.4
LAO-5	1967	1	42	28	0.4	2.6	208	7.2
	1968	2	17	25	0.8	0.4	224	7.2
	1969	2	52	33	<0.1	0.9	210	7.4
LAO-6	1968	1	49	26	0.5	<0.4	227	7.4
	1969	1	51	33	0.1	0.4	195	7.3

[a]No units.

TABLE A-XXXII

METAL-ION ANALYSES OF WATER IN ALLUVIUM IN LOS ALAMOS CANYON
1971 AND 1972
(average of a number of analyses in μg/ℓ)

	LAO-C	LAO-1	LAO-2	LAO-3	LAO-4.5
In Solution					
Cadmium	2.1	4.5	3.7	2.6	2.8
Beryllium	<0.25	<0.25	<0.25	0.27	<0.25
Lead	4.8	1.3	4.8	1.9	<1.0
Mercury	<0.02	0.07	<0.02	0.38	<0.02
Particulates					
Cadmium	2.1	0.65	1.4	1.3	0.55
Beryllium	1.7	<0.25	0.78	0.77	0.42
Lead	23	11	10	12	13
Mercury	0.11	0.07	0.5	0.04	<0.02

TABLE A-XXXIII

RADIOCHEMICAL QUALITY OF WATER IN ALLUVIUM FROM LOS ALAMOS CANYON
1966 AND 1967
(average of a number of analyses in pCi/ℓ, except as noted)

Station	Year	No. of Analyses	Gross Beta	Plutonium	Total U[a]
LAO-1	1966	3	17	<0.5	<0.5
	1967	1	113	<0.5	<0.5
LAO-2	1966	2	32	0.6	<0.5
LAO-3	1966	3	32	<0.5	2.6
LAO-4	1966	2	<14	<0.5	<0.5
	1967	1	15	<0.5	<0.5
LAO-5	1966	1	<14	<0.5	<0.5

[a]μg/ℓ.

TABLE A-XXXIV

RADIOCHEMICAL QUALITY OF WATER IN ALLUVIUM FROM LOS ALAMOS CANYON 1967 THROUGH 1975

(average of a number of analyses in pCi/ℓ, except as noted)

Station	Year	No. of Analyses	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu	^{137}Cs	^{3}H	Total U[a]
LAO-C	1970	1	<1	4	<0.05	<0.05	---	<1000	0.4
	1971	2	<1	3	<0.05	<0.05	<350	<1000	1.0
	1972	4	<1	5	0.06	0.07	<350	<1000	1.0
	1973	4	<1	3	<0.05	<0.05	<40	1150	<0.4
	1974	4	1	8	<0.05	<0.05	<40	650	0.5
	1975	3	3	5	<0.05	<0.05	<40	1000	0.5
LAO-1	1967	1	<1	50	<0.05	<0.05	---	41 000	1.3
	1968	3	3	37	<0.05	0.08	<250	30 000	<0.4
	1969	3	<1	36	<0.05	0.06	---	22 000	0.4
	1970	4	<1	76	0.05	0.05	---	---	<0.4
	1971	4	1	94	0.05	0.27	<350	20 750	0.6
	1972	4	1	127	0.17	0.18	<350	19 600	<0.4
	1973	5	2	140	<0.05	0.06	<40	36 000	<0.4
	1974	4	2	147	<0.05	<0.05	40	27 000	<0.4
	1975	3	1	56	<0.05	<0.05	<20	7000	<0.4
LAO-2	1967	1	<1	91	<0.05	<0.05	---	475 000	2.0
	1968	3	3	59	<0.05	0.06	<250	273 000	1.5
	1969	2	1	77	0.10	0.60	---	337 000	1.6
	1970	3	<1	80	<0.05	0.14	<250	184 000	0.6
	1971	2	1	101	0.15	0.33	<350	52 000	0.9
	1972	3	2	188	0.09	0.19	<350	153 000	2.6
	1973	4	22	294	<0.05	0.11	<40	46 000	<0.4
	1974	3	2	247	<0.05	0.10	<40	18 000	<0.4
	1975	3	4	157	<0.05	0.05	<20	7200	0.7
LAO-3	1967	1	<1	45	<0.05	0.05	---	214 000	<0.4
	1968	3	2	61	0.07	0.08	<250	126 000	0.8
	1969	2	2	49	<0.05	0.06	---	350 000	1.3
	1970	4	2	56	<0.05	0.08	<250	73 000	0.8
	1971	3	3	95	0.07	0.08	<350	38 000	1.2
	1972	4	3	92	0.10	0.15	<350	187 000	3.0
	1973	5	3	47	0.06	0.05	50	35 000	<0.4
	1974	3	2	75	0.35	0.08	50	11 000	0.9
	1975	3	6	81	<0.05	<0.05	---	11 000	3.1
LAO-4	1967	1	<1	9	<0.05	0.06	---	222 000	0.8
	1968	3	5	16	0.05	0.05	250	61 000	1.2
	1969	2	<1	9	<0.05	<0.05	---	55 500	<0.4
	1970	1	<1	10	<0.05	<0.05	---	66 000	<0.4
LAO-4:5	1969	3	<1	5	<0.05	<0.05	---	43 000	0.7
	1970	5	1	26	0.06	0.07	---	78 000	<0.4
	1971	3	1	5	0.07	0.08	---	24 000	0.4
	1972	4	2	10	0.09	0.06	<350	28 000	1.1
	1973	4	1	8	<0.05	<0.05	<40	22 000	<0.4
	1974	3	1	107	<0.05	<0.05	<20	8000	<0.4
	1975	3	2	47	<0.05	0.06	---	18 000	0.8
LAO-5	1967	1	<1	4	<0.05	<0.05	---	126 000	<0.4
	1968	2	1	8	<0.05	0.09	<250	70 000	1.2
	1969	2	<1	5	<0.05	<0.05	---	56 000	0.7
LAO-6	1968	1	2	18	0.17	0.25	<250	75 000	0.4
	1969	1	<1	7	<0.05	<0.05	<250	51 000	<0.4

[a] μg/ℓ.

TABLE A-XXXV

CLASSIFICATION OF CHANNEL SEDIMENTS

Classification	Size Range (mm)		
Granules	2.36	to	3.96
Very coarse sand	1.17	to	2.36
Coarse sand	0.589	to	1.17
Medium sand	0.295	to	0.589
Fine sand	0.147	to	0.295
Very fine sand	0.074	to	0.147
Silt and clay			<0.074

TABLE A-XXXVI

PARTICLE-SIZE DISTRIBUTION OF CHANNEL SEDIMENTS IN ACID-PUEBLO CANYON

	Distribution (% by weight)						
Classification	AC-4	Acid Weir	PC-1	PC-5	PC-7	PC-9	APSC
Granules	4.5	6.5	3.0	10.5	5.0	2.0	1.0
Very coarse sand	47.0	42.5	36.5	34.5	28.0	10.0	17.0
Coarse sand	44.0	39.5	50.5	37.0	31.0	40.0	50.5
Medium sand	2.0	6.0	7.0	11.0	19.0	21.0	19.0
Fine sand	1.0	1.5	1.0	3.0	11.5	9.5	7.0
Very fine sand	1.0	1.0	0.5	1.5	2.5	6.5	2.0
Silt and clay	0.5	3.0	1.5	3.0	3.0	11.0	3.5

TABLE A-XXXVII

GROSS-ALPHA AND GROSS-BETA ACTIVITY IN SEDIMENTS FROM ACID-PUEBLO CANYON 1954 THROUGH 1961

(analyses in pCi/g, except as noted)

	Gross-Alpha Activity							
Station	**1954**	**1955**	**1956**	**1957**	**1958**	**1959**	**1960**	**1961**
AC-3	1600	2600	34	390	2900	360	120	130
AC-4	320	500	140	170	1600	220	67	40
AC-5	190	---	120	64	52	100	57	37
Acid Weir	---	---	---	---	34	50	48	220
PC-2	35	---	2	---	11	5	3	57
PC-3	16	---	3	---	6	9	3	20
PC-4	52	---	---	---	3	---	41	10
PC-5	9	---	---	---	---	4	11	11
PC-6	4	---	---	---	---	4	9	10
PC-7	54	---	---	---	---	2	5	120
PC-8	---	---	---	---	---	4	2	33

	Gross-Beta Activity[a]					
Station	**1956**	**1957**	**1958**	**1959**	**1960**	**1961**
AC-3	360	370	11 300	990	1500	70
AC-4	142	70	10 400	290	730	60
AC-5	11	90	440	155	480	120
Acid Weir	---	---	830	107	340	3650
PC-2	<1	---	120	50	<1	120
PC-3	17	---	120	7	40	20
PC-4	---	---	370	---	90	<1
PC-5	---	---	---	---	<1	<1
PC-6	---	---	---	60	20	10
PC-7	---	---	---	10	40	190
PC-8	---	---	---	20	70	<1

[a]cm/g.

TABLE A-XXXVIII

RADIOCHEMICAL ANALYSES OF SEDIMENTS FROM ACID-PUEBLO CANYON 1965 AND 1970

November 1965 (analyses in c/m/g)

Station	Gross Alpha	Gross Beta	Gross[a] Gamma
AC-3	27	5	<1
Acid Weir	22	20	6
PC-1	1	19	16
PC-5	1	6	<1
PC-7	3	<1	30
PC-9	3	32	6
APSC	4	9	14

April 1970 (analyses in pCi/g, except as noted)

Station	Gross Alpha	Gross Beta	Gross[a] Gamma	^{238}Pu	^{239}Pu
AC-4	41	11	7	0.19	29.0
Acid Weir	36	14	7	0.21	25.0
PC-1	2	2	<1	<0.011	0.04
PC-2	8	2	2	0.08	4.9
PC-5	8	12	<1	0.011	4.5
PC-7	4	2	<1	<0.001	1.2
PC-9	1	<1	<1	<0.001	0.4
APSC	3	4	<1	0.006	1.1

[a]cm/g.

TABLE A-XXXIX

RADIOCHEMICAL ANALYSES OF SEDIMENTS FROM PUEBLO CANYON 1971 THROUGH 1975
(analyses in pCi/g, except as noted)

Station	Date	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu	^{137}Cs	Total U[a]
PC-6	5-71	7	2	0.016	2.93	---	0.19
	10-71	10	2	0.007	2.20	<1.5	0.22
	10-72	<1	4	0.012	2.55	3.4	0.42
	6-73	2	26	0.005	0.005	0.9	---
APSC	5-71	2	2	0.006	0.760	---	0.12
	10-71	4	2	0.001	0.390	<1.5	0.10
	10-72	<1	4	<0.001	0.370	3.9	0.32
	6-73	2	29	0.025	0.560	1.6	---
	5-75	2	5	0.008	0.420	---	0.30
	7-75	1	<1	0.009	0.046	----	<0.10
	10-75	2	4	0.008	0.350	---	1.3

[a]μg/g.

TABLE A-XL

PLUTONIUM AND CESIUM IN SEDIMENTS FROM ACID-PUEBLO CANYON SPECIAL STUDY, 1972
(analyses in pCi/g)

Location[a]	^{238}Pu	^{239}Pu	^{137}Cs
Control	0.009	0.20	0.36
Outfall	0.02	2.3	0.02
20	0.09	2.2	1.5
40	0.03	6.9	0.74
80	1.0	54	14
160	0.08	8.5	1.1
320	0.08	12	1.5
640	0.08	11	1.1
2 560	0.02	1.5	0.31
5 120	0.01	0.35	0.20
10 240	0.02	0.74	0.33

[a]m below outfall.

TABLE A-XLI

PLUTONIUM IN SEDIMENTS FROM ACID-PUEBLO CANYON SPECIAL STUDY, 1973
(analyses in pCi/g)

Location[a]	Depth of Sediment in cm 0-2.5	2.5-7.5	7.5-12.5	>12.5[b]
Control	0.122	0.137	---	---
Outfall	16.6	8.52	---	---
20	16.8	---	---	---
40	5.78	8.72	11.4	28.7
80	6.21	6.60	21.1	505
160	8.61	10.1	---	20.4
320	8.28	7.92	10.8	12.3
640	7.86	12.4	10.4	19.1
2 560	36.6	369	2250	---
5 120	1.39	---	0.617	1.65
10 240	0.40	0.518	0.435	---

[a]m below outfall.
[b]Remainder varied from 12.5 to 30 cm.

TABLE A-XLII

PARTICLE-SIZE DISTRIBUTION OF CHANNEL SEDIMENTS FROM DP AND UPPER LOS ALAMOS CANYONS

	Distribution (% by weight)					
	DP Canyon		Upper Los Alamos Canyon			
Classification	DPS-1	DPS-4	LAO-C	LAO-1	LAO-3	LASC
Granules	8.0	4.0	16.5	<0.5	0.5	4.5
Very coarse sand	48.5	42.5	38.0	23.0	13.0	26.0
Coarse sand	29.0	36.0	32.0	53.0	40.0	33.0
Medium sand	8.0	10.5	10.5	18.5	23.5	19.0
Fine sand	3.0	4.5	2.0	4.0	11.0	10.5
Very fine sand	1.5	1.0	0.5	0.5	4.5	4.0
Silt and clay	2.0	1.5	0.5	0.5	7.5	3.0

TABLE A-XLIII

RADIOCHEMICAL ANALYSES OF SEDIMENTS IN DP-LOS ALAMOS CANYON 1965 THROUGH 1970

	November 1965 (analyses in c/m/g)		
Station	Gross Alpha	Gross Beta	Gross Gamma
DPS-1	6	566	130
DPS-4	3	25	8
LAO-C	2	7	30
LAO-1	2	8	2
LAO-3	2	4	12
LASC	1	<1	<1

		DP Canyon 1967 and 1968 (average of a number of analyses in pCi/g)			
Station	No. of Analyses	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu
DPS-1	2	16	536	0.62	7.68
DPS-2	1	3	140	0.12	1.32
DPS-3	1	2	122	0.12	0.79
DPS-4	3	3	29	0.07	0.69

	February 1970 (analyses in pCi/g)			
Station	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu
DPS-1	28	391	15.8	2.69
DPS-4	5	92	0.219	1.40
LAO-C	2	1	<0.001	<0.001
LAO-1	1	4	0.026	0.101
LAO-3	2	9	0.09	0.189
LAO-4	2	12	0.011	0.153
LAO-6	2	9	0.032	0.364
LASC	2	8	0.003	0.845

TABLE A-XLIV

RADIOCHEMICAL ANALYSES OF SEDIMENTS FROM UPPER LOS ALAMOS CANYON 1971 THROUGH 1975 (analyses in pCi/g, except as noted)

Station	Date	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu	^{137}Cs	Total U[a]
Near LAO-3	5-71	3	1	0.007	0.961	---	0.8
	10-71	8	73	2.45	1.36	103	0.2
	10-72	<1	2	0.037	0.370	7	0.4
	6-73	<1	18	0.008	0.097	2	---
	4-75	3	2	0.002	0.076	---	1.1
	10-75	---	---	0.032	0.106	---	---
LASC	5-71	2	4	0.007	0.112	---	0.09
	10-71	<1	<1	0.003	0.054	3	0.02
	10-72	<1	6	0.004	<0.004	5	0.33
	6-73	<1	33	<0.001	0.136	---	---
	7-75	<1	4	<0.001	0.160	---	---
	10-75	<1	3	<0.001	0.050	---	---

[a]μg/g.

TABLE A-XLV

PLUTONIUM AND CESIUM IN SEDIMENTS FROM DP-LOS ALAMOS CANYON SPECIAL STUDY, 1972 (analyses in pCi/g)

Location[a]	^{238}Pu	^{239}Pu	^{137}Cs
Control	0.02	0.03	0.3
Outfall	2.1	28	1700
20	1.5	7.9	190
40	0.06	0.58	5.9
80	0.20	2.5	49
160	0.15	0.61	24
320	0.17	0.50	15
640	0.23	0.70	51
2 560	0.03	0.17	13
5 120	0.03	0.36	3.6
10 240	0.05	0.13	1.6

[a]m below outfall.

TABLE A-XLVI

PLUTONIUM IN SEDIMENTS FROM DP-LOS ALAMOS CANYON SPECIAL STUDY, 1973 (analyses in pCi/g)

Location[a]	Depth of sediment in cm			
	0-2.5	2.5-7.5	7.5-12.5	>12.5[b]
Control	0.036	0.036	0.044	0.051
Outfall	957	1640	---	---
20	24.8	16.4	2.63	---
40	18.2	---	11.4	0.488
80	---	10.4	1.87	0.831
160	0.332	2.25	0.369	0.328
320	0.196	0.252	0.225	2.34
640	0.344	0.481	0.445	---
1 280	0.864	0.878	0.644	1.78
2 560	0.183	0.090	0.114	---
5 120	0.599	0.186	---	---

[a]m below outfall.
[b]Remainder varied from 12.5 to 30 cm.

TABLE A-XLVII

PARTICLE-SIZE DISTRIBUTION OF CHANNEL SEDIMENTS IN LOWER LOS ALAMOS CANYON

Classification	Distribution (% by weight)		
	LAS-3	LAS-4	LAS-7
Granules	0.5	1.0	10.5
Very coarse sand	7.0	17.0	29.5
Coarse sand	25.0	47.0	38.5
Medium sand	37.0	19.5	11.5
Fine sand	21.0	9.5	4.0
Very fine sand	6.0	2.0	2.0
Silt and clay	3.5	4.0	4.0

TABLE A-XLVIII

RADIOCHEMICAL ANALYSES OF SEDIMENTS FROM LOWER LOS ALAMOS CANYON 1968 THROUGH 1975 (analyses in pCi/g)

Station	Date	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu
LAS-1	5-68	2	32	0.09	0.06
	7-68	<1	6	0.02	0.20
	8-68	3	10	0.03	0.12
	7-75	1	1	---	---
LAS-2	5-68	2	17	0.03	0.59
	8-68	2	<1	<0.01	0.53
	2-70	3	2	<0.01	0.33
	7-75	---	---	0.01	0.07
LAS-3	2-70	---	---	<0.01	0.34
	4-75	<1	<1	<0.01	0.23
	5-75	3	4	<0.01	0.27
	6-75	4	3	<0.01	0.18
	7-75	---	---	<0.01	0.10
LAS-4	5-68	2	19	0.04	0.30
	8-68	<1	3	<0.01	0.02
	2-70	3	4	<0.01	0.59
	4-75	2	3	<0.01	0.15
	7-75	---	---	<0.01	0.22
LAS-5	7-75	---	---	<0.01	0.22
LAS-6	7-75	---	---	<0.01	0.12
LAS-7	5-68	2	11	0.02	0.22
	8-68	2	2	<0.01	<0.01
	2-70	---	---	<0.01	0.37
	4-75	<1	<1	<0.01	0.11
	7-75	2	4	<0.01	0.13

TABLE IL

PHYSICAL CHARACTERISTICS OF STREAM SECTIONS IN ACID-PUEBLO AND DP-LOS ALAMOS CANYONS

A. Acid-Pueblo Canyon

1. 0 to 480 m (Acid Canyon)
   Width 1.5 m; Depth 0.15 m
   g/cm^3 1.57; Weight 170 $\times$ 10^6 g

2. 480 m to 2600 m
   Width 2.5 m; Depth 0.15 m
   g/cm^3 1.57; Weight 1790 $\times$ 10^6 g

3. 2600 m to 6800 m
   Width 3 m; Depth 0.15 m
   g/cm^3 1.57; Weight 2967 $\times$ 10^6 g

4. 6800 m to 10 280 m (Confluence)
   Width 4 m; Depth 0.15 m
   g/cm^3 1.57; Weight 3278 $\times$ 10^6 g

B. DP-Upper Los Alamos Canyon

1. 0 to 1800 m
   Width 1.5 m; Depth 0.15 m
   g/cm^3 1.57; Weight 459 $\times$ 10^6 g

2. 1800 m to 6600 m
   Width 2.5 m; Depth 0.15 m
   g/cm^3 1.57; Weight 2832 $\times$ 10^6 g

C. Lower Los Alamos to Rio Grande

1. Confluence to 4800 m
   Width 3m; Depth 0.15 m
   g/cm^3 1.57; Weight 3408 $\times$ 10^6 g

2. 4800 m to 7200 m (Rio Grande)
   Width 4 m; Depth 0.15 m
   g/cm^3 1.57; Weight 2261 $\times$ 10^6 g

TABLE A-L

PLUTONIUM INVENTORY IN CHANNEL SEDIMENTS FROM ACID-PUEBLO AND DP-LOS ALAMOS CANYONS

		May 1968		August 1968		February 1970		October 1972		July 1975	
		Av Con (pCi/g)	Total Pu (mCi)	Av Con (pCi/g)	Total Pu (mCi)	Av Con (pCi/g)	Total Pu (mCi)	Av Con (pCi/g)	Total Pu (mCi)	Av Con (pCi/g)	Total Pu (mCi)
Acid-Pueblo Canyon											
	0 - 480	---	---	---	---	27.0	4.6	14.0	2.4	---	---
	480 - 2600	---	---	---	---	4.8	8.7	2.4	4.3	---	---
	2600 - 6800	---	---	---	---	0.78	2.3	0.78	2.3	---	---
	6800 - 10 280	---	---	---	---	0.77	2.5	0.78	2.6	---	---
Subtotal			---		---		18.1		11.6		---
DP-Upper Los Alamos Canyon											
	0 - 1800	8.5	3.9	0.91	0.4	10.1	4.6	6.9	3.2	---	---
	1800 - 6600	0.4	1.1	0.38	1.1	0.4	1.1	0.17	0.5	---	---
Subtotal			5.0		1.5		5.7		3.7		---
Lower Los Alamos Canyon											
	0 - 4800	0.48	1.6	0.28	1.0	0.60	2.0	---	---	0.14	0.5
	4800 - 7200	0.29	0.7	0.01	<0.02	0.48	1.1	---	---	0.18	0.4
Subtotal			2.3		≃1.0		3.1		---		0.9
Total			---		---		26.9		---		---

TABLE A-LI

CESIUM INVENTORY IN CHANNEL SEDIMENTS FROM ACID-PUEBLO AND DP-LOS ALAMOS CANYONS 1972

		Av Con (pCi/g)	^{137}Cs (mCi)
Acid-Pueblo Canyon			
	0 - 480	2.8	0.48
	480 - 2600	1.1	2.0
	2600 - 6800	0.31	0.92
	6800 - 10 280	0.20	0.66
Subtotal			4.1
DP-Upper Los Alamos Canyon			
	0 - 1800	284	130
	1800 - 6600	8.3	24
Subtotal			154
Lower Los Alamos Canyon			
	0 - 4800	0.20	1.1
	4800 - 7200	1.6	9.1
Subtotal			10.2
Total			168

TABLE A-LII

FLOOD FREQUENCY AND MAXIMUM DISCHARGE AT STATE ROAD 4 FOR ACID-PUEBLO AND DP-LOS ALAMOS CANYONS

	Maximum Discharge (m^3/s)	
Frequency	**Acid-Pueblo**	**Upper Los Alamos**
2 year	3.1	3.0
5 year	7.1	6.8
10 year	10	11
25 year	17	16
50 year	21	20

TABLE A-LIII

CHEMICAL AND RADIOCHEMICAL QUALITY OF SUMMER RUNOFF IN DP CANYON
(average of a number of analyses)

Year	No. of Analyses	Chemical Quality[a]				
		Na	Cl	F	NO_3	TDS
1967	14	103	47	4.5	13	354
1968	10	125	38	4.1	6	343

Year	No. of Analyses	Radiochemical Quality[b]					
		Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu	^{241}Am	^{137}Cs
1967	10	2	1090	0.16	0.19	0.27	<250
1968	15	4	770	0.35	1.01	0.91	<350

[a]mg/ℓ.
[b]pCi/ℓ in solution.

TABLE A-LIV

GROSS-ALPHA AND GROSS-BETA IN SOLUTION AND SUSPENDED SEDIMENTS DURING TWO RUNOFF EVENTS IN DP CANYON 1968

July 30

Hour	Discharge (ℓ/s)	Suspended Sediment Concentration (mg/ℓ)	In Solution (pCi/ℓ) Gross Alpha	In Solution (pCi/ℓ) Gross Beta	Suspended Sediment (pCi/g) Gross Alpha	Suspended Sediment (pCi/g) Gross Beta
14:50	1540	19 500	<1	1800	39	1120
15:00	1540	11 200	<1	1700	43	1050
15:30	1410	20 400	<1	1080	17	520
16:15	525	9 920	3	1360	15	670
17:00	270	4 010	<1	1150	48	1170
18:20	165	1 340	14	1190	47	1680

July 31

Hour	Discharge (ℓ/s)	Suspended Sediment Concentration (mg/ℓ)	In Solution (pCi/ℓ) Gross Alpha	In Solution (pCi/ℓ) Gross Beta	Suspended Sediment (pCi/g) Gross Alpha	Suspended Sediment (pCi/g) Gross Beta
13:50	56	1 080	<1	920	64	890
14:20	1730	43 000	<1	1080	9	260
14:30	1640	26 000	<1	820	14	300
14:45	2040	13 000	<1	770	10	350
14:50	1700	11 000	<1	860	52	390
15:00	1410	37 000	<1	1180	6	210
15:05	1260	37 000	3	1190	9	210
15:10	1220	48 000	8	1190	6	180
15:20	1190	27 000	<1	1090	7	220
15:30	1020	56 000	14	1220	4	140
15:40	570	4 900	8	1000	21	650
15:50	480	4 800	6	1100	79	610
16:00	490	4 400	8	1070	16	650
16:10	480	4 600	19	1120	20	520
16:20	440	2 500	41	1060	15	790

TABLE A-LV

GROSS-ALPHA AND GROSS-BETA ACTIVITY
IN SOLUTION AND SUSPENDED SEDIMENTS
DURING A RUNOFF EVENT IN DP AND LOS ALAMOS CANYONS
AUGUST 6, 1968

Hour	Discharge (ℓ/s)	Suspended Sediment Concentration (mg/ℓ)	In Solution (pCi/ℓ)		Suspended Sediments (pCi/g)	
			Gross Alpha	Gross Beta	Gross Alpha	Gross Beta
DP Canyon						
15:35	690	24 000	19	1180	3	227
15:55	525	18 000	<1	920	3	191
16:15	450	7 700	3	710	4	300
16:30	305	5 900	11	800	93	324
16:45	240	5 400	3	740	2	280
17:00	210	2 800	8	730	4	420
17:15	160	1 700	3	760	10	580
17:30	135	1 800	14	840	2	590
17:45	120	1 000	3	832	<1	620
Los Alamos Canyon[a]						
15:40	2040	20 000	6	16	6	6
16:10	1560	10 000	<1	14	8	6
16:25	1130	9 400	<1	11	4	6
16:45	880	6 800	<1	18	2	4
16:55	760	5 800	<1	18	3	6
17:15	680	4 200	11	17	5	7
17:40	590	4 800	<1	<1	<1	<1

[a]Above junction with DP Canyon.

TABLE A-LVI

PLUTONIUM IN SOLUTION AND SUSPENDED SEDIMENTS DURING SUMMER RUNOFF IN LOWER LOS ALAMOS CANYON 1975

September 4

Station	Temp (°C)	Discharge (ℓ/s)	Suspended Sediment Concentration (mg/ℓ)	Plutonium (pCi/ℓ) Solution	Plutonium (pCi/ℓ) Suspended Sediments
LASC	13	25	600	0.07	1.9
APSC	14	60	5000	0.04	5.6
LAS-3	15	85	2000	<0.01	1.2
LAS-4	15	85	5000	0.02	2.2
LAS-7	15	30	4000	0.01	1.0

September 12

Station	Temp (°C)	Discharge (ℓ/s)	Suspended Sediment Concentration (mg/ℓ)	Plutonium (pCi/ℓ) Solution	Plutonium (pCi/ℓ) Suspended Sediments
LASC	14	3	200	0.11	0.45
APSC	15	85	3500	0.42	11.0
LAS-3	13	100	2500	0.38	8.0
LAS-4	13	85	2500	0.47	9.0
LAS-7	15	115	---	0.59	---

TABLE A-LVII

TRANSPORT OF PLUTONIUM IN SPRING RUNOFF
1975

Station	Volume $m^3 \times 10^3$	Av Pu Con (pCi/ℓ) Solution	Av Pu Con (pCi/ℓ) Suspended Sediments	Total Pu Transported (μCi) Solution	Total Pu Transported (μCi) Suspended Sediments	Total Pu Transported (μCi) Total
LASC	302	0.03	0.26	10	71	81
APSC	3.4	0.43	2.8	1.5	9.7	11
LAS-3	111	0.13	1.2	14	145	159
LAS-7	26	0.33	12	9	312	321

TABLE A-LVIII

CHEMICAL QUALITY OF WATER FROM TEST WELL T-2A
1951 THROUGH 1965
(average of a number of analyses in mg/ℓ)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS
1951	1	---	2	0.4	2	109
1952	2	---	2	0.2	2	115
1953	8	---	3	0.4	0.2	116
1956	8	12	7	0.5	2	144
1957	2	11	8	0.4	0.4	130
1958	4	8	27	0.6	4	140
1959	7	11	16	0.5	4	130
1960	6	14	15	0.4	31	170
1961	4	16	16	0.7	8	179
1962	3	15	14	0.5	14	164
1963	3	20	16	0.6	19	188
1964	3	16	16	0.5	24	148
1965	2	18	10	0.9	15	172

TABLE A-LIX

RADIOCHEMICAL QUALITY OF WATER FROM TEST WELL T-2A
1958 THROUGH 1965
(average of a number of analyses in pCi/ℓ)

Year	No. of Analyses	Gross Beta	Total Plutonium
1958	2	<14	<0.5
1959	10	<14	<0.5
1960	10	<14	<0.5
1961	2	<14	<0.5
1962	4	<14	<0.5
1963	3	<14	<0.5
1964	3	<14	<0.5
1965	2	<14	<0.5

TABLE A-LX

CHEMICAL QUALITY OF WATER FROM OBSERVATION HOLE PO-3B
1957 THROUGH 1975
(average of a number of analyses in mg/ℓ)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS
1957	3	11	7	0.4	2	176
1958	8	9	8	0.6	4	176
1959	3	10	9	0.5	3	187
1960	3	12	12	0.4	3	198
1961	2	12	14	0.4	5	209
1963	1	16	15	0.4	3	180
1964	1	17	24	0.4	3	240
1970	2	31	31	1.8	3	307
1971	1	28	34	0.9	3	258
1972	2	24	31	1.8	7	265
1973	1	23	32	0.6	2	318
1974	2	42	42	0.8	15	292
1975	2	30	31	0.4	13	299

TABLE A-LXI

CHEMICAL QUALITY OF WATER FROM TEST WELL T-1A
1951 THROUGH 1975
(average of a number of analyses in mg/ℓ)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS
1951	4	46	24	0.6	27	298
1952	3	34	19	0.5	23	243
1953	9	26	12	0.5	14	216
1954	5	---	15	0.8	26	465
1955	6	---	10	1.1	27	311
1956	5	---	13	0.6	18	279
1957	2	---	31	0.6	14	231
1958	10	25	26	0.5	12	195
1959	8	15	54	0.5	---	165
1960	6	36	23	0.6	19	230
1961	4	40	25	0.6	24	319
1962	3	53	26	0.7	31	340
1963	1	60	27	1.2	62	388
1964	4	53	30	1.2	35	313
1968	2	85	33	2.1	18	318
1969	1	77	27	1.8	13	339
1971	2	60	37	2.1	31	318
1974	2	60	43	2.1	29	320
1975	2	63	39	1.6	26	326

TABLE A-LXII

CHEMICAL QUALITY OF WATER FROM BASALT SPRING 1951 THROUGH 1975

(average of a number of analyses in mg/ℓ)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS
1951	1	---	16	0.5	8	220
1952	4	---	15	0.4	13	215
1953	3	---	16	0.4	10	198
1954	3	---	16	0.4	15	195
1955	2	---	16	0.5	12	198
1956	18	17	17	0.6	18	212
1957	3	16	13	0.5	14	191
1958	6	13	13	0.6	11	169
1959	5	14	15	0.4	10	190
1960	2	15	13	0.5	8	175
1961	1	14	14	0.5	8	174
1962	2	20	17	0.8	13	256
1963	2	24	20	1.2	13	198
1964	1	20	20	0.8	13	229
1965	2	10	14	0.8	13	197
1967	1	25	15	0.3	13	150
1968	1	24	14	0.6	13	168
1969	2	24	14	0.3	9	207
1971	2	15	11	0.6	13	220
1972	2	19	14	0.4	10	197
1973	2	15	14	0.9	10	263
1974	2	16	17	0.7	11	206
1975	2	13	15	0.6	10	209

TABLE A-LXIII

METAL-ION ANALYSES OF WATER FROM TEST WELL T-1A AND BASALT SPRING 1971 AND 1972

(average of a number of analyses in μg/ℓ)

	T-1A	Basalt Spring
In Solution		
Cadmium	4.3	1.7
Beryllium	0.31	<0.25
Lead	1.6	<1.0
Mercury	<0.02	<0.02
Particulates		
Cadmium	8.8	0.29
Beryllium	0.48	<0.25
Lead	470	1.4
Mercury	0.07	0.03

TABLE A-LXIV

RADIOCHEMICAL QUALITY OF WATER FROM OBSERVATION HOLE PO-3B, TEST WELL T-1A, AND BASALT SPRING 1967 THROUGH 1975

(average of a number of analyses in pCi/ℓ, except as noted)

Station	Year	No. of Analyses	Gross Alpha	Gross Beta	^{238}Pu	^{239}Pu	^{137}Cs	^{3}H	Total U[a]
Obs Well PO-3B	1970	2	<1	8	<0.05	<0.05	---	1400	<0.4
	1971	1	<1	6	<0.05	<0.05	<300	1400	<0.4
	1972 [b]	2	1	6	0.13	0.07	<350	1800	1.1
	1973 [b]	1	2	10	0.05	1.5	<300	1300	<0.4
	1974 [b]	4	2	13	0.30	0.80	<300	1000	1.2
	1975 [b]	3	7	38	<0.02	0.23	---	6000	2.1
Test Well T-1A	1968	2	1	12	<0.05	<0.05	---	<1000	1.1
	1969	1	2	7	<0.05	<0.05	---	<1000	0.8
	1970	---	---	---	---	---	---	---	---
	1971	2	1	94	<0.05	<0.05	<350	<1000	0.4
	1972	---	---	---	---	---	---	---	---
	1973	---	---	---	---	---	---	---	---
	1974	3	<1	8	<0.05	<0.05	<300	<1000	<0.4
	1975	2	<1	14	<0.05	<0.05	---	<1000	<0.4
Basalt Spring	1967	1	1	4	<0.05	<0.05	---	---	0.4
	1968	2	<1	4	<0.05	<0.05	---	---	0.7
	1969	1	<1	3	<0.05	<0.05	---	---	1.6
	1970	1	<1	5	<0.05	<0.05	---	---	0.4
	1971	2	1	2	<0.05	<0.05	---	<1000	1.6
	1972	2	<1	4	<0.05	<0.05	<350	<1000	3.0
	1973	2	<1	2	<0.05	<0.05	<300	<1000	<0.4
	1974	4	<1	4	<0.05	<0.05	<300	<1000	---
	1975	3	1	7	<0.05	<0.05	---	1300	1.2

[a] μg/ℓ.

