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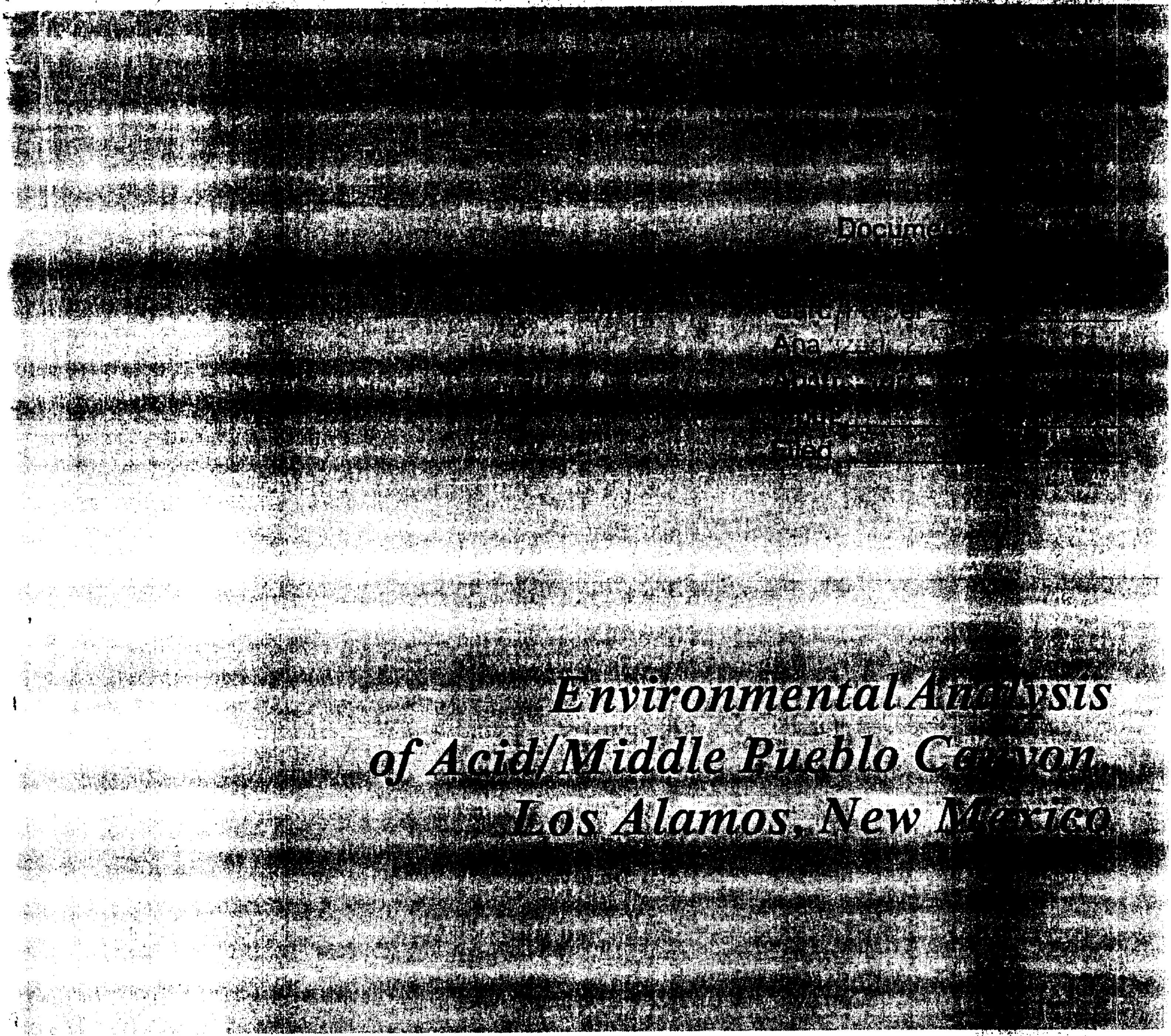

Environmental Analysis of Acid/Middle Pueblo Canyon, Los Alamos, New Mexico

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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ENVIRONMENTAL ANALYSIS OF ACID/MIDDLE PUEBLO CANYON, LOS ALAMOS, NEW MEXICO

by

Roger W. Ferenbaugh, Thomas E. Buhl,
Alan K. Stoker, and Wayne R. Hansen

ABSTRACT

The radiological survey of the former radioactive waste treatment plant site (TA-45), Acid Canyon, and Pueblo Canyon found residual radioactivity at the site itself and in the channel and banks of Acid, Pueblo, and lower Los Alamos Canyons, all the way to the Rio Grande. The largest reservoir of radioactive material is in lower Pueblo Canyon, which is on DOE property. The only areas where residual radioactivity exceeds the proposed cleanup criteria are at the former vehicle decontamination facility, located between the former treatment plant site and Acid Canyon, around the former untreated waste outfall and for a short distance below, and in two small areas farther down in Acid Canyon. The three alternatives proposed are (1) to take no action, (2) to fence the areas where the residual radioactivity exceeds the proposed criteria (minimal action), and (3) to clean up the former vehicle decontamination facility and around the former untreated waste outfall. Calculations based on actual measurements indicate that the annual dose at the location having the greatest residual radioactivity would be about 12% of the applicable guideline. Most doses are much smaller than that. No environmental impacts are associated with either the no-action or minimal action alternatives. The impact associated with the cleanup alternative is very small. The preferred alternative is to clean up the areas around the former vehicle decontamination facility and the untreated waste outfall. This course of action is recommended not because of any real danger associated with the residual radioactivity, but rather because the cleanup operation is a minor effort and would conform with the ALARA (as low as reasonably achievable) philosophy.

1.0 INTRODUCTION AND BACKGROUND

1.1 The FUSRAP Program

In 1976, the Energy Research and Development Administration (ERDA) identified Acid/Pueblo Canyon as one of the locations to be re-evaluated under the Formerly Utilized Sites Remedial Action Program (FUSRAP). The area considered in Acid/Pueblo Canyon consists of the former treatment plant site, the former vehicle decontamination facility, the treated and untreated waste discharge outfalls, and the Acid/Pueblo Canyon system into which the outfall effluents passed. The treatment plant site and vehicle decontamination facility were designated as TA-45.

The locations identified in the FUSRAP program were to be resurveyed for residual radioactivity using modern instrumentation and analytical methods. The resurveys are the bases for determining whether further remedial action is necessary. The Acid/Pueblo Canyon resurvey was performed by the Los Alamos National Laboratory under contract to ERDA and, subsequently, the Department of Energy (DOE).

The results of the survey[1] indicated subsurface residual radioactivity at the old treatment plant site and along the path of the untreated waste line. Surface residual radioactivity was found at the former vehicle decontamination facility, in the area of the untreated waste line outfall, on the cliff face where the treated wastes were discharged, and along the length of Acid Canyon. Residual radioactivity also was found in the sediments and banks of the stream channels in Pueblo and Los Alamos Canyons. It consists primarily of $^{239/240}Pu$, although detectable quantities of ^{238}Pu, ^{241}Pu, ^{241}Am, ^{90}Sr, ^{137}Cs and uranium also are present.