[b] Observation hole contaminated during clean out.

TABLE A-LXV

CHEMICAL QUALITY OF WATER FROM TEST WELL T-1
1952 THROUGH 1970
(average of a number of analyses in mg/ℓ)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS
1952	18	16	8	1.3	1.8	161
1953	10	18	5	1.1	2.2	161
1954	2	---	10	1.3	2.5	147
1955	1	---	10	1.1	3.4	194
1956	8	20	5	1.4	3.5	191
1957	10	20	5	1.1	3.1	131
1958	6	17	5	1.0	7.4	120
1959	2	18	4	1.1	6.9	130
1960	3	18	5	1.0	6.8	135
1961	5	17	4	1.3	4.3	149
1962	1	19	4	1.2	10	178
1963	1	34	6	0.8	1.7	186
1965	1	17	8	0.7	3.6	149
1967	1	21	14	0.7	1.7	173
1969	1	33	8	0.1	1.7	188
1970	1	11	8	0.5	1.7	161

TABLE A-LXVI

CHEMICAL QUALITY OF WATER FROM TEST WELL T-2
1951 THROUGH 1974
(average of a number of analyses in mg/ℓ)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS
1951	10	8	6	0.5	0.5	159
1952	14	8	5	0.7	0.4	158
1953	3	9	4	0.5	0.3	146
1954	1	---	4	0.8	0.5	172
1955	1	---	3	0.4	3.0	164
1958	1	9	7	0.4	0.1	---
1960	3	10	3	0.4	0.3	102
1961	4	10	2	0.7	0.5	158
1962	4	11	3	0.9	1.9	152
1963	3	10	2	0.4	1.7	119
1964	3	9	3	0.5	1.3	130
1968	1	19	4	1.0	1.2	96
1969	1	17	3	0.1	<0.4	90
1970	1	11	5	0.5	1.6	98
1971	1	10	5	0.8	<0.4	86
1972	1	10	6	0.5	0.4	78
1973	1	8	4	0.6	<0.4	112
1974	2	9	7	0.7	0.3	146

TABLE A-LXVII

CHEMICAL QUALITY OF WATER FROM TEST WELL T-3
1951 THROUGH 1975
(average of a number of analyses in mg/ℓ)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS
1951	7	25	4	0.5	1.1	186
1952	4	17	6	0.6	1.8	194
1953	3	11	4	0.7	0.5	195
1954	3	---	5	0.3	0.6	185
1956	7	16	6	0.5	1.6	200
1957	5	14	4	0.4	0.8	205
1958	1	13	7	0.4	1.1	200
1959	4	13	5	0.5	0.7	180
1960	3	14	5	0.4	0.7	195
1961	3	16	5	0.6	0.4	176
1962	3	14	5	0.6	2.6	199
1963	1	17	5	0.4	2.4	200
1964	2	13	5	0.4	0.7	199
1965	2	11	5	0.7	1.3	156
1967	1	25	5	0.4	0.6	191
1968	1	24	4	0.4	1.2	201
1969	1	22	5	<0.1	0.4	224
1970	1	15	5	<0.1	3.1	180
1971	1	15	5	0.6	0.4	212
1972	1	19	6	0.5	<0.4	198
1973	2	12	6	0.4	<0.4	178
1974	2	15	8	0.3	1.8	179
1975	2	17	6	0.7	1.1	188

TABLE A-LXVIII

CHEMICAL QUALITY OF WATER FROM TEST WELL T-4 1952 THROUGH 1965
(average of a number of analyses in mg/ℓ)

Year	No. of Analyses	Na	Cl	F	NO_3	TDS
1952	8	8	5	0.2	1.3	101
1953	1	5	2	0.1	1.3	180
1961	1	11	5	0.3	1.4	190
1962	2	10	3	0.6	3.9	191
1963	4	12	3	0.5	1.4	172
1964	4	9	2	0.4	4.4	141
1965	3	15	3	0.6	1.3	129

TABLE A-LXIX

METAL-ION ANALYSES OF WATER FROM TEST WELLS T-2 AND T-3, 1971
(average of two analyses in μg/ℓ)

	T-2	T-3
In Solution		
Cadmium	1.1	2.8
Beryllium	<0.25	<0.25
Lead	11	3.5
Mercury	<0.02	<0.02
Particulates		
Cadmium	2.1	5.6
Beryllium	<0.25	<0.25
Lead	43	8.2
Mercury	<0.02	<0.02

TABLE A-LXX

RADIOCHEMICAL QUALITY OF WATER FROM TEST WELLS T-1, T-2, T-3, AND T-4
(analyses in pCi/ℓ, except as noted)

Well	Years	Gross Beta	Total Pu	Total U[a]
TW-1	1961-67	<14	<0.5	<0.4 to 3.0
TW-2	1961-68	<14	<0.5	<0.4 to 2.8
TW-3	1961-67	<14	<0.5	<0.4 to 2.2
TW-4	1962-65	<14	<0.5	<0.4 to 5.0

Well	Years	Gross Alpha	Gross Beta	Total Pu	Total U[a]
TW-1	1968-70	<1	<5	<0.05	<0.4
TW-2	1968-74	<2	<3	<0.05	<0.4 to 1.1
TW-3	1967-75	<1	<7	<0.05	<0.4 to 2.2
TW-4	No Analyses	---	---	--	---

[a]μg/ℓ.

TABLE A-LXXI

PLUTONIUM AND CESIUM IN VEGETATION IN ACID-PUEBLO AND DP-LOS ALAMOS CANYONS
(mean concentrations in pCi/g)

ACID-PUEBLO CANYON

	Control		0 to 640[a]		640 to 10 280[a]	
	Pu	^{137}Cs	Pu	^{137}Cs	Pu	^{137}Cs
Sediments	0.20	0.36	21.3	3.3	0.86	0.22
Grass	0.08	0.33	4.2	0.68	0.35	0.60
Shrub	0.04	0.22	1.6	0.66	0.02	0.27
Tree	---	---	---	---	<0.01	0.26
Moss	---	---	67	34	---	---
Lichen	---	---	2.9	8.3	---	---

DP-LOS ALAMOS CANYON

	Control		0 to 20[a]		20 to 10 280[a]	
	Pu	^{137}Cs	Pu	^{137}Cs	Pu	^{137}Cs
Sediments	0.05	0.31	19.8	920	0.85	19
Grass	0.11	0.05	2.5	194	0.12	2.4
Shrub	0.18	0.28	---	---	0.04	0.74
Tree	0.04	0.18	---	---	0.06	0.41
Moss	0.36	1.0	---	---	1.7	28

[a]m below outfall.

TABLE A-LXXII

PLUTONIUM AND CESIUM IN RODENTS NEAR EFFLUENT OUTFALLS IN ACID AND DP CANYONS
(mean concentration in pCi/g)

ACID CANYON

	Control		Near Outfall	
	Pu	^{137}Cs	Pu	^{137}Cs
Lung	0.04	---	0.10	---
Pelt	0.01	---	0.39	---
Liver	0.02	---	0.11	---
Carcass	<0.01	0.20	0.04	0.35

DP CANYON

	Control		Near Outfall	
	Pu	^{137}Cs	Pu	^{137}Cs
Lung	0.08	---	0.12	---
Pelt	1.36	---	0.85	---
Liver	0.02	---	0.12	---
Carcass	0.02	3.2	0.08	103

TABLE A-LXXIII

RADIOCHEMICAL ANALYSES OF SOIL AND VEGETATION FROM LAND PARCEL C, PUEBLO CANYON, 1972

(analyses from five locations in pCi/g, except as noted)

Material	Analyses	Range Min	Range Max	Av
Vegetation Bkg	H-3[a]	---	<1.0	<1.0
Vegetation	H-3[a]	1.3	2.8	1.7
Soil Bkg	Gross Beta	16.2	31.7	21.4
Soil	Gross Beta	20.9	26.9	24.2
Vegetation Bkg	Gross Beta	4.2	5.1	4.6
Vegetation	Gross Beta	3.7	6.7	5.0
Soil Bkg	^{137}Cs	1.2	5.7	3.6
Soil	^{137}Cs	2.4	3.6	3.0
Vegetation Bkg	^{137}Cs	0.5	2.4	1.6
Vegetation	^{137}Cs	0.5	3.0	1.3
Soil Bkg	^{238}Pu	0.1	0.50	0.13
Soil	^{238}Pu	---	0.03	0.03
Vegetation Bkg	^{238}Pu	0.002	0.005	0.004
Vegetation	^{238}Pu	---	<0.001	<0.001
Soil Bkg	^{239}Pu	0.02	0.11	0.05
Soil	^{239}Pu	---	0.12	0.12
Vegetation Bkg	^{239}Pu	<0.001	0.003	0.002
Vegetation	^{239}Pu	---	0.002	0.002
Soil Bkg	^{241}Am	0.03	0.09	0.06
Soil	^{241}Am	---	0.05	0.05
Vegetation Bkg	^{241}Am	0.003	0.012	0.012
Vegetation	^{241}Am	---	0.004	0.004
Soil Bkg	Total U[b]	0.16	1.24	0.58
Soil	Total U[b]	---	0.65	0.65
Vegetation Bkg	Total U[b]	<0.02	0.05	<0.03
Vegetation	Total U[b]	---	0.07	0.07

[a]pCi/mℓ.
[b]μg/g.

APPENDIX B

INSTRUMENTATION AND RADIOCHEMICAL ANALYSES

I. *In Situ* RADIATION MEASUREMENTS

In situ radiation measurements of x and gamma radiation were made by four different measurement systems: a micro-R meter, thermoluminescent dosimeters or TLDs, a high-pressure ionization chamber (HPIC), and the field phoswich (phosphor sandwich).

The micro-R meter is a Ludlum Model 12S count rate meter in which a NaI (Tl) scintillation crystal is used as the detector (see Fig. B-1). This detector has the advantage of being sensitive enough to read μR/h directly. A disadvantage is that its response is quite dependent upon photon energy (Fig. B-2). The instrument was calibrated with a known flux of ^{226}Ra (and daughters) gamma rays. Earlier experience at Los Alamos National Laboratory (Ref. B1) indicates that the Ludlum 12S readings would be reduced about 30% if normalized to agree with thermoluminescent dosimeters (TLD), or with the high pressure ion chamber (HPIC).

The TLD measurement system is a dose integrating measurement system or dosimeter rather than a dose rate instrument. It has the advantage that it can be left in the field for long periods of time to record total dose received, regardless of temporal variations in dose rate. TLDs also show the least energy dependence of any measurement technique used in the survey (see Fig. B-2). The TLDs were calibrated to a known flux of ^{60}Co gamma rays.

A Reuter-Stokes Model RSS-111 spherical, high-pressure ionization chamber (HPIC) filled to 14 atm with pure argon was also used. Its factory calibrated response was checked at various TLD measurement locations. In contrast to the micro-R meter, it has a flat energy response over a wide range of energies (Fig. B-2) and is thus well suited to make environmental gross-gamma measurements.

A field portable phoswich was used in this survey to identify the presence of low energy x and gamma rays. This unit, shown in Fig. B-3, was also equipped with a timer-scaler to allow timed, integrated response, thereby attaining a lower detection limit less dependent on subjective interpretations of the rate meter. For work in Acid/Pueblo Canyon, the phoswich was adjusted to the x-ray energy band from 5 keV to 25 keV in order to enhance the detection of the uranium excitation x ray from plutonium decay while minimizing interference from ^{137}Cs at 30 keV. Detection limits vary as a function of national background, detector height, window setting, count length, etc. As used in this study, detection limits would be on the order of 200-400 pCi/g for ^{239}Pu in soil.

II. SAMPLE ANALYSES

A. Gross Alpha and Gross Beta

All soil samples were analyzed for gross-beta and gross-alpha activity by exposing an appropriate scintillator (alpha or beta) to the gross particle emission from a petri dish full of the dried soil sample. This procedure screened all samples for concentrations of alpha or beta emitting contaminants that would exceed those attributable to naturally occurring radionuclides or weapons testing fallout by a significant margin. The method was originated by R. D. Evans

during the 1930s and adapted as a screening device for alpha contamination by Los Alamos National Laboratory during the TA-1 cleanup (Ref. B2).

The alpha probe was calibrated with a petri dish of dried soil containing 2000 pCi/g of ^{239}Pu. The calibration factor was 1.14 pCi per net count in 5 min. Repetitive counts of empty petri dishes gave an instrument background of 15.2 ± 3.9 counts in 5 min, which was equivalent to 17.3 ± 4.4 alpha pCi/g of soil. The average net gross-alpha activity from 7 uncontaminated local soil samples was 30 ± 8 alpha pCi/g of soil. Assuming uniform natural soil radioactivity, the detection limit for gross-alpha contamination in soil would be 22 pCi/g at the 99.7% confidence level (based on Poisson statistics).

The beta probe was calibrated with a petri dish of dried soil containing ^{90}Sr. Because of the considerable variation in response to different energy beta particles, the values are reported only as relative values. Both detectors are shown in Fig. B-4.

B. Radiochemical Analyses

Samples were oven dried, homogenized, and submitted to the subcontractor for analysis. Soil samples were submitted in weighted 10 g-aliquots as described in Appendix B. The subcontractor dissolved the samples in an acid and chemically separated the species of interest. Alpha emitters were analyzed by alpha spectrometry; beta emitters by low background proportional counting.

Ten per cent of the samples sent to the subcontractor were either spikes* or blanks** submitted to evaluate the quality of analytical results reported. The quality control samples were prepared from silt from the bottom of a deep water well known to be free from the man-made radionuclides ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$. Table B-I presents analyses of blank control samples submitted to the subcontractor. The accuracy of the subcontractor's analyses can be summarized by the ratio of the amount of activity reported for a spike sample to the amount actually added. Table B-II summarizes the quantity of each nuclide spiked into each control sample, as well as the reported analytical result and the quality control ratio. Reported analytical results are not background corrected. Table B-III summarizes, for each radionuclide analyzed, the mean, the standard deviation, and the range of both blanks and quality control ratios.

It must be noted that most spikes were of low concentration in an attempt to simulate low-level environmental contamination with the attendant difficulty in attaining complete homogeneity. The consequent spread in analytical results is augmented in the case of naturally occurring radionuclides because they have a variable distribution in soils including our control soil.

Seventeen uranium values were reported for blank samples in Table B-II. Fourteen of those were normally distributed about a mean of 1.23 μg uranium per gram of soil. The remaining blanks were 11.0, 5.7, and 2.5 μg/g. Because these concentrations were well above the analytical detection limit, they could be resolved to the nearest 0.5 μg/g and readily distinguished from background. Therefore, the three results were considered outliers and deleted from data reduction. The value 1.23 μg/g is considered representative of natural uranium in the silt control soil, and it was subtracted from each of the spike results.

Nineteen uranium values were reported for spike samples in Table B-II. Eighteen of these were normally distributed and produced quality control ratios that averaged 0.89 as shown in Table B-III. The nineteenth result (0.38 μg/g) was less than two standard deviations different from either

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*A spike is a quantity of standard sample matrix into which is injected a specified quantity of test material—in this case radionuclide.

**A blank is the quantity of the standard sample matrix that has not been treated with test material.

the detection limit or the sensitivity of analysis. The uncertainty in these numbers produces meaningless results in the calculation of a QC ratio so 0.38 μg/g was deleted from the data set.

Blanks analyzed for ^{137}Cs, ^{90}Sr, and ^{239,240}Pu were generally at the detection limit of the analytical procedure. Moreover, the source of control soil precludes all but the remote prospect that fallout radioactivity could contaminate control so no background corrections were made in the case of ^{137}Cs, ^{90}Sr, or ^{239,240}Pu. The mean quality control ratio for 26 ^{90}Sr spikes was 0.93, and that for 11 ^{137}Cs spikes was 0.81. The mean quality control ratio for five ^{239,240}Pu spikes was 1.16. Four additional spikes were deleted from the data set. Three of these were 0.0065 pCi/g (less than the detection limit of 0.01 $\pm$ 0.01 pCi/g), which produced a meaningless quality control ratio. The fourth additional spike (0.032 pCi/g) was analyzed in a sequence of test samples that contained sufficient activity (~100 pCi/g max) to be analyzed in a segregated laboratory. The analytical result of 0.14 pCi/g is believed to contain cross contamination from the adjacent samples and was deleted.

Thorium-232 and ^{226}Ra were allocated one blank each. Analysis of this blank gave 4.38 μg ^{232}Th and 0.77 pCi ^{226}Ra per gram of soil. By comparison, the mean for all ^{232}Th samples was 10.8 μg/g and the mean for all ^{226}Ra samples was 1.16 pCi/g. Reference B3 indicates average ^{232}Th concentrations of 14.3 μg/g by radiochemistry and 17.2 μg/g by *in situ* measurement of surface soil in an adjacent canyon. Because the control soil originates in a distinctly different formation from the available comparisons, 3.48 μg/g and 0.77 pCi/g for ^{232}Th and ^{226}Ra, respectively, are presumed to be representative of the control soil. Whether 3.48 μg/g or one of the comparison values is taken as representative, all are of minor significance when compared to the magnitude of spikes used. The same is true of the ^{226}Ra blank compared to its spikes. The mean quality control ratio for six ^{232}Th spikes was 0.88, whereas that for six ^{226}Ra spikes was 0.82.

Some samples were analyzed by the Los Alamos National Laboratory Environmental Surveillance Group. Details on methods and quality control information are available in Refs B4 and B5.

Quite late in this survey *in situ* measurements showed ^{241}Am and ^{241}Pu of interest at the head end of Acid Canyon. A few samples were analyzed radiochemically to verify these radionuclides both at the head end of the canyon and downstream. The results of these analyses are included in Tables D-II, D-XII, and D-XXII of Appendix D. Because the analyses were done to support the field observation of these radionuclides rather than to define their distribution or estimate their inventory, no quality control effort was undertaken.

REFERENCES

B1. L. J. Johnson, "Los Alamos Land Areas Environmental Radiation Survey 1972," Los Alamos Scientific Laboratory report LA-5097-MS (1972).

B2. A. J. Ahlquist, C. J. Umbarger, and A. K. Stoker, "Recent Developments for Field Monitoring of Alpha Emitting Contaminants in the Environment," Health Physics **34**: 489-492 (May 1978).

B3. U.S. Department of Energy, "Radiological Survey of the Bayo Canyon, Los Alamos, New Mexico," U.S. DOE, Assistant Secretary for Environment, Division of Environmental Control Technology, Formerly Utilized MED/AEC Sites Remedial Action Program, report DOE/EV-0005/15, prepared by Environmental Surveillance Group, Health Research Division, Los Alamos National Laboratory (June 1979).

B4. Environmental Surveillance Group, "Environmental Surveillance at Los Alamos During 1978," Los Alamos Scientific Laboratory report LA-7800-ENV (April 1979).

B5. Environmental Surveillance Group, "Environmental Surveillance at Los Alamos During 1979," Los Alamos Scientific Laboratory report LA-8200-ENV (April 1980).

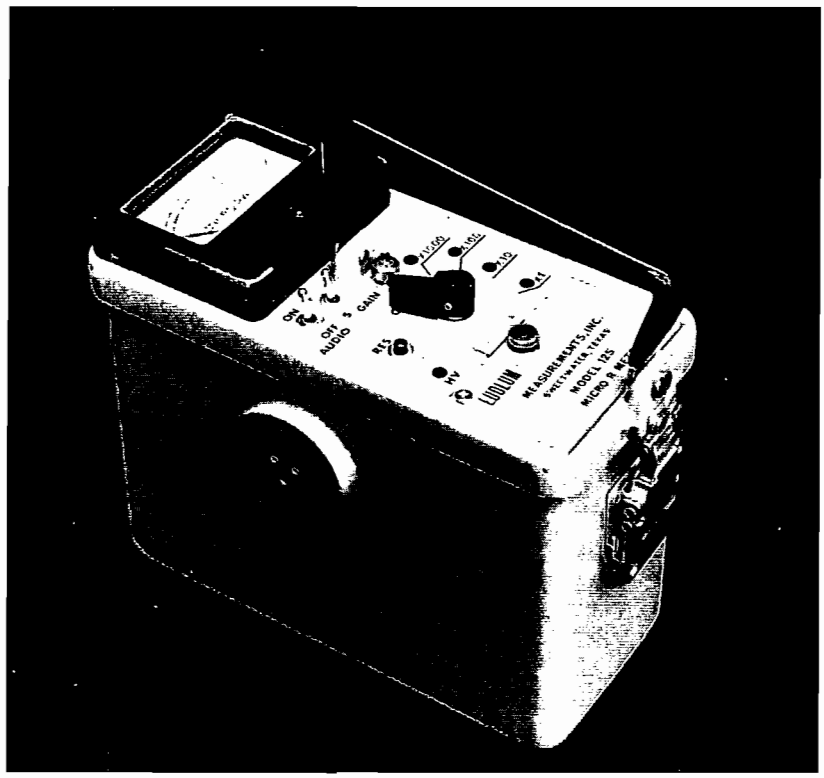

Fig. B-1.
μR meter.

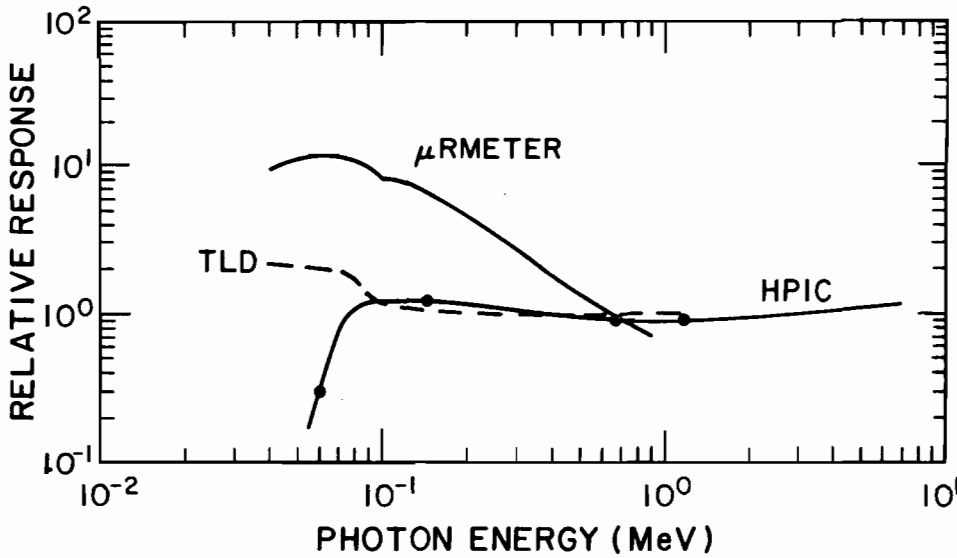

Fig. B-2.
Relative energy response of external radiation detection methods.

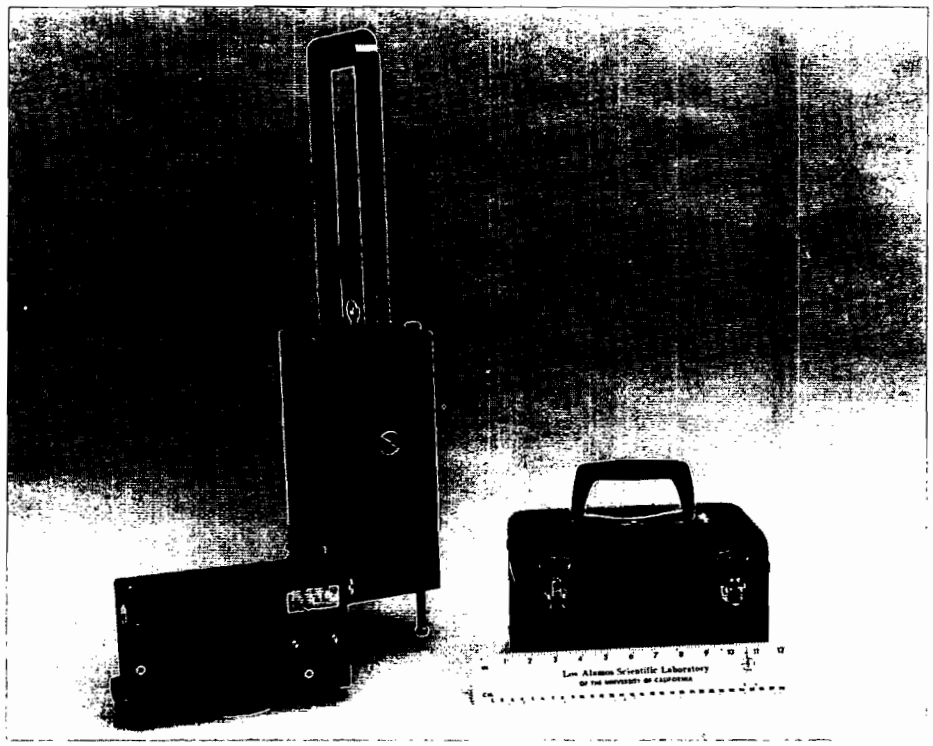

Fig. B-3.
Field phoswich survey meter. Left to right: readout, detector, and signal processor modules.

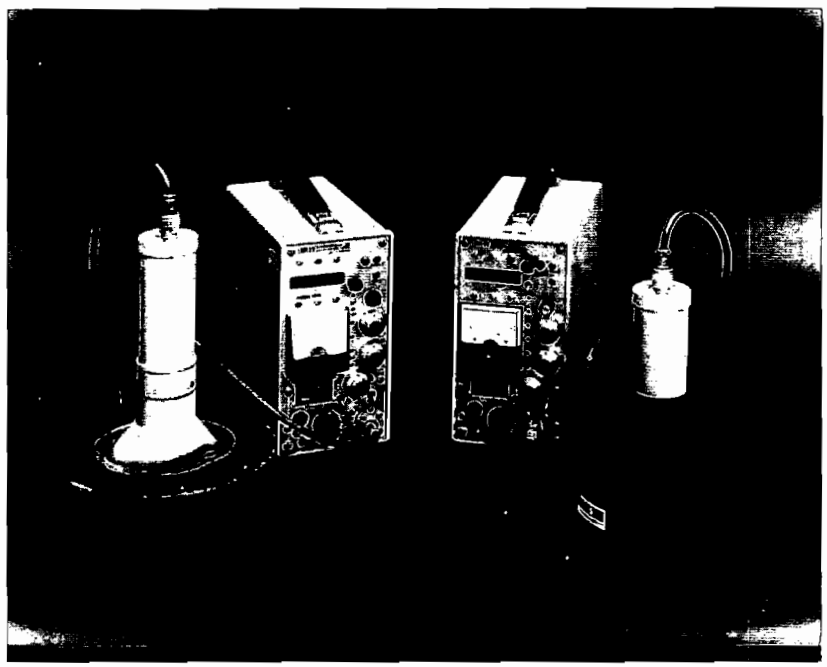

Fig. B-4.
Gross-alpha (left) and gross-beta (right) detectors with scaler-timer instruments.

TABLE B-I

RESULTS OF
INDIVIDUAL RADIOCHEMICAL ANALYSES
OF BLANK (UNSPIKED)
QUALITY CONTROL SOIL SAMPLES

Uranium (μg/g)	^{90}Sr (pCi/g)
1.9 ± 0.0038	0.0 ± 0.32
11.0 ± 11.0	0.32 ± 0.11
5.7 ± 0.0342	0.0 ± 0.82
1.7 ± 0.0034	0.0 ± 0.77
4.2 ± 0.0168	0.0 ± 0.23
1.7 ± 0.0034	0.0 ± 0.23
2.5 ± 0.0075	0.13 ± 0.04
1.2 ± 0.0024	0.12 ± 0.05
1.0 ± 0.0020	0.17 ± 0.03
0.8 ± 0.0016	0.0 ± 0.05
1.0 ± 0.0020	
1.0 ± 0.0020	
1.1 ± 0.0022	
0.9 ± 0.0027	
1.0 ± 0.0030	
0.5 ± 0.0005	
0.9 ± 0.0027	

^{137}Cs (pCi/g)	$^{239,240}Pu$ (pCi/g)
0.0 ± 0.019	0.026 ± 0.007
0.0 ± 0.17	0.0 ± 0.005
	0.0 ± 0.005

^{232}Th (μg/g)	^{226}Ra (pCi/g)
3.48 ± 0.52	0.77 ± 0.046

TABLE B-II

RESULTS OF INDIVIDUAL RADIOCHEMICAL ANALYSIS OF SPIKED QUALITY CONTROL SOIL SAMPLES

Uranium			^{90}Sr		
Analysis (μg/g)	Spike (μg/g)	QC Ratio	Analysis (pCi/g)	Spike (pCi/g)	QC Ratio
48.8 ± 2.51	37.8	1.29	514 ± 51.40	520	0.99
34.8 ± 1.39	37.8	0.92	50.9 ± 0.51	49	1.04
61 ± 0.05	3.78	1.61	45.5 ± 0.23	52	0.88
309 ± 46.35	454	0.68	0.50 ± 0.00	0.52	0.96
34.8 ± 0.69	37.8	0.92	10.4 ± 0.21	10.6	0.98
3.7 ± 0.03	3.8	0.97	96.2 ± 1.92	106	0.91
0.07 ± 0.00	0.38	0.18	0.14 ± 0.01	0.11	1.27
2.3 ± 0.01	2.3	1.00	1.07 ± 0.04	1.06	1.01
2.8 ± 0.02	2.8	0.74	0.16 ± 0.07	0.21	0.76
7.0 ± 0.01	7.6	0.92	1.30 ± 0.09	2.1	0.62
40.8 ± 1.63	37.8	1.08	21.03 ± 21.20	21.2	0.99
2.2 ± 0.01	3.8	0.58	39.5 ± 0.79	212	0.19
3.0 ± 0.02	3.8	0.79	19.63 ± 0.39	21.2	0.93
17.8 ± 0.18	15.1	1.18	41.35 ± 0.83	53	0.78
10.3 ± 0.06	15.1	0.68	1.23 ± 0.09	1.06	1.16
20.8 ± 0.21	37.8	0.55	29.37 ± 0.58	31.8	0.92
10.8 ± 0.11	15.1	0.72	46.1 ± 0.92	53	0.87
1.7 ± 0.01	3.8	0.45	43.9 ± 1.32	53	0.83
7.2 ± 0.06	7.6	0.95	9.72 ± 0.49	10.6	0.92
			2.07 ± 0.10	2.1	0.99
			46.2 ± 2.31	53	0.87
			27.0 ± 1.35	21.2	1.27
			2.16 ± 0.11	2.1	1.03
			10.3 ± 0.52	10.6	0.97
			1.03 ± 0.06	1.06	0.97
			0.142 ± 0.06	0.11	1.29

^{239}Pu			^{137}Cs		
Analysis (pCi/g)	Spike (pCi/g)	QC Ratio	Analysis (pCi/g)	Spike (pCi/g)	QC Ratio
0.0 ± 0.005	0.0065	0.00	17.5 ± 0.18	21.6	0.81
0.0 ± 0.005	0.0065	0.00	41.0 ± 0.41	43.2	0.95
0.03 ± 0.017	0.0065	4.62	1.76 ± 0.09	2.2	0.80
0.012 ± 0.007	0.013	0.92	38.8 ± 0.39	43.2	0.90
0.14 ± 0.027	0.032	4.38	8.67 ± 0.43	10.8	0.80
0.039 ± 0.011	0.032	1.22	16.6 ± 0.83	21.6	0.77
0.078 ± 0.013	0.064	1.22	16.1 ± 0.81	21.6	0.75
0.048 ± 0.016	0.032	1.50	40.9 ± 2.05	43.2	0.95
0.012 ± 0.004	0.013	0.92	16.6 ± 0.83	21.6	0.77
			8.5 ± 0.43	10.8	0.79
			1.38 ± 0.12	2.2	0.63

^{232}Th			^{226}Ra		
Analysis (μg/g)	Spike (μg/g)	QC Ratio	Analysis (pCi/g)	Spike (pCi/g)	QC Ratio
87.5 ± 3.50	91.7	0.92	96.8 ± 4.84	100	0.96
52.1 ± 2.60	45.9	1.06	15.1 ± 0.76	20	0.72
233.8 ± 11.69	458.5	0.50	18.9 ± 0.95	20	0.91
169.6 ± 8.48	229.3	0.72	27.3 ± 1.37	40	0.66
48.0 ± 2.40	45.9	1.05	16.5 ± 0.83	20	0.79
95.4 ± 4.77	91.7	1.04	90.9 ± 0.45	100	0.90

TABLE B-III

INTERPRETATION OF QUALITY CONTROL RESULTS

Analysis	Blanks			Quality Control Ratios		
	Range	$\bar{x} \pm \sigma$	N	Range	$\bar{x} \pm \sigma$	N
Total uranium μg/g)	0.5 - 2.5	1.23 ± 0.53	14	0.45 - 1.61	0.89 ± 0.28	18
^{90}Sr (pCi/g)	0.0 - 0.32	0.07 ± 0.11	10	0.19 - 1.29	0.93 ± 0.22	26
^{137}Cs (pCi/g)	0.0 - 0.0	0.0	2	0.63 - 0.95	0.81 ± 0.009	11
^{239,240}Pu (pCi/g)	0.0 - 0.026	0.009 ± 0.015	3	0.92 - 1.50	1.16 ± 0.24	5
^{232}Th (μCi/g)		3.48 ± 0.51	1	0.50 - 1.60	0.88 ± 0.23	6
^{226}Ra (pCi/g)		0.77 ± 0.046	1	0.66 - 0.96	0.82 ± 0.12	6

APPENDIX C

SAMPLE COLLECTION AND PREPARATION METHODOLOGY

Surface soil samples (~5 cm) were collected by two methods. Near the former waste treatment plant, the samples were taken with a ring 9 cm diam by 10 cm deep. The ring was driven 5 cm into the ground and the soil around the ring was removed with a trowel. The trowel was slid under the sample, which was then placed in a plastic bag. Additional shallow samples were taken in canyon channels at special locations. These locations were sampled by running a stainless steel scoop to roughly 5-cm depth in the sediment and across the direction of stream flow. Samples were immediately placed in 30- by 30-cm plastic bags for transfer to the laboratory, and the bags were marked as they were obtained with sample point identity (by stratum, grid point, depth, sample technique, and data). Each sampling device was cleaned before taking the next sample.

Near-surface soil samples (~30 cm) were collected with 2.5-cm-diam plastic pipe sections driven 30 cm into the soil. When the tube was extracted from the soil, the core sample remained in the tube until it was shaken into a plastic bag. The bag was marked and transferred to the laboratory. Subsurface samples (~240 cm) were collected with a truck-mounted auger to a minimum drilling depth of 240 cm. Cuttings were lifted to the surface by the auger for selected intervals. Cuttings were spooned into a plastic bag, marked, and transferred to the laboratory.

Once the samples were in the laboratory, 75 to 100 g of soil were transferred from the plastic bag into a sterile plastic petri dish and leveled to the rim with a clean wooden tongue depressor. To minimize cross contamination, the transfer was done within the plastic bag and in a fume hood. The tongue depressors and surgeon's gloves used in transfers were discarded after each transfer. After transfer, the soil samples were dried under an infrared light for about 4 min. Samples prepared in this way were screened for gross-alpha and gross-beta activity according to the method described in Appendix B.

An additional 10-g portion of soil from samples chosen for radiochemistry was homogenized with stainless steel mortar and pestle, placed in a plastic vial, dried 15 min in an oven at 75°C, sealed, marked, packed, and shipped to the subcontracted analytical laboratory.

APPENDIX D

DATA

This Appendix contains the detailed results of the measurements performed on the soil and sediment samples collected for the survey. The results are organized into tables by strata or substrata and identified by individual sample numbers. The sample numbers may be keyed to sample locations shown on the maps in Figs. E-1 through E-6 and E-8 in Appendix E. The last table in this Appendix, D-XXIII, contains information about the location of samples in active channel, inactive channel, or banks for the canyon transects.

TABLE D-I

TREATMENT PLANT SITE GROSS-ALPHA ACTIVITY AND GROSS-BETA ACTIVITY IN THE 0-5-cm SOIL LAYER

Location	Gross α (pCi/g)	Gross β (relative)
1	40	4
2	90	4
3	60	4
4	30	9
5	40	4
12	52490	17
9	87890	25
8	10010	8
6	1960	60
7	670	12
16	100	68
15	20	4
17	20	4
45-2	90	1
45-3	150	4

TABLE D-II

TREATMENT PLANT SITE RADIOLOGICAL ANALYSIS OF SELECTED SOIL SAMPLES IN THE 0-5-cm SOIL LAYER

	pCi/g								μg/g	
Location	^{90}Sr	^{137}Cs	Gross α	^{239}Pu	^{238}Pu	^{241}Pu[a]	^{241}Am	^{226}Ra	Total Uranium	^{232}Th
2	0.90	1.85	90	63.90	0.26	---	0.93	1.20	4.7	13
3	0.50	2.19	60	61.40	0.08	---	1.46	1.28	5.5	9.7
12	1.0	10.70	52 490	86 900.0	326.0	7970	55.0	1.20	79.0	71
9	0.9	1.13	87 890.0	163 000.0	696.0	14 900	1200.0	0.0	122.0	93
8	2.4	2.26	10 010	16 300.0	70.4	1620	126.0	2.0	20.0	---
6	5.1	36.0	1960	3690.0	26.4	---	106.0	1.8	600.0	75
7	1.8	25.1	670	433.0	2.72	---	10.0	1.24	105.0	20
16	229.0	176.0	100	41.9	0.26	---	---	0.87	126.0	11.7
15	1.50	1.82	20	0.61	0.0	---	---	0.94	4.4	12.9
17	0.79	1.22	20	0.22	0.023	---	---	1.03	4.8	11.5
45-2	0.52	0.29	90	43.9	0.25	---	---	0.68	1.5	19.2
45-3	0.24	0.13	150	259.0	1.14	---	---	0.56	3.5	12.1

[a] ^{241}Pu, a beta emitter, is included here because it is a precurser of ^{2421}Am, an alpha emitter. Moreover, ^{241}Pu betas are too weak to register on our gross-beta counter.

TABLE D-III

TREATMENT PLANT SITE
GROSS-ALPHA ACTIVITY AND GROSS-BETA ACTIVITY IN THE 0-25-cm SOIL LAYER

Location	Gross α (pCi/g)	Gross β (relative)
A1	40	2
A2	20	4
A3	30	3
A4	30	2
A5	40	4
A6	40	3
A7	20	2
B1	30	4
B2	30	3
B8	40	4
C1	80	3
C2	40	1
C3	40	3
D2	60	1
D3	40	0
E2	80	4
E3	60	3
E6	30	3
E7	40	1
F3	40	2
F4	30	1
F5	20	3

TABLE D-IV
TREATMENT PLANT SITE
RADIOLOGICAL ANALYSIS OF SELECTED SOIL SAMPLES
IN THE 0-25-cm SOIL LAYER

	pCi/g						μg/g	
Location	^{90}Sr	^{137}Cs	Gross α	^{239}Pu	^{238}Pu	^{226}Ra	Total Uranium	^{232}Th
A1	0.31	0.28	40	0.12	0.0	1.15	2.5	13.7
A6	0.29	0.45	40	0.18	0.006	0.70	2.6	13.9
A8	0.62	0.99	---	0.15	0.10	0.52	2.0	13.4
B1	0.45	0.41	30	0.42	0.0	1.13	4.2	14.9
C1	0.61	0.31	80	34.0	0.32	0.94	2.4	13.7
C5	0.27	0.14	---	0.45	0.01	0.61	2.3	13.3
D1	183.0	77.6	---	38.2	0.25	0.75	110.0	12.1
E2	0.41	0.23	80	0.61	0.012	1.12	3.4	12.4
F2	0.33	0.88	---	0.29	0.005	0.34	1.7	10.2
14	---	---	20	---	---	---	---	---
14a	---	---	50	---	---	---	---	

TABLE D-V

TREATMENT PLANT SITE GROSS-ALPHA AND GROSS-BETA ACTIVITY IN THE 0-120-cm SOIL LAYER

Location	Depth (cm)	Gross α (pci/g)	Gross β (relative)	Location	Depth (cm)	Gross α (pCi/g)	Gross β (relative)
45-1	0-120	30	3	C6-1	0-60	40	1
45-4	0-120	20	3	C6-2	60-120	50	3
45-5	0-120	50	4	C7-1	90-180	40	3
45-6	0-120	20	4	C7-2	60-120	60	2
45-7	0-120	60	3	D7-1	0-60	50	1
45-8	0-120	50	3	D7-2	60-120	50	3
45-9	0-120	10	4	A-1	0-60	(lost)	(lost)
45-10	0-120	60	4	A-2	60-120	20	3
45-11	0-120	50	2	B-1	0-60	40	3
45-12	0-120	50	5	B-2	60-120	30	1
45-13	0-120	20	2	Ba-1	0-60	10	2
45-14	0-120	50	4	Ba-2	60-120	20	2
45-15	0-120	30	2	C-1	0-60	60	3
45-16	0-120	80	3	C2	60-120	30	3
45-17	0-120	60	2	D-1	0-60	60	4
45-18	0-120	60	3	D-2	60-120	50	2
45-19	0-120	40	1	Ea-1	0-60	50	3
45-20	0-120	60	2	Ea-2	60-120	40	1
45-21	0-120	50	2	Eb-1	0-60	40	3
45-22	0-120	40	3	Eb-2	60-120	60	3
45-23	0-120	40	6	F-1	0-490	40	2
45-24	0-120	40	7	PA-1	0-150	40	2
45-25	0-120	40	2	PB-A-1	0-150	70	2
45-26	0-120	30	4	PB-B-1	0-150	70	1
B3-1	0-91	40	2	PC-1	0-150	40	2
B3-2	90-180	80	3	HB-1	0-60	60	3
B4-1	90-180	60	3	HB-2	60-120	40	2
B5-1	0-60	40	2	SB-1	0-60	10	3
B5-2	60-120	40	1	SB-2	60-120	40	1
B6-1	0-60	40	3	SP1-1	0-60	30	2
B6-2	60-120	40	2	SP1-2	60-120	40	2
C5-1	0-60	60	2	SP2a-1	0-370	40	3
C5-2	60-120	30	1	SP2b-1	0-150	40	2

TABLE D-VI

TREATMENT PLANT SITE
RADIOLOGICAL ANALYSIS OF SELECTED SOIL SAMPLES
IN THE 0-120-cm SOIL LAYER

	pCi/g						μg/g	
Location	^{90}Sr	^{137}Cs	Gross α	^{239}Pu	^{238}Pu	^{226}Ra	Total Uranium	^{232}Th
45-1	2.85	2.23	30	11.7	0.13	1.05	2.7	14.5
45-4	0.50	0.73	20	0.20	0.006	0.78	2.0	9.6
45-5	2.58	1.76	50	0.24	0.0	0.96	2.0	11.0
45-6	0.43	0.16	20	0.15	0.006	1.16	2.2	12.3
45-7	0.39	0.34	60	0.26	0.010	1.02	2.6	12.4
45-9	1.05	0.96	10	4.04	0.063	1.07	2.9	11.7
45-13	0.55	0.18	20	0.12	0.003	0.68	3.8	9.1
45-16	0.42	0.21	80	35.2	0.33	0.78	2.1	12.1
45-18	0.56	0.18	60	2.00	0.036	0.72	3.5	10.9
45-22	0.52	0.25	40	2.64	0.032	0.92	3.8	11.6
45-24	9.62	3.20	40	24.4	0.27	0.39	36.0	11.4
45-26	0.51	0.44	30	0.26	0.01	0.97	2.5	11.7
PB-b-1	0.24	0.07	70	12.3	0.15	1.03	2.0	11.9
F-1	0.14	0.0	40	1.56	0.017	0.76	1.6	13.1

TABLE D-VII

TREATMENT PLANT SITE GROSS-ALPHA AND GROSS-BETA ACTIVITY IN THE 120-240-cm SOIL LAYER

Location	Depth (cm)	Gross α (pCi/g)	Gross β (relative)
B3-2	90-180	80	3
B4-1	0-180	60	3
B5-3	120-180	20	2
B6-3	120-180	20	1
C5-3	120-180	120	1
C5-4	180-240	90	0
C6-3	120-180	30	3
C6-4	180-240	60	3
C7-3	120-180	30	1
C7-4	180-240	60	2
D7-3	120-180	20	3
D7-4	180-240	60	3
A-3	120-180	40	2
A-4	180-240	50	3
Ba-3	120-180	50	1
Ba-4	180-240	30	4
C-3	120-180	40	1
C-4	180-240	20	2
D-3	120-180	40	4
D-4	180-240	80	3
Eb-3	120-240	30	3
F-1	0-490	40	2
PA-2	150-300	70	3
PB-A-2	150-300	30	2
PC-2	150-300	30	3
HB-3	120-180	40	2
HB-4	180-240	30	1
SB-3	120-180	40	2
SB-4	180-240	30	1
SP1-3	120-180	60	3
SP1-4	180-240	50	2
SP2a-1	0-365	40	3
SP2b-2	150-360	30	2

TABLE D-VIII

TREATMENT PLANT SITE
RADIOLOGICAL ANALYSIS OF SELECTED SOIL SAMPLES
IN THE 120-240-cm SOIL LAYER

		pCi/g						μg/g	
Location	Depth	^{90}Sr	^{137}Cs	Gross α	^{239}Pu	^{238}Pu	^{226}Ra	Total Uranium	^{232}Th
A-3	120-180	0.11	0.0	40	0.0	0.0	0.94	1.8	13.5
Ba-3	120-180	0.0	0.0	50	0.11	0.006	0.84	1.8	14.0
C-3	120-180	0.08	0.0	40	0.25	0.005	1.02	2.7	12.0
D-3	120-180	0.18	0.0	40	5.95	0.08	0.69	1.3	10.5
Eb-3	120-140	0.0	0.0	30	0.046	0.0	1.00	1.5	11.9
F-1	0-490	0.14	0.0	40	1.56	0.017	0.76	1.6	13.1
PB-A-2	150-300	0.14	0.0	30	0.028	0.004	0.75	0.7	8.5
PC-2	150-300	0.14	0.0	30	0.18	0.0	0.87	1.5	10.7
HB-3	120-180	0.09	0.0	40	0.36	0.018	1.37	1.5	11.6
SB-3	120-180	0.17	0.0	40	1.82	0.041	0.94	1.8	13.2

TABLE D-IX

TREATMENT PLANT SITE GROSS-ALPHA AND GROSS-BETA ACTIVITY IN THE 240-850-cm SOIL LAYER

Location	Depth	Gross α (pCi/g)	Gross β (relative)
C5-5	240-300	90	1
C7-5	240-300	40	3
C7-6	300-360	60	2
C7-7	360-420	50	2
C7-8	420-480	50	3
C7-9	480-540	50	3
C7-10	540-600	40	3
C7-11	600-660	60	3
C7-12	660-720	60	4
D7-5	240-300	50	2
D7-6	300-390	60	2
A-5	240-300	30	3
A-6	300-360	40	2
Ba-5	240-300	20	3
Ba-6	300-390	40	3
C-5	240-300	40	4
C-6	300-360	30	4
D-5	240-300	40	4
F-1	0-490	40	2
PA-4	450-600	50	1
PA-5	600-750	40	2
PB-A-3	300-450	30	2
PB-A-4	450-600	50	1
PB-A-5	600-750	30	3
PB-B-3	300-450	90	2
PB-B-4	450-600	70	2
PC-3	300-450	20	2
PC-4	450-600	40	1
PC-5	600-750	50	1
SB-5	240-300	30	3
SB-6	300-360	40	3
SP1-5	240-300	40	2
SP1-6	300-360	40	2
SP2a-1	0-360	40	3
SP2a-2	360-670	20	2
SP2b-2	150-360	30	2

TABLE D-X

TREATMENT PLANT SITE
RADIOLOGICAL ANALYSIS OF SELECTED SOIL SAMPLES
IN THE 240-850-cm SOIL LAYER

		pCi/g						μg/g	
Location	Depth	^{90}Sr	^{137}Cs	Gross α	^{239}Pu	^{238}Pu	^{226}Ra	Total Uranium	^{232}Th
F-1	0-490	0.14	0.0	40	1.56	0.017	0.76	1.6	13.1
PA-3	300-450	0.20	0.04	---	0.95	0.027	0.36	1.7	11.92
PA-4	450-600	0.16	0.0	50	0.062	0.0	0.91	1.8	10.09
PA-5	600-750	0.40	0.90	40	0.15	0.0	0.90	1.7	11.5
PBA-3	300-450	0.09	0.0	30	0.080	0.012	0.96	1.6	12.56
PBA-4	450-600	0.0	0.0	50	0.160	0.011	0.75	1.3	10.55
PBA-5	600-750	0.0	0.0	30	0.074	0.0	0.80	2.2	11.83
PB-B-3	300-450	0.0	0.0	90	0.0	0.0	1.10	2.2	15.59
PB-B-4	450-600	0.0	0.0	70	0.032	0.0	0.64	1.3	7.24
PC-3	300-450	0.0	0.0	20	0.011	0.0	0.80	1.6	11.55
PC-4	450-600	0.17	0.0	40	0.033	0.003	0.88	1.5	10.73
PC-5	600-750	0.10	0.0	50	0.029	0.004	1.03	1.4	13.48
SP1-5	240-300	0.35	0.0	40	0.470	0.012	0.89	1.3	10.73
SP2a-2	360-670	0.10	0.05	20	0.171	0.0	0.59	1.1	6.6

TABLE D-XI

ACID CANYON
GROSS-ALPHA AND GROSS-BETA ACTIVITY
IN THE 0-5-cm SOIL LAYER

Location	Gross α (pCi/g)	Gross β (relative)
18	20	3
19	20	1
20	580	5
25	60	5
26	50	6
27	40	4
28	40	3
23	20	9
24	30	6
21	460	5
29	110	2
30	80	3

TABLE D-XII

ACID CANYON
RADIOLOGICAL ANALYSIS OF SELECTED SOIL SAMPLES
IN THE 0-5-cm SOIL LAYER

	pCi/g							μg/g	
Location	^{90}Sr	^{137}Cs	Gross α	^{239}Pu	^{238}Pu	^{241}Am	^{226}Ra	Total Uranium	^{232}Th
20	1.1	0.79	580	629.0	3.13	43.4	1.1	10.0	13
25	0.70	0.20	60	33.5	0.15	1.67	1.30	3.0	15
26	4.5	12.1	50	38.4	0.10	1.82	1.10	3.7	9.7
27	0.4	0.54	40	8.20	0.0	0.41	1.90	3.9	14
28	0.4	1.64	40	5.20	0.04	0.33	2.00	2.8	13

TABLE D-XIII

ACID CANYON
GROSS-ALPHA ACTIVITY IN THE
0-25-cm SOIL LAYER

Location	Depth (cm)	pCi/g
24 (stream channel)	0-15	40
24 (banks)	0-15	50
32 (stream channel)	0-30	70
32 (banks)	0-30	40
33 (stream channel)	0-30	70
33 (banks)	0-30	60

TABLE D-XIV

ACID CANYON
TRANSECT AC 20 AT STATION 33
RADIOLOGICAL ANALYSIS OF SELECTED SOIL SAMPLES
IN THE 0-25-cm SOIL LAYER

	pCi/g						μg/g	
Location	^{90}Sr	^{137}Cs	Gross α	^{239}Pu	^{238}Pu	^{226}Ra	Total Uranium	^{232}Th
North bank	0.78	1.05	40	12.5	0.83	0.77	0.9	7.24
Active channel	1.69	1.28	40	15.8	0.095	0.86	1.5	9.35
South bank	0.23	0.25	10	0.11	0.0	0.77	1.8	9.54

TABLE D-XV

MIDDLE PUEBLO CANYON GROSS-ALPHA AND GROSS-BETA ACTIVITY IN THE 0-25-cm SOIL LAYER

Location	Gross α (pCi/g)	Gross β (relative)
15900-0	30	5
15900-1	10	3
15900-2	40	3
15500-0	100	3
15500-1	0	5
15500-2	40	3
14950-2	30	3
14150-0	30	3
14150-1	40	10
14150-2	40	12
13650-1	20	2
13650-2	20	3
OAPII-1	0	3
OAPII-2	0	5
OAPII-3	0	4
OAPII-4	0	4
OAPII-5	0	4
OAPII-6	0	4
OAPII-7	0	4
OAPII-8	0	5
OAPII-9	10	6
OAPII-10	0	3
OAPII-11	0	6
OAPII-12	0	3
OAPII-13	0	3
OAPII-14	0	4

TABLE D-XVI

MIDDLE PUEBLO CANYON
RADIOLOGICAL ANALYSIS OF SELECTED SOIL SAMPLES
IN THE 0-25-cm SOIL LAYER

	pCi/g							μg/g	
Location	^{40}Sr	^{137}Cs	Gross α	^{239}Pu	^{238}Pu	^{241}Pu	^{226}Ra	Total Uranium	^{232}Th
15900-0	0.30	0.30	30	0.072	0.016	---	1.64	2.9	17.61
15900-1	0.71	0.43	10	3.99	0.018	---	1.64	0.9	5.10
15900-2	0.64	0.46	40	4.46	0.052	---	0.69	1.6	10.45
15500-0	---	---	100	87.90	0.600	52	---	---	---
14150-0	0.74	0.81	30	8.72	0.060	1.5	1.62	2.8	13.20
14150-1	0.22	0.25	40	1.35	0.013	---	0.82	1.3	7.51
14150-2	0.25	0.20	40	0.669	0.004	---	0.96	2.2	11.37
OAPII-1	---	---	0	1.620	0.004	---	---	---	---
OAPII-2	---	---	0	1.000	0.0	---	---	---	---
OAPII-3	---	---	0	0.910	0.004	---	---	---	---
OAPII-4	---	---	0	0.127	0.001	---	---	---	---
OAPII-5	---	---	0	0.570	0.007	---	---	---	---
OAPII-6	---	---	0.0	0.770	0.025	---	---	---	---
OAPII-7	---	---	0	0.430	0.0	---	---	---	---
OAPII-8	---	---	0	0.140	0.0	---	---	---	---
OAPII-9	---	---	10	3.300	0.033	---	---	---	---
OAPII-10	---	---	0	0.140	0.0	---	---	---	---
OAPII-11	---	---	0	0.810	0.0	---	---	---	---
OAPII-12	---	---	0	0.270	0.001	---	---	---	---
OAPII-13	---	---	0	0.930	0.0	---	---	---	---
OAPII-14	---	---	0	1.190	0.006	---	---	---	---

TABLE D-XVII

LOWER PUEBLO CANYON GROSS-ALPHA AND GROSS-BETA ACTIVITY IN THE 0-25-cm SOIL LAYER

Location	Gross α (pCi/g)	Gross β (relative)
13150-0	30	4
13150-1	0	4
13150-2	20	4
12850-2	30	2
12850-3	30	4
APII5-0	40	4
APII5-1	10	5
APII5-2	20	4
APII10-0	20	5
APII10-1	30	5
APII10-2	10	5
12650-0	40	3
12650-1	10	3
12650-2	10	3
12650-3	10	5
11850-0	40	3
11850-1	30	4
11850-2	20	5
11850-3	20	5
11850-4	30	4
11550-0	20	3
11550-2	20	3
10650-0	50	3
10650-1	20	3
10650-2	30	3
10050-2	20	1
10050-3	0	3
10050-4	10	2
10050-5	30	3
9650-0	30	0
9650-1	30	2
9650-2	20	2
9650-3	40	4
9650-4	30	3
8150-0	40	5
8150-1	20	3
8150-2	30	4
8150-3	10	2
8150-4	20	4
8150-5	10	3
8150-6	30	4
8150-7	10	4
8150-8	20	2
7950-0	0	4
7950-1	0	3
7950-2	10	3
7950-3	40	4
7650-0	20	1
7650-1	30	0
7650-2	0	1
7650-3	20	0

TABLE D-XVIII

LOWER PUEBLO CANYON
RADIOLOGICAL ANALYSES OF SELECTED SOIL SAMPLES
IN THE 0-25-cm SOIL LAYER

	pCi/g							μg/g	
Location	^{90}Sr	^{137}Cs	Gross α	^{239}Pu	^{238}Pu	^{241}Pu	^{226}Ra	Total Uranium	^{232}Th
13150-0	0.68	0.84	30	7.150	0.072	---	1.80	3.2	17.97
13150-1	0.34	0.15	0	0.409	0.013	1.1	1.91	4.3	17.42
13150-2	0.47	0.43	20	0.720	0.018	---	1.79	3.4	16.23
11850-0	0.90	1.50	40	9.69	0.116	9.5	1.70	4.1	15.68
12850-2	---	---	30	6.4	0.037	---	---	---	---
12850-3	---	---	30	15.5	0.077	---	---	---	---
12650-0	---	---	40	0.7	0.01	---	---	---	---
12650-1	---	---	10	1.06	0.009	---	---	---	---
12650-2	---	---	10	4.89	0.026	---	---	---	---
12650-3	---	---	10	0.55	0.006	---	---	---	---
APII5-0	---	---	40	10.6	0.064	---	---	---	---
APII5-1	---	---	10	1.90	0.017	---	---	---	---
APII5-2	---	---	20	7.50	0.035	---	---	---	---
APII10-0	---	---	20	8.9	0.049	---	---	---	---
APII10-1	---	---	30	1.97	0.013	---	---	---	---
APII10-2	---	---	10	7.1	0.040	---	---	---	---
11850-1	0.42	0.81	30	5.88	0.054	---	1.90	3.9	17.79
11850-2	0.28	0.49	20	0.94	0.019	---	2.20	3.8	14.03
11850-3	0.22	0.17	20	0.43	0.013	---	1.62	3.6	13.30
11850-4	0.18	0.17	30	1.15	0.013	---	1.09	2.0	10.45
10650-0	0.35	0.40	50	10.8	0.064	2.2	1.50	5.7	12.29
10650-1	0.12	0.0	20	0.584	0.006	---	0.80	1.8	8.99
10650-2	0.41	0.61	30	3.81	0.047	---	1.67	3.2	15.96
9650-3	---	---	40	7.14	0.100	4.0	---	---	---
8150-0	0.94	1.75	40	15.30	0.125	8.1	1.51	3.5	14.49
8150-1	0.17	0.18	20	0.97	0.0	---	1.59	1.8	15.86
8150-2	0.31	0.24	30	1.00	0.010	---	1.12	1.3	11.74
8150-3	0.12	0.06	10	0.59	0.031		0.86	1.8	6.05
8150-4	0.18	0.22	20	0.91	0.0	---	0.74	1.6	8.99
8150-5	0.18	0.13	10	0.85	0.014	---	0.59	1.7	6.33
8150-6	0.39	0.63	30	4.09	0.081	---	0.96	2.5	13.20
8150-7	0.12	0.0	10	0.35	0.0	---	0.60	1.9	6.33
8150-8	0.34	0.42	20	3.32	0.019	---	1.24	3.5	12.56
7950-0	0.12	0.0	0	0.34	0.009	---	0.72	2.2	5.50
7950-1	0.087	0.0	0	0.27	0.0	---	0.42	1.1	3.48
7950-2	0.16	0.11	10	0.77	0.008	---	0.79	3.6	6.88
7950-3	0.37	0.05	40	9.72	0.081	4.5	1.94	3.3	15.77

TABLE D-XIX

LOWER LOS ALAMOS CANYON GROSS-ALPHA AND GROSS-BETA ACTIVITY IN THE 0-25-cm SOIL LAYER

Location	Gross α (pCi/g)	Gross β (relative)
7250-0	10	4
7250-1	10	2
7250-2	10	3
5900-0	30	1
5900-1	10	0
5900-2	20	2
5800-0	10	5
5800-1	10	4
5800-2	10	2
5700-0	40	0
5700-1	30	2
5700-2	10	2
5100-0	10	1
5100-1	30	4
5100-2	30	0
5100-3	30	1
5000-0	40	2
5000-1	40	2
5000-2	20	2
5000-3	20	2
4300-0	20	1
4300-1	20	1
3700-0	20	3
3700-1	20	3
3700-2	0	4
3700-3	0	5
3200-0	20	1
3200-1	0	4
3200-2	0	3
3200-3	0	3
3200-4	0	4
3200-5	20	3
3100-0	20	3
3100-1	10	1
3100-2	10	3
3100-3	20	2
2500-0	30	1
2500-1	20	2
2500-2	10	3
2500-3	20	1
2500-4	10	0
2500-5	40	3
1900-0	30	4
1900-1	40	4
1900-2	30	4
1300-0	30	3
1300-1	20	3
1300-2	50	4
800-0	10	2
800-1	30	3
800-2	10	4
800-3	10	5
800-4	30	3
400-0	30	4
400-1	40	5
400-2	30	5
0-0	20	4
0-1	10	3
0-2	40	3

TABLE D-XX

LOWER LOS ALAMOS CANYON RADIOLOGICAL ANALYSES OF SELECTED SOIL SAMPLES IN THE 0-25-cm SOIL LAYER

	pCi/g							μg/g	
Location	^{90}Sr	^{137}Cs	Gross α	^{239}Pu	^{238}Pu	^{241}Pu	^{226}Ra	Total Uranium	^{232}Th
7250-0	0.31	0.57	10	9.30	0.027	0.9	1.74	5.3	12.10
7250-1	0.24	0.64	10	0.27	0.013	---	0.60	3.9	7.43
7250-2	0.49	1.75	10	3.34	0.015	---	1.57	5.6	16.69
5900-0	---	---	30	0.880	0.007	---	---	---	---
5900-1	---	---	10	0.157	0.016	---	---	---	---
5900-2	---	---	20	5.62	0.019	---	---	---	---
5800-0	0.64	1.51	10	0.27	0.0	---	1.51	4.7	14.76
5800-1	0.30	1.30	10	1.23	0.0	---	0.95	2.9	8.85
5800-2	0.74	1.80	10	0.69	0.008	13	2.16	4.7	15.68
5700-0	---	---	40	1.32	0.0002	---	---	---	---
5700-1	---	---	30	0.67	0.011	---	---	---	---
5700-2	---	---	10	1.49	0.003	---	---	---	---
3700-0	0.19	0.24	20	0.018	0.014	<3	1.44	5.1	11.00
3700-1	0.18	0.20	20	0.145	0.026	---	1.34	3.2	11.19
3700-2	0.11	0.51	0	0.259	0.019	---	0.79	2.8	7.61
3700-3	0.25	0.46	0	0.510	0.014	---	1.29	4.2	12.56
3200-0	0.23	0.33	20	0.0	0.0	---	0.77	2.6	6.42
3200-1	0.10	0.16	0	0.032	0.016	---	0.41	5.3	12.29
3200-2	0.19	0.33	0	---	0.0	---	0.78	3.6	7.36
3200-3	0.0	0.14	0	---	0.0	---	0.74	2.4	7.05
3200-4	0.0	0.23	0	0.083	0.005	---	0.69	1.7	5.96
3200-5	0.49	1.08	20	0.133	0.012	---	0.89	3.0	10.64
2500-5	---	---	40	0.43	0.0048	1	---	---	---
800-0	0.30	0.26	10	0.117	0.0	---	0.89	2.8	7.38
800-1	0.23	0.21	30	0.097	0.008	---	0.92	4.5	10.55
800-2	0.17	0.18	10	0.051	0.0	---	1.27	4.5	10.18
800-3	0.25	0.26	10	0.066	0.004	---	1.09	4.0	7.57
800-4	0.24	0.21	30	0.075	0.0	---	0.90	2.0	7.54

TABLE D-XXI

INSTRUMENT READINGS FROM CLIFF SURVEYS

Depth Below Mesa Rim (m)	Ludlum 12S[a] (μR/h)	Phoswich[b] (counts/100 s)
8 in. Outfall: Line N South of Line M (11/2/77)		
−9.2[c]	30	501 ± 30
−1.5	30	---
0.0	30	698
1.5	35	713
3.1	35	746
4.6	35	753
6.1	40	701
7.6	40	742
9.2	40	704
10.7	40	729
12.2	40	735
M12.2[e]	40	727
−9.2	---	559 ± 8
8 in. Outfall: Line O North of Line M (11/2/77)		
−9.2[c]	---	394 ± 35
−1.5[d]	40	493
0.0	35	657
1.5	35	576
3.1	40	649
4.6	35	659
6.1	40	698
7.7	40	721
9.2	40	826
10.7	40	720
12.2	40	683
13.8[e]	40	679
15.3[f,d]	40	650
M12.2[e]	20	570
−9.2	30	415

Depth Below Mesa Rim (m)	Ludlum 12S[a] (μR/h)	Phoswich[b] (counts/100 s)
8 in. Outfall: Line M Center of Outfall (11/2/77)		
−9.2[c]	---	559 ± 8
−3.10	35	606
−1.5[d]	40	637
0.0	35	638
1.5	35	704
3.1	35	784
4.6	40	641
6.1	40	695
7.6	40	648
9.2	40	702
10.7	40	689
12.2[e]	40	676
−9.2[c]	---	539
8 in. Outfall: Line P West of Line O (11/3/77)		
---	---	---
−9.2[c]	0	415
−1.5	35	586
0.0	30	665
1.5	40	578
3.1	40	580
4.6	35	578
−9.2[c]	---	---
---	---	---
---	---	---
---	---	---
---	---	---
---	---	---
---	---	---

[a]The Ludlum 12-S responds to photons over 20 keV. See Appendix for details.

[b]The phoswich responds to photons from 5 to 25 keV. See Appendix for details.

[c]Background count. A preliminary background count as well as a concluding background count were made for most descents.

[d]Some measurements were made back from the rim of the mesa on the mesa top. Others were made down the talus slope below the base of the cliff. In these cases the distance conforms to the orientation of the ground surface rather than being projected onto the vertical plane above or below the cliff.

[e]These readings are at the base of the cliff.

[f]These readings were taken on the talus slope.

TABLE D-XXI (cont)

INSTRUMENT READINGS FROM CLIFF SURVEYS

Depth Below Mesa Rim (m)	Ludlum 12S[a] (μR/h)	Phoswich[b] (counts/100 s)
8 in. Outfall: Line Q West of Line P (11/3/77)		
−9.2[c]	---	---
0.0	30	552
1.5	35	552
3.1	35	533
4.6	35	629
6.1	35	615
7.7	40	628
9.2	40	669
10.7	35	709
12.2	40	715
13.8	40	779
−9.2[c]	---	---
8 in. Outfall: Line S South of Line N (11/3/77)		
−9.2[c]	---	540
−1.5	30	613
0.0	30	643
1.5	35	681
3.1	40	728
9.2	40	747
---	---	---
---	---	---
---	---	---
---	---	---
---	---	---
---	---	---

Depth Below Mesa Rim (m)	Ludlum 12S[a] (μR/h)	Phoswich[b] (counts/100 s)
8 in. Outfall: Line R West of Line Q (11/3/77)		
−9.2[c]	---	557 ± 29
0.0	35	639
1.5	35	725
3.1	35	707
4.6	35	802
6.1	35	748
8.2	35	741
7.7	40	761
9.2	40	757
10.7	40	838
M12.2	---	750
−9.2	---	540
8 in. Outfall: Line T South of Line S (11/3/77)		
−9.2[c]	---	541
−1.5	30	622
0.0	30	560
1.5	30	626
3.1	40	683
4.6	40	595
6.1	40	640
7.7	40	616
9.2	40	688
10.7	40	578
12.2	40	607
M12.2[c]	---	591

TABLE D-XXI (cont)

INSTRUMENT READINGS FROM CLIFF SURVEYS

	Depth Below Mesa Rim (m)	Ludlum 12S[a] (μR/h)	Phoswich[b] (counts/100 s)
6 in. Outfall: Line A (11/4/77)			
Center	−9.2[c]	30	45 ± 3
W wall	0.0	35	508
E wall	0.9	30	467
W wall	0.9	35	509
Center	1.8	35	525
E wall	1.8	40	543
W wall	1.8	35	567
Center	2.7	35	542
E wall	2.7	35	531
W wall	2.7	35	518
	3.7	35	610

Line C: Untreated Outfall (11/4/77)			
	−9.2[c]	---	602
	−1.5[d]	30	451
	−0.8[d]	35	2956
	−0.5[d]	35	701
	0.0	35	712
	1.5	40	525
	3.0	35	476
	4.6	40	503
	6.1	40	411
	7.6[e]	35	402
	7.9[f]	40	427
	−9.2[c]	---	543

	Depth Below Mesa Rim (m)	Ludlum 12S[a] (μR/h)	Phoswich[b] (counts/100 s)
6 in. Outfall: Line A (11/4/77)			
Center	3.7	40	578
E wall	3.7	35	845
W wall	4.6	35	814
Center	4.6	40	652
E wall	4.6	35	756
W wall	5.5	40	791
Center	5.5	40	675
E wall	5.5	40	661
W wall	6.4	40	775
Center	6.4	40	721
E wall	6.4	35	769
---	−9.2[c]	---	553
Line B: Truck Wash Drain (11/4/77)			
	−10.0[c]	---	419
	0.0	35	429
	1.5	35	336
	3.1	40	383
	4.6	40	423
	6.1	40	477
	8.3[e]	60	637
	−10.0[c]	---	457
	---	---	---
	---	---	---
	---	---	---
	---	---	---

TABLE D-XXII

SCOOP SAMPLES 0-5 cm

Location	Gross β	Gross α	$^{239,240}Pu$	^{238}Pu
Middle Pueblo Canyon				
G-17	1	20		
Lower Pueblo Canyon				
G-19	2	30		
G-1	2	20		
G-28	0	30		
G-18	2	40	4.49	0.0
G-23	0	10		
G-25	3	60	6.82	0.085
G-26	1	30		
G-20	2	20		
G-4	4	20		
G-9	2	10		
G-14	1	30		
G-13	2	10		
G-11	4	30		
G-30	0	10		
G-12	2	20		
G-2	1	20		
G-3	4	20		
G-10	3	20		
Lower Los Alamos Canyon				
G-8	4	20		
G-6	3	30		
G-27	2	30		
G-22	1	20		
G-16	1	30		
G-15	1	20		
G-29	0	10		
G-24	1	0		

TABLE D-XXIII

TRANSECT SAMPLE IDENTIFICATION

Transect	Active Channel		Inactive Channel		Banks	
	Sample Numbers	Width (m)	Sample Numbers	Width (m)	Sample Numbers	Width (m)
Middle Pueblo Canyon						
15900	−1	1.5		0	−0, −2	14
15500		1.5		0	−0	10.5
14950		2		0		15
14150	−1	5		0	−0, −2	25
OAPII	all					
13650		3.5[a]		0		2
Lower Pueblo Canyon						
13150	−1	1		0	−0, −2	7
APII	10-1, 5-1	---		---	10-0, 10-2, 5-0, 5-2	---
12850		2	−3	8	−3	9
12650	−1	3	−0, −2	15	−3	8
11850	−3	4	−0, −1, −2, −4	10		2
11550		3		14		6
10650	−1	6	−0	11	−2	4
10050		6		20		2
9650		4	−3	16		0.3
8150	−1, −2, −3, −5, −7	26	−4, −6, −8	104	−0	9
7950	−1, −2	8	−3	10	−0	10
7650		5		20		8
Lower Los Alamos Canyon						
7250	1	1.3		0	−0, −2	3
5900	−1	1.3		0	−0, −2	2
5800	−1	2		0	−0, −2	2
5700	−1	3		0	−0, −2	2
5100		4		13		4
5000		6		15		2
4300		4		2		0.6
3700	1, −2	9	−0, −3	37		0.6
3200	−1, −2, −3, −4	25	−5	35	−0	0.6
2500		---		---	−5	---
800	−1, −2	32	−0, −3, −4	47	−0	2
400		36		32		1
0		39		0		0.6

APPENDIX E

INTERPRETATION OF DATA

I. RADIOACTIVITY IN SOILS AND SEDIMENTS

A. Background from Natural and Fallout Radioactivity

Reference values for background concentrations of radioactivity in soils and sediments attributable to natural constituents or general worldwide fallout were assembled from several studies to provide a basis for comparison (Refs. E1, E2, E3, and E4). This information is summarized in Table E-I. Most of the data was from a compilation on soils and sediments collected in northern New Mexico over the period 1974-1977 as part of the Los Alamos National Laboratory routine environmental surveillance program. Some of the data was taken from other studies representing generally smaller numbers of samples. The gross-alpha and gross-beta information is included only to indicate the general expected ranges observed by using the particular instrumental screening techniques (ZnS and plastic scintillators) described in Appendix B.