Because of this residual radioactivity, a set of alternatives for remedial action for Acid/Pueblo Canyon was identified. An engineering evaluation of the proposed alternatives was prepared by Ford, Bacon & Davis Utah in a separate report.[2] This report describes the environmental impacts associated with the proposed alternatives for the former TA-45 site, Acid Canyon, and middle Pueblo Canyon. Alternatives for lower Pueblo Canyon and lower Los Alamos Canyon will be considered in a separate report.

1.2 Preferred Alternative

The range of alternatives being considered for TA-45/Acid/Middle Pueblo Canyon includes no action, minimal action, and remedial action. The minimal action alternative requires fencing off an area encompassing the former vehicle decontamination facility and the untreated waste line outfall. These are the primary areas where surface residual radioactivity exceeds the proposed cleanup criteria. The remedial action alternative involves removal of surface residual radioactivity exceeding the proposed criteria.

The preferred alternative for TA-45/Acid/Middle Pueblo Canyon is remedial action. The potential radiological dose resulting from surface residual radioactivity at the former vehicle decontamination facility and the untreated waste line outfall is, under the worst conditions, only a small fraction of the applicable Radiation Protection Standards (RPS). However, these sites are readily accessible, and, thus, they should be cleaned up to conform to the ALARA (as low as reasonably achievable) philosophy. Remedial action at these sites will prevent further transport of radionuclides into the Acid/Pueblo/Los Alamos Canyon system. This alternative turns out to be less expensive than fencing the area to limit access. Costs of future surveillance and maintenance of fences in the extremely rugged terrain make the fencing alternative unacceptable. Two small areas of above-criteria residual radioactivity would not be treated under this alternative because they are located farther down in the canyon in an area that is rather inaccessible to either people or cleanup equipment.

2.0 ACID/PUEBLO CANYON

2.1 Summary History and Description

2.1.1 Description. Los Alamos County is located in northcentral New Mexico, about 100 km NNE of Albuquerque and 40 km NW of Santa Fe by air, as shown in Fig. 1. Acid Canyon is a small tributary near the head of Pueblo Canyon, which is one of many canyons cut into the Pajarito Plateau (Fig. 2). Acid/Middle Pueblo Canyon is located within the townsite of Los Alamos at T19N, R6E, Section 9. Figure 3 shows the location of the canyon system and the former TA-45 radioactive waste treatment plant site relative to surrounding features in the Los Alamos townsite. Access to the former waste treatment plant site is from Canyon Road, which runs just to the south of it.

2.1.2 History of Site.[1]

2.1.2.1 Operations and Waste Disposal. The radioactive liquid wastes handled at the TA-45 site resulted from work started in 1943 as part of Project Y of the US Army's secret Manhattan Engineer District. The purpose of the project was to develop a nuclear fission weapon. Los Alamos was selected in November, 1942, as the site for Project Y. The War Department acquired the Los Alamos Ranch School, which consisted of 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. The total land area included essentially all of what is 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 then-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

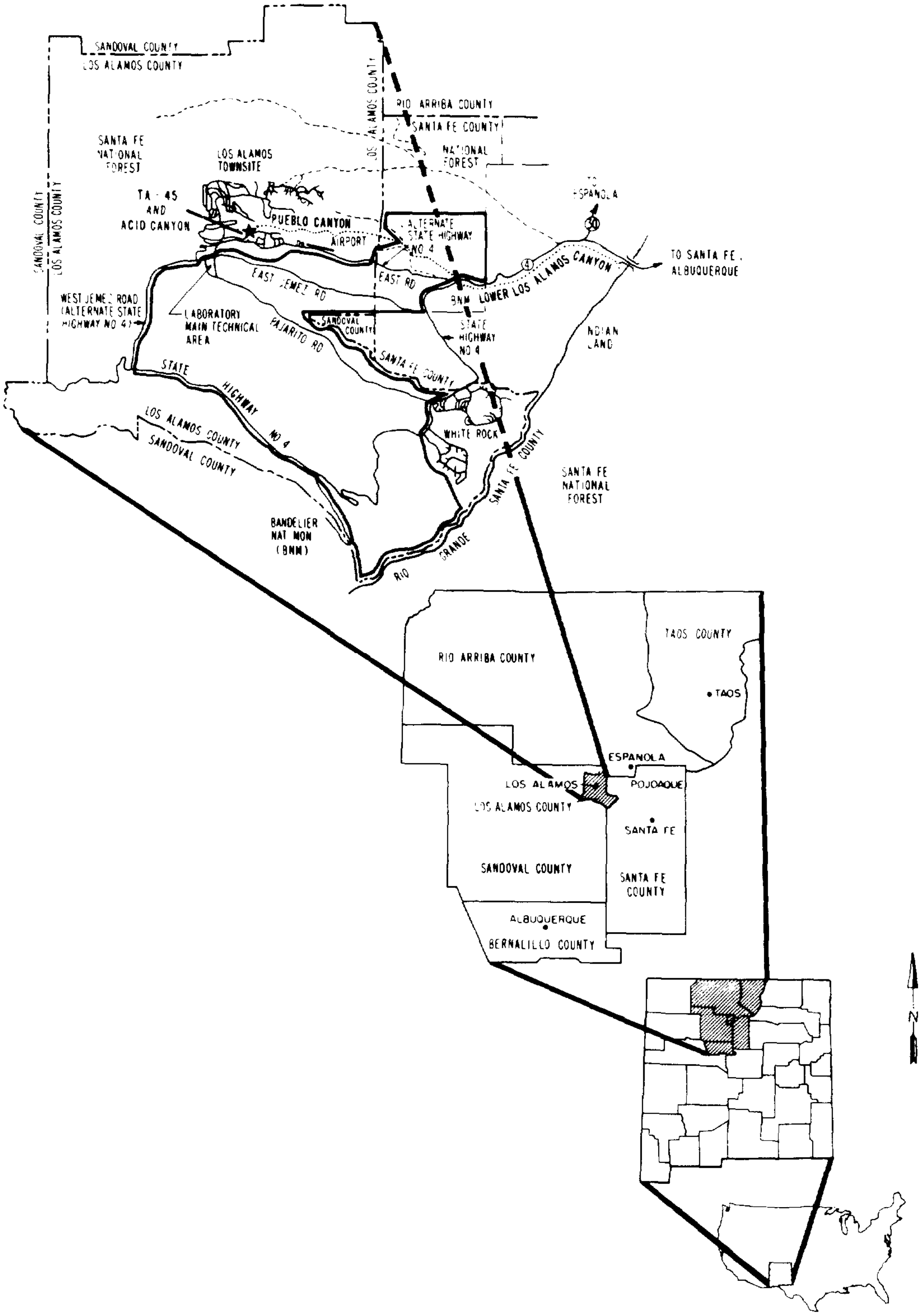

Fig. 1. Regional location of study area.