Most of the background data is for samples collected in the surface layer, generally to a depth of 5 cm. These values were used as a basis of comparison for all survey samples including those taken at other greater depths. This is considered appropriate in most cases because of mechanical mixing that has taken place in the past in many of the areas surveyed. Many of the deeper samples taken in the former waste treatment plant site came from trenches or fill material. The active and inactive portions of the channels have been subject to turbulent mixing of the sediments during runoff events. The assumption of uniform distribution at depths greater than 5 cm is least valid for the stream bank soils that have been relatively undisturbed; however, it leads to overestimates of net activity present. The nonuniform bank distribution was taken into account for some of the pathway analyses described later.

B. Survey Sample Results

1. Treatment Plant and Outfall Site. The site of the untreated waste outfall and the former treatment plant (TA-45) on the south rim of Acid Canyon was sampled at 86 locations. The locations are shown in Fig. E-1, which has symbols keyed to indicate the approximate depth range of the sample and whether the analytical results exceeded selected threshold values for gross-alpha or plutonium concentrations. Analytical results for the 37 above-threshold sample locations are summarized in Table E-II. Detailed results for all of the Treatment Plant Site samples were presented in Appendix D, Tables D-I through D-X.

For purposes of data summary, sample locations were identified if gross alpha concentrations in any individual sample exceeded 50 pCi/g, i.e., about 2 standard deviations above typical background, and therefore had a significant probability of representing residual contamination. Similarly, locations from which individual samples contained plutonium concentrations of 1 pCi/g or more were identified as being useful for determining the extent of areas having significant residual contamination.

Shallow, near-surface contamination is present in the vicinity of the untreated waste outfall (Table E-II and lower left portion of Fig. E-1), generally in an area about 5 m wide by 30 m long (15 by 100 ft) centered on a line extending from the location of manhole structure TA-0-37, past the outfall location, to the point where the natural drainage goes over the canyon rim. The locations with the highest levels of contamination were found by portable instrument (including phoswich and alpha proportional detectors) surveys in the natural drainage close to the outfall location. The portable meter surveys showed scattered spots of maximum activity with dimensions on the order of 15 cm (~6 in.) superimposed on a 30-75 cm wide (12-30 in.) band of elevated activity. This band extends along the west side of the natural drainage channel, primarily between sample locations 8 and 13, a distance of about 5 m (~15 ft). The activity is primarily adsorbed onto solid tuff exposed in the natural drainage course. The soil and rock samples taken to depths of about 5 cm from these locations (especially 6, 7, 8, 9, and 12) had the highest concentrations of gross alpha, plutonium, americium, and uranium found during the resurvey project (see Table D-II). These samples had concentrations ranging from 430 to 163 000 pci/g ^{239}Pu,* 1620 to 14 900 pCi/g ^{241}Pu, 10 to 1200 pCi/g ^{241}Am, 20 to 600 μg/g total uranium, and 20 to 93 μg/g of ^{232}Th. Concentrations of fission products were also elevated in these samples, ranging from 1 to 5 pCi/g ^{90}Sr and 1 to 36 pCi/g ^{137}Cs.

Some near-surface (≤30 cm) contamination is present in the vicinity of the vehicle decontamination facility site (see Fig. E-1). One surface sample (16) and two core samples (C1 and D1) within about 15 m (~50 ft) of the site had elevated concentrations of radioactivity including 34 to 42 pCi/g ^{239}Pu, 2 to 130 μg/g total uranium, <1 to 230 pCi/g ^{90}Sr, and <1 to 180 pCi/g ^{137}Cs. These samples were generally south and southwest from the structure location, in a swale that undoubtedly carried drainage away from the site.

Subsurface (~1 m) contamination was found in several samples taken from short trenches cut by backhoe across the alignment of the industrial waste sewer leading to the treatment plant (see Fig. E-1). The samples came from depths of as much as 120 cm. Samples from locations 45-7, 45-9, and 45-10 exceeded the concentration thresholds and are included in Table E-II. However, the concentrations were relatively low, with no more than 4 pCi/g ^{239}Pu and no more than 1 pCi/g of ^{90}Sr and ^{137}Cs. Samples from locations 45-4, 45-5, 45-6, and 45-7 were also analyzed for specific isotopes (see Table D-VI) with the results indicating above background but low concentrations (^{239}Pu ≤ 0.3 pCi/g, ^{90}Sr ≤ 2.6 pCi/g, ^{137}Cs ≤ 1.8 pCi/g.

About 40% of the subsurface samples collected in the immediate vicinity of the treatment plant structure location showed gross-alpha activity above the 50 pCi/g threshold. In particular, samples from the trench (~30 to ~120 cm) and auger (down to ~240 cm) locations near the southwest end of the building indicated relatively consistent contamination (see Fig. E-1 and Table E-II). At depths of <240 cm, the concentration ranges were <1 to 35 pCi/g ^{239}Pu, <1 to 9.6 pCi/g ^{90}Sr, 0 to 3 pCi/g ^{137}Cs, and 1.3 to 36 pCi/g total uranium. Generally less activity was found in samples at depths >240 cm from these locations, with the maximum ^{239}Pu concentration being 1.6 pCi/g.

No quantitative inventory estimate was made for the Treatment Plant Site because of the extremely spotty nature of the observed contamination and the small volume of potentially affected material in comparison with the other canyon areas.

2. Acid Canyon. This stratum encompasses the steep cliff faces and the natural drainage channels on the floor of Acid Canyon, which carried the various effluents, to the main channel of Pueblo Canyon. The portion closest to the outfall locations including the recent sampling locations is depicted in Fig. E-1. The more general overview including sampling locations utilized in

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*The designation ^{239}Pu is used in this report to signify the sum of ^{239}Pu and ^{240}Pu that are not separately distinguishable by normal alpha spectroscopy because their alpha particles have nearly the same energies.

previous studies as well as the current work is depicted in Fig. E-2. A compilation of data collated from the current and previous studies (Ref. E5, E6, and E7) is presented in Table E-III. The summarized concentration statistics appear in Table E-IV for ^{239}Pu and Table E-V for other isotopes of interest. Detailed data for individual samples from the present work were in Tables D-XI through D-XIV.

The surfaces of the solid tuff cliff faces below the outfalls or natural drainages were surveyed instrumentally to document current conditions and attempt to identify any exceptional spots of radioactivity left after the decontamination efforts of the mid-1960s. These results are discussed in more detail in the subsequent section on *in-situ* measurements (see Appendix E, Sec. III.A.). Essentially no measurements departed sufficiently from expected background values to warrant collection of any samples from the cliffs. The measurements indicate there is little likelihood of surface transuranic contamination at levels greater than about 200-300 pCi/g when averaged over areas of approximately 500 cm^2. Any such contamination would be well bound to the rock and nearly unavailable for transport by dissolution or resuspension.

Soil and sediment samples were collected from the natural drainage courses leading from the base of the cliffs. The sampling locations specifically for this survey were selected to complement previous sampling efforts, and all the relevant data are tabulated in Table E-III. As could be expected, the highest concentrations of plutonium occurred closest to the cliff bases below where the untreated and main 8 in. treated waste outfalls released effluents (Fig. E-2). The maximum ^{239}Pu concentrations (~600 pCi/g) occurred in the channel that carried the untreated effluents.

Summary statistics of the concentration data for plutonium are in Table E-IV. The "^{239}Pu concentration" column gives the arithmetic mean and standard deviation for ^{239}Pu concentrations for several subdivisions of Acid Canyon (see Fig. E-2 for locations) as well as an area weighted channel average concentration based on the data from Table E-VI. The concentration value shown for the banks in Acid Canyon is based on measurements of 22 samples within the 50-m-long AP-I intensive study site examined during a special radioecology research effort conducted by Nyhan *et al.* (Ref. E7). Other transuranics including ^{238}Pu, ^{241}Pu, and ^{241}Am are accounted for in evaluation of the results from all strata by using activity ratios with ^{239}Pu activity. The data used to develop the activity ratios are summarized in Table E-VII. This approach was taken because of the relatively small number of samples that could be subjected to detailed isotopic analysis. The ratios assumed were selected to be nearer the higher observed values so that evaluations based on them would tend to overestimate potential doses. It should be noted that the ratios are generally lower than typical worldwide fallout in the cases of ^{241}Pu and ^{241}Am because most of the activity, which was released from the untreated waste outfall, would have been from the earlier, low-burnup plutonium.

Table E-IV also includes estimates of the ^{239}Pu inventory in the various portions of Acid, Pueblo, and Los Alamos Canyons. (The activity ratios from Table E-VII can be used to estimate inventories for other transuranics.) Two basic types of inventory estimates are given. One is based on geometric mean values for both concentrations and channel widths for the individual strata; the other is based on arithmetic means. The original concentration data were examined for best fit to arithmetic and geometric statistical distributions with no preferred conclusion possible because of the relatively small number of samples in each strata and the relatively large variability. Accordingly, both types of estimates were prepared to indicate the range of interpretations. The geometric mean-based inventories were smaller but had much larger ranges of uncertainty than the arithmetic mean-based inventories. For subsequent evaluations based on inventories, the values calculated from arithmetic means were utilized. The arithmetic mean has been shown to be the preferred unbiased estimator of the expected value (true mean) of a sampled population regardless of the underlying distribution and, therefore, the best choice for estimating inventories (Ref. E8). Use of the arithmetic mean can lead to some possible misinterpretations of

physical data where the variability is high. In such cases, use of standard deviations can lead to the misinterpretation that some actual concentration values are negative, an obvious physical impossibility. For the concentration data in Tables E-IV and E-V, the standard deviation values can also be taken as the upper limits of confidence intervals on the means with 95% or higher confidence. For calculations of inventory, the standard errors of the means were used as the basis for propagating uncertainty. The inventory estimates (based on arithmetic means) in Table E-IV are shown with twice the standard error as an estimate of the 95% confidence limits for the calculated inventory. No more rigorous treatment was considered worthwhile for this study because of the large variability.

All of the inventory estimates, with the exception of Acid Canyon Banks, were developed as the product of the volume of contaminated soil, the concentration, and the bulk soil density (1.57 g/cm^3, from Appendix A). The inventory of the Acid Canyon Banks was estimated as being 10 times the channel inventory based on the results from the intensive study site AP-I reported by Nyhan *et al.* (Ref. E7). The basic data for widths were presented in Table D-XXIII. The data used for depths and lengths are summarized in Table E-VI. Active channel refers to the narrowest, deepest part of the channel that carries any normal flow from current sanitary sewage effluents and most smaller runoff events. Inactive channel refers to the broader portion of the channel that is inundated only during the larger events, is basically sand and gravel with no developed soil, and has relatively sparse vegetation. Banks refers to the higher sides adjacent to the channel that are rarely wet by flow and have a relatively stable soil with moderate vegetation.

Summary statistics for data on concentrations of ^{90}Sr, ^{137}Cs, ^{226}Ra, and total uranium are presented in Table E-V. The average of all measurements of a given isotope in each stratum is presented in one column along with the result of a two-sided normal test comparing that average with the background value for Northern New Mexico soils and sediments from Table E-I. If there was no significant difference (α = 0.05), the entry is "N.S."; if there was a significant difference, that difference and its 95% confidence interval is given. In the case of uranium, an extra column is included that gives a value in pCi/g of ^{234}U for the excess uranium above background. This value was calculated by assuming about 7 pCi of ^{234}U per microgram of uranium, which corresponds to approximately a 20% enrichment. (This is assumed to be a conservative upper limit for the residual uranium contamination based on knowledge of the maximum apparent enrichments found in environmental samples at TA-1, Ref. E4, and from inspection of the correlation of gross alpha activity and total uranium content of samples taken in this survey.) None of the thorium measurements made in this survey were high enough to be considered significantly above background.

A final note regarding Acid Canyon: some instrumental survey data indicated the presence of contamination adsorbed onto boulders in and adjacent to the channel. One large boulder not far south of the 0-m sampling location had activity estimated at several nanocuries of transuranics based on *in situ* spectrometry. Screening measurements on samples from the channel and banks adjacent to the boulder showed ≤50 pCi/g gross-alpha activity. Thus, it is likely that such adsorbed deposits do not constitute significant transportable or resuspendable contamination.

3. Middle Pueblo Canyon. This stratum encompasses the portion of Pueblo Canyon from Acid Canyon to a point about 3250 m downstream. The stratum and sampling locations in it are depicted in Fig. E-3. Summary statistics on ^{239}Pu concentrations and inventory estimates appear in Table E-IV. Summary statistics on concentrations of other nuclides appear in Table E-V. (Explanatory text on these tables appears in the section on Acid Canyon.) Detailed sample results were in Tables D-XV and D-XVI.

This portion of Pueblo Canyon has a relatively steep gradient and has flow for much of the year because of effluent from the County-owned and -operated Pueblo Treatment Plant.

Two special points are worth noting. Sample 15 500-0, from the bank at a point about one-third of the way down the reach, had a relatively high gross-alpha screening measurement of 100 pCi/g. This sample was analyzed radiochemically and had about 88 pCi/g ^{239}Pu. As a statistical outlier in the data set and not being from a sample location selected in the sampling scheme for radiochemical analysis, the value was not included in the calculation of the average value for this stratum. This anomalously high result is consistent with previous highly variable results for this portion of the canyon as explained in the next paragraph.

A special radioecology study (Ref. E7) collected extensive samples in 1973 from a location near the downstream end of the stratum, designated OAP-II on Fig. E-3. A core sample for that study had about 2250 pCi/g ^{239}Pu in the 7.5-12.5-cm interval and a weighted average of about 1050 pci/g for the entire 22-cm core. A previous study (Ref. E5), which collected samples in 1972, showed results of about 1.5 pCi/g for the same location. The current study collected a series of 14 samples spaced at 7 arithmetically increasing intervals out to 320 m upstream and downstream of the suspect location (Samples OAPII-1 through -14 in Table D-XVI). The maximum result was about 3.3 pCi/g of ^{239}Pu. The wide-ranging changes are plausible given the extreme variability in the hydrologic processes operating in the canyon systems. Thus, there is the expectation for change in concentrations and distribution with time as sedimentary materials are transported by intermittent water flows that can range from very low to high discharge rates.

4. Lower Pueblo Canyon. This stratum includes about 6050 m of channel length in Pueblo Canyon from the end of Middle Pueblo Canyon to Los Alamos Canyon. The stratum and sampling locations in it are depicted in Fig. E-4. Summary statistics on ^{239}Pu concentrations and inventory estimates appear in Table E-IV. Summary statistics on concentrations of other nuclides appear in Table E-V. (Explanatory text on these tables appeared in the section on Acid Canyon.) Detailed sample results were in Tables D-XVII and D-XVIII.

This part of the canyon is characterized by a shallow, wider channel, with a large proportion of meanders and braiding around sandbars. The lower portion has some flow most of the year because of effluent from the County-owned and -operated Bayo Sewage Treatment Plant.

Results from the current survey transect location 12650 and results from samples taken nearby in 1972 and 1973 (Refs. E5 and E6) show the same general levels of ^{239}Pu but considerable fluctuation with time: 0.3 pCi/g in 1972, 0.6 to 1.6 pCi/g in 1973 depending on depth, and 0.7 to 4.9 pCi/g in 1977 at various positions across the channel.

Results from 1976 samples collected in a 100-m-long intensive study location (shown as APII on Fig. E-4) showed average ^{239}Pu concentrations in the active channel of 1.56 ± 0.52 pCi/g and in the banks of 2.50 ± 1.3 pCi/g (unpublished detailed data from study reported in Ref. E7). Samples collected in 1977 for the current study from the same part of the channel (Samples APII5 and APII10 in Table D-XVIII) had about 2 pCi/g in the active channel and between about 7 and 11 pCi/g in the banks. The temporal changes tend to indicate a general downstream movement toward the broader part of Lower Pueblo Canyon. However, the problems of truly representative sampling over large areas with high variability limit this inference of movement to speculation.

This stratum yielded the largest amount of estimated ^{239}Pu inventory, both absolute values and percentages (see Table E-IV). About 70% of the estimated inventory for Lower Pueblo Canyon is attributed to the banks. Of the portion estimated to be in the banks, about 80% is attributed to the interval between transect locations 8150 and 10650, when estimated by a scheme using linear interpolation of concentrations and widths between each data point. This may be an overestimate of the actual inventory resulting from the large width estimates and assuming that the average concentrations do occur across the entire width.

5. Lower Los Alamos Canyon. This stratum includes about 7400 m of channel length in Lower Los Alamos Canyon extending between the mouth of Pueblo Canyon and the Rio Grande. The stratum and sampling locations in it are depicted in Fig. E-5. Summary statistics on ^{239}Pu concentrations and inventory estimates appear in Table E-IV. Summary statistics on concentrations of other nuclides appear in Table E-V. (Explanatory text on these tables appeared in the section on Acid Canyon.) Detailed sample results were in Tables D-XIX and D-XX.

It must be noted that this part of Los Alamos Canyon is influenced by flows of runoff and attendant transport of contaminated sediments from both the Acid-Pueblo Canyon system and Upper Los Alamos Canyon. Treated effluents from the radioactive liquid waste treatment facilities serving Technical Area 21 have been discharged into DP Canyon, a tributary of Upper Los Alamos Canyon, since 1952. Through December 1977, a total of 32 mCi of ^{239}Pu had been released in those effluents. Appendix A summarized results of studies in 1970 through 1972 that showed about 12 to 20% of the amount released remained on channel sediments. That, combined with estimates from Nyhan (Ref. E7) of 34% of the inventory being on bank soils in Upper Los Alamos Canyon, suggests that a total of 16-25% of the ^{239}Pu released remains in DP and Upper Los Alamos Canyons. Thus, it can be estimated that 75-84% or about 24 to 27 mCi have been transported from Upper into Lower Los Alamos Canyon.

II. AIRBORNE RADIOACTIVITY MEASUREMENTS

Continuous sampling of airborne radioactivity is performed at Los Alamos National Laboratory as part of the routine environmental monitoring program (Refs. E2, E9, E10, E11, and E12). Data were compiled on ^{239}Pu concentrations measured at several stations to provide a basis for estimating the potential contribution of resuspension from Acid and Pueblo Canyons. Data for three locations were selected as having a likelihood of showing influence because of proximity to the canyon. These locations include the Bayo Sewage Plant, located on the north side of the Lower Pueblo Canyon floor; Cumbres Junior High School, located on the mesa north of Middle Pueblo Canyon and just east of the interaction with Acid Canyon; and the Los Alamos Airport, located on the mesa south of Pueblo Canyon near the boundary between Lower and Middle Pueblo Canyon.

Other locations or groups were selected for comparison and as a basis for estimating the amount of airborne radioactivity present from worldwide fallout. These included monitoring locations at Technical Area 21 (see Figs. 3 and 4), one of the Los Alamos National Laboratory facilities that released some airborne plutonium emissions near the Los Alamos Airport; Bandelier lookout, a station located on a mesa just south of the Los Alamos National Laboratory boundary and about 12-13 km south of Acid-Pueblo Canyon; Santa Fe, one of the regional background stations about 40 km to the southeast across the Rio Grande Valley and at about the same elevation; and New York City, the Environmental Measurements Laboratory (EML) (Ref. E13).

A summary of annual averages for these locations for the five years 1974 through 1978 is presented in Table E-VIII. The most important feature of the data is that there is a temporal pattern that is followed within the limits of statistical uncertainty by almost all of the annual averages. The pattern is basically the one observed throughout the northern hemisphere for the variation of fallout from nuclear weapons testing. The data for 1976 showed an anomalously low value at all sampling locations in the US because the typical spring peak from stratosphere-troposphere mixing did not occur. In 1977, one measurement at the Bayo Treatment Plant was anomalously high. Detailed data for all sampling periods in 1976 and 1977 are shown in Table E-IX. (Measurement

data for New York, EML, were reported by calendar month; the values shown here are appropriate combinations of the monthly data to correspond to Los Alamos National Laboratory sampling periods.)

The 1976 data provided an unusual opportunity to make an estimate of the potential amount of airborne plutonium attributable to local resuspension. Because worldwide fallout was uniformly low for 12-14 months, any significant deviation from the worldwide pattern would be much easier to identify. The average concentration measured at the Los Alamos Airport station is at least slightly higher than the other averages for 5 of the 8 sampling periods covering 1976. This is most probably due to the release of airborne plutonium from Technical Area 21, which amounted to 12.2 μCi for the year. The Airport station measured higher concentrations of ^{239}Pu than the Cumbres station during 7 of the 8 sampling periods, supporting the conclusion that there is no measurable contribution of airborne radioactivity on the mesa tops from resuspension of residual contamination in the canyons. This same inference is also supported by inspection of the annual averages shown in Table E-VIII.

During 1976, the average concentrations of airborne ^{239}Pu at the Bayo Treatment Plant were statistically no different or less than the Santa Fe (regional) and New York locations during 6 of the 8 sampling periods with the largest sampling period difference being 2.8 ± 2.8 aCi/m^3 (90% confidence interval). The apparent difference in the time-weighted annual averages (Table E-VIII) was 1.3 aCi/m^3 but was not statistically significant (significance level $\alpha = 0.05$). The highest dust loading in the atmosphere as measured in the Los Alamos townsite south of Acid Canyon occurred during the months of February, March, May, and June with geometric mean particulate concentrations of 47, 60, 48, and 60 μg/m^3, respectively. During the sampling period including February and March, the average ^{239}Pu concentration at Bayo Treatment Plant exceeded that of the Santa Fe location by 2.0 aCi/m^3; in the sampling period including most of May and June the difference was 0.9 aCi/m^3. Neither of these apparent differences is statistically significant (significance level $\alpha = 0.1$).

The 1976 data suggest that, over 1- to 2-month sampling periods, the largest apparent increments of airborne ^{239}Pu concentrations measured in the canyon bottom (at the Bayo Treatment Plant) that could possibly be attributed to resuspension of residual contamination are about 1 to 3 aCi/m^3. Potential increments in concentration on the mesas adjacent to the canyon are expected to be less because of additional dispersion over greater distances. This is further supported by actual measurements that show any apparent incremental concentrations of airborne ^{239}Pu on the mesas probably are related to emissions from Los Alamos National Laboratory operational facilities.

The 1977 data raise some other considerations. There is increasing variability in the 1977 data, especially for the last 3 sampling periods (see Table E-IX). The normal spring mixing of stratosphere and troposphere occurred causing an increase in the concentrations by factors of 5 or more compared to the averages of the preceding year. The mixing also reflected some of the fresh fallout products from the two Chinese atmospheric tests in September and November of 1977. Averages for different sampling locations that had shown no statistically significant differences during most of 1976 (e.g., Bandelier, Santa Fe, and New York), differed by factors of 2 or more during these three sampling periods. In spite of these expectations of higher variability, the Bayo Treatment Plant recorded an abnormally high concentration, 166 aCi/m^3, during the last sampling period. There is no way to ascertain if this is attributable to worldwide fallout or to resuspension of contaminants. Measured airborne particles during the sampling period showed monthly geometric means ranging from 22 to 34 μg/m^3, the lowest of the 1976-1977 periods. This argues against attributing the value to resuspension, though vehicular traffic to the treatment plant could plausibly result in very brief periods of mechanical resuspension. By making the

assumption that the value was due to resuspension, it will serve as a good indicator of the peak short-term concentration likely to occur over a many year period.

One way of interpreting these concentrations is by comparison with standards for concentrations. The U.S. DOE concentration guide (CG), as given in ERDA Health and Safety Manual Chapter 0524, is applicable to uncontrolled (i.e., general public) areas for annual average airborne ^{239}Pu is 6×10^{-14} $\mu Ci/m\ell$ or 60 000 aCi/m^3. The maximum quarterly concentration observed at the Bayo Treatment Plant, 166 aCi/m^3, is about 0.28% of the CG. The estimated range of the likely maximum ^{239}Pu concentration increment is 1 to 3 aCi/m^3 or about 0.0017% to 0.005% of the CG. The U.S. EPA, in its proposed guidance to Federal Agencies (Refs. E14 and E15), suggests a derived annual average air concentration of 1 fCi/m^3 (1000 aCi/m^3) for alpha-emitting transuranium nuclides as a conservative limit to assure that the EPA proposed dose limits are met. The EPA derived limit is based on 0.1 μm activity median aerodynamic particle diameter. The quarterly peak concentration measured at the Bayo Treatment Plant, which includes total ^{239}Pu activity on all particle sizes sampled, is about 17% of the EPA derived limit. The estimated likely maximum annual average increment attributable to resuspended contamination, 3 aCi/m^3, is about 0.3% of the EPA derived limit.

III. DOSE MEASUREMENTS AND EVALUATIONS

The significance of radioactivity in the environment, whether naturally occurring or not, is usefully evaluated in terms of the doses that may result from the penetrating radiation given off or its transference to humans through various pathways such as inhalation or ingestion. The doses can then be compared to standards, natural background, or used to derive estimates of risk of injury. The next several sections of this Appendix will present data and interpretation of doses as actually measured or theoretically calculated from data on measured concentrations of radioactivity. Appendix F, Evaluation of Radiation Exposures, provides some additional material for readers desiring more background on concepts of radiation and radioactivity.

A. *In-Situ* Measurements

Measurements of the external penetrating radiation dose, including gamma and x rays from normal cosmic and terrestrial radiation, were made utilizing thermoluminescent dosimeters (TLDs). The standard methodology is described in annual surveillance reports for Los Alamos (Ref. E2). The TLDs were placed at various locations in the field during the period December 20, 1977 through March 10, 1978. The measured dose rates, in μrem/h, are shown in Figs. E-6 and E-7 and summarized by strata in Table E-X. For comparison, data collected by measurement with a High Pressure Ion Chamber (HPIC) during a special study in 1973 (Ref. E16) are included on the figures and in the table. Finally, data for the first quarter of 1978 from 12 stations in the routine Los Alamos environmental monitoring program are also given in the table. Several factors must be kept in mind for interpretation of the data: (1) the standard deviations of individual 1978 TLD measurements are in the range of ± 1.8 to 2.1 μrem/h ($\pm 10\%$ to 17%); (2) the dose rates vary considerably with time (because variation in soil moisture traps radon daughter isotopes in different amounts) as evidenced by fluctuations in the 12 routine monitoring program perimeter stations, which can vary by about 25% from one quarter to the next and during the period 1976-1978 ranged from a low of 9.4 μrem/h to a high of 17.4 μrem/h; and (3) there are considerable spatial variations in background dose rates in the Los Alamos area due to different geological formations containing different proportions of natural radioactive isotopes (especially from the uranium and

thorium chains) and the topography, which presents very different geometries for exposure from terrestrial sources in canyon bottoms compared to mesa tops.

Given these factors, it is evident that most of the differences among measurements in Middle Pueblo Canyon, Acid Canyon, the Treatment Plant Site, and the routine network perimeter stations (mainly mesa top locations) are likely due to natural conditions. Measurements from Lower Los Alamos and Lower Pueblo Canyons show no apparent difference or potential increase above natural background and compare well with *in-situ* gamma spectral analyses in Lower Los Alamos Canyon that accounted for all of the measured penetrating dose from naturally occurring isotopes. Some of the measurements at the Treatment Plant Site, especially near the vehicle decontamination facility and in the vicinity of the untreated waste outfall, may include an elevation above natural background caused by residual contamination. These elevated doses are in the range of 5 to 10 μrem/h (40 to 80 mrem/yr) above what can be attributed to natural sources; however, they are confined to small areas coincident with some of the locations known to have residual contamination.

Extensive measurements with portable instrumentation were made of the cliff faces between the Treatment Plant Site and Acid Canyon. Phoswich and μR meter readings were taken on 11 separate vertical traverses in the TA-45 outfall areas (identified on Fig. E-8) to monitor for possible contamination of the cliff faces. The phoswich was placed 4 cm from the surface being monitored and the μR meter was held ~0.5 m from the cliff face. Access to the cliff faces was accomplished by rapelling down fixed ropes with stops at points of interest to do the monitoring. Because the phoswich shows some temperature drift and because it was virtually impossible to avoid bumping the phoswich against the cliff face, most of the traverses included a background reading at a fixed location before and after the descent (designated 9.2° in most data sets in Table D-XXI) to monitor for instrument drift between the top and bottom of the traverse. Several data sets include a reading taken at the bottom of line M (M 12.2) to check for instrument drift. Data in Table D-XXI are presented in order of collection.

In Table D-XXI it becomes clear there was some drift in the phoswich readings (e.g., background readings on 11/4/77 at location −9.2 ranged from 454 to 602 counts/100 s) and that the background check locations had a lower average count than the cliff faces. Traverses P, Q, and R were on cliff locations that were highly unlikely to have been exposed to effluents and averaged 600, 638, and 765 counts/100 s, respectively. After allowing for this drift, the two highest readings were selected for further analysis. Detection limits for this application of the phoswich would range between 200 and 300 pCi/g for ^{239}Pu contamination averaged over an area of about 500 cm^2. If the reading above background on Line A at 3.7 m on the east wall of the 6 inch outfall traverse represents ^{239}Pu, the contamination is about 350 pCi/g. It is in an inaccessible place 2.7 m above the talus slope. The highest reading, at −0.8 m on the untreated outfall traverse, represents a small spot of actual contamination (~5600 pci/g) based on Phoswich reading under a rock at the base of a ~35° slope just above a cliff edge. It would be normally inaccessible as it is difficult to approach even with rock climbing gear. Thus personal contamination, much less internal deposition through wound abrasion, is highly unlikely. The possible skeletal dose one would get from an abrasion is discussed in detail later in Sec. III.C.4 of this Appendix.

The μR meter readings that monitor higher energy gamma rays (such as those associated with fission products) are consistently 30-40 μR/h, which is typical near rock material. The exception is one 60-μR/h reading at the base of the cliff below the truck wash drain (location 8.3). The phoswich readings at that location are also somewhat elevated, indicating some gamma contamination. As the maximum levels of ^{137}Cs were found on the mesa top above this location, it is not unexpected.

Because of the inaccessibility of the cliff faces, their low potential for wind or water erodibility, and the absence of any substantial contaminated areas, no further attempt at sampling was considered necessary.

B. External Penetrating Radiation Exposure Estimates

The external penetrating radiation (x and gamma ray) dose attributable to above background concentrations of contaminants can be theoretically calculated to varying degrees of accuracy using standard methods. For this study the basic approach was to estimate the doses as being from a theoretical infinite plane with the radioactivity distributed vertically according to an exponential curve. Dose factors giving the 5-cm-depth dose at 1 m above a plane with uniform surface distribution of radioactivity were taken from Ref. E17. These factors were adjusted to account for an exponential distribution with depth below the surface having a relaxation length of 10 cm and accounting for absorption and scattering of different energies down to 100 keV taken from data presented in Ref. E18. The areal concentrations ($\mu Ci/m^2$) for the canyon strata were calculated by taking the highest channel or bank average in the stratum for ^{239}Pu (from Table E-IV), ^{137}Cs and ^{234}U (from Table E-V), and assuming it persisted for a 30 cm depth. These areal concentrations were multiplied by the appropriate dose and depth distribution factors to obtain the estimated whole body dose rates presented in Table E-XI. The dose factor used for combined tranuranics was computed by combining the dose factors for ^{239}Pu, ^{238}Pu, ^{241}Pu, and ^{241}Am according to the activity ratios used for other evaluations (see Table E-VII). These assumptions result in overstatement of the estimated doses for the following reasons: (1) The contaminants are limited to relatively small areas especially in Acid Canyon and in the vicinity of the treatment plant site and the untreated outfall (this could overestimate effects by a factor of 10 or more); (2) the assumed exponential distribution places more emphasis on contaminants near the surface where absorption is less; and (3) the energies of the dose-contributing x rays are generally less than 100 keV for the transuranics.

C. Internal Exposure Potential Under Present Land Use

Radioactivity may reach humans and be deposited internally as a result of transport through various natural processes such as inhalation of resuspended dust, ingestion of water or foodstuff, or uptake through a wound. Various mechanisms for such exposure mechanisms are evaluated and interpreted in the next several sections, all with a common assumption that no significant changes in land use occur.

1. General Resuspension. The residual contamination on the channel and bank sediments provides a source of particulate matter that may be resuspended by wind movement or other mechanical action. Such airborne particulate matter could be inhaled by persons occupying the canyon areas for various proportions of time or, at probably lower dilutions, by the normal inhabitants of the Los Alamos area. Direct measurements of total airborne radioactivity have been made in the Los Alamos area for a number of years as part of the Los Alamos National Laboratory routine environmental monitoring program. Some of these results were discussed earlier (see Appendix E, Sec. II). Another method of evaluating the potential contribution of resuspension of residual contamination in the Acid-Pueblo-Lower Los Alamos Canyon areas is described here. The theoretical model selected is the straightforward mass loading approach, which has been assessed as being suitable for conditions where the contaminant has been aged in the environment for some time (Ref. E19). Refinements to account for unequal distribution of the contaminant on different particle sizes and for the limited size of the contaminated area were included. The basic approach predicts the concentration of airborne activity (activity/unit volume of air) as the product of the mass of particulates in the air (mass/unit volume of air) and the concentration of activity on the soil (activity/unit mass of soil) in the area. This predicted air concentration is

modified by an enrichment factor to account for the generally higher concentration per unit mass on smaller particles in the respirable range and for the generally small weight fraction of small particles in soils. The final modification is an attempt to account for the relatively small proportion of the canyon bottom area occupied by the contaminated stream channel and banks. This was done by multiplying by the ratio of the area of the stream channel or banks to the horizontal projection of the overall canyon area.

The various parameters and the estimated airborne concentrations of ^{239}Pu for the individual canyon strata are summarized in Table E-XII. The arithmetic mean ^{239}Pu soil concentration came from Table E-IV. This concentration for inactive channel and banks was adjusted by a factor of 1.1 to estimate the concentration in the top 1 cm depth based on soil profile data taken to depths of 30 cm in the Los Alamos area (Ref. E20).

The enrichment factors for each substratum where particle size and activity distribution data were available were calculated as shown in Table E-XIII. The enrichment ratio g_i is the quotient of the activity fraction for a given particle size increment i and the mass fraction for that size increment. These fractions were taken from or based on actual measurements of soils in the canyons as indicated by the references in the table. The airborne mass fraction f_i for the size increment was taken from Fig. A2-3 in Ref. E15. The enrichment factor ($\Sigma_i f_i g_i$) is the sum over the size increments of the respective $f_i g_i$ products.

For substrata where actual data was not available, the value of 2.3 was assumed as the enrichment factor. This is considered a reasonable assumption even for banks where the smaller particles constitute a larger mass fraction because available measurements in Pueblo and Los Alamos Canyons (Ref. E21) indicate a lower activity-mass ratio (g_i) as the mass fraction of the smallest particles increases. Thus, the assumed value is probably an overestimate.

The area proportion was taken from Table E-VI and is simply the ratio of the stratum area to the horizontal projected area of the canyon reach containing the stratum as estimated from a topographic contour map. The rationale for using this proportion may be considered either as an approximate dilution factor during times when winds are blowing perpendicular to the channel or as an approximate occupancy factor when winds are blowing parallel to the channel.

The annual average mass loading was taken to be 35 $\mu g/m^3$ based on measurements made in the Los Alamos townsite by the New Mexico Environmental Improvement Division (see Refs. E2, E12, and E22). This value is an annual geometric mean. Monthly geometric means typically range from about 20 to 60 $\mu g/m^3$; daily measurements typically range from about 10 to 150 $\mu g/m^3$.

The estimated annual average ^{239}Pu air concentration is shown for each substratum and the combined effect summed for each stratum. Table E-XII also shows estimated annual average air concentrations for ^{234}U, ^{90}Sr, and ^{137}Cs for each stratum in which these isotopes occurred at concentrations on soil statistically above background as summarized in Table E-V.

The estimated ^{239}Pu air concentrations from resuspension range from 2.9 aCi/m^3 for Lower Los Alamos Canyon to 71 aCi/m^3 for Acid Canyon. For Lower Pueblo Canyon, the estimate is 36 aCi/m^3, which is similar to the 5-year average (1974-1978, see Table E-VIII) of about 29 aCi/m^3 measured at the Bayo Treatment Plant. However, as discussed earlier in Sec. II, the measurements at the Bayo Treatment Plant include worldwide fallout and the high estimate of average resuspension contribution at that location was about 3 aCi/m^3. Thus the estimated concentrations from resuspension are in a plausible range and probably overestimate the actual effect by as much as a factor of 10. The theoretical estimates range from about 0.005% to 0.12% of the DOE Concentration Guide for uncontrolled areas (60 000 aCi/m^3) and from about 0.3% to 7.1% of the proposed EPA derived limit for transuranics (1000 aCi/m^3).

Potential doses that could result from the estimated air concentrations were calculated by using standard inhalation rates to determine intakes and appropriate dose conversion factors (Ref. E17). For dose estimation, the presence of transuranics other than ^{239}Pu (i.e., ^{238}Pu, ^{241}Pu, and

^{241}Am) was accounted for in the following manner. The activity ratios from Table E-VII were used as weighting factors for the individual isotope dose factors to derive a single, effective-dose factor increment attributable to these other transuranics. Table E-XIV presents a summary of the dose factors and calculations. The top section of the table lists the dose factors for first year and 50-year commitments for the isotopes and organs of interest. The middle section shows the activity ratios and the weighted effective dose factors, i.e., the product of the activity ratio (from Table E-VII) and the dose factors from the top section. These weighted, effective dose factors can be multiplied by an amount of ^{239}Pu intake to give the dose attributable to the other transuranics found in the residual soil contamination. These weighted factors were summed for the various condition-organ combinations and ratioed with the corresponding ^{239}Pu dose factor to get the proportions shown in the bottom section of the table. These values represent the fractional dose increment attributable to other transuranics that must be added to the ^{239}Pu dose. For example, the first year, whole body dose for the mixture of all the transuranics found under current conditions would be 34% greater than the dose for ^{239}Pu alone.

Doses for transuranics were estimated as the product of the estimated average airborne ^{239}Pu concentrations for each stratum (from Table E-XII), a standard average breathing rate of 23 m^3 day (from Ref. E23), continuous occupancy, and the dose factors and ratios discussed above. These results are summarized in Table E-XV by stratum for ^{239}Pu and total transuranics including ^{239}Pu. Doses estimated for ^{234}U, ^{90}Sr, and ^{137}Cs are shown in Table E-XVI. They are the products of the estimated resuspended air concentration attributable to above-background contamination (from Table E-XII), the breathing rate, and the appropriate dose factor (from Ref. E17).

2. Beef Cattle Food Pathway. In Lower Los Alamos Canyon cattle are often grazed, especially in the spring. A food chain analysis was made to estimate the potential exposure to humans through this pathway. The largest potential uptake would occur during years when spring snowmelt results in continuous flow in the stream channel for an extended period, and cattle stay near the river more consistently. For calculation the assumptions were that a beef steer obtained all its water and vegetation for 3 months during the spring of each of 2 years from Lower Los Alamos Canyon. The soils were assumed to have about 2 pCi/g of ^{239}Pu (see Table E-IV) and the water an average of about 5 pCi/ℓ of ^{239}Pu, including that on suspended sediments (see Table A-LVII) as based on measurements. Uptake modeling parameters, including that for soil ingested on vegetation surfaces (which represents the majority of the intake), were based on experimental studies (Ref. E24). Assuming that an individual adult human ate the entire liver from the hypothetical steer, the 50-year dose commitments would be 1.3×10^{-8} mrem to the bone and 3×10^{-5} mrem to the whole body. These doses are larger than would result from consumption of all other meat from the steer.

3. Transport into Rio Grande. Some sediments are transported into the Rio Grande from Lower Los Alamos Canyon during runoff from large spring snowmelt and summer thundershower events as discussed in Appendix A, Sec. VII. As noted in Appendix A, there must be some input of radioactivity from Los Alamos Canyon into the Rio Grande during such events, but the theoretically calculated dilution confirmed by actual measurements shows that the increments are small, usually at or below detection limits and less than the measured variability from natural distribution. Nevertheless, measurements have been made of fish and other foodstuffs to document actual levels of potential contaminants in the pathways.

Analyses of fish muscle samples collected in 1973 and 1976 showed no differences between radioactivity (^{137}Cs, ^{238,239}Pu, and total uranium) in fish at Cochiti Lake on the Rio Grande below

the confluence with Los Alamos Canyon, Heron Reservoir on the Rio Chama (a tributary of the Rio Grande), and Costilla Lake (a high mountain lake in northern New Mexico).

In 1979 fish samples were collected from Cochiti Lake and background locations at Abiquiu, El Vado, and Heron Reservoirs, all on the Rio Chama (Ref. E25). Muscle samples (with the bone remaining) were taken from bottom feeders (carp and suckers) and higher trophic levels (trout, walleye, catfish). Gut material was taken from bottom feeders. All samples were analyzed for gross gamma, $^{238,239}Pu$, ^{90}Sr, and total uranium. Detectable gross-gamma activity was measured in the El Vado gut samples and on many of the muscle samples. There were no statistically significant differences in gross-gamma activity in the muscle samples between Cochiti and the background stations. None of the samples had detectable ^{238}Pu activity. Only two samples (both gut samples) had detectable ^{239}Pu activity. One from Cochiti had 0.47 fCi/g and one at Abiquiu had 2.8 fCi/g, which indicates fallout levels of plutonium in ingested sediment in the gut. One El Vado gut sample had detectable ^{90}Sr (0.64 pci/g). Muscle samples had no statistically different results for ^{90}Sr between Cochiti and the background stations.

Total uranium was higher in all gut samples than in muscle samples, indicating ingested sediments as would be expected. Total uranium in muscle samples was statistically different (95% confidence level) between Cochiti (8 samples with an average 9.21 ± 6.16 ng/g) and background locations (12 samples with an average 2.64 ± 1.53 ng/g). Because uranium is ubiquitous in nature, the reasons for this elevation are difficult to determine.

Uranium analyses of the eight sediment samples taken in 1979 from the Rio Grande, both above and below the confluence with Los Alamos Canyon, were similar and were statistically higher than the single sample taken from the Rio Chama. However, concentrations of dissolved uranium were higher in water from the Rio Chama than from the Rio Grande. Uranium in sediments from the Rio Grande was about the same as from Los Alamos Canyon, indicating there could be no significant input from Los Alamos Canyon because of the much greater mass of sediments carried in the Rio Grande. Thus, there is no evidence that the higher uranium concentrations in muscle are correlated with input from Los Alamos Canyon.

Whatever the reason, the maximum dose increment one could get from eating 18 kg of fish from Cochiti over what one would get from eating fish from the Rio Chama would be a 50-year dose commitment of 0.03 mrem to the bone and 0.007 mrem to the kidney.

Foodcrops grown using the water from the Rio Grande at Cochiti have not shown any statistically significant differences in radioactivity concentrations from crops grown with river water from the Rio Grande and Rio Chama above confluence with Los Alamos Canyon during the 5 years foodstuff monitoring has been done (Refs. E2, E10, E11, E12, and E25). Analyses were done for $^{238,239}Pu$, tritiated water, and total uranium in all years, and in 1 year ^{90}Sr was included. There is no measurable effect of released effluents on the food chain pathways along the Rio Grande, with the possible unlikely exception of the uranium discussed above.

4. Abrasion Wound Contamination. It is possible that children will enter the untreated outfall area of the Treatment Plant Site during play. Predominant hazards in this area are nonradiological such as falling from a cliff, snakebite, twisted ankles, etc. In this area radiological contamination is spotty. During play children often sustain cuts and abrasions. For a maximum individual dose, it is assumed that a child falls and gets a wound that is contaminated with soil from a location in the untreated outfall area. Soil concentrations were assumed to be the maximum measured for ^{239}Pu, with ^{238}Pu and ^{241}Am assumed in proportion to maximum activity ratios. Wound size is assumed to be fairly large (~3 by 3 cm). Unpublished measurements by W. J. Wenzel, Los Alamos National Laboratory, show that clean hands in contact with house-dust transfer 5.7 g of dust to every m^2 of skin. Assuming the abrasion can transfer approximately 2

times this amount to the skin, we assume soil is deposited on the skin at 12 g/m^2. Thus the wound site will have ~0.01 g of soil. When wounds are dirty, they are generally cleaned or dirt is brushed away. We assume 70% of the soil is removed in this manner. Human experience at Los Alamos National Laboratory indicates 95% of the remaining soil will be removed in the scab. Finally, the material deposited in the wound has been in the environs for 20-30 years and is undoubtedly oxidized or polymerized. As such it is tightly bound to the soil and unlikely to be soluble in blood. Animal experiments indicate when insoluble ^{239}Pu is deposited subcutaneously, between 25 and 99+% of the deposited material remains at the wound site (Ref. E26). Los Alamos National Laboratory experience with humans suggests >99% of the metallic and oxide forms remain at the wound site. Americium is somewhat more mobile (1.5 times) in the blood than plutonium, and uranium is highly mobile in the blood (Ref. E27). Thus concentrations in the blood are calculated as the product:

$$\text{Concentration} = \left[\frac{\text{pCi}}{\text{g}}\right] [0.01\ \text{g}]\ [1-0.7]\ [1-0.95] \cdot [\text{mobile fraction}]\ ,$$

where

A = activity in soil,
mobile fraction = 0.01 for ^{239}Pu, 0.015 for ^{241}Am, and 1.0 for ^{234}U (Ref. E27), and

fractional quantities transferred from the blood to bone = 0.45 and from blood to liver =0.45 for both ^{239}Pu and ^{241}Am (Ref. E28).

Dose calculations were based on the formula (Ref. E29):

$$D = q\ 51.2\ Q\ \epsilon/m\ ,$$

where

D = dose in rems ,

q = organ burden ,

51.2 = the product of disintegrations per day per μCi (3.2×10^9) and ergs per MeV (1.6×10^{-6}), divided by ergs per gram of tissue per rad (100) ,

Q = time integral of internal contamination expressed in μCi—days resulting from an uptake or deposition of 1 μCi,

ϵ = effective absorbed energy per disintegration, and

m = mass of critical organ in gm

Results are given in Table E-XVII. Other isotopes yielded smaller estimated doses.

D. Exposure Potential Under Development Scenario Conditions

The most significant possible change in land use patterns that would have implications for potential mechanisms of exposure different from those already considered would be development. Lower Pueblo Canyon has been discussed in recent years in the Los Alamos community and considered by the County Planning and Zoning Commission as potentially developable for residential use. Most of the land in Lower Pueblo Canyon suitable for development lies within the DOE controlled Otowi Section, or in and adjacent to the DOE controlled Pueblo Canyon Tract No. 1 (see Figs. 12 and 13 in the Introduction and Background, Sec. 2). The balance of the land is owned by Los Alamos County. Middle Pueblo Canyon and Acid Canyon, also owned by Los Alamos County, are unlikely to be developed because of terrain difficulties though there is no legal preclusion. The former Treatment Plant Site, owned by Los Alamos County, could have some minor development; a municipal sewage lift station is currently located there.

Potential doses to hypothetical future residents of Lower Pueblo Canyon would include those from external penetrating radiation and general resuspension exposure as discussed in Sec. III.B. and III.C.1 above. Additional exposures considered possible were those due to extra inhalation of dust resuspended during home garden tilling or to ingestion of produce grown in the contaminated soils.

Development would require construction, so the potential exposure of construction workers involved in digging activities was considered for both the Lower Pueblo Canyon and former waste treatment plant site.

1. Construction Worker. For estimating the exposure of a construction worker, the basic assumptions were taken to be a high breathing rate associated with physically demanding labor, 43 ℓ/min (Ref. E22), and very dusty conditions where the airborne particulate concentration is 10 mg/m^3, the present threshold limit value for nuisance dust (Ref. E30). For work done in Lower Pueblo Canyon, the time spent working in contaminated soils is taken to be 60 hours. Soil concentrations were taken to be those for bank soils from Tables E-IV and E-V, activity ratios from Table E-VII, enrichment factors from Table E-IX, and dose factors from Table E-XIV. For work done in the vicinity of the former vehicle decontamination facility, the assumptions were different only in that soil concentrations were taken to be an average of samples 16 and D-1 from Table E-II, and the time spent reduced to 10 hours because of the smaller area potentially involved. Results of the calculations are presented in Table E-XVIII. The results for ^{239}Pu would be lower by a factor of about 3 if the work involved the subsurface soils of the treatment plant location assuming an average concentration of about 14 pCi/g.

2. Gardening. The estimated dose to a home gardener during rototilling and soil preparation took the same basic assumptions as used for a construction worker in terms of breathing rate, suspended particulate concentration, enrichment factor, activity ratios, and dose factors. The soil concentration was taken to be half of that for banks, assuming that the sandy soil present would be mixed with other loamy soil or organic amendments in the ratio of 1:1 in order to support reasonable growth. The soil preparation time was assumed to be 30 hours for a growing season. The calculated doses are presented in Table E-XIX.

For consumption of produce, the same assumption regarding soil concentration was made. Transfer factors for specific isotopes were taken from Ref. E17. An annual intake of fresh produce of 46.5 kg was taken from U.S. Dept. of Agriculture data (Ref. E31) and assumed to be completely supplied from the garden. The calculated doses are presented in Table E-XIX.

REFERENCES

E1. W. D. Purtymun, R. J. Peters, and A. K. Stoker, "Radioactivity in Soils and Sediments in and Adjacent to the Los Alamos Area, 1974-1977," Los Alamos Scientific Laboratory report LA-8234-MS (February 1980).

E2. Environmental Surveillance Group, "Environmental Surveillance at Los Alamos During 1978," Los Alamos Scientific Laboratory report LA-7800-ENV (April 1979).

E3. U.S. Department of Energy, "Radiological Survey of the Bayo Canyon, Los Alamos, New Mexico," U.S. DOE, Assistant Secretary for Environment, Division of Environmental Control Technnology, Formerly Utilized MED/AEC Sites Remedial Action Program, report DOE/EV-0005/15, prepared by Environmental Surveillance Group, Health Research Division, Los Alamos National Laboratory (June 1979).

E4. A. J. Ahlquist, A. K. Stoker, and L. K. Trocki, compilers, "Radiological Survey and Decontamination of the Former Main Technical Area (TA-1) at Los Alamos, New Mexico," Los Alamos Scientific Laboratory report LA-6887 (December 1977).

E5. T. E. Hakonson and K. V. Bostick, "Cesium-137 and Plutonium in Liquid Waste Discharge Areas at Los Alamos," in *Radioecology and Energy Resources,* C. E. Cushing, Jr., Ed., Proceedings of the Fourth National Symposium on Radioecology (Douden, Hutchinson and Ross, Inc., Stroudsburg, PA, 1975).

E6. J. W. Nyhan, F. R. Miera, Jr., and R. J. Peters, "The Distribution of Plutonium in Alluvial Soils of the Los Alamos Environs," in *Radioecology and Energy Resources,* C. E. Cushing, Ed., Proceedings of the Fourth National Symposium on Radioecology (Douden, Hutchinson and Ross, Inc., Stroudsburg, PA, 1975).

E7. J. W. Nyhan, G. C. White, and G. Trujillo, "Soil Plutonium and Cesium in Stream Channels and Banks of Los Alamos Liquid Effluent-Receiving Areas," Los Alamos Scientific Laboratory manuscript (LA-UR-80-1184) submitted to Health Physics Journal (1980).

E8. R. O. Gilbert and G. C. White, "TRAN-STAT, Studies for Environmental Transuranic Studies," Number 5, Battelle Memorial Institute, Pacific Northwest Laboratory publication PNL-SA-7061, Richland, Washington (July 1978).

E9. K. E. Apt and V. J. Lee, compilers, "Environmental Surveillance at the Los Alamos Scientific Laboratory During 1974," Los Alamos Scientific Laboratory report LA-5977- PR (May 1975).

E10. K. E. Apt and V. J. Lee, compilers, "Environmental Surveillance at Los Alamos Scientific Laboratory During 1975," Los Alamos Scientific Laboratory report LA-6321-MS (April 1976).

E11. Environmental Studies Group, "Environmental Surveillance at Los Alamos During 1976," Los Alamos Scientific Laboratory report LA-6801-MS (April 1977).

E12. Environmental Surveillance Group, "Environmental Surveillance at Los Alamos During 1977," Los Alamos Scientific Laboratory report LA-7263-MS (March 1978).

E13. L. E. Toonkel, "Appendix to Environmental Measurements Laboratory Environmental Quarterly," U.S. DOE Environmental Measurements Laboratory report EML-370 Appendix (January 1980).

E14. U.S. Environmental Protection Agency, "Persons Exposed to Transuranium Elements in the Environment," Proposed Federal Radiation Protection Guidance on Dose Limits, in Federal Register, Vol. **42**, No. 230, Wednesday, Nov. 30, 1977, pp. 60956-60959 (1977).

E15. U.S. Environmental Protection Agency, "Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment," U.S. EPA Office of Radiation Programs report EPA 540/4-77-016 (September 1977).

E16. K. J. Schiager and K. E. Apt, compilers, "Environmental Surveillance at Los Alamos During 1973," Los Alamos Scientific Laboratory report LA-5586 (May 1974).

E17. U.S. Energy Research and Development Administration, "A Guide for Environmental Radiological Surveillance at ERDA Installations," U.S. ERDA Division of Safety, Standards, and Compliance report ERDA 77-24 (March 1977).

E18. H. L. Beck, J. DeCampo, and C. Gogolak, "*In Situ* Ge(Li) and NaI (Tℓ) Gamma-Ray Spectroscopy," U.S. AEC Health and Safety Laboratory report HASL-258 (September 1972).

E19. U.S. Environmental Protection Agency, "Selected Topics: Transuranium Elements in the General Environment," U.S. EPA Office of Radiation Programs Technical Note ORP/CSD-78-1 (June 1978).

E20. T. E. Hakonson, G. C. White, E. S. Gladney, and M. Dreicer," The Distribution of Mercury, Cesium-137, and Plutonium in an Intermittent Stream at Los Alamos," Journal of Environmental Quality, Vol. 9, p. 289 f.f. (1980).

E21. J. W. Nyhan, F. R. Miera, Jr., and R. J. Peters, "Distribution of Plutonium in Soil Particle Size Fractions of Liquid Effluent-Receiving Areas at Los Alamos," Journal of Environmental Quality **5**:1, pp. 50-56 (January-March 1976).

E22. U.S. Department of Energy, "Final Environmental Impact Statement, Los Alamos Scientific Laboratory Site, Los Alamos, New Mexico," U.S. DOE report DOE/EIS-0018 (December 1979).

E23. International Commission on Radiological Protection, "Report of the Task Group on Reference Man," ICRP Publication 23, Pergamon Press, Inc., Elmsford, New York (1975).

E24. W. E. Martin and S. G. Bloom, "Model for Estimating Plutonium Transport and Dose to Man," in *Transuranics in Natural Environments,* M. G. White and P. B. Dunaway, Eds., Nevada Applied Ecology Group, U.S. Energy Research and Development Administration report NVO-178 (June 1977).

E25. Environmental Surveillance Group, "Environmental Surveillance at Los Alamos During 1979," Los Alamos Scientific Laboratory report LA-8200-ENV (April 1980).

E26. International Commission on Radiological Protection—Task Group of Committee 2, "The Metabolism of Compounds of Plutonium and Other Actinides," ICRP Publication 19, Pergamon Press, New York (1972).

E27. H. C. Hodge, J. N. Stannad, and J. B. Hursh, Eds., *Uranium, Plutonium, Transplutonic Elements,* Vol. XXXVI of *Handbook of Experimental Pharmacology,* E. O. Eichler, A. Farah, H. Herken, A. D. Welch, Editorial Board (Springer Verlag, New York, 1973).

E28. International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," Annals of the ICRP, Vol. 2, No. 3/4, ICRP Publication 30 (1979).

E29. International Commission on Radiological Protection, "Report of Committee IV on Evaluation of Radiation Doses to Body Tissues from Internal Contamination due to Occupational Exposures," ICRP Publication 10, Pergamon Press, Ltd., Oxford (1959).

E30. American Conference of Governmental Industrial Hygienists, "Threshold Limit Values of Airborne Contamination for 1978, Recommended and Intended Values," ACGIH (1978).

E31. U.S. Department of Agriculture, "Food Consumption, Prices, Expenditures," Supplement for 1976 to Agricultural Economic report No. 138 (March 1978).

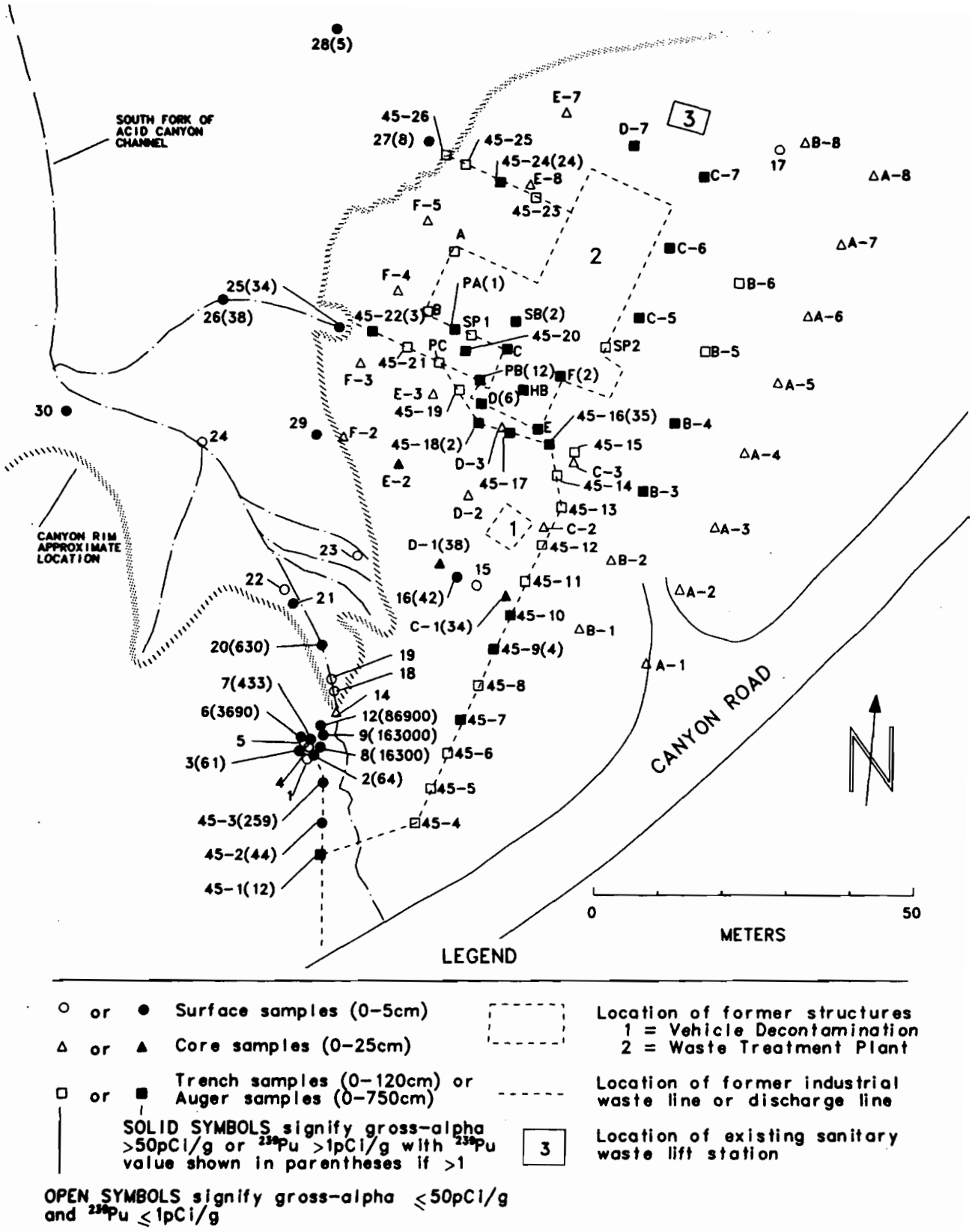

Fig. E-1.
Sampling locations and summary results, treatment plant site and part of Acid Canyon.

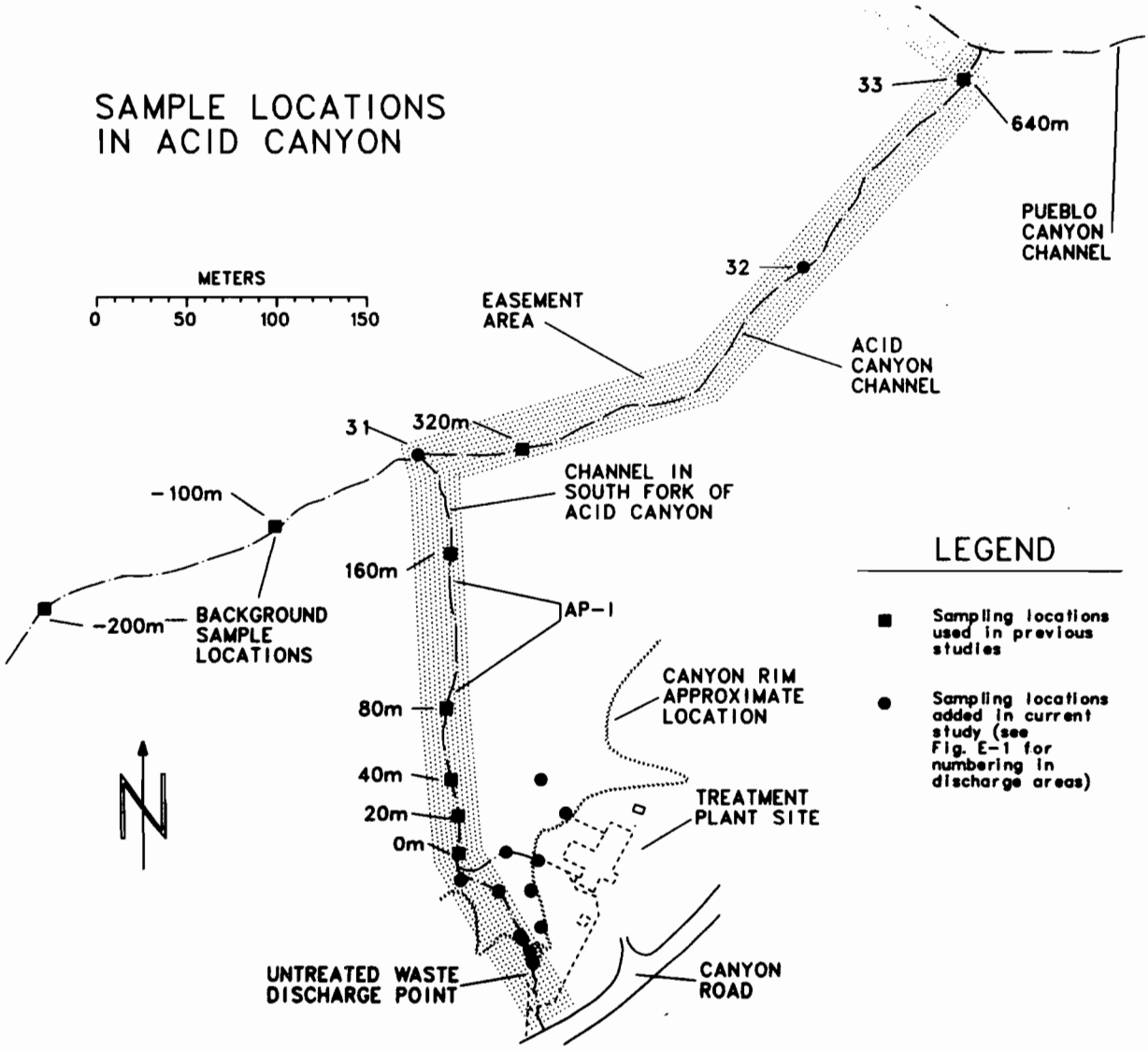

Fig. E-2.
Sampling locations in Acid Canyon.

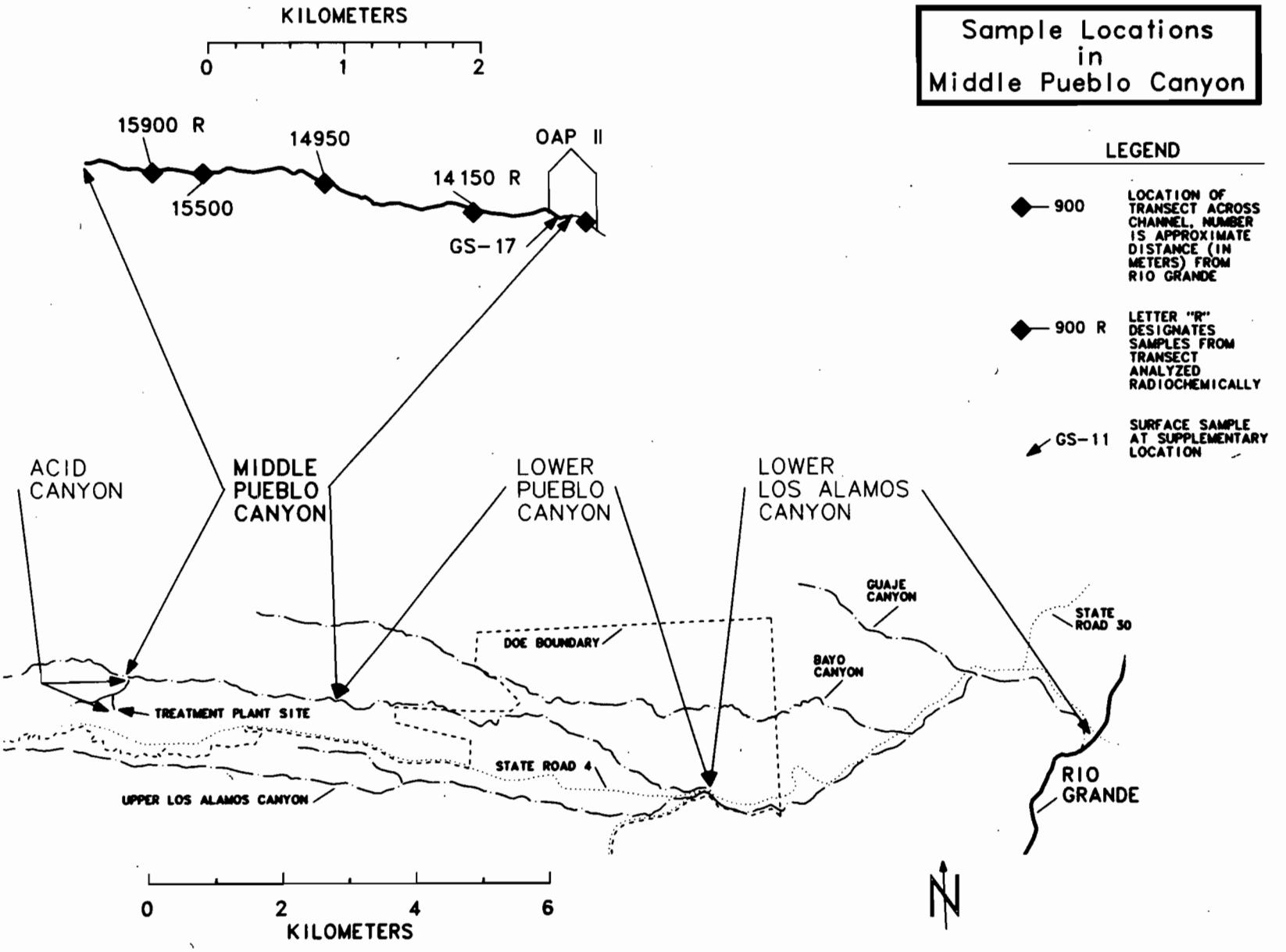

Fig. E-3.
Sampling locations in Middle Pueblo Canyon.