Fig. 2. Physiographic setting of Los Alamos County.

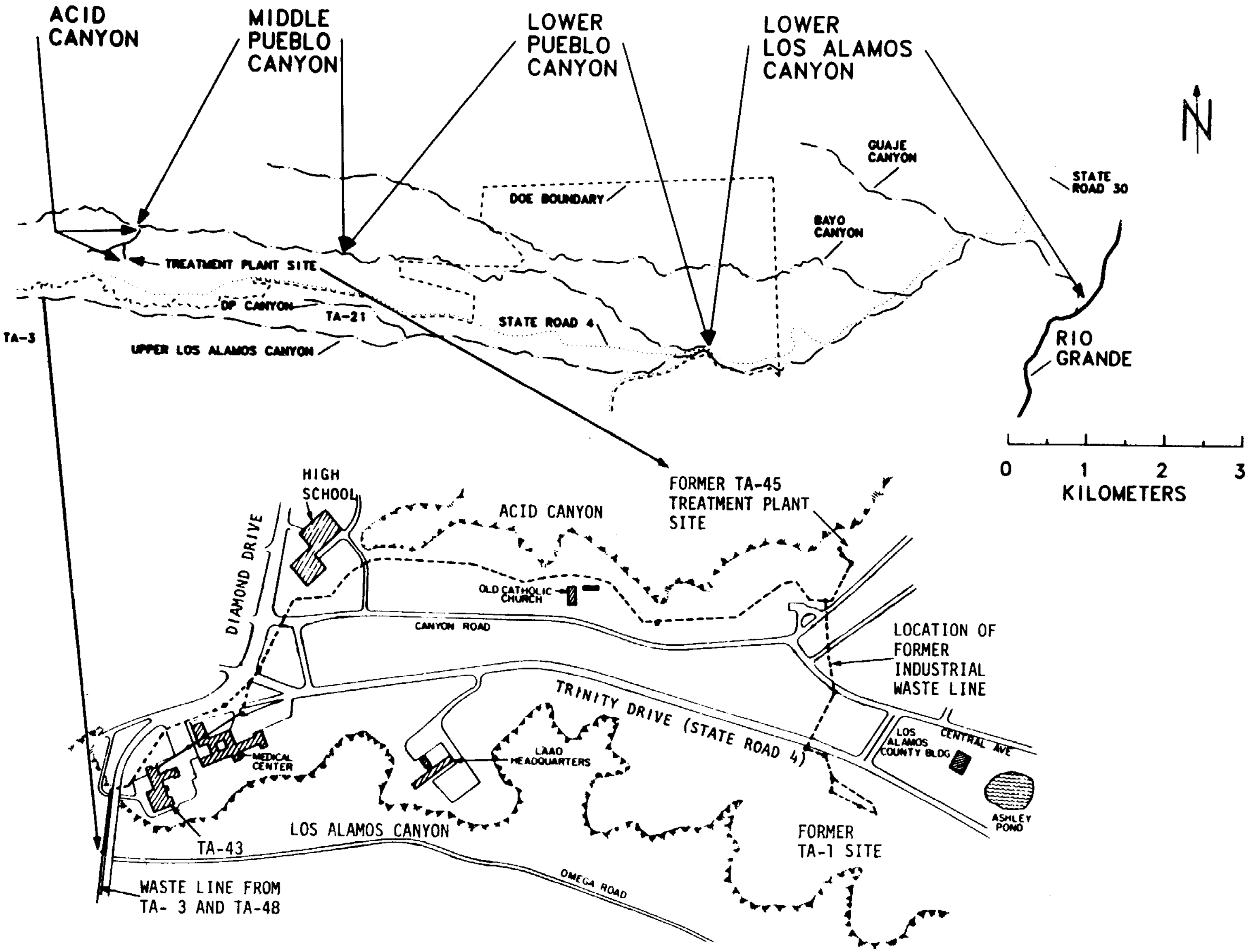

Fig. 3. Former liquid waste handling facilities and relation to effluent receiving canyons.

into a main acid sewer that extended generally north to a discharge point at the edge of Acid Canyon (Figs. 3 and 4).

The untreated liquid waste discharge started in late 1943 or early 1944 and continued through April, 1951. These effluents contained a variety of radioactive isotopes from research and processing operations associated with nuclear weapons development. No detailed analyses are available, but the radioisotopes of interest included tritium and isotopes of strontium, cesium, uranium, plutonium, and americium. From limited data, estimates were made of the major isotopes released in the untreated effluents. These estimates are summarized in Table I. The plutonium concentrations in these releases must have averaged about 1000 pCi/ℓ with maximum concentrations of about 10 000 pCi/ℓ.

In 1948, a joint effort was started between the Laboratory and the US Public Health Service to develop a method for removing plutonium and other radionuclides from radioactive liquid waste. Bench scale experiments showed that conventional physicochemical water treatment methods could be modified for treatment of radioactive waste. By June, 1951, a treatment plant, identified as TA-45, had been designed and constructed. It began processing radioactive and other laboratory wastes by a flocculation-sedimentation-filtration process. The final effluent, containing about 1% of the influent plutonium concentration, was sampled before release into Acid Canyon. The ^{239}Pu concentrations in the effluent ranged from about 20 to 150 pCi/ℓ while the plant was in operation. Summary data on the radioactivity content of the released effluent are in Table I. The plant typically removed 98 to 99% of the plutonium in the influent. Thus, a total of about 0.34 g of plutonium was released in treated effluent during the 14 yr that the plant was in operation, compared to an estimated 1.9 g released in untreated waste during the previous 8 yr. These mass values show the small quantity of plutonium that ended up in liquid waste streams during the early years of Los Alamos National Laboratory operation.

From startup until mid-1953, the TA-45 plant treated liquid wastes only from 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. This complex 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 levels were monitored to determine whether treatment was required to maintain the 2-wk effluent average from TA-45 below 330 disintegrations/min/ℓ, the level adopted 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

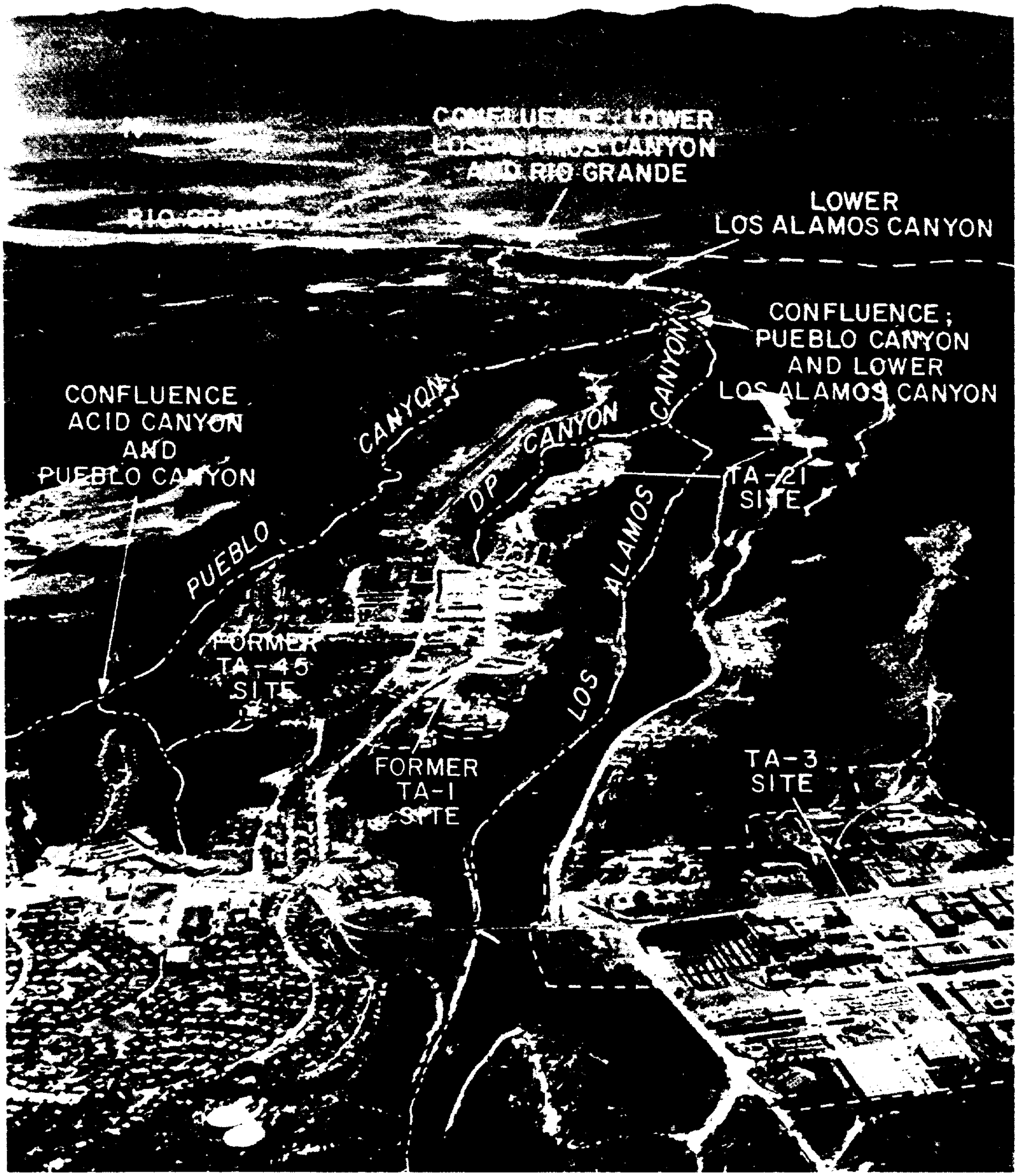

Fig. 4. Aerial view of Los Alamos and study area looking east.

TABLE I

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 US 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 are 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.

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 I for 1960 through 1963.

In July, 1963, wastes from TA-3 and TA-48 were redirected to a new Central Waste Treatment Plant (TA-50) located south of Los Alamos Canyon, which is still within the present Los Alamos National Laboratory site. 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 fission products from decommissioning the Sigma Building at TA-1 were released until June, 1964. After this time, no further effluents were released into Acid Canyon.

2.1.2.2 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. 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 undertaken. 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. The debris was loaded into dump trucks at the bottom of the cliff. Some contaminated rock, soil, and sediment also were 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, additional decontamination was undertaken, including other portions of buried waste lines in the TA-45 area, 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 removal of signs designating it as a contaminated area. Remaining residual radioactivity at that time was documented to be less than 500 counts/min of alpha activity (as measured by a portable air proportional alpha detector) in some generally inaccessible spots and was not considered to be a health hazard.

2.1.2.3 Land Ownership. Pursuant to the Community Disposal Act, the Atomic Energy Commission (AEC) transferred ownership of substantial portions of the Los Alamos 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 a reserved easement for continued access to and maintenance of sampling locations and test wells in and adjacent to the channel in Acid and Pueblo Canyons.

2.2 Need for Action

2.2.1 Potential Dose Evaluation and Interpretation. The significance of the data on radioactivity concentrations 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. These doses can be compared to natural background and appropriate standards or guides for one type of perspective. The doses also can 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 presented in the radiological survey.[1]

2.2.1.1 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 the radiological survey.[1] 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; that is, 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. It accounts for the differences in biological effects from the energy absorbed from different radiations and isotope distributions. These doses can be compared to the DOE RPS, which are expressed as permissible dose or dose commitment above 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-yr dose commitments also were calculated. The 50-yr dose commitment represents the total dose that would be accumulated in the body or specific critical organs over a 50-yr period from ingestion or inhalation during the first year. (Alternatively, the numerical values can be interpreted to represent the annual dose rate during the 50th yr given continuous exposure over all 50 yr.) The 50-yr commitments always are as large or larger than first year doses. In this summary, only the 50-yr commitments are compared to the standards.

Conceptually, this agrees with recommendations of the International Commission on Radiological Protection (ICRP) that, for regulatory purposes, in effect charge the entire dose commitment against the year in which exposure occurs.[3] Use of the 50-yr dose commitment also permits 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.[4,5]

2.2.1.2 Potential Doses Under Present Conditions. Given present conditions of land use and the residual radioactivity 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 increments of radiation exposure attributable to the residual radioactivity. 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 potential for exposure is more-or-less linearly dependent 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 in Table II for each canyon segment. These estimates should overstate average annual doses by varying amounts, even for continuous occupancy, because of the assumptions used for the analysis and interpretation of data, as detailed in the radiological survey.[1] 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 Pueblo Canyon suggest that the theoretically estimated resuspension of soils containing residual radioactivity probably overstates actual average levels by a factor of about 10.

In the canyon areas, the calculated external penetrating radiation whole-body dose for 1-yr occupancy ranges from less than 0.1 mrem in Pueblo Canyon to about 10 mrem in Acid Canyon. (All of the external penetrating radiation dose is received in the year of exposure, but for risk estimation that dose also can be considered to be the entire dose commitment from that exposure.) The calculated 50-yr dose commitments from inhalation of resuspended dust during 1-yr 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. None of these are more than about 2% of the appropriate DOE RPS, and most are less than 0.5%.