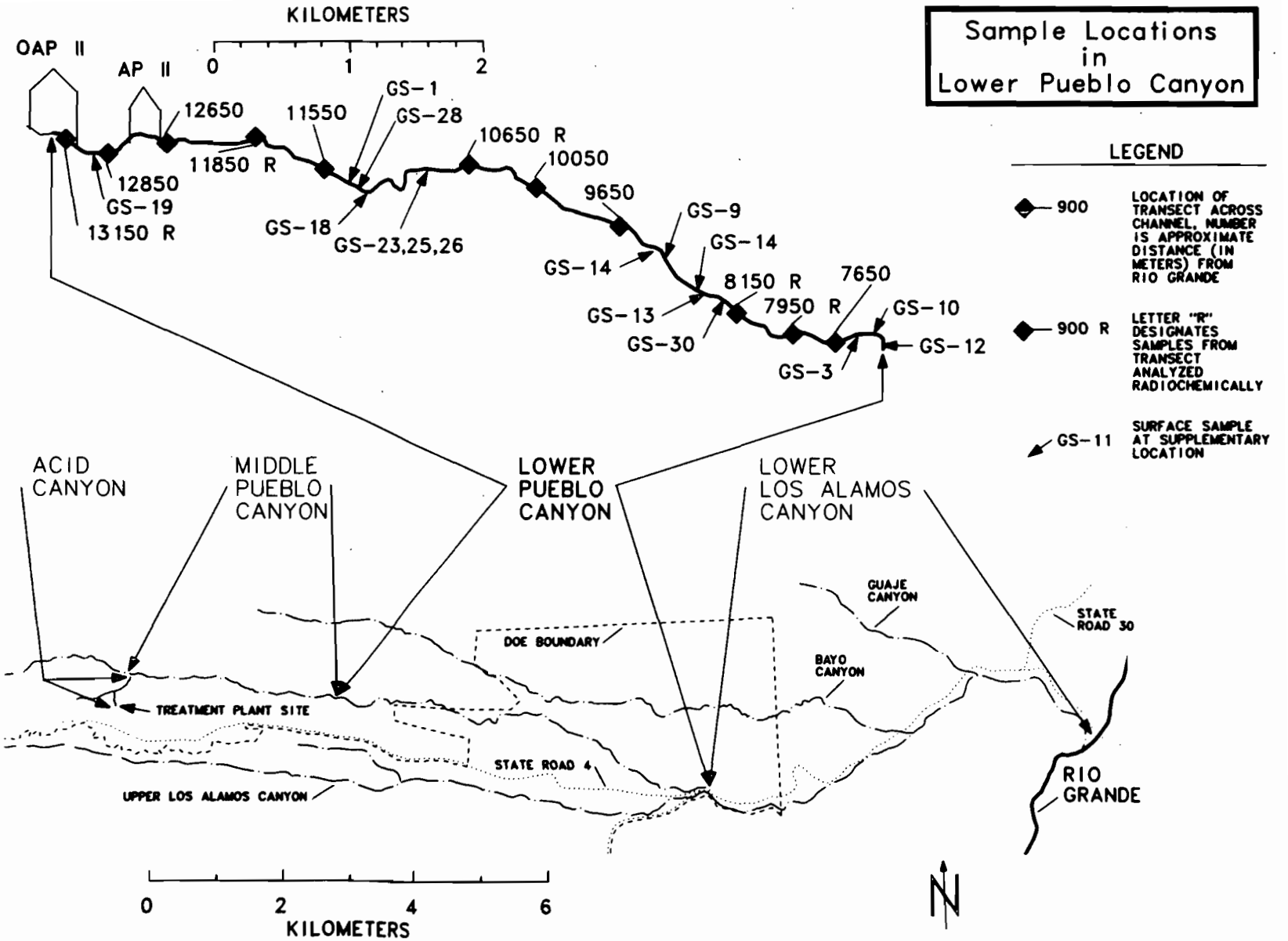

Fig. E-4.
Sampling locations in Lower Pueblo Canyon.

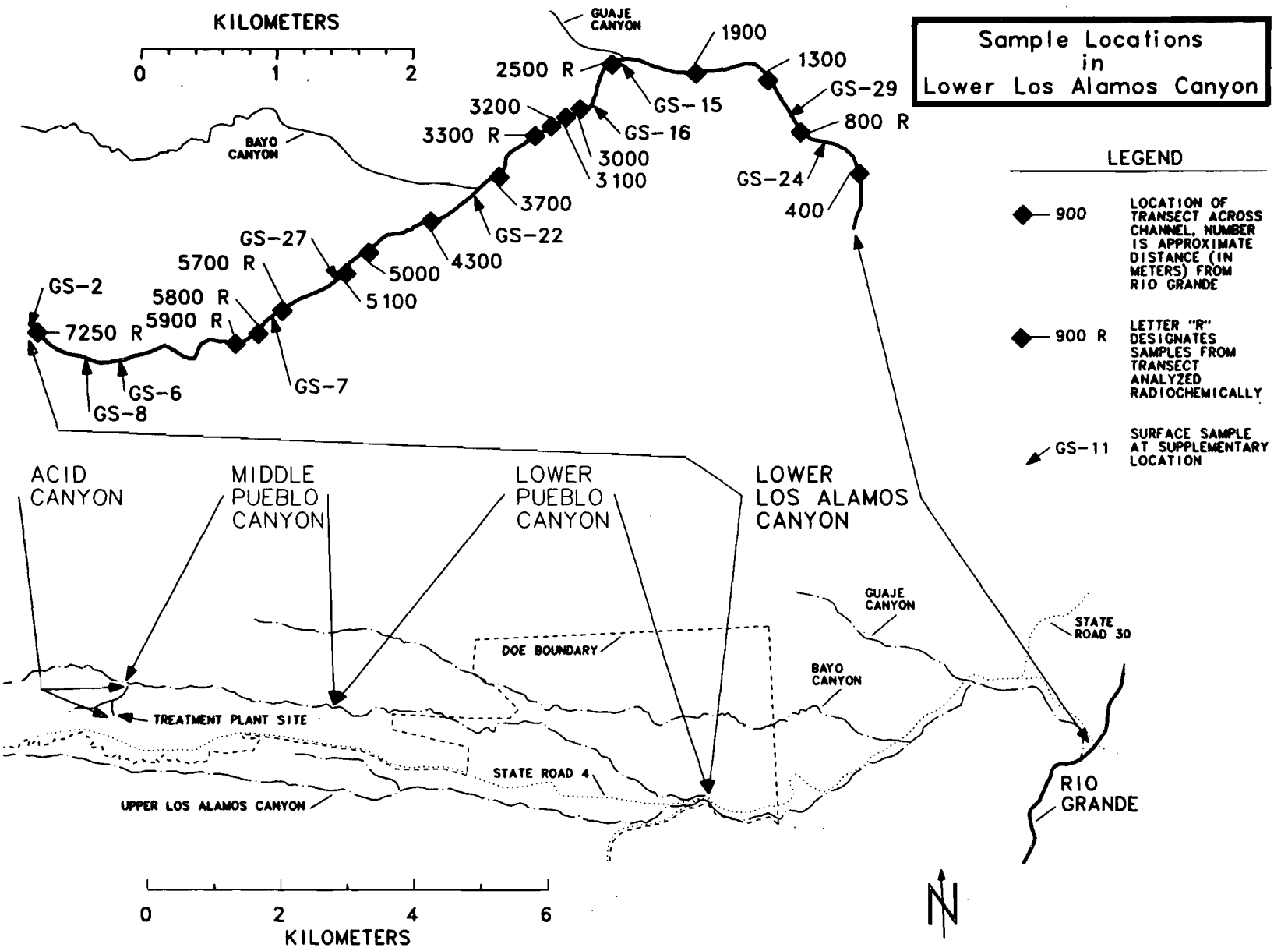

Fig. E-5.
Sampling locations in Lower Los Alamos Canyon.

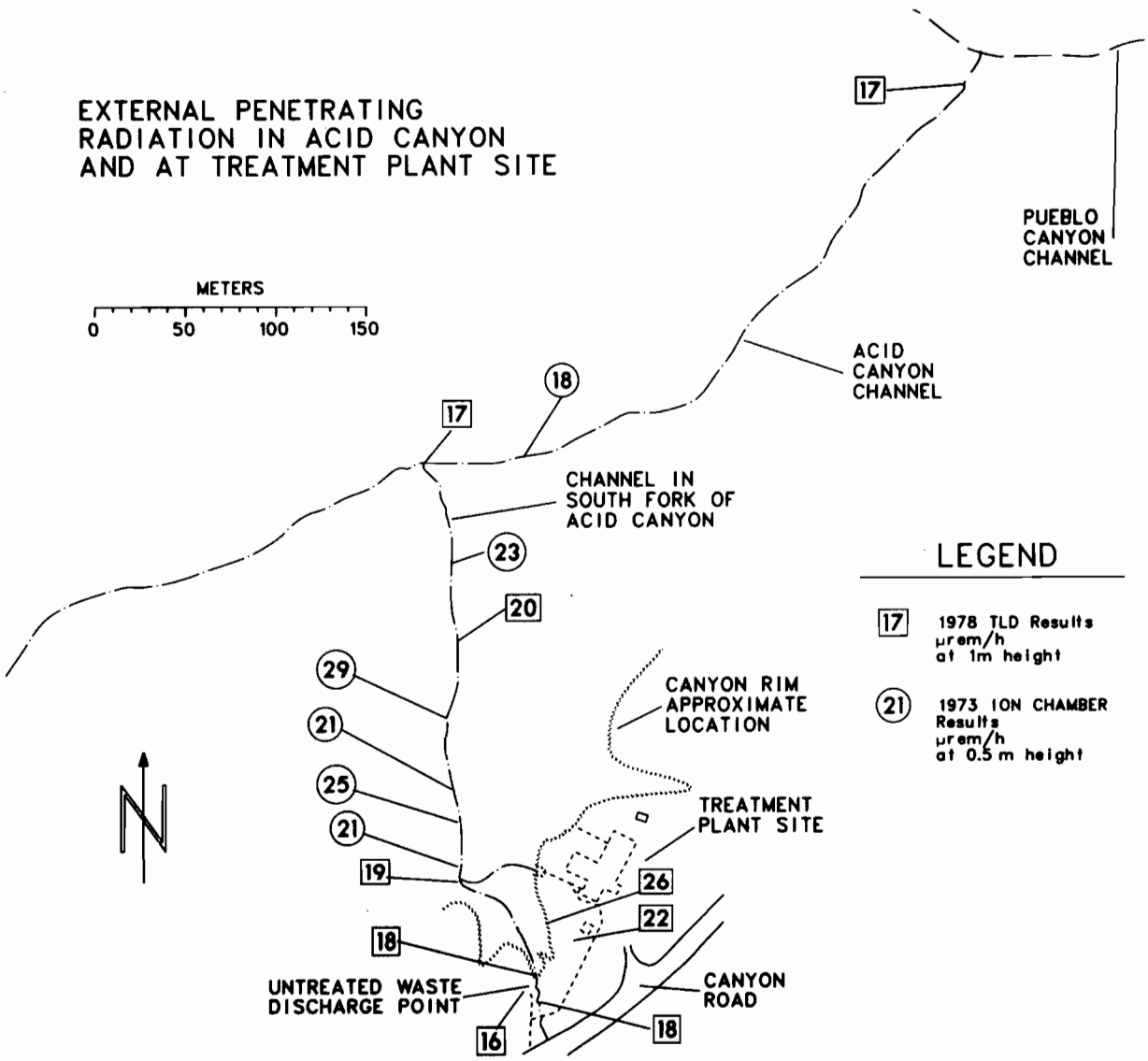

Fig. E-6.
External penetrating radiation measurements, Treatment Plant Site and Acid Canyon.

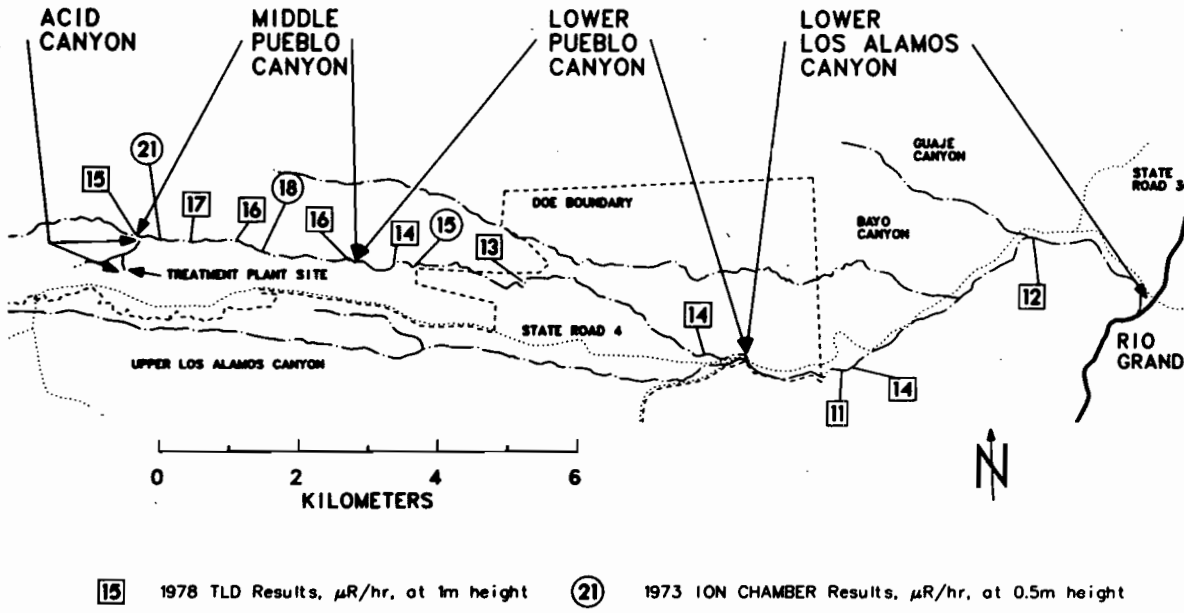

Fig. E-7.
External penetrating radiation measurements, Pueblo and Los Alamos Canyons.

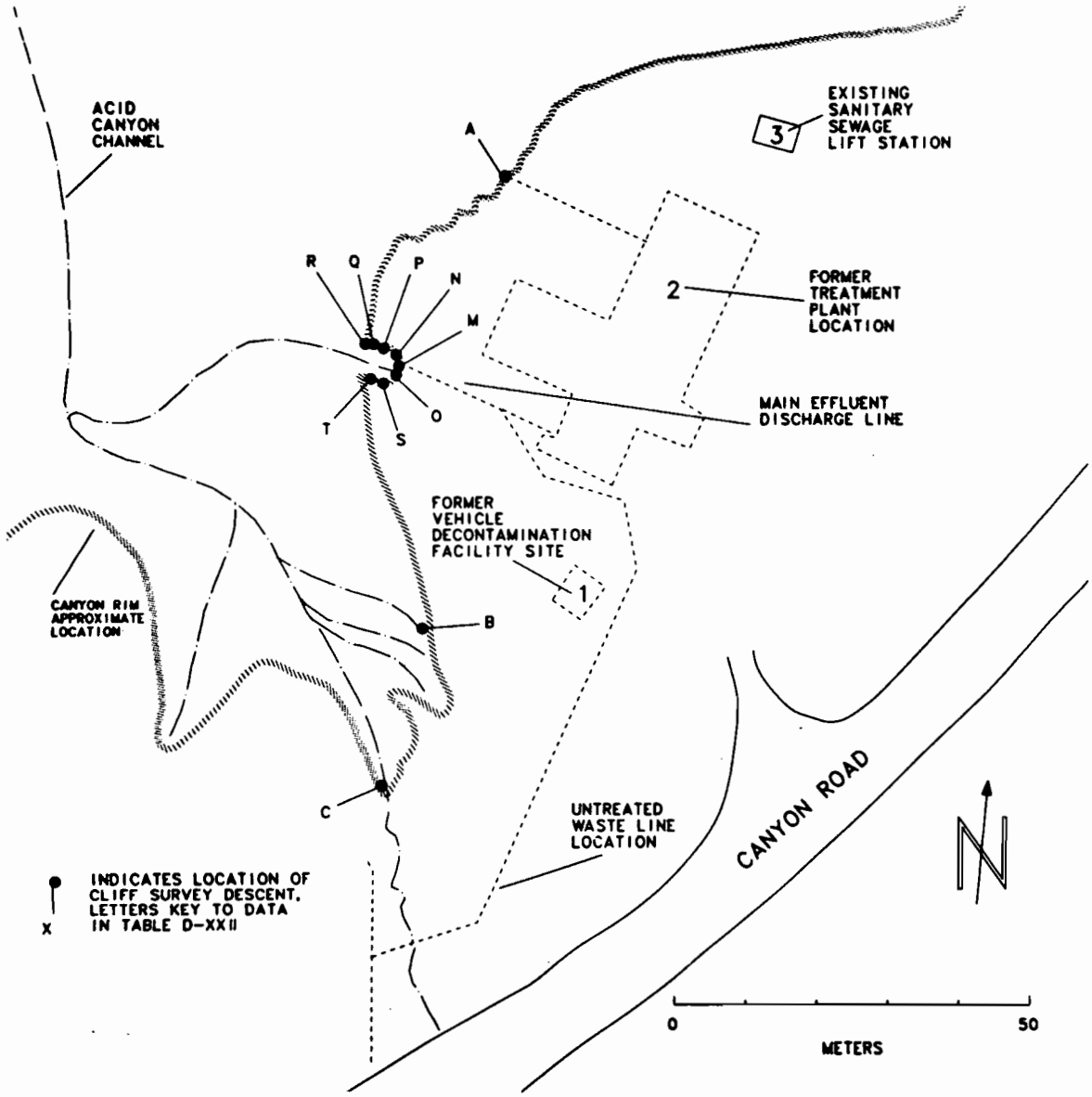

Fig. E-8.
Locations of cliff survey descents in vicinity of Treatment Plant Site and Acid Canyon.

TABLE E-I

NORTHERN NEW MEXICO BACKGROUND REFERENCE VALUES FOR NATURAL OR FALLOUT LEVELS OF RADIOACTIVITY

Isotope	Mean Concentration	Range of Concentrations	Units	No. of Samples	Comment	Reference
	$\bar{x} \pm s$					
^{239}Pu	0.008 ± 0.010	<0.002-0.045	pCi/g	149	Soils and sediments 0-5 cm	E1
^{238}Pu	<0.000 ± 0.004	<0.003-0.010	pCi/g	151	Soils and sediments 0-5 cm	E1
^{241}Am	0.004 ± 0.004	<0.001-0.009	pCi/g	7	Sediments 0-5 cm	E2
^{90}Sr	0.25 ± 0.27	<0.05-1.0	pCi/g	68	Soils and sediments 0-5 cm	E1
^{137}Cs	0.32 ± 0.30	<0.10-1.06	pCi/g	76	Soils and sediments 0-5 cm	E1
Total U	1.8 ± 1.3	<0.1-5.1	μg/g	118	Soils and sediments 0-5 cm	E1
^{232}Th	14.3 ± 3.6	9.2-20.1	μg/g	8	Soils 0-30 cm	E3
^{226}Ra	2.4 ± 0.8	1.6-3.9	pCi/g	7	Soil 0-5 cm	E4
Gross alpha	30 ± 8	17-39	pCi/g	7	Soil and sediments 0-5 cm by ZnS technique	Appendix B
Gross beta	4.9 ± 1.3	2.7-6	relative value	8	Soil and sediments 0-5 cm by plastic scintillator	Appendix B

TABLE E-II

TREATMENT PLANT SITE DATA SUMMARY FOR SAMPLES WITH ELEVATED ALPHA OR ^{239}Pu ACTIVITY

Sample Location	Maximum Gross Alpha		Maximum ^{239}Pu		Additional Radiochemistry on Pu Sample		
	Sample Depth Interval (cm)	Gross α Conc. (pCi/g)	Sample Depth Interval (cm)	^{239}Pu Conc. (pCi/g)	^{90}Sr (pCi/g)	^{137}Cs (pCi/g)	U (μg/g)
Untreated Waste Outfall							
2	0 - 5	90	0 - 5	64	0.9	1.9	4.7
3	0 - 5	60	0 - 5	61	0.5	2.2	5.5
6	0 - 5	1960	0 - 5	3700	5.1	36	600
7	0 - 5	670	0 - 5	430	1.8	25	110
8	0 - 5	10 000	0 - 5	16 300	2.4	2.3	20
9	0 - 5	88 000	0 - 5	163 000	0.9	1.1	120
12	0 - 5	52 000	0 - 5	87 000	1.0	11	79
45 - 1	0 - 120	30	0 - 120	12	2.9	2.2	2.7
45 - 2	0 - 5	90	0 - 5	44	0.5	0.3	1.5
45 - 3	0 - 5	150	0 - 5	260	0.2	0.1	3.5
Vehicle Decontamination Facility							
16	0 - 5	100	0 - 5	42	230	180	130
C1	0 - 25	80	0 - 25	34	0.6	0.3	2.4
D1	0 - 25		0 - 25	39	180	78	110
E2	0 - 25	80	0 - 25	0.6	0.4	0.2	3.4
Acid Sewer Alignment							
45 - 7	0 - 120	60	0 - 120	0.3	0.4	0.3	2.6
45 - 9	0 - 120	10	0 - 120	4	1	1	2.9
45 - 10	0 - 120	60					
B3	0 - 240	80					
B4	0 - 240	60					

TABLE E-II (cont)

Sample Location	Maximum Gross Alpha		Maximum ^{239}Pu		Additional Radiochemistry on Pu Sample		
	Sample Depth Interval (cm)	Gross α Conc. (pCi/g)	Sample Depth Interval (cm)	^{239}Pu Conc. (pCi/g)	^{90}Sr (pCi/g)	^{137}Cs (pCi/g)	U (μg/g)
Treatment Plant and Outfalls							
C	0 - 120	60	120 - 240	0.3			
D	120 - 240	80	120 - 240	5.9	0.2	0.0	1.3
E	0 - 120	60	120 - 240	0.05			
F	0 - 240+	40	0 - 240+	1.6	0.1	0.0	1.6
PA	120 - 240	70	0 - 240+	1			
PB	0 - 240+	90	0 - 120	12	0.2	0.1	2.0
HB	0 - 120	60	120 - 240	0.4	0.1	0.0	1.5
SB	0 - 240+	40	120 - 240	1.8	0.2	0.0	1.3
C5	120 - 240	120	0 - 25	0.5			
C6	120 - 240	60					
C7	0 - 240+	60					
D7	120 - 240+	60					
45 - 16	0 - 120	80	0 - 120	35	0.4	0.2	2.1
45 - 17	0 - 120	60					
45 - 18	0 - 120	60	0 - 120	2.0	0.6	0.2	3.5
45 - 20	0 - 120	60					
45 - 22	0 - 120	40	0 - 120	2.6	0.5	0.3	3.8
45 - 24	0 - 120	40	0 - 120	24	9.6	3.2	36

[a]Gross α >50 pci/g (total) or ^{239}Pu >1 pCi/g.

TABLE E-III

ACID CANYON DATA SUMMARY FOR FOUR SURVEYS

Location[a]	Depth (cm)	Year(s)	(pCi/g) ^{239,240}Pu	^{238}Pu	^{241}Am	^{90}Sr	^{137}Cs	Gross α	(relative) Gross β	(μg/g) U Total	^{232}Th
18 sc	0-5	77						20	3		
19 sc	0-5	77						20	1		
100 m[b] sc	0-8	73[d]	0.132								
20 sc	0-5	77	629	3.13	43.4	1.10	0.79	580	5	10	13
21 sc	0-5	77	500 [e]					460	5		
22 sc	0-5	77									
23 sc	0-5	77						20	9		
24 sc	0-5	77						30	6		
24 sc	0-15	77	20[f]					40			
24 b	0-15	77						50			
25 sc	0-5	77	33.5	0.15	1.67	0.70	0.20	60	5	3	15
26 sc	0-5	77	38.4	0.10	1.82	4.5	12.1	50	6	3.7	9.7
27 sc	0-5	77	8.20	0.0	0.41	0.40	0.54	40	4	3.9	14
28 sc	0-5	77	5.20	0.04	0.33	0.40	1.64	40	3	2.8	13
29 b	0-5	77						110	2		
30 b	0-5	77						80	3		
0 m sc	0-21	72	2.3	0.02			0.02				
	0-8	73	11.2								
20 m sc	0-21	72	2.2	0.09			1.5				
	0-3	73[d]	16.8								
40 m sc	0-21	72	6.9	0.03			0.74				
	0-13	73[d]	9.2								
80 m sc	0-22	72	54	1.0			14				
	0-13	73[d]	12.3								
AP-I sc	0-20	76	13.4	0.057			1.0				
AP-I b	0-40	76	110	0.28			1.8				
160 m sc	0-21	72	8.5	0.08			1.1				
	0-8	73[d]	8.6								
31 sc	0-21	77	50					70			
1 b	0-21	77						60			
100 m[c] sc	0-8	72	0.2	0.009			0.36				
−200 m[c] sc	0-21	72	3								
320 m sc	0-21	72	12	0.08			1.5				
	0-13	73[d]	9.02								
32 sc	0-21	77	50					70			
32 b	0-21	77						40			
640 m sc	0-21	72	11	0.08			1.1				
	0-13	73[d]	10.6								
33 (AC-20) sc	0-21	77	15.8	0.10		1.69	1.28	40	4	1.5	9.35
33 (AC-20) nb	0-21	77	12.5	0.83		0.78	1.05	40	5	0.9	7.24
33 (AC-20) sb	0-21	77	0.11	0.0		0.23	0.25	10	5	1.8	9.54

[a]sc means channel sample; b means bank sample; nb means north bank; and sb means south bank.

[b]Control location 100 m south of 8 in. outfall, i.e., station 0-m in the south fork of Acid Canyon.

[c]Control locations 100 and 200 m west of the confluence of the west fork and the south fork of Acid Canyon.

[d]Calculated values for Pu conc based on integrated profile concentrations weighted by mass of depth interval analyzed. Pu is total Pu.

[e]Estimated values for Pu conc based on ratio of Pu concentration to gross-alpha activity at location 20 sc.

[f]Estimated Pu conc based on the mean ratio of the Pu to gross alpha at locations 25 and 26.

TABLE E-IV

$^{239,240}Pu$ AVERAGE CONCENTRATIONS AND ESTIMATED INVENTORY

Stratum	Arithmetic Mean ^{239}Pu concentration ($\bar{x} \pm s$)[b] pCi/g	Estimated Inventory: Geometric Means mCi	Estimated Inventory: Geometric Means % of Total	Estimated Inventory: Arithmetic Means mCi ($\bar{x} \pm 2s_{\bar{x}}$)[c]	Estimated Inventory: Arithmetic Means % of Total
Acid Canyon		**66.4**	**27.0**	**98.9 ± 52.3**	**15.7**
Active Channel		6.64		8.93 ± 5.2	
−100-0	154 ± 256	0.084		0.6 ± 0.7	
0-80	8.1 ± 5.6	0.094		0.1 ± 0.07	
80-160	19.5 ± 19.4	0.36		0.5 ± 0.5	
160-650	27.8 ± 20.4	6.11		7.7 ± 5.1	
Area Weighted Average	30.6 ± 29.4				
Banks[a]	110 ± 75	59.8		90 ± 52	
Middle Pueblo Canyon		**20.2**	**8.2**	**74.6 ± 83.4**	**11.8**
Active Channel	1.10 ± 1.10	1.88		3.7 ± 3.0	
Banks	3.48 ± 4.0	18.3		70.9 ± 83.3	
Lower Pueblo Canyon		**149.6**	**60.8**	**422 ± 281**	**66.8**
Active Channel	0.86 ± 0.54	8.95		15.1 ± 11.6	
Inactive Channel	5.05 ± 3.60	102.		298 ± 272	
Banks	6.43 ± 5.77	38.7		109 ± 69	
Lower Los Alamos Canyon		**9.83**	**4.0**	**35.8 ± 19.9**	**5.7**
Active Channel	0.24 ± 0.26	3.56		11.3 ± 10.4	
Inactive Channel	0.15 ± 0.18	1.81		10.5 ± 11.7	
Banks	2.34 ± 2.98	4.46		13.9 ± 12.2	
	Totals	**246 mCi**	**100%**	**631 ± 298 mCi**	**100%**

[a]Banks in Acid Canyon assumed to have average concentration shown based on samples in 50-m long intensive study site located between the 80- and 160-m points and 91% of total inventory based on data from Ref. E7. Thus, the bank inventory was taken as 10 times channel inventory rather than being calculated from volume.

[b]s represents the standard deviation of the population.

[c]$s_{\bar{x}}$ represents the standard error of the mean.

TABLE E-V

CONCENTRATIONS ABOVE BACKGROUND FOR Sr, Cs, Ra, and U

Stratum	^{90}Sr $\bar{x} \pm s$ (pCi/g)	^{90}Sr Significant Difference Above Background[a]	^{137}Cs $\bar{x} \pm s$ (pCi/g)	^{137}Cs Significant Difference Above Background[a]	^{226}Ra $\bar{x} \pm s$ (pCi/g)	^{226}Ra Significant Difference Above Background[a]	U Total $\bar{x} \pm s$ (μg/g)	U Total Significant Difference Above Background[a]	Estimated ^{234}U Concentration Above Bkg. (Assume 7 pci/μg)
Acid Canyon	1.2 ± 1.4 (N=8)	1.0 ± 1.4	2.2 ± 4 (N=6)	1.9 ± 4	1.22 ± 0.48 (N=8)	N.S.	3.45 ± 2.85 (N=8)	1.25 ± 1.03	8.8
Middle Pueblo Canyon	0.48 ± 0.24 (N=6)	N.S.	0.41 ± 0.22 (N=6)	N.S.	1.22 ± 0.45 (N=6)	N.S.	1.9 ± 0.8 (N=6)	N.S.	---
Lower Pueblo Canyon	0.36 ± 0.25 (N=24)	N.S.	0.39 ± 0.46 (N=24)	N.S.	1.29 ± 0.52 (N=24)	N.S.	2.87 ± 1.15 (N=24)	1.07 ± 0.56	7.5
Lower Los Alamos Canyon	0.27 ± 0.19 (N=21)	N.S.	0.59 ± 0.55 (N=21)	0.27 ± 0.18	1.08 ± 0.43 (N=21)	N.S.	3.75 ± 1.16 (N=21)	1.95 ± 0.60	14
Background Soil and Sediment	0.25 ± 0.27 (N=68)		0.32 ± 0.30 (N=76)		2.4 ± 0.8 (N=7)		1.8 ± 1.3 (N=118)		

[a]Value is difference ±95% confidence interval; N.S. means "no significant difference;" significance level α = 0.05.

TABLE E-VI

CANYON CHANNEL PHYSICAL CHARACTERISTICS

Stratum	Arithmetic Mean Width (m) ($\bar{x}$ + s)	Assumed Depth (m)	Length (m)	Stratum Area (m^2)	Projected Canyon Area (m^2)	Proportionate Area [Stratum Area / Canyon Area]
Acid Canyon	-		750	1750	1.21×10^5	
Active Channel				1150		9.5×10^{-3}
−100 m - 0 m	0.5	0.05	100	50		
0 m - 80 m	1.2	0.10	80	96		
80 m - 160 m	1.5	0.15	80	120		
160 m - 650 m	1.8	0.20	490	882		
Banks[a]	0.8	<0.40	750	600		4.9×10^{-3}
Middle Pueblo Canyon			3250		5.65×10^5	
Active Channel	2.2 ± 1.6	0.3		7150		1.3×10^{-2}
Banks[a]	13.3 ± 8.3	0.3		43 200		7.6×10^{-2}
Lower Pueblo Canyon			6050		2.36×10^6	
Active Channel	6.2 ± 6.9	0.3		37 500		1.6×10^{-2}
Inactive Channel	20.7 ± 28.2	0.3		125 000		5.3×10^{-2}
Banks[a]	5.9 ± 3.3	0.3		35 700		1.5×10^{-2}
Lower Los Alamos Canyon			7400		2.13×10^6	
Active Channel	13.6 ± 14.9	0.3		101 000		4.7×10^{-2}
Inactive Channel	20.1 ± 18	0.3		149 000		7.0×10^{-2}
Banks[a]	1.7 ± 1.1	0.3		12 600		5.9×10^{-3}

[a]Value for banks is sum of both sides.

TABLE E-VII

ACTIVITY RATIOS

CURRENT CONDITIONS (1978)		FUTURE CONDITIONS (2050)
$^{241}Am/^{239}Pu$	**Ratio**	**^{241}Am**
Data:		Theoretical Decay and Ingrowth
Samples from Treatment Plant Site (N=7) and Acid Canyon (N=1) Associated with Untreated Waste Outfall	0.022 ± 0.021	^{241}Am (2050) = 0.89 × ^{241}Am (1978) + 0.029 × ^{241}Pu (1978)
Samples from Acid Canyon (N=5) Associated with Treated Waste Outfalls	0.054 ± 0.007	Relation to current ^{239}Pu used for evaluation ^{241}Am (2050) = 0.15 × ^{239}Pu (1978)
Samples from Middle (N=1) and Lower Pueblo Canyon (N=2) from Routine Laboratory Environmental Monitoring Ref. E2	0.21 ± 0.3	
Value Assumed for Evaluation:	0.1	
Typical Worldwide Fallout:	0.25	
$^{241}Pu/^{239}Pu$[a]		**^{241}Pu**
Data:		Theoretical Decay
Samples from Treatment Plant Site (N=3) Associated with Untreated Waste Outfall	0.094 ± 0.004	^{241}Pu (2050) = 0.03 × ^{241}Pu (1978)
Samples from Lower (N=8) and Middle Pueblo Canyon (N=2) Associated with Mixed Effluents	0.76 ± 0.72	Relation to current ^{239}Pu used for evaluation ^{241}Pu (2050) = 0.045 × ^{239}Pu (1978)
Value Assumed for Evaluation:	1.5	
Typical Worldwide Fallout:	4.to 6	
$^{238}Pu/^{239}Pu$		**^{238}Pu**
Data:		Theoretical Decay
Samples from all Strata (N=153)	0.032	^{238}Pu (2050) = 0.57 × ^{238}Pu (1978)
Samples from all Strata (N=148) 5 Outliers deleted	0.018	
Value Assumed for Evaluation:	0.03	Relation to current ^{239}Pu used for evaluation
Typical Worldwide Fallout:	0.024	^{238}Pu (2050) = 0.017 × ^{239}Pu (1978)

[a] ^{241}Pu is primarily a β-particle emitter; the ratios in the Table are for total activity; α activity is about 2.3×10^{-5} of the total.