TABLE II

MAXIMUM LIKELY INCREMENTS OF RISK BASED ON EXPOSURE ATTRIBUTABLE TO RESIDUAL RADIOACTIVITY IN ACID AND MIDDLE PUEBLO CANYONS[a]

	Incremental Risk (Increased Probability Based on 50-yr Dose Commitment)[b]			Incremental Dose Commitment (mrem in 50 yr from Given Exposure)			
					Internal Exposure		
Location/Exposure	Overall Cancer Mortality	Bone Cancer	Lung Cancer	External Whole Body	Whole Body	Bone	Lung
1-yr 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
Treatment Plant Site	6.0×10^{-6}	---	---	60	---	---	---

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[a] All calculations based on 1978 conditions.

[b] 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 (x) 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 (cont)

	Incremental Risk (Increased Probability Based on 50-Yr Dose Commitment)[b]			Incremental Dose Commitment (mrem in 50 Yr from Given Exposure)			
				External	Internal Exposure		
Location/Exposure	Overall Cancer Mortality	Bone Cancer	Lung Cancer	Whole Body	Whole Body	Bone	Lung
Other Mechanisms Currently Possible							
Uptake through abrasion wound on rocks with highest contamination near Treatment Plant Site	---	2.8×10^{-8}	---	---	---	5.6	---
Possible with Hypothetical Development							
Construction Worker Treatment Plant Site	---	4.1×10^{-7}	1.1×10^{-7}	---	---	82	5.6
Natural Background in Los Alamos County							
1-yr occupancy	1.6×10^{-5}	---	---	134	24	---	---
50-yr occupancy	8×10^{-4}	---	---	6700	1200	---	---

TABLE II (cont)

	Incremental Risk (Increased Probability Based on 50-Yr Dose Commitment)[b]			Incremental Dose Commitment (mrem in 50 Yr from Given Exposure)			
					Internal Exposure		
Location/Exposure	Overall Cancer Mortality	Bone Cancer	Lung Cancer	External Whole Body	Whole Body	Bone	Lung
Cleanup Operations							
Workers	4.5×10^{-7}	8.4×10^{-7}	1.8×10^{-7}	0.38	4.1	168	9.1
Truck Drivers	9.4×10^{-8}	9.2×10^{-8}	2.2×10^{-8}	0.44	0.50	18.4	1.1
General Public							
Routine	1.8×10^{-8}	1.2×10^{-9}	2.6×10^{-10}	0.17	0.0059	0.24	0.013
Accident	1.4×10^{-7}	2.8×10^{-7}	6.0×10^{-8}	---	1.4	56	3.0
Radiation Protection Standard				500	500	1500	1500

Several other mechanisms of exposure that might affect a few individuals were considered. The estimated doses from these pathways also are presented in Table II. 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 of about 60 mrem above natural background (12% DOE RPS, 40% of natural background). A person who wounds himself on a rock in the former untreated waste outfall drainage may sustain an uptake of residual radioactivity through an abrasion wound from the rock surfaces with the highest concentrations. Contact with the highest concentrations is estimated to result in a 50-yr dose commitment of about 5.6 mrem to bone (0.3% of DOE RPS, 3.7% of natural background).

2.2.1.3 Potential Doses Under Future Conditions. Several types of changes could occur in the future that would alter potential exposures. One is the possibility of residential development of some of the areas, although such development is not presently being considered (Sec. 4.1.2). Doses to future residents are shown in Table II, where they are seen to be, at worst, about 12% of the applicable RPS.

An additional pathway associated with residential development is the inhalation of dust by construction workers. Estimates of maximum likely doses from these activities also are summarized in Table II. Conservative assumptions of high breathing rates, extremely dusty conditions, and the highest average soil concentrations for the stratum should overstate these estimates. Another consideration is that the construction worker dose would likely be a one-time occurrence. The maximum doses for construction workers are about 6% of DOE RPS or 60% of natural background.

Another change that could occur is the alteration of the current occurrence and distribution patterns of residual radioactivity by natural processes. With time, 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 the effect on total dose rates due to transuranics inhaled on resuspended dust. The conclusion is that the differences in potential doses in the future, at the time of maximum ingrowth of ^{241}Am (about year 2050), would be, at most, 4% higher (whole body, 1st-yr dose) and 4% lower (bone, 1st-year dose) than for current conditions. These are much smaller differences than already implicit in the uncertainties of the calculations. Portions of the doses attributable to the fission products strontium and cesium, which have half-lives of about 30 yr, will continuously decline by a factor of about 2 every 30 yr. Concentrations of ^{137}Cs were largely responsible for the calculated external penetrating doses in the vicinity of the former waste treatment plant site.

Redistribution of the sediments carrying residual radioactivity by hydrologic transport is another likely mechanism of change. Moderate flows in Pueblo Canyon, such as those associated with snowmelt runoff and thunderstorm peaking events of the magnitude that have evidently occurred in the last 10 to 20 yr, would be expected to continue the patterns of change in distribution as detailed in the radiological survey.[1]

2.2.1.4 Potential Doses Associated with Cleanup. Radiation doses resulting from removal of residual radioactivity from the former treatment plant site were evaluated for cleanup workers, truck drivers hauling the material to the waste disposal site, and the general public. Both routine and accident situations were considered. Resulting doses were then compared with the appropriate RPS.[6] A discussion of the dose calculation procedures and assumptions is presented in Appendix A.

The calculated doses were used as the basis for estimating health risks associated with remedial action at the former plant site. The associated risks are discussed in Sec. 2.2.2.2.

Ford, Bacon, and Davis Utah estimated that 10 to 12 days would be required for cleanup and restoration of the site.[2] Contact with soil containing residual radioactivity would require about 7 days: 2 days for site preparation and 5 days for excavation and hauling soil. The doses presented below are calculated assuming 56 h (7 days) of exposure to this material.

2.2.1.4.1 Doses to Cleanup Workers. Radiation protection personnel would supervise cleanup operations to ensure that soil containing residual radioactivity is kept wet so that dust generated by heavy machinery and wind is minimized. Continuous air samplers would monitor airborne concentrations of radioactivity, which constitute the major pathway of exposure to the crew. Respiratory protection equipment would be used in all areas where there is any indication that above-background concentrations of local airborne radioactivity exists, as well as in areas having soil activity in the several mCi (1 mCi = 1000 pCi) per gram range. Nose swipes would be taken after each use of a respirator.

Members of the cleanup crew would be radiation workers. These workers carry personal radiation monitoring devices that record their exposure to external radiation. They undergo periodic bioassay monitoring, including urinalysis and chest counting, to confirm that radiation prevention measures are working effectively and to determine any incremental radiation dose. All personnel involved in the cleanup would wear protective clothing: coveralls, gloves, footwear, and head coverings.