TABLE E-VIII

ANNUAL AVERAGE ^{239}Pu AIR CONCENTRATIONS
(aCi/m^3) (10^{-12} μCi/m^3)

Location	1974	1975	1976	1977	1978
Bayo Sewage Plant (Bottom of Lower Pueblo Canyon)	27 ± 3	19 ± 2	5.1 ± 1.0	65 ± 240	27 ± 61
Cumbres School (North Rim, Middle Pueblo Canyon)	31 ± 4	15 ± 2	4.0 ± 0.9	13 ± 39	24 ± 47
Los Alamos Airport (South Rim, Lower Pueblo Canyon)	25 ± 2	24 ± 4	6.8 ± 1.1	18 ± 28	20 ± 41
Technical Area 21	23 ± 2	18 ± 2	6.2 ± 1.1	21 ± 32	23 ± 51
Bandelier	32 ± 3	23 ± 2	6.2 ± 1.2	28 ± 58	40 ± 66
Santa Fe	21 ± 2	16 ± 2	3.8 ± 0.8	16 ± 23	24 ± 46
New York City	39	20	6.0	21	32 (1st quarter only)

Values are $\bar{x}$ ± 2 S.D.

Standard deviations for the 1974 and 1975 data represent only the uncertainty in the composited measurement.

Standard deviations for the 1976, 1977, and 1978 data are the standard deviations of the populations of individual period measurements used to compute the annual averages.

TABLE E-IX

AIR CONCENTRATION OF ^{239}Pu IN 1976-1977
(aCi/m³) or (10^{-12} μCi/m³)[a]

	Sample Period					
Begin	12-22-75	2-2-76	3-29-76	5-10-76	6-21-76	8-2-76
End	2-2-76	3-29-76	5-10-76	6-21-76	8-2-76	9-13-76
Location						
Bayo Sewage Plant	6.0 ± 1.3	6.6 ± 1.3	7.4 ± 1.5	8.1 ± 1.4	2.4 ± 1.2	1.6 ± 1.0
Cumbres School	5.7 ± 1.4	4.7 ± 1.2	5.7 ± 1.5	6.5 ± 1.6	0.9 ± 0.9	0.3 ± 0.7
Los Alamos Airport	7.4 ± 1.4	10.3 ± 1.6	12.1 ± 2.2	9.6 ± 1.7	7.0 ± 1.5	1.1 ± 1.0
Bandelier	6.1 ± 1.5	7.4 ± 1.3	9.3 ± 1.7	8.7 ± 1.5	4.9 ± 1.3	0.8 ± 0.8
Santa Fe	3.2 ± 1.1	4.6 ± 1.0	7.5 ± 1.5	7.2 ± 1.4	6.9 ± 1.4	1.1 ± 1.4
New York City	---	4.2	9.9	9.1	5.7	1.9
Chinese Nuclear Tests						

	Sample Period					
Begin	9-13-76	10-26-76	12-20-76	1-31-77	3-28-77	6-20-77	9-12-77
End	10-26-76	12-20-76	1-31-77	3-28-77	6-20-77	9-12-77	12-19-77
Location							
Bayo Sewage Plant	6.1 ± 1.3	2.7 ± 1.3	4.3 ± 1.7	9.0 ± 2.3	26.0 ± 2.0	10.5 ± 1.4	166 ± 6
Cumbres School	5.6 ± 1.5	3.0 ± 1.2	5.4 ± 1.8	4.5 ± 1.5	---	2.3 ± 10	24.4 ± 2.6
Los Alamos Airport	2.6 ± 0.8	4.0 ± 1.1	7.1 ± 4.0	6.4 ± 1.9	22.8 ± 1.9	---	17.7 ± 1.5
Bandelier	6.4 ± 1.9	5.7 ± 2.4	5.6 ± 2.4	8.0 ± 1.8	64.3 ± 4.2	9.9 ± 1.9	27.9 ± 2.9
Santa Fe	3.5 ± 0.8	2.0 ± 1.2	3.2 ± 1.5	10.2 ± 1.6	31.0 ± 3.8	14.0 ± 1.4	12.1 ± 1.2
New York City	4.0	3.3	7.1	7.1	33	27.7	16
Chinese Nuclear Tests	0.2 MT	4 MT					0.02 MT
	26 Sept. '76	17 Nov. '76					17 Sept '77

[a]Values are $\bar{x}$ ± 1 S.D.

TABLE E-X

EXTERNAL PENETRATING RADIATION MEASUREMENTS

Location	1972 TLD Data First Quarter		1973 HPIC Data Second Quarter		1978 GeLi Spectral Analysis	
	μrem/h ($\bar{x} \pm s_{\bar{x}}$)	No. of Sites	μR/h ($\bar{x} \pm s_x$)	No. of Sites	μrem/h	No. of Sites
Treatment Plant Site	19 ± 3	3	---	---	---	---
Acid Canyon	19 ± 3	7	23 ± 4	6	---	---
Middle Pueblo Canyon	16 ± 1	4	20 ± 2	2	---	---
Lower Pueblo Canyon	13 ± 1	3	15	1	---	---
Lower Los Alamos Canyon	12 ± 1	3	---	---	12 ± 1	3
Surveillance Program Perimeter Stations	12 ± 1	12	---	---	---	---

TABLE E-XI

ESTIMATED EXTERNAL RADIATION DOSES BASED ON MEASURED CONTAMINANT CONCENTRATIONS

(μrem/h; whole body, 5-cm-depth dose, ~1 m above surface)

Location	Source of Exposure					
	^{137}Cs		^{234}U		Combined Transuranics	
	Conc.[a] (pCi/g)	Dose (μrem/h)	Conc.[a] (pCi/g)	Dose (μrem/h)	Conc.[a] (pCi/g) of ^{239}Pu	Dose (μrem/h)
Lower Los Alamos Canyon	0.3	0.14	14	0.01	2.3	<0.01
Lower Pueblo Canyon	N.S.	---	7.5	<0.01	6.4	0.02
Middle Pueblo Canyon	N.S.	---	N.S.	---	3.5	<0.01
Acid Canyon	2	1	8.8	<0.01	31	0.09
Treatment Plant Site						
Vehicle Decontamination Facility Area	100	50	800	0.06	41	0.1
Untreated Outfall Area	35	18	3800	2.9	(^{241}Am only) 1000	19

[a]Values are significant difference above background; N.S. means "no significant difference;" significance level $\alpha = 0.05$.

TABLE E-XII

PARAMETERS FOR ESTIMATING RESUSPENSION OF TRANSURANICS USING MASS LOADING

Stratum	$^{239,240}Pu$ Concentration (pCi/g) Data Mean	$^{239,240}Pu$ Concentration (pCi/g) Adjusted for 1 cm Depth	Enrichment Factor ($\Sigma f_i g_i$)	Area Proportion	Estimated Annual Average Air Concentrations ($\mu Ci/m^3$) $^{239-240}Pu$	^{234}U	^{90}Sr	^{137}Cs
Acid Canyon								
Active Channel	30.6	31	2.3	9.5×10^{-3}	2.4×10^{-11}			
Bank	110	121	2.3	4.9×10^{-3}	4.7×10^{-11}			
				$\Sigma =$	7.1×10^{-11}	1.1×10^{-11}	1.1×10^{-11}	2.2×10^{-12}
Middle Pueblo Canyon								
Active Channel	1.10	1.1	2.3	1.3×10^{-2}	1.1×10^{-12}			
Bank	3.48	3.9	2.3	7.6×10^{-2}	2.4×10^{-11}			
				$\Sigma =$	2.5×10^{-11}	---	---	---
Lower Pueblo Canyon								
Active Channel	0.86	0.86	6.2	1.6×10^{-2}	3.0×10^{-12}			
Inactive Channel	5.05	5.6	2.3	5.3×10^{-2}	2.4×10^{-11}			
Banks	6.43	7.1	2.3	1.5×10^{-2}	8.6×10^{-12}			
				$\Sigma =$	3.5×10^{-11}	6.2×10^{-11}	---	---
Lower Los Alamos Canyon								
Active Channel	0.24	0.24	1.9	4.7×10^{-2}	7.5×10^{-13}			
Inactive Channel	0.15	0.17	2.3	7.0×10^{-2}	9.6×10^{-13}			
Banks	2.34	2.6	2.3	5.9×10^{-3}	1.2×10^{-12}			
				$\Sigma =$	2.9×10^{-12}	1.3×10^{-10}	---	2.5×10^{-12}

TABLE E-XIII

ENRICHMENT FACTORS FOR RESUSPENDABLE PARTICULATES

Strata	Size Increment (μm)	Wt. Fraction	^{239}Pu Activity Fraction	Activity Mass Ratio g_i	Airborne Mass Fraction f_i	Enrichment $g_i f_i$	$\Sigma g_i f_i$
Acid Canyon							
−100 to 160 m	53-105	0.03[a]	0.07[a]	2.33	0.35	0.82	
Active Channel	<53	0.03[a]	0.07[a]	2.33	0.65	1.50	2.3
Middle Pueblo Canyon							
Active Channel	53-105	0.03[a]	0.07[a]	2.33	0.35	0.82	
	<53	0.03[a]	0.07[a]	2.33	0.65	1.50	2.3
Lower Pueblo Canyon							
Active Channel	53-105	0.014[a]	0.056[a]	4.00	0.35	1.40	
	<53	0.006[a]	0.044[a]	7.33	0.65	4.76	6.2
Lower Los Alamos Canyon							
Active Channel	53-105	0.03[b]	0.07[c]	2.33	0.35	0.82	
	<53	0.04[b]	0.07[c]	1.75	0.65	1.10	1.9

[a]Data from Ref. E21.

[b]Appendix A Tables A-XXXV and A-XLVII for very fine sand (74 μm-147 μm) and silt and clay (<74 μm).

[c]Lower Los Alamos Canyon stream bed activity fraction assumed from comparison of Lower Los Alamos Canyon weight fractions with Acid Canyon and Middle Pueblo Canyon activity fractions and weight fractions.

TABLE E-XIV

DOSE FACTORS FOR TRANSURANICS
(mrem/μCi inhaled)

Dose Factors	Activity Ratio (to ^{239}Pu Activity)	First Year Dose			50-Year Dose Commitment Factor		
		Whole Body	Bone	Lung	Whole Body	Bone	Lung
Isotope							
^{239}Pu		1.7×10^{2}	7.1×10^{3}	4.8×10^{4}	7.7×10^{4}	3.2×10^{6}	1.7×10^{5}
^{238}Pu		1.9×10^{2}	7.3×10^{3}	5.1×10^{4}	6.9×10^{4}	2.7×10^{6}	1.8×10^{5}
^{241}Pu		7.2	3.6×10^{2}	4.4×10^{1}	1.3×10^{3}	6.4×10^{4}	1.5×10^{2}
^{241}Am		4.2×10^{2}	5.2×10^{3}	3.5×10^{4}	6.7×10^{4}	1.0×10^{6}	6.0×10^{4}
Activity Ratio-Dose Factor Products— Current Conditions (1978)							
^{238}Pu	0.03	5.7	2.2×10^{2}	1.5×10^{3}	2.1×10^{3}	8.1×10^{4}	5.4×10^{3}
^{241}Pu	1.5	1.1×10^{1}	5.4×10^{2}	6.6×10^{1}	2.0×10^{3}	9.6×10^{4}	2.3×10^{2}
^{241}Am	0.1	4.2×10^{1}	5.2×10^{2}	3.5×10^{3}	6.7×10^{3}	1.0×10^{5}	6.0×10^{3}
Future Conditions (2050)							
^{238}Pu	0.017	3.2	1.2×10^{2}	8.7×10^{2}	1.2×10^{3}	4.6×10^{4}	3.1×10^{3}
^{241}Pu	0.045	3.2×10^{-1}	1.6×10^{1}	2.0	5.9×10^{1}	2.9×10^{3}	6.8
^{241}Am	0.15	6.3×10^{1}	7.8×10^{2}	5.3×10^{3}	1.0×10^{4}	1.5×10^{5}	9.0×10^{3}
Summed Products as Proportion of ^{239}Pu Dose Factor							
Current Conditions (1978)		0.34	0.18	0.11	0.14	0.09	0.07
Future Conditions (2050)		0.39	0.13	0.13	0.15	0.06	0.07
Ratio Future Conditions/ Current Conditions		1.04	0.96	1.02	1.01	0.97	1.00

TABLE E-XV

DOSE ESTIMATES FOR INHALATION OF TRANSURANICS ON RESUSPENDED DUST

	Acid Canyon	Middle Pueblo Canyon	Lower Pueblo Canyon	Lower Los Alamos Canyon
^{239}Pu				
Average Air Concentration (μCi/m^3)	7.1×10^{-11}	2.5×10^{-11}	3.6×10^{-11}	2.9×10^{-12}
Annual Intake (μCi) (at 8.45×10^3 m^3/yr)	6.0×10^{-7}	2.1×10^{-7}	3.0×10^{-7}	2.4×10^{-8}
^{239}Pu Doses (mrem)				
First Year				
Whole Body	1.0×10^{-4}	3.6×10^{-5}	5.0×10^{-5}	4.1×10^{-2}
Bone	4.2×10^{-3}	1.5×10^{-3}	2.1×10^{-3}	1.7×10^{-4}
Lung	2.9×10^{-2}	1.0×10^{-2}	1.4×19^{-2}	1.2×10^{-3}
50-Year Commitment				
Whole Body	4.6×10^{-2}	1.6×10^{-2}	2.3×10^{-2}	1.9×10^{-3}
Bone	1.9×10^{0}	6.7×10^{-1}	9.4×10^{-1}	7.8×10^{-2}
Lung	1.0×10^{-1}	3.6×10^{-2}	5.0×10^{-2}	4.1×10^{-3}
Total Transuranics Doses (mrem)				
Doses (mrem)				
First Year				
Whole Body	1.4×10^{-4}	4.8×10^{-5}	6.7×10^{-5}	5.5×10^{-6}
Bone	5.0×10^{-3}	1.8×10^{-3}	2.5×10^{-3}	2.0×10^{-4}
Lung	3.2×10^{-2}	1.1×10^{-2}	1.6×10^{-2}	1.3×10^{-3}
50-Year Commitment				
Whole Body	5.2×10^{-2}	1.8×10^{-2}	2.6×10^{-2}	2.1×10^{-3}
Bone	2.1	7.3×10^{-1}	1.0	8.5×10^{-2}
Lung	1.1×10^{-1}	3.8×10^{-2}	5.3×10^{-2}	4.4×10^{-3}

TABLE E-XVI

DOSE ESTIMATES FOR INHALATION OF U, Cs, and Sr ON RESUSPENDED DUST

	Acid Canyon	Lower Pueblo Canyon	Lower Los Alamos Canyon
^{234}U			
Average Air Concentration ($\mu Ci/m^3$)	1.1×10^{-11}	6.2×10^{-11}	1.3×10^{-10}
Annual Intake (μCi) (at 8.4×10^3 m^3/yr)	9.2×10^{-8}	5.2×10^{-7}	1.1×10^{-6}
Doses (mrem)			
First Year			
Whole Body	1.9×10^{-5}	1.1×10^{-4}	2.3×10^{-4}
Bone	1.5×10^{-4}	8.3×10^{-4}	1.7×10^{-3}
Lung	2.8×10^{-3}	1.6×10^{-2}	3.3×10^{-2}
50-Year Commitment			
Whole Body	6.0×10^{-5}	3.4×10^{-4}	7.1×10^{-4}
Bone	9.2×10^{-4}	5.2×10^{-3}	1.1×10^{-2}
Lung	4.8×10^{-3}	2.7×10^{-2}	5.7×10^{-2}
^{90}Sr			
Among Air Concentrations ($\mu ci/m^3$)	1.1×10^{-12}	---	---
Annual Intake (μCi)	9.2×10^{-9}	---	---
Doses (mrem)			
First Year			
Whole Body	7.6×10^{-8}	---	---
Bone	1.1×10^{-6}	---	---
Lung	6.4×10^{-6}	---	---
50-Year Commitment			
Whole Body	7.0×10^{-6}	---	---
Bone	1.1×10^{-4}	---	---
Lung	1.1×10^{-5}	---	---
^{137}Cs			
Average Air Concentration	2.2×10^{-12}	---	2.5×10^{-12}
Annual Intake (μCi)	1.8×10^{-8}	---	2.1×10^{-8}
Doses (mrem)			
First Year			
Whole Body	5.9×10^{-7}	---	6.7×10^{-7}
Bone	5.9×10^{-7}	---	6.7×10^{-7}
Lung	9.4×10^{-8}	---	1.1×10^{-7}
50-Year Commitment			
Whole Body	1.0×10^{-6}	---	1.1×10^{-6}
Bone	1.1×10^{-6}	---	1.3×10^{-6}
Lung	1.7×10^{-7}	---	2.0×10^{-7}

TABLE E-XVII

TREATMENT PLANT SITE DOSE FROM ABRASION WOUND

Isotope	Concentration on Soil (pCi/g)	Amount in Blood (pCi)	Dose (mrem) First Year Bone	Dose (mrem) First Year Liver	Dose (mrem) 50-Year Commitment Bone	Dose (mrem) 50-Year Commitment Liver
^{238}Pu	4900	0.0033	0.0083	0.0016	0.17	0.034
^{239}Pu	163 000	0.11	0.28	0.054	5.3	1.1
^{241}Am	3600	0.0036	0.0094	0.0019	0.18	0.037
		Totals	0.3	0.057	5.6	1.2

TABLE E-XVIII

DOSES TO A CONSTRUCTION WORKER

Isotope	Assumed Soil Concentration (pCi/g)	Dose (mrem) First Year Bone	Dose (mrem) First Year Lung	Dose (mrem) 50-Year Dose Commitment Bone	Dose (mrem) 50-Year Dose Commitment Lung
Lower Pueblo Canyon					
^{239}Pu	7.0	0.19	1.3	83	4.4
^{241}Am	1.5	0.03	0.19	5.4	0.32
^{234}U	7.5	0.04	0.84	0.28	1.5
Total mrem		0.26	2.3	89	6.2
Treatment Plant Site					
^{239}Pu	41	0.18	1.2	80	4.3
^{241}Am	0.9	0.003	0.019	0.54	0.032
^{234}U	40	0.036	0.65	0.23	1.1
^{90}Sr	205	0.014	0.084	1.4	0.14
^{137}Cs	130	0.003	4×10^{-4}	0.005	7.3×10^{-4}
Total mrem		0.24	2.0	82	5.6

TABLE E-XIX

LOWER PUEBLO CANYON INHALATION DOSES FROM GARDENING

Isotope	Assumed Soil Concentration (pCi/g)	Dose (mrem) First Year Bone	First Year Lung	50-Year Commitment Bone	50-Year Commitment Lung
Ingestion Doses from Soil Preparation					
^{239}Pu	3.5	0.048	0.33	21	1.1
^{241}Am	0.75	0.007	0.048	1.4	0.08
^{234}U	3.8	0.011	0.21	0.07	0.38
Total		0.066	0.59	22	1.6

Isotope	Quantity Ingested (pci)	Bone Dose (mrem) First Year	50-Year Commitment
Ingestion Dose from Produce Consumption			
^{239}Pu	41	3.5×10^{-4}	0.032
^{241}Am	8.7	8.1×10^{-5}	0.007
^{234}U	440	0.12	0.37
Total		0.12	0.41

APPENDIX F

EVALUATION OF RADIATION EXPOSURES

I. INTRODUCTION

This appendix provides additional background on some of the technical aspects of radiation and its effects. It will familiarize the interested reader with the concepts and terminology used in the evaluations presented in the main body of this report and other appendixes. It is not comprehensive in that other concepts and terminology applicable to other circumstances are not included. A short bibliography is included at the end for those desiring to read further.

Examples of data and interpretation from the report are used to illustrate the discussions in this appendix. Sections of the main report giving data and evaluations are noted.

II. RADIATION

Radiation is the transmission of energy through space. There are many kinds of radiation including visible light, microwaves, radio and radar waves, and x rays. All of these are electromagnetic radiations because they consist of a combined electrical and a magnetic impulse traveling through space. Much of this radiation is vital to us. For example, light is necessary so that we can see. These radiations can also be harmful: too much ultraviolet radiation from the sun can cause sunburn or even skin cancer on prolonged exposure. Energy can also be transmitted through space by particulate radiations by virtue of their motion. Some of the most common particulate radiations include alpha particles, beta particles, and neutrons. The first two were given names of the first letters of the Greek alphabet by their discoverers as a convenient way of designating them. It turns out that the beta particle is an electron. The electron is the fundamental negative charge in all matter and is responsible for electric currents. However, beta particles are electrons moving at very high speeds, even approaching the speed of light. The other particulate radiations are also fundamental particles from atoms.

The class of radiation important to this report is ***ionizing radiation.*** Ionizing radiations are either waves or particles with sufficient energy to knock electrons out of the atoms or molecules in matter. This disruption is termed "ionization."

The simplest example is the ionization of a single atom. The ***nucleus***, or center of the atom, is composed of particles called protons and neutrons. The ***proton*** has a positive charge and the ***neutron*** has no charge. Negatively charged particles called ***electrons*** orbit around the nucleus and are held in place by the attraction between the positive and negative charges. A simple analogy to this is the planets in orbit around the sun held in place by gravitational attraction. In a neutral atom there are exactly the same number of electrons as protons and the positive and negative charges are balanced. When ionizing radiation knocks an electron out of an atom, the atom is left with a positive charge, and the free electron is negatively charged. These two are referred to as an "ion pair." ***Ion pairs*** are chemically active and will react with neighboring atoms or molecules. The resulting chemical reactions are responsible for causing changes or damage to matter, including living tissue.

This brief description covers the basic concepts of radiation and its effects. The rest of the discussion will elaborate on particular aspects: the types and sources of ionizing radiation, the basic units for measuring energy deposited in matter by ionization, ways to estimate the amount of biological effect and its significance, and the nature of radiation standards.

III. TYPES OF IONIZING RADIATION

The most common types of ionizing radiation are x rays, gamma rays, alpha particles, beta particles, and neutrons.

A. X and Gamma Radiation

X rays are pure energy having no mass. They are part of the electromagnetic spectrum, as are light and microwaves, but with much shorter wavelengths and, therefore, the ability to transmit larger amounts of energy. ***Gamma rays*** are identical to x rays except that they originate in the nucleus of an atom, whereas x rays are produced by interactions of electrons. An x or gamma ray, having no electrical charge to attract or repel it from the protons or electrons, can pass through the free space in many atoms and, hence, through relatively thick materials before interacting. The most likely interaction occurs when the x or gamma ray encounters an electron. When this occurs, some or all of the energy of the x or gamma ray will be transferred to the electron, which then will be ejected from the atom. The electron may have enough energy that it can, in turn, produce additional ionizations in other atoms it passes through. The electron, once its energy is spent, becomes a free electron (an electron not directly associated with an atom) found in all matter.

B. Alpha Radiation

Alpha particles are made up of two neutrons and two protons. This combination is the same as the nucleus of a helium atom. Because of the two protons, with no negative electrons to balance their positive charge, the alpha particle is positively charged. Alpha particles transmit energy as kinetic energy, or the energy of motion. The faster they move, the more energy they carry.

The comparatively large size and the positive charge of an alpha particle mean that it interacts readily with electrons and will not slip through the spaces between the atoms easily. It causes many ionizations in a short distance of travel. Because each of these ionizations dissipates energy, the alpha particle travels only a very short distance. For example, most alpha particles will not pass through a piece of paper or the protective layer on a person's skin. However, if an alpha particle is produced by radioactive material inside the body, it may cause many ionizations in more sensitive tissue.

C. Beta Radiation

Beta particles are electrons moving at high speeds. They transmit energy as kinetic energy. High energy electrons approach the speed of light. They have comparatively small mass and a negative charge, so their penetration through matter is intermediate between the alpha particle and the gamma ray. They produce fewer ionizations along their path than the alpha particle, but

more than gamma radiation. They can be absorbed by a sheet of rigid plastic or a piece of plywood. However, they can pass through the protective outer layer of the skin and reach the more sensitive skin cells in lower layers. They can irradiate internal tissues if produced by radioactive materials inside the body.

D. Neutrons

Neutrons are the particles that, with protons, form the nuclei of atoms. When free from the nucleus, they can transmit energy as kinetic energy. There are two major types of neutrons, fast and slow. Fast neutrons are moving rapidly and, when they strike a nucleus of an atom, they will give up some of their energy. With heavy nuclei such as those of lead, little energy is lost because the neutron rebounds. However, with light nuclei, such as those of hydrogen (hydrogen has one proton with the same mass as a neutron), the neutron undergoes a "billiard ball" type of collision with considerable energy transferred to the proton. The proton then moves through surrounding matter, producing less ionization than an alpha particle, but more than a beta particle.

Slow neutrons do not have enough energy to cause ionization. But, because they have no charge, they can penetrate into the nucleus of an atom. This disrupts the balance in the nucleus and can result in the emission of radiations that produce ionization in the surrounding matter. One example of this is the transmutation of certain atoms of uranium into atoms of plutonium.

IV. SOURCES OF RADIATION

Radiation arises from radioactivity, both natural and man-made, cosmic sources, and radiation-producing machines. In this report, the sources of interest include cosmic radiation and natural radioactivity, which both contribute to normal background, and man-made or technologically enhanced radioactivity, which contribute radiation in addition to background. This report does not address the production of radiation by devices such as x-ray machines or accelerators.

A. Radioactivity

The atoms of most familiar things are structurally the same as when they were formed and have little prospect of changing. Thus, most atoms of carbon in a tree or in our bodies will remain atoms of carbon. In time, an atom may change its association with other atoms in chemical reactions and become part of other compounds, but it will still be a carbon atom.

There is a class of atoms, however, which are not stable and will spontaneously emit radiation and change to another type of atom or element. These atoms are said to be ***radioactive***.

Many radioactive atoms such as isotopes of uranium and radium, ^{40}K (potassium-40), and ^{14}C (carbon-14) occur naturally. In the cases of potassium and carbon, only certain proportions of the naturally occurring elements are radioactive and are known as ***radioactive isotopes.*** (The radioactive isotopes have the same number of protons in the nucleus as do the stable isotopes and, therefore, the same chemical properties. However, the radioactive isotopes have a different number of neutrons than the stable atoms. A particular radioactive isotope is symbolized by the letter symbol for the chemical element with a numerical superscript representing the total number of protons and neutrons in the nucleus. See Table F-I for the symbols and names of isotopes of concern in this report.)

Many radioactive atoms can also be "man-made" in the sense that ^{137}Cs, ^{90}Sr, and radioactive isotopes of plutonium can be produced in large quantities during nuclear fission of uranium in a reactor. However, these isotopes are also produced during the normal spontaneous fissioning of uranium in nature. The difference is that in nature the reaction happens at a slow enough rate that the number of naturally produced radioactive atoms of cesium, strontium, and plutonium is small and dispersed. Other man-made radioactive elements produced in nuclear reactors or by accelerators are not normally present in nature.

Unstable radioactive atoms attempt to achieve a more stable state by spontaneously ***decaying*** to alter the ratio of protons and neutrons in the nucleus toward a more stable condition.

Radioactive atoms decay at a characteristic rate dependent upon the degree of stability of the individual atom. The rate is characterized by a period of time called the ***half-life***. In one half-life, one-half of the initial number of atoms decay. The amount of radiation emitted also decreases by one-half in the same period. In the next half-life, the number of atoms and the amount of radiation will again decrease by one-half, down to one-quarter of the original amount. Half-lives are unique for each particular type of radioactive atom: that is, each isotope has its own half-life that cannot be changed by man. Half-lives for different radioactive materials range from a fraction of a second to billions of years. In fact, some are so long that certain radioactive materials made at the time of the formation of the universe are still around. Examples include some isotopes of thorium and uranium.

When an atom decays, radiation may be emitted from the nucleus as alpha particles, beta particles, neutrons, or gamma rays. This changes the character of the nucleus, and the atom changes to an atom of a new element. (One particular type of decay, known as fission, results in the production of two new atoms.) Each type of radioactive atom decays with emission of characteristic types of radiation, each carrying specific amounts of energy. For example, natural ^{234}U always emits alpha particles with energies of about 4.8 relative energy units, and man-made ^{239}Pu emits alpha particles with energies of about 5.1 relative energy units. Other than the slight difference in the initial amount of energy, the alpha particles are indistinguishable.

Atoms resulting from radioactive decay are called "daughter" atoms, whereas the original atom is called the "parent" atom. In some cases, the daughter atom resulting from the decay of a radioactive atom is, itself, radioactive. For naturally occurring uranium and thorium, there may be a sequence of as many as 12-14 radioactive daughters before the original uranium or thorium atom finally reaches stability as an atom of lead.

Table F-I lists the radioactive materials of primary importance to this report giving the half-lives and the principal types of radiation they emit during decay.

B. Cosmic Radiation

The high-energy radiations that enter the earth's atmosphere from outer space are known as ***primary cosmic rays***. The origin of primary cosmic rays is still not completely determined, but most of the observed radiation originates in our galaxy. Some is produced by solar flares. Primary galactic cosmic rays are largely high-energy protons. Primary solar cosmic rays have relatively low energy and have little effect at the earth's surface.

When primary cosmic ray particles enter the atmosphere, a complex variety of reactions occur, especially with oxygen and nitrogen nuclei. These reactions result in the continuous production of radioactive elements including tritium, ^{7}Be (beryllium-7), ^{14}C, and ^{22}Na (sodium-22) among many others. The reactions also result in the production of neutron and beta particle radiation, referred to as secondary cosmic radiation. The amount of radioactivity and radiation from cosmic rays increases significantly with altitude above sea level because of the decreasing thickness of

the atmosphere. The influence of the earth's magnetic field results in more cosmic radiation in polar latitudes responsible for the so-called northern and southern lights.

V. UNITS FOR RADIATION AND RADIOACTIVITY

Units to quantify radiation or radioactivity provide for uniformity in measurements or comparisons and permit the establishment of standards specifying the amount of radiation allowable under various circumstances. Radiation units may initially seem obscure and difficult to understand. However, as in the case of the pound or kilogram, familiarity with the units makes them understandable and useful.

A. Radiation Units

The basic unit for measuring radiation is the ***rad***. It is the amount of radiation that deposits a specified amount of energy by ionization in each gram of material (about 1/28 of an ounce). The amount of energy released in the material is small: it increases the temperature of the gram of material by a few billionths of a degree. However, it is not the amount of heat liberated or the temperature rise that is important. Rather, it is the ionization that induces chemical changes. The rad applies to all radiations and all materials that absorb the radiation.

The most commonly used radiation unit is the ***rem***. The rem quantifies the biological response to radiation rather than the amount of energy delivered to the tissue. To understand this, remember that different types of radiation produce ionizations at different rates as they pass through tissue. The alpha particle travels only a short distance causing intense closely-spaced ionization along its track. The beta particle travels much farther causing much less ionization in each portion of its track. Therefore, the alpha particle is more damaging to tissue than the beta particle for the same number of ionizations because the damage to cells in the tissue is localized. The biological effectiveness of the alpha particle is greater than that of the beta particle for the same total amount (rads) of energy deposited, and this difference is accounted for by the use of appropriate factors. In general, the factors used are 1 for x or gamma radiations and most beta particles, 5 to 10 for neutrons, and 10 to 20 for alpha particles. The rem is defined as the amount of radiation (in rads) from a given type of radiation multiplied by the factor appropriate for that type of radiation to approximate the biological damage that it causes. Thus, 1 rad of energy from gamma rays would result in 1 rem, and 1 rad from alpha particles would result in 10 to 20 rem of dose. Because the approximate relative degree of damage from each of the types of radiation is known, the rem can measure the approximate biological effect. Within these limits of uncertainty, the rem permits evaluation of potential effects without regard to the type of radiation or its source. One rem of exposure from natural cosmic radiation results in the same biological consequences as 1 rem from medical x rays or 1 rem from radiation produced by decay of either natural or man-made radioactivity.

A frequent source of confusion encountered in the use of radiation units is their application to a standard weight of tissue, rather than all of the tissue irradiated. Thus, a person can receive one rad or one rem of radiation from an x ray of the teeth, where little tissue is irradiated; from a chest x ray, where a moderate amount of tissue is irradiated; or from full body radiation, where all tissue in the body is irradiated. Although these are all 1 rem of radiation, the effects will be different depending upon the organs involved. Thus, one must always keep in mind the portion of the body or organs involved and make comparisons only for corresponding exposures. In this report, radiation doses were evaluated for the whole body, for the lungs, and for bone. Whole body doses must be compared only to other whole body doses or to whole body dose standards, and so on.

Because many of the radiation doses discussed in this report were small, the metric prefixes ***milli*** for "one-thousandth" (1/1000 or 0.001, symbolized as "m") or ***micro*** for "one-millionth" (1/1000 000 or 0.000001, symbolized "μ") were often used. One million microrem (μrem) = 1000 millirem (mrem) = 1 rem. Millirem (mrem) are used exclusively in the rest of this appendix to simplify comparisons.

In some cases, radiation measurements are expressed as a dose rate, or the amount of radiation received in a unit of time. For example, some instrument measurements of background are reported in "microrem per hour" or μrem/h. To get total dose, the rate is multiplied by the time of exposure. This is conceptually similar to multiplying speed (rate of travel, say in miles per hour) by time to get total distance travelled.

Dose or ***dose rate*** may be expressed using rads or rems, depending on whether the reference is to energy deposited or to biological effect.

B. Radioactivity Units

The basic unit for measuring the amount of radioactivity or quantity of radioactive material is the ***curie***, named in honor of Madame Curie. The curie (abbreviated Ci) is the amount of radioactive material in which 37 000 000 000 (37 billion) atoms are decaying each second. This apparently peculiar number is the approximate number of atoms decaying each second in 1 gram of pure radium, the element discovered by Madame Curie. The mass of material in a curie varies from one isotope to another. The different half-lives of each radioactive material are the main cause for this variation. For materials with short half-lives, a large fraction of the atoms present are decaying in any given second, and the weight of one curie is small. For radioactive materials with long half-lives, the weight of one curie will be large. For example, the weight of one curie of naturally occurring ^{40}K is about 310 pounds, or about 140 000 times as much as one curie of radium.