Cleanup experience at other former technical areas[7,8] has shown operational control measures to be effective in keeping radiation exposures low. Personnel monitoring has shown that doses received by individuals involved in these operations are usually only a few per cent of the RPS for workers. Cleanup operations at Acid Canyon were evaluated on the basis of radiation exposures to personnel involved in similar cleanup operations carried out elsewhere at the Laboratory. The procedures followed in making these dose calculations are described in Appendix A. The maximum 50-yr dose commitment to a worker from inhalation of dust containing residual radioactivity is estimated to be 168 mrem to bone, the organ receiving the highest dose. The maximum whole-body dose resulting from exposure to above-background gamma radiation is 0.4 mrem. The total dose to bone is 169 mrem, 2% of the RPS for bone dose to workers for a calendar quarter.[6] The total whole-body dose is estimated to be 4.5 mrem, 0.1% of the RPS for whole body for a calendar quarter.[6]

These dose estimates do not include a standard respiratory protection factor of 100 due to the use of full-face masks. Full-face masks would be worn for that part of the project when soil with higher levels of residual radioactivity would be excavated. Use of respiratory protection equipment would lower the above dose estimates accordingly.

2.2.1.4.2 Doses to Truck Drivers. Trucks would haul the estimated 230 m^3 of soil containing residual radioactivity to the radioactive waste disposal site (TA-54) located on Laboratory property. Drivers would spend approximately 11% of their time at TA-45 in areas that might have above-background levels of airborne radioactivity. They would receive additional exposure to external penetrating radiation, which is emitted by their cargo, while traveling to the waste disposal site. Total exposure times were based on estimates that drivers would spend 16 h of the estimated 40 h (5 days) for excavation carrying a full load of soil to TA-54, 3 h at TA-54, another 16 h returning to the TA-45 site, and 5 h at the site. The maximum 50-yr dose commitment for drivers is estimated to be 19 mrem to bone, 0.2% of the RPS for workers (calendar quarter). The maximum whole-body dose is 0.94 mrem, 0.02% of the RPS for workers (calendar quarter) (see Appendix A).

2.2.1.4.3 Doses to the General Public. Radiation exposures to the general public from routine operations were evaluated using data from previous similar cleanup projects. Doses to the general public through exposure to external radiation as a result of cleanup would be negligible because of the small external radiation fields (the maximum external radiation field was measured to be 50% of the natural background radiation field), the limited area where these fields are present, and the short time that individuals would be exposed (Appendix A). Consequently, the principal exposure mechanism for the general public would be inhalation of dust generated by the cleanup activities. Environmental monitoring performed during similar cleanup projects found no gross alpha and gross beta concentrations in air that were significantly different from concentrations measured by the environmental air sampling network.[7,8] In one project, ^{239}Pu concentrations in air samplers were occasionally found to be somewhat higher than those in control locations.[7] The maximum ^{239}Pu concentration was 0.46 fCi/m^3 (0.46 x 10^{-15} μCi/mℓ), which is 0.8% of the Radiation Concentration Guide for ^{239}Pu in controlled areas.[6]

No significant doses are expected to result from the routine transportation of soil containing residual radioactivity to the radioactive waste disposal site. Truck loads will have covers to prevent any release of material during transportation, which will effectively eliminate the potential for inhalation of material blowing off the trucks. Doses from external radiation to those individuals momentarily near the truck are estimated to be less than 0.17 mrem, which is 0.03% of the RPS.[6]

Using conservative assumptions, the maximum 50-yr dose commitment incurred by a member of the public as a result of the cleanup is estimated to be 0.41 mrem to the bone, which is 0.03% of the RPS (Appendix A) for the general public.

Radiation doses to the general public as a result of a truck accident resulting in a spill of soil containing residual radioactivity in a populated area also were evaluated. If such an accident were to occur, measures would be taken immediately to control the dusting from the soil. These would include keeping the soil covered before removal and wet during removal. The soil would be removed as quickly as possible. The maximum 50-yr dose commitment to the general public resulting from a spill of soil having radionuclide concentrations typical of the more radioactive material to be handled during this project is 56 mrem to the bone, 4% of the RPS for members of the public[6] (Appendix A).

2.2.2 Health Risks from Acid/Pueblo Residual Radioactivity

2.2.2.1 Risks from Existing Conditions. Estimates of radiological risks are presented in Table II. These risks were calculated using risk factors recommended by the ICRP.[9] Multiplying an estimated dose and the appropriate risk factor yields an estimate of the probability of injury to an individual as a result of that exposure. The risk factors used are

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

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

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 11 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 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, a rounded value of 150 mrem/yr is used 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 8×10^{-4} (8 chances in 10 000) in 50 yr of exposure to natural background radiation. As perspective, estimates of the overall US population lifetime risk of mortality from cancer induced by all causes is currently about 0.2 (2 chances in 10).[10]

Another context for judging the significance of risks associated with exposure to radiation, whether from natural background or other sources, is comparison with risks from activities or hazards encountered in routine experience. Table III presents a sampling of risks for activities that may result in early mortality and annual risks of death from accidents or natural phenomena. The largest incremental risks from exposure to the residual radioactivity are about the same as the incremental risk of a 1000-mile automobile trip; most are smaller than the annual risk of death from lightning. Radiation from various natural external and internal sources results in exactly the same types of interactions with body tissues as those from so-called "manmade" radioactivity. Thus, the risks from a given dose are the same, regardless of the source.

2.2.2.2 Risks from Cleanup. Dose estimates from Sec. 2.2.1.4 and risk factors presented in Sec. 2.2.2.1 were used to calculate the incremental risk of cancer mortality resulting from radiation doses received during cleanup operations. The estimated risks are presented in Table II. The risks are calculated for cleanup workers, drivers, and the general public.

As can be seen in the table, the largest risk of injury from radiation exposure would occur to the cleanup workers. The incremental lifetime risk of cancer mortality from bone cancer is 8.4×10^{-4} (1 chance in 1 200 000). All other risks of cancer mortality to the drivers and the general public would be lower.

The risk estimates in Table II can be compared to those incurred from exposure to natural background radiation, as discussed in Sec. 2.2.2.1. The

TABLE III

RISK COMPARISON DATA[a]

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}

US Average Individual Risk of Death in One Year Due to Selected Causes

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}

US Population Lifetime Cancer Risk

Contracting Cancer from All Causes	0.25
Mortality from Cancer	0.20

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[a] Taken from Ref. 1.

lifetime risk of cancer mortality from a 1-yr exposure to background radiation is 1.5×10^{-5} (15 chances in 1 000 000). During 56 h of cleanup work, the lifetime risk of cancer from natural background radiation work is 1×10^{-7} (1 chance in 10 000 000).