The curie is a relatively large quantity of radioactivity for most purposes of this report. Accordingly, the metric prefixes are used to indicate units in fractional parts of a curie, such as microcurie or picocurie. The units used most often in the report are summarized in Table F-II.

The text often discusses radioactivity in environmental media, such as air or soil. In these cases, radioactivity is reported as a ***concentration***, or the amount of radioactivity in or associated with a certain amount of air or soil. Much of the information on radioactivity in soils is reported as ***picocuries per gram*** (abbreviated pCi/g) of some particular radioactive isotope. This means that there are a certain number of picocuries of the isotope associated with each gram (454 grams = 1 pound) of soil. For example, a value of 2 pci/g means that each gram of soil has an associated radioactivity of about 4.4 decays each minute. Concentrations of radioactivity in air are generally reported as ***attocuries per cubic meter*** (abbreviated aCi/m^3). This means that there are a certain number of attocuries of a radioactive isotope dispersed throughout the volume of air equivalent to a cube 1 meter on each side (1 meter = 1.09 yards). For example, a value of 3 aCi/m^3 would mean that a cubic meter of air contains radioactivity of about 3.6 decays in a year.

VI. DETERMINING HOW MUCH RADIATION IS RECEIVED

Radiation doses can be received from sources external to the body, such as cosmic radiation or radiation produced by radioactivity in the earth. Radiation doses can also be received from radiation produced by radioactivity taken into the body by inhalation or ingestion. These two modes of exposure are important in this study in terms of both normal doses from background radiation or

radioactivity and incremental doses attributable to residual contaminants. Table F-III summarizes the dose information discussed in this section. The table is broken up into three sections: the top section gives data on doses that affect the whole body; the bottom two sections give data on doses that affect bone or lungs, respectively. Headings permit locating doses for the Los Alamos area, including those attributable to contaminants in the canyon areas, or for the United States as a whole. Values for the United States population were taken from the first three reports listed in the bibliography.

The important distinction between radiation and radioactivity must be emphasized at this time to avoid confusion. When radiation interacts with a person's body, it is quickly dissipated as ionization and eventually heat. However, radioactive materials can enter a person's body and remain there for some period of time, emitting radiation. Thus, it is incorrect to say that there is "radiation in a person's body." It is correct to say the person has radioactive material in his body and radiation is emitted from these radioactive materials.

A. External Penetrating Radiation

Normal external penetrating radiation doses come primarily from natural terrestrial sources or natural cosmic sources. These doses affect the entire body, including all internal organs.

1. Natural Terrestrial Sources. The radioactivity in rocks, soils, and other natural materials arises primarily from three sources: uranium and its daughters (such as radium), thorium and its daughters, and potassium. There are many other natural radioactive materials, but their contributions to human dose are small. The amount of gamma radiation from these sources varies in different parts of the country depending upon the amounts of natural radioactivity in the soil. The average for the coastal plain is about 15 mrem per year, for the noncoastal plain excluding the Colorado plateau area it is about 30 mrem per year, and for the Colorado plateau area it is about 60 mrem per year. There are, however, variations within these averages with higher values in given localities. For example, radiation up to 100 mrem per year from soils and rocks has been measured in central Florida and in the granitic regions of New England. In India and Brazil, terrestrial radiation reaches several hundred mrem per year over large regions and even higher values in smaller parts of these regions.

Measurements in the Los Alamos area indicate an average of about 57 mrem per year from natural terrestrial sources (see Table F-III). Because of the variety of geologic formations in the area, the range is from about 30 to about 90 mrem per year. Thus, the average is about 40% higher than for the U.S., as a whole, but the range is less than for the U.S.

The same natural radioactive materials, especially uranium and thorium, are responsible for penetrating radiation doses from masonry structures that are frequently higher. A United Nations study reports doses average about 30% higher inside masonry structures than outdoors. Conversely, structures of wood or metal materials afford some shielding and may reduce indoor doses from natural terrestrial radioactivity by 25% compared to outdoor doses.

2. Natural Cosmic Sources. As previously discussed, cosmic radiation arises primarily from space outside of our solar system. The atmosphere provides some shielding, but there is a definite increase in cosmic ray intensity as one goes to higher altitudes. At sea level, cosmic rays including cosmic neutrons, produce about 30 mrem a year. At the altitude of Denver, Colorado (5000 ft), they produce about 55 mrem per year, and at Leadville, Colorado (10,000 ft), they produce about 120 mrem per year.

At Los Alamos (7200 ft) cosmic radiation produces doses of about 77 mrem a year (see Table F-III). Airline travel at even higher altitudes can result in doses of 0.2 to 0.3 mrem per hour or 1.5 to 2 mrem total for a single transcontinental trip.

3. Medical Diagnostic X Rays and Other Man-Made Radiation. People receive man-made radiation from a number of sources. By far, the most important are medical procedures, including diagnostic x rays and the medical use of radioactive isotopes. The average annual whole-body dose to a resident of the U.S. from diagnostic medical procedures is estimated at 70 to 90 mrem per year, or an amount about equal to normal background radiation.

Other sources of man-made or man-enhanced radiation, including television, smoke detectors, luminous dial watches, mining and milling of phosphate, and burning coal and natural gas add 2 to 5 mrem per year.

4. Residual Contaminants in Los Alamos. Some of the residual radioactivity at the former Treatment Plant Site and in the canyon channels emit penetrating radiation. This radiation results in doses to people while they are in the immediate vicinity of the contaminants. The maximum dose rates that would result from continuous occupancy of these sites were measured or estimated from 0.1 to 9.6 mrem per year in the canyon areas. In two localized areas within the old plant site, doses could range up to 60 mrem a year (see Table F-III).

B. Radiation From Internally Deposited Radioactivity

Many radioactive materials, both natural and man-made, can be incorporated into tissues because their chemical properties are identical or similar to other stable isotopes in the tissues. For example, 0.012% of natural potassium is the radioactive isotope ^{40}K. The radioactive portion of potassium is incorporated into plant and animal tissues in the same manner as the stable potassium isotopes because the chemical properties are identical. Radioactive ^{90}Sr, which results from nuclear fission, can be incorporated in tissues because its chemical behavior is similar to that of calcium. Once such radioactive isotopes are deposited in biological tissue, they emit radiation that results in an internal dose to the organ or organism. An important point is that internally deposited alpha emitters can be significant because the alpha particle radiation is emitted directly into tissue, whereas external alpha particle radiation is stopped by the outermost skin layers.

1. Pathways. Although radiation from internally deposited radioactivity causes the same ultimate effects as external penetrating radiation, the evaluation is more complex. This is because the physical and chemical processes that govern movements of the materials in nature and biological systems must be considered. The evaluation of movements of materials by such processes as dispersion in the atmosphere, transport in water, uptake in plants or animals, and, ultimately, the biochemistry of the human body is often termed ***pathway analysis***. There is nothing unique to pathway analysis of radioactive materials; the methods and principles are equally applicable to movements of natural substances and nonradioactive pollutants.

The major types of environmental pathway analyses considered in the radiological survey were resuspension, hydrologic transport, and food chains. These are all ways of transporting contaminants to the human body.

Resuspension encompasses various mechanisms, such as wind or mechanical disturbance, for making particles of dust and soil airborne. Once airborne, the particles and any contaminants on

them, are potentially available for inhalation. The resuspension evaluations are summarized in Chapter 4, Sec. II.B, and explained in more detail in Appendix E, Sec. III.C.1.

Hydrologic transport encompasses movement of materials dissolved in water and movement of materials attached to sediments. Such movements can make contaminants available for ingestion with drinking water and uptake in plants or animals or can redistribute sediments to different locations. Hydrologic transport analyses are summarized in Chapter 5, Sec. II, and Appendix E, Sec. III.C, and are documented in detail in Appendix A.

Food chains encompass the movement of materials through natural biological systems. A typical sequence starts with plants taking up materials from soil or water during natural plant growth or gardening. The next step could be ingestion of plant material by cattle or fish, followed by ingestion of beef or fish by humans. Food chain analyses are summarized in Chapter 5, Sec. II, and are explained in more detail in Appendix E, Sec. III.C.

Once environmental pathways have made materials available for entry into the human body, the analysis must determine how the substances of concern will be assimilated within the body. This requires an understanding of the complex biochemistry of the body to determine where particular substances will be deposited and how long they will be retained. For example, both strontium and plutonium can ultimately be preferentially deposited in bone and are then retained for long periods. However, the amount deposited depends strongly on the chemical form of the element and whether the materials gain entry by inhalation or ingestion. For the same amounts of radioactivity, strontium is deposited to a greater degree when entry is by ingestion, and plutonium is deposited to a greater degree when inhaled.

Internally deposited radioactivity gives off radiation, and thereby produces doses as long as it is in the body. Accordingly, doses delivered must be accounted for over a period of time beyond the period during which the radioactivity was ingested or inhaled. This was done by two methods in the radiological survey: the calculation of 50-year dose commitments resulting from intake during the first year, and the calculation of a maximum year dose resulting from continuous intake.

The ***50-year dose commitments*** represent the total dose accumulated in the body or specific organs over a 50-year period because of ingestion or inhalation of radioactivity during the first year. The 50-year commitments are always as large as or larger than 1st-year doses. In this summary, only the 50-year commitments are compared to the standards.

Conceptually, this is in agreement with the recommendations of the International Commission on Radiological Protection (ICRP), and, in effect, for regulatory purposes charges the entire dose commitment against the year in which exposure occurs. The use of the 50-year dose commitment also permits making estimates of risk over a lifetime from the given exposure and simplifies comparisons between different exposure situations.

The dose commitments were calculated using published factors from references currently used in regulation. The mathematical dose models employed in the derivation of these factors were based primarily upon recommendations of the International Commission on Radiological Protection.

Other methods of computing doses are available, and some are considered more up-to-date in terms of utilizing the best current understanding of the behavior of isotopes within the body. Additionally, there are conceptually different approaches that emphasize the dose at the time of maximum dose rate following exposure as the basis for comparison with standards. This is significant for isotopes such as plutonium that accumulate in certain parts of the body and can lead to a constantly increasing dose rate under conditions of chronic exposure. One such approach has been proposed by the EPA as guidance for Federal agencies in regard to plutonium. This approach was used as an alternative means of evaluating potential doses from continuous occupancy of one canyon area.

These other approaches do not result in dose estimates or comparisons with standards for the radionuclides of concern sufficiently different from the methods used in this report to make any significant difference in the conclusions drawn. For example, under conditions of chronic exposure to airborne ^{239}Pu, the dose in the year of maximum dose rate (taken to be the 70th year) calculated by alternate methods gave estimates ranging from about 1/4 (for bone) to 2.6 (for lung) times the values given in this report (see Chapter 5, Sec. I, and Appendix E, Sec. III.C.). These differences are of about the same magnitude as other uncertainties in the data (see Chapter 4, Sec. I.D) and are smaller than some of the intentionally overestimated assumptions (see Chapter 4, Sec. II.B) incorporated into this evaluation. Thus, there would be no significant changes in the relative ranking or general magnitude of estimated doses and risks if other methodologies were used.

2. Radiation from Natural Radioactivity. The most prominent internal natural radioactive material in the body is the radioactive isotope of potassium. Potassium is one of the elements needed to sustain life. Potassium-40 is distributed throughout the body and contributes about 17 mrem per year to the whole body. Other natural radioactivity taken in with food or air add enough radiation to bring the total whole body dose to about 27 mrem per year (see Table F-III).

Some natural radioactive materials tend to concentrate in particular parts of the body. For example, radium and its daughters concentrate in bone and contribute a major part of the approximately 47 mrem per year bone dose.

Radon, a natural radioactive gas given off by all terrestrial materials including soil and masonry products, is the largest contributor to internal lung doses (see Table F-III). Radon is inhaled with air and decays by alpha particle radiation through a chain of other radioactive daughters that contribute doses as they, in turn, decay. Concentrations of natural radon in the air can be greatly increased in masonry structures or in tightly sealed structures where dilution by ventilation air exchange is low.

3. Radiation from Worldwide Fallout Radioactivity. Radioactive materials released by atmospheric nuclear weapons testing have been dispersed worldwide and deposited on soils everywhere. By various pathways including resuspension and food chains, small amounts of such radioactivity are incorporated into every human body. The average dose from worldwide fallout radioactivity to the population in the United States for the whole body is about 4.4 mrem a year. For lungs and bones, the doses are less than about 1% of doses from natural materials, as shown in Table F-III.

4. Radiation from Residual Contaminants. Internal doses potentially resulting from the residual contaminants at the treatment plant site and in the canyon channels were evaluated for a variety of pathways. The ranges of the estimates for both general canyon occupancy and specific maximum case scenarios are summarized for whole body, bone, and lung in Table F-III. Summary discussions of the results are in Chapters 1 and 5, Sections II and III. They are explained in detail in Appendix E, Section III.

VII. POTENTIAL HARM OR RISK FROM RADIATION

The damage done by radiation results from the way it affects molecules essential to the normal function of body cells. Four things may happen when radiation strikes a cell.

1. It may pass through the cell without doing any damage.

2. It may damage the cell, but the cell partially repairs the damage. (The ability of a cell to repair some of the damage from radiation explains why a given dose of radiation delivered in small amounts over a long period of time is generally believed to be less damaging than the same total dose given all at once.)

3. It may damage the cell so that the cell fails to repair itself and reproduces in damaged form over a period of years.

4. It may kill the cell.

The death of a single cell may not be harmful, but serious problems occur if so many cells are killed in a particular organ than the organ no longer can function properly. Incompletely or incorrectly repaired cells may, over a period of time, produce delayed health effects such as cancer, genetic mutations, or birth defects.

Radiation at high enough doses will kill in a short time. The lethal dose is estimated to be 400 000 to 500 000 mrem for gamma radiation with death occurring in 10-30 days. However, the public is seldom, if ever, subjected to such high doses. We will, therefore, concentrate our attention on the effects that occur later—cancer and genetic effects.

A. Cancer

Information on the induction of cancer in humans arises from several sources. The most important data on external radiation are for the Japanese who survived the blast effects but received radiation at Hiroshima and Nagasaki and for the people who were exposed to radiation during medical therapy. Information on internal emitters are for the radium dial painters who ingested radium while painting dials in the early 1920s, from a group of patients who were administered radium as a tonic, and from uranium miners who were exposed to radon and its daughter products. Evaluations of such data have led to estimates of the likelihood of radiation-induced cancer. These estimates are accepted by the vast majority of the national and international scientists working with radiation.

Before discussing the actual risks, there are several points that are fundamental in interpreting the values. First, cancers or genetic changes caused by radiation cannot be distinguished from those that are occurring every day spontaneously or from other carcinogenic chemicals. About 400 000 deaths occur from cancers in the U.S. each year, or about 15 to 20 per 10 000 people. We can infer an effect from radiation only if the total number of cancers (or of a particular type of cancer) is increased by an amount we can detect. Valid comparisons are made even more difficult because some population groups have higher normal rates of cancer than others. This may be due to differences in the way they live and the possible carcinogens in their environment. Cancer also occurs more often in older people than in younger people. Thus, to detect increases in effects, a comparison (or control) group that is the same as the exposed group is necessary.

This all leads to the fact that there have been no direct measurements of increased cancer for low–level radiation exposures (1000-5000 mrem). Data exist only for much higher exposures (100 000 mrem and above delivered in a short time). Thus, scientists have estimated risks for the lower doses by assuming that any dose results in some effect (no threshold for effect) and that the relation between the radiation dose and the effect (cancer) is linear. That is, for each doubling of the dose there will be a doubling of the effect. This is an assumption that is generally believed to provide an overestimate of any effects. In fact, many scientists are now using a more complex mathematical relation between dose and effect that estimates risks at 2 to 10 times lower than the values given in this report.

Second, another characteristic of cancer or genetic effects from any cause is that they are statistical in nature. That is, not all of the individuals will be affected. Rather, a few individuals in the population will get cancer or have genetic defects and the remainder will not be affected. Therefore, we express the risk as the likely number of effects in a given population. For example, 30 cancers per million people means we expect 30 cancers out of this group of 1 000 000 people, but cannot tell which of the 30 will get cancer. Or, this example could also be stated that an average individual in that population has a risk of cancer of 30 chances in a million.

Cancers of many types can result from radiation or other carcinogens. These cancers do not occur for some period of time after exposure, usually 5 to 25 years. This period of time is called the latent period. For example, there is information from the Japanese survivors that the latent period for leukemia is 1 to 4 years. The risk of leukemia is limited to about 25 years after the exposure. After this time, the risk of leukemia goes down to the normal incidence. For other cancers, the latent period is longer, about 10 to 20 years. However, information is incomplete.

Estimates have been made of the number of cancers that could result from a given radiation exposure using the data for humans. These estimates generally are considered to be high because of the use of the linear, no-threshold assumption in extrapolating from the high levels at which the people actually were exposed. In spite of this, these estimates are useful for illustrating the amount of additional cancer that could be induced in a population exposed to radiation (or conversely, the chance that an individual exposed to radiation will get cancer).

The estimates of health effects ***risks*** given in this report were based on the factors recommended by the International Commission on Radiological Protection. Multiplying an estimated dose by the appropriate risk factor gives an estimate of the probability of injury to the individual as a result of that exposure. The risk factors used are

For uniform whole body dose	
Cancer mortality	0.0000001 per mrem whole body,
For specific organ doses	
Lung cancer	0.00000002 per mrem to lung,
Bone cancer	0.000000005 per mrem to bone.

As an example, a whole body dose of 10 mrem per year would be estimated to add a risk of cancer mortality to the exposed individual of one chance in a million (1/1 000 000) per year of exposure.

Such risk estimates must be placed in appropriate contexts to be useful as a decision-making tool. One comparison is with other types of risks encountered in normal life that may result in early mortality. Table II in Chapter 1 of this report presented a range of selected examples of activities that increase chances of death and their associated risks. A second useful comparison is an estimate of the risk that can be attributed to natural background radiation. Radiation from various natural external and internal sources results in exactly the same types of interactions with body tissues as that from so-called "man-made" radioactivity. Thus, the risks from a given dose are the same regardless of the source.

Natural background radiation for people in the Los Alamos area consists of the external penetrating dose from cosmic and terrestrial sources, cosmic neutron radiation, and self-irradiation from natural isotopes in the body. As shown in Table F-III, these sources give a combined whole body dose averaging about 158 mrem per year. This can be interpreted using the ICRP risk factors to represent a contribution to the risk of cancer mortality of 15 chances in a million for each year of exposure, or a risk of 8 chances in 10 000 for 50 years of exposure

to natural background radiation. As perspective, the overall U.S. population lifetime risk of mortality from cancer induced by all causes is currently estimated at about two chances in ten. The maximum likely incremental risks estimated from all pathways of potential exposure in the areas having residual contaminants range from about six chances in a million to one chance in ten billion under current conditions of land use. These estimates are summarized in Chapter 1, Table I. The pathways include direct exposure to penetrating radiation and inhalation of resuspended dust. Potential future changes in land use could result in other types of exposures. Potential maximum exposures for hypothetical home gardeners and construction workers in one of the canyon areas lead to maximum incremental bone cancer risk estimates ranging from about one to five chances in ten million.

B. Genetic Effects

One of the concerns of many people is the possible effect of their exposure to radiation on future children. An effect on the reproductive cells of the body that can be inherited by children is called a genetic effect and the change itself is called a mutation. Many of these mutations are unnoticeable or barely noticeable.

There is no information based on human exposure that will allow an estimate of the risk of mutations. Thus, data from animals, fruit flies, and mice, along with known abnormalities in human births and general knowledge of genetics, have been used to arrive at an estimate of the risks. Careful study of the survivors of the Hiroshima and Nagasaki bombs and their descendents has shown that these estimates are reasonable. The information available is not sufficient to provide a precise estimate, but a range of values will illustrate the magnitude of the risk.

About 10% of all births are estimated to have some form of genetic mutation. These range in importance from the trivial, such as a change in eye color, to the serious, such as a stillbirth or a deformity in the body of the child. Exposure to 1000 mrem of radiation during the childbearing years is estimated to result in 6 to 100 additional changes per million births in the first generation. This may be compared to the 100 000 estimated to occur in the same group without above-background radiation. Continued exposure to 1000 mrem for generation after generation is estimated to eventually lead to 10 to 150 additional births with genetic mutations per million births. If the actual radiation received is higher or lower, the numbers given above will change in proportion. Because the radiation levels attributable to residual contaminants were low, no estimates of genetic effects were calculated in this report.

C. Effects on the Fetus

You will often see signs in the x-ray departments of hospitals asking women to see the doctor if they have reason to believe they are pregnant. The reason is that the fetus, particularly in the first three months, is especially sensitive to radiation and may be damaged if exposed to excessive radiation. The doctor, therefore, may wish to reevaluate his procedure.

Animal information on single exposures to radiation indicates that some changes detectable by sophisticated tests have occurred with a few rems. At present, no specific relationship between dose and the likelihood of damage has been developed. Because of this and the relatively low doses attributable to residual contaminants, no estimates of effects were made in this report.

VIII. STANDARDS FOR EXPOSURE TO RADIATION

There are a number of organizations that provide standards or regulations governing the amount of radiation people should receive. Voluntary standards, or recommendations, are provided by the International Commission on Radiological Protection (ICRP) and the U.S. National Council on Radiation Protection and Measurements (NCRP). These are both groups of scientists knowledgeable about radiation, who study the available data and recommend appropriate limitations on the maximum amount of exposure that should be received. They also make recommendations on appropriate equipment and procedures. Their recommendations are nonbinding but have been accepted by many of the regulatory agencies.

The principal regulatory agencies in the U.S., which provide regulations on radiation exposure, are the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC). Other agencies that provide regulations in their own areas of interest include the Food and Drug Administration (FDA) and the Occupational Safety and Health Administration (OSHA).

The EPA is the lead agency in the sense that it provides basic guidance to be used by all Federal agencies. The EPA has the responsibility to provide general environmental standards for the Nuclear Regulatory Commission and specific responsibilities to produce standards under the Clean Air Act, the Clear Water Act, and the Resources Recovery and Conservation Act. The EPA has adopted a policy of setting standards at as low a level as is believed economically feasible. For this reason, the EPA standards are frequently lower than those from the ICRP or the NCRP.

The Nuclear Regulatory Commission provides regulations to cover nuclear reactors and all products associated with reactors, including the radioactive materials used for medicine. Because the Nuclear Regulatory Commission does not regulate natural radioactive materials or x rays, the states have taken responsibility, usually using the recommendations of the NCRP.

The standards and regulations, or guides, fall into two general categories: (1) the primary radiation protection standards and (2) the secondary standards for intake of radioactive materials. Within each category there are generally two sets of values, one applicable to occupationally exposed persons and the second applicable to members of the public. All comparisons in this report are made to the standards appropriate for the general public.

An important principle in all radiation protection recommendations and regulations is that the amount of radiation received by people should be kept as far below the actual dose limit as is reasonably achievable. That is, the goal of a radiation protection program is not to see that everyone is kept at or just below the limits; instead, the goal is to see that working conditions and practices are such that both the workers and the public receive the smallest amount of radiation that can practically be achieved.

A. Primary Radiation Protection Standards

Primary radiation protection standards give limits for total exposure to external and internal radiation for the whole body or for specific organs. The standards, or upper limits, for the public are basically one-tenth of the values permitted for occupationally exposed workers. The standards apply to increments of exposure in addition to natural background and in addition to medical exposures.

The upper limit adopted by all Federal agencies, including the Department of Energy, for whole body radiation to an individual member of the public is 500 millirem per year. For average

radiation doses to an exposed population, the Federal Radiation Council (which has been incorporated into the EPA) recommended that the average exposure to that portion of the population receiving the highest annual dose be limited to 170 millirem in addition to natural or medical radiation exposure. (This average limit was set to minimize potential genetic damage and was derived from a limit of 5000 millirem over 30 years for large populations.)

The basic radiation standards as used by the Department of Energy are shown in Table F-IV. These include both whole body limits and specific organ limits. The EPA has proposed Federal guidance for exposure to transuranium elements, also shown in Table F-IV.

A final word about these standards and their meaning is appropriate. Exposure to more radiation than permitted by the standards is not analogous to stepping off a cliff. That is, there is no sharp line between doses causing excessive harm and doses causing little or no harm. The opposite situation is true for many chemical poisons. An additional exposure of one millirem increases a person's risk of cancer or genetic mutation by the same amount whether it is a millirem of background radiation, the first millirem above background radiation, or the first millirem above the 500 millirem limit.

All of the doses evaluated in this radiological survey under current conditions of land use were small fractions of those permitted above natural background and medical exposure by the DOE Radiation Protection Standards. The highest dose, from the unlikely circumstance of a full year occupancy of a small portion of the former waste treatment plant site, was estimated about 12% of the standard. All other doses were less than 2% of the standard.

For projected possible land use conditions, the maximum dose estimates were for hypothetical home gardeners in one of the canyon areas (about 1.5% of the standard) and construction workers (about 6% of the standard). Continuous exposure to resuspended dust in the canyons was estimated to result in less than 1.3% of the EPA proposed guidance for persons exposed to transuranium elements in the general environment.

The various doses evaluated are summarized in Chapter 1 and described more completely in Chapter 5, Sections II and III.

B. Secondary Standards for Intake of Radioactive Materials

Secondary standards to be used in control of exposure by limiting the intake of radioactive materials are calculated from the primary standards using knowledge of the fate of the particular radioactive material in the body and the time it remains in individual organs. These standards are estimated for ingestion of water and inhalation of air. They are expressed as concentrations and are generally calculated so that the doses received from internal radioactivity will not exceed the primary standard under conditions of continuous exposure to the contaminants in air or water.

The assumption of continuous inhalation of air or ingestion of water, upon which the secondary limits are based, leads to a problem in their use. A frequent misinterpretation is that the secondary standards represent maximum concentrations to which a person can be exposed regardless of the time of exposure. This is not true. The total *intake* of radioactivity determines the dose received, not the particular concentration in air or water at any given time. The secondary standards are calculated as annual averages. Thus, a person could be exposed to 10 times the secondary standard concentration for a week and receive only about 20% of the annual intake permitted by the secondary standard.

The secondary standards account for the fact that some radioactive materials have a short half-life or are rapidly eliminated from the body. Tritium is eliminated from the body with a half-life of 12 to 13 days. Thus, the radiation received from a single drink at the secondary limit will be only a fraction of the annual limit that is calculated for continuous intake. Another example, plutonium, which is very well retained in the body and has a long half-life, will reach the annual

radiation limit only after continuous inhalation or ingestion at the secondary limits for 50 years. Thus, intake at or above this limit for days, weeks, or even months will not result in reaching or even approaching the primary standard dose limit.

The secondary standards are usually stated as concentrations of radioactivity in air or in water, as defined in Sec. V.B of this Appendix. The values used for comparison in this report are presented in Table F-IV. The DOE secondary standards are called Concentration Guides. The EPA secondary standards for drinking water are called Maximum Contaminant Levels, and for airborne transuranics are called Derived Air Concentrations. None of the relevant secondary standards were exceeded by any measured or theoretically estimated concentrations. Evaluations in the radiological survey were carried through to estimates of doses to permit comparison with the primary standards. Accordingly, no emphasis was placed on comparisons with the secondary standards.

TABLE F-I

RADIOACTIVE MATERIALS OF PRIMARY INTEREST IN THE RADIOLOGICAL SURVEY

Isotope	Approximate Half-Life	Principal Types of Radiation
Natural Radioactivity of Interest as Background		
Natural Uranium Isotopes		
^{234}U (Uranium-234)	247 000 years	alpha, gamma
^{235}U (Uranium-235)	710 000 000 years	alpha, beta, gamma
^{238}U (Uranium-238)	4 500 000 000 years	alpha, beta, gamma
^{232}Th (Thorium-232)	14 100 000 000 years	alpha
^{226}Ra (Radium-226)	1 600 years	alpha, gamma
^{222}Rn (Radon-222)	3.8 days	alpha, gamma
^{40}K (Potassium-40)	1 300 000 000 years	beta, gamma
Radioactivity of Interest as Residual Contaminants or Worldwide Fallout from Atmospheric Testing		
^{239}Pu (Plutonium-239)	24 000 years	alpha, gamma
^{238}Pu (Plutonium-238)	87 years	alpha, gamma
^{241}Pu (Plutonium-241)	15 years	beta
^{241}Am (Americium-241)	458 years	alpha, gamma
^{137}Cs (Cesium-137)	30 years	beta, gamma
^{90}Sr (Strontium-90)	28 years	beta
^{3}H (Hydrogen-3 or Tritium)	13 years	beta
Uranium and radium as given above		

TABLE F-II

UNITS OF RADIOACTIVITY USED IN THE RADIOLOGICAL SURVEY

Unit	Abbreviation	Disintegrations per Second	Equivalent Value in Other Time Units
curie	Ci	37 000 000 000	---
millicurie	mCi	37 000 000	---
microcurie	μCi	37 000	---
picocurie	pCi	0.037	2.22 per minute
attocurie	aCi	0.000000037	1.2 per year

TABLE F-III

COMPARISONS OF RADIATION DOSES FROM VARIOUS SOURCES INCLUDING RESIDUAL CONTAMINANTS IN CANYONS IN THE LOS ALAMOS AREA

Dose From One Year Exposure to Given Source (mrem)	Los Alamos: Range Attributable to Residual Contamination	Los Alamos: Normal Average	United States: Population Average	United States: Normal Range
I. Whole Body Doses				
A. From External Penetrating Radiation				
1. Normal Terrestrial	N/A[a]	57	40	30-160
2. Normal Cosmic	N/A	77	44	30-160
3. Average Annual Medical Diagnostic X Rays	N/A	---[b]	70-90	---
4. Residual Contaminants				
a. Canyon Area General Occupancy	0.1-9.6	N/A	N/A	N/A
b. Specific Maximum Scenario	60	N/A	N/A	N/A
B. From Internally Deposited Radioactivity				
1. Normal (mainly ^{40}K)	N/A	24	24	---
2. Normal Worldwide Fallout	N/A	---	4.4	---
3. Residual Contaminants	<0.001-0.053	N/A	N/A	N/A
II. Bone Doses				
A. From External Penetrating Radiation (Terrestrial and Cosmic)	N/A	134	84	---
B. From Internally Deposited Radioactivity				
1. Natural Radioactivity (mainly Radium and its daughters)	N/A	---	47	---
2. Normal Worldwide Fallout Radioactivity	N/A	---	<0.5	---
3. Residual Contaminants				
a. Canyon Area General Occupancy	0.1-5.6	N/A	N/A	N/A
b. Specific Maximum Scenarios	23-89	N/A	N/A	N/A
III. Lung Doses				
A. From External Penetration Radiation (Terrestrial and Cosmic)	N/A	134	84	84
B. From Internally Deposited Radioactivity				
1. Natural Radioactivity (mainly Radon and its daughters)	N/A	---	---	100-900
2. Normal Worldwide Fallout Radioactivity	N/A	---	<0.6	---
3. Residual Contaminants				
a. Canyon Area General Occupancy	0.06-0.11	N/A	N/A	N/A
b. Specific Maximum Scenarios	1.6-6.2	N/A	N/A	N/A

[a]N/A means "not applicable."
[b]--- means "data not readily available."

TABLE F-IV

STANDARDS AND GUIDES FOR RADIATION AND RADIOACTIVITY

DOE Radiation Protection Standards for External and Internal Exposures[a]

Individuals and Population Groups in Uncontrolled Areas

Type of Exposure	Annual Dose Equivalent or Dose Commitment[b]: Based on Dose to Individuals at Points of Maximum Probable Exposure	Annual Dose Equivalent or Dose Commitment[b]: Based on an Average Dose to a Suitable Sample of the Exposed Population
Whole body, gonads, or bone marrow	0.5 rem (or 500 mrem)	0.17 rem (or 170 mrem)
Other organs	1.5 rem (or 1500 mrem)	0.5 mrem (or 500 mrem)

DOE Concentration Guides for Radioactivity in Air and Water Above Natural Background in Uncontrolled Areas[c]

Isotope	Media	Concentration: In Units of Original Reference	Concentration: In Units Used in This Report
^{239}Pu	Water	5×10^{-6} μCi/mℓ	5000 pCi/ℓ
^{239}Pu	Air	6×10^{-14} μCi/mℓ	60 000 aCi/m^3
^{3}H	Water	3×10^{-3} μCi/mℓ	3 000 000 pCi/ℓ

EPA Maximum Contaminant Levels from Natural Interim Primary Drinking Water Regulations[d]

Isotope	Media	Concentration
^{3}H	Water	20 000 pCi/ℓ
Gross Alpha (including ^{226}Ra but excluding radon and uranium)	Water	15 pCi/ℓ

TABLE F-IV (cont)

EPA Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment[e]

Maximum Annual Alpha Radiation Dose Rate
as Result of Exposure to Transuranium Elements:

1 mrad/yr to pulmonary lung	(approximately 10 mrem/yr)
3 mrad/yr to bone	(approximately 150 mrem/yr)

Derived Air Concentration Reasonably Predicted to Result
in Dose Rates Less Than the Guidance Recommendations:

In Units of Original Reference	In Units Used in This Report
1 fCi/m^3	1000 aCi/m^3

(for alpha emitting transuranium nuclides
on an activity median aerodynamic particle
diameter not to exceed 0.1 μm)

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[a]See Reference 29.
[b]To meet the above dose commitment standards, operations must be conducted in such a manner that it would be unlikely for an individual to assimilate in a critical organ, by inhalation, ingestion, or absorption, a quantity of a radionuclide(s) that would commit the individual to an organ dose exceeding the limits specified in the above table.
[c]See Reference 29.
[d]See Reference 30.
[e]See Reference 18.

BIBLIOGRAPHY

Natural and Background Radiation in the U.S.

D. T. Oakley, "Natural Radiation Exposure in the Unites States," U.S. Environmental Protection Agency report ORP/SID 72-1 (June 1972).

A. W. Klement, Jr., C. R. Miller, R. P. Minx, and B. Shleien, "Estimates of Ionizing Radiation Doses in the United States 1960-2000," U.S. Environmental Protection Agency report ORP/CSD 72-1 (August 1972).

National Council on Radiation Protection and Measurements, "Natural Background Radiation in the United States," NCRP report No. 45 (November 1975).

Sources and Effects of Radiation

United Nations Scientific Committee on the Effects of Atomic Radiation," Sources and Effects of Ionizing Radiation, 1977 Report to the General Assembly," United Nations Publication E.77.IX.1 (1977).

M. Eisenbud, *Environmental Radioactivity*, second ed., (Academic Press, New York, 1973).

International Commission on Radiological Protection, Annals of the ICRP, Vol. 1, No. 3, ICRP Publication 26, Pergamon Press, New York (1977).

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