2.2.3 Criteria Upon Which Cleanup Action is Based. The proposed criteria for determination of cleanup action are shown in Table IV. These data are taken from Refs. 11, 12, and 13. The basis for these criteria is the determination of the soil level for each radioisotope that would result in an annual dose to any organ greater than 500 mrem. This determination is made by analyzing various pathways of exposure and then calculating the proposed criteria based on the worst exposure. The derivation of the criteria also assumes that the residual radioactivity is near the soil surface. The 500 mrem/yr dose for any organ is based on recommendations of the National Council on Radiation Protection and Measurements for dose limits for the general public.[14]

In evaluating the areas containing residual radioactivity to determine where cleanup might be necessary, Ford, Bacon & Davis Utah used the formula

$$\frac{C_1}{M_1} + \frac{C_2}{M_2} + \dots + \frac{C_n}{M_n} ,$$

where

$C_1, C_2, \dots, C_n$ = concentration of radionuclides

and

$M_1, M_2, \dots, M_n$ = working criteria for these radionuclides.

Using this formula, cleanup was determined to be necessary if

$$\sum_{o}^{n} \frac{C_i}{M_i} \geq 1.0 \quad .$$

However, the engineering evaluation notes that, in every area where cleanup was necessary, some single radionuclide exceeded its proposed criterion. In no case did the summation call for cleanup when all radionuclides were below their individual proposed criteria.[2]

TABLE IV

PROPOSED CRITERIA FOR SOIL CLEANUP ACTION

Nuclide	Concentration (pCi/g)
^{241}Am	20
^{239}Pu	100
^{238}Pu	100
$^{238}U/^{234}U$	40
^{232}Th	20
^{230}Th	280
^{228}Th	50
^{137}Cs	80
^{90}Sr	100

2.3 Other Agencies Involved in Implementation of the Proposed Action

Middle Pueblo Canyon, Acid Canyon, and the former TA-45 site presently are owned by Los Alamos County. Therefore, interaction and cooperation are necessary among DOE, the County, and the organization undertaking the remedial action.

Other agencies that may be involved are the State Environmental Division regarding radiological matters, the US Fish and Wildlife Services regarding the penegrine falcons in Pueblo Canyon (Sec. 4.6.3.2), and the State Historic Preservation Organization regarding archaeological and other historic sites.

3.0 ALTERNATIVES

Five general FUSRAP alternatives are modified to produce a range of alternatives for a given site. Modification or elimination of alternatives is based on site-specific conditions. The five general alternatives are as follows.

(1) No action.

(2) Minimal action--Limit public exposure to radioactive sources.

(3) Stabilization/entombment--Cover contamination with clean soil or encapsulate it.

(4) Partial decontamination--Remove easily accessible or potentially active sources to prevent further contamination.

(5) Decontamination and restoration--Remove and rehabilitate all contaminated areas to make site available for unrestricted use.

Using these alternatives and considering the conditions at TA-45/Acid/middle Pueblo Canyon, Ford, Bacon & Davis Utah proposed three working alternatives.[2] These alternatives are discussed in the following sections. A summary of the actions associated with each option and their respective advantages and disadvantages is presented in Table V.

TABLE V

ACTIONS, ADVANTAGES, AND DISADVANTAGES ASSOCIATED WITH ACID/PUEBLO CANYON ALTERNATIVES

Actions	Advantages	Disadvantages
Alternative I (Minimal Action)		
1) Maintain County ownership of restricted area. 2) Install fence around areas where residual radioactivity exceeds cleanup criteria. 3) Provide surveillance during fence installation with quarterly surveillance and annual radiological monitoring thereafter.	1) Potential for exposure to low-level onsite radiation minimized by fencing. 2) Essentially no environmental impact.	1) Highest cost option. 2) Above-criteria radioactivity remains on site with potential for further dispersion. 3) Restrictions and fencing prohibit use of areas of above-criteria radioactivity. 4) Quarterly surveillance and annual monitoring required, with attendant cost. 5) County must maintain ownership of fenced area. 6) Fencing of rugged area involved would be extremely difficult.
Alternative II (Remedial Action)		
1) Remove residual radioactivity as necessary to meet working criteria. 2) Transport soil containing residual radioactivity to solid waste disposal site (TA-54). 3) Provide radiological survey support and surveillance during cleanup. 4) Obtain DOE certification of cleanup site.	1) Radioactivity is reduced to working criteria levels. 2) No County ownership of site is required. 3) The site is available for unrestricted use. 4) No surveillance or monitoring is required after cleanup. 5) Permanent solution to problem.	1) Highest potential for an accident to occur. 2) Highest potential for short-term adverse environmental impacts.
Alternative III (No Action)		
None	1) No cost. 2) No new environmental impacts. 3) Accomplished immediately. 4) No accident potential.	1) Low-level radiation exposure potential from onsite residual radioactivity is unchanged. 2) Above criteria residual radioactivity remains onsite with potential for further dispersion. 3) No restricted use.

3.1 Alternative I--Minimal Action

In this alternative, a 0.45-hectare area encompassing the former vehicle decontamination facility, the untreated waste effluent outfall, and a portion of upper Acid Canyon would be fenced to prevent access. This area encompasses all of the surface residual radioactivity known to exceed the proposed criteria. The exact location of the proposed fence is shown in Fig. 5. No other areas, including the former treatment plant site, lower Acid Canyon, or

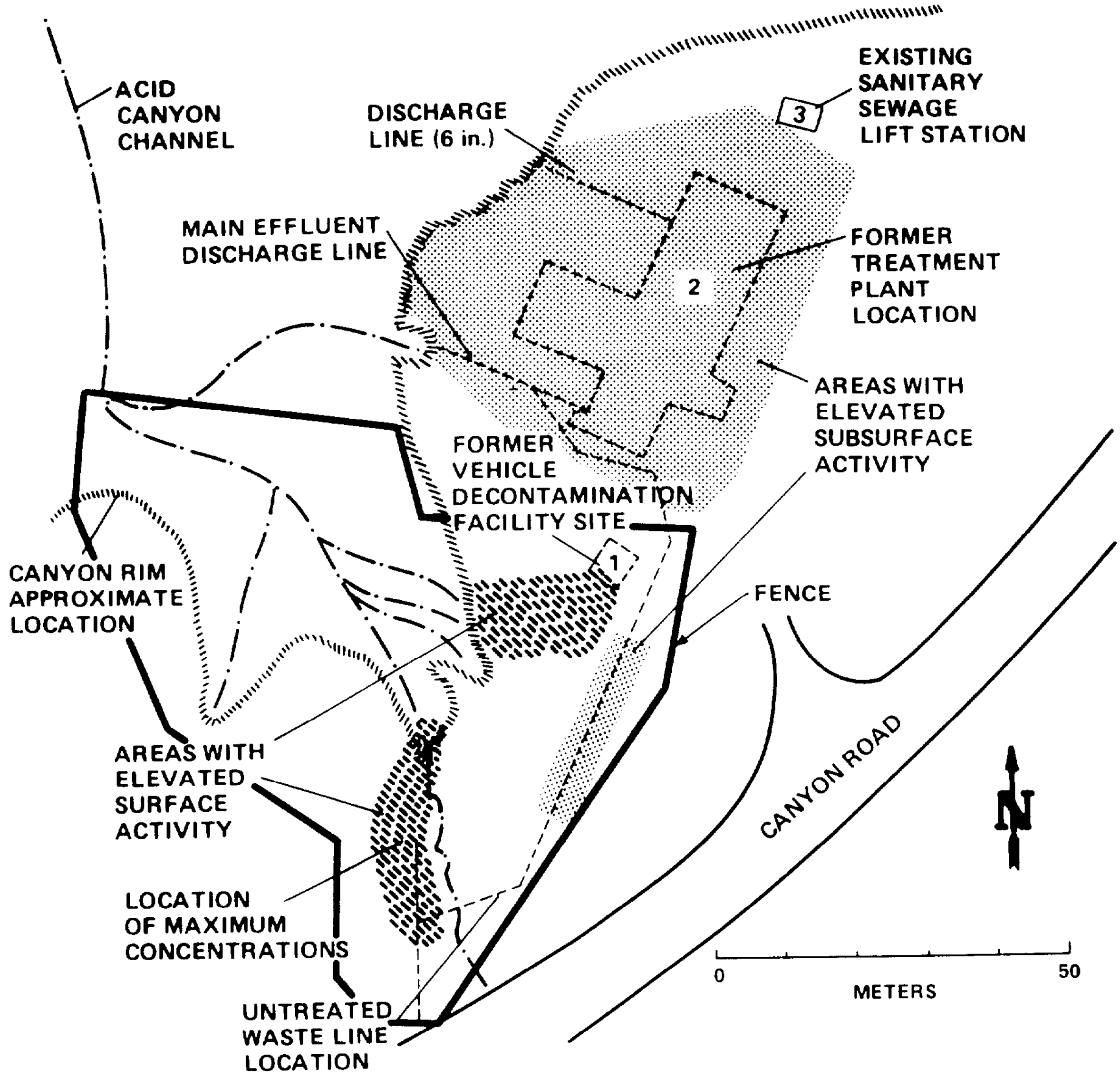

Fig. 5. Location of proposed fence and areas of residual radioactivity.

middle Pueblo Canyon, would be affected by this alternative because the residual radioactivity in these areas does not exceed the proposed criteria. The unfenced areas would continue to be available for recreational purposes or other desired uses.

3.2 Alternative II--Remedial Action (Preferred Alternative)

This alternative proposes cleanup of the readily accessible areas of surface radioactivity exceeding the proposed criteria at the site of the former vehicle decontamination facility and around the former untreated waste effluent outfall. The smaller, more inaccessible sites of above-criteria surface radioactivity, which are farther down in the more rugged portion of Acid Canyon, would not be addressed by this alternative.

The areas to be cleaned up are shown in Fig. 5. The soil in these areas would be removed to a depth of 30 to 45 cm, which would result in a soil volume of about 230 m^2. The excavated soil would be hauled to the current Los Alamos National Laboratory radioactive solid waste disposal site (TA-54) for disposal.

3.3 Alternative III--No Action

In this alternative, no action would be taken at TA-45/Acid/middle Pueblo Canyon, which means that the property would remain unchanged and no costs would be incurred. This alternative represents current conditions as compared with the impacts that would result from implementation of other alternatives.

4.0 AFFECTED ENVIRONMENT

4.1 Land Use

4.1.1 Acid Canyon and the Former TA-45 Site. The former TA-45 site is located on the rim of Acid Canyon, which is a small tributary of Pueblo Canyon (Fig. 3). Most of Acid Canyon is rather inaccessible because of its steep-sided and generally rugged nature. Acid Canyon presently is accessible to the public for recreational use, but there is no evidence that such use occurs. The upper, more accessible part of Acid Canyon and former TA-45 site constitute an area of 1 to 2 hectares. This land is owned by Los Alamos County. Part of it is flat and conceivably could be built upon, although there are no immediate plans to do so. The County presently is using the former TA-45 site as a landfill. Figure 6 shows some of the debris located on the former TA-45 site. This type of debris is interspersed throughout the landfill. Use of this site for construction is unlikely both because of the debris and because the uncompacted fill, which is present to a depth of 4 to 6 m would make a poor foundation.

Fig. 6. Debris on former TA-45 site.

4.1.2 Middle Pueblo Canyon. This portion of Pueblo Canyon is narrow and steep sided. It is bordered on the north by North Mesa and on the south by the Los Alamos townsite. Some residential housing exists along the southern edge of North Mesa. The northern part of North Mesa is the location of the rodeo grounds and horse stables.

Although lower Pueblo Canyon, which is relatively broad and flat, has some potential for residential development, the middle section of the canyon is too narrow and steep sided for this use. The present primary use of middle Pueblo Canyon is for recreational purposes, and the long-range use plan of the County calls for its retention as a recreational area.[15]

A dirt road provides access to lower and middle Pueblo Canyon. This road leaves State Road 4 just west of the junction of Pueblo and Los Alamos Canyons, proceeds across DOE property in lower Pueblo Canyon, through middle Pueblo Canyon, and leaves the canyon to the north at about the junction of Acid and Pueblo Canyons. The upper portion of this road is rough and probably accessible only by four-wheel drive vehicles. Also, a County sewage line runs down the canyon from residential areas near the head of the canyon to the sewage treatment plant in lower Pueblo Canyon. Recently, a new sewage line running along the stream channel was placed in the canyon. Its installation caused considerable disturbance of the radioactivity in the sediments.

4.1.3 TA-54. Soil containing residual radioactivity would be removed from Acid Canyon and the former vehicle decontamination site and would be taken for disposal to TA-54, the radioactive solid waste disposal facility at the Los Alamos National Laboratory. TA-54 is located on Mesita del Buey and is entirely on Laboratory property as shown in Fig. 7. At TA-54, the soil would be handled according to Los Alamos National Laboratory disposal procedures.[16] A general description of TA-54 is given in a 1977 Los Alamos Scientific Laboratory report on waste disposal sites at the Laboratory.[17] The current status of the site is given in the most recent waste management site plan.[18]

4.1.4 Transportation Route. Trucks would transport excavated soil along the route outlined in Fig. 7. The distance from the former TA-45 site to TA-54 is about 12 km. The transportation route proceeds along Canyon Road to Diamond Drive, Diamond Drive to Pajarito Road, and Pajarito Road to the entry road for TA-54. Although this route proceeds for a few kilometers through the Los Alamos townsite, any alternate route would traverse a greater distance through the townsite. The alternate White Rock route is several times the distance of the route outlined in Fig. 7.

Diamond Drive and Pajarito Road are heavily used during the hours of 7:00 to 9:00 a.m. and 3:30 to 6:00 p.m. by Laboratory employees commuting from the Los Alamos townsite, outlying areas of Los Alamos County, and Española, Santa Fe, and other regional communities. Unpublished data from the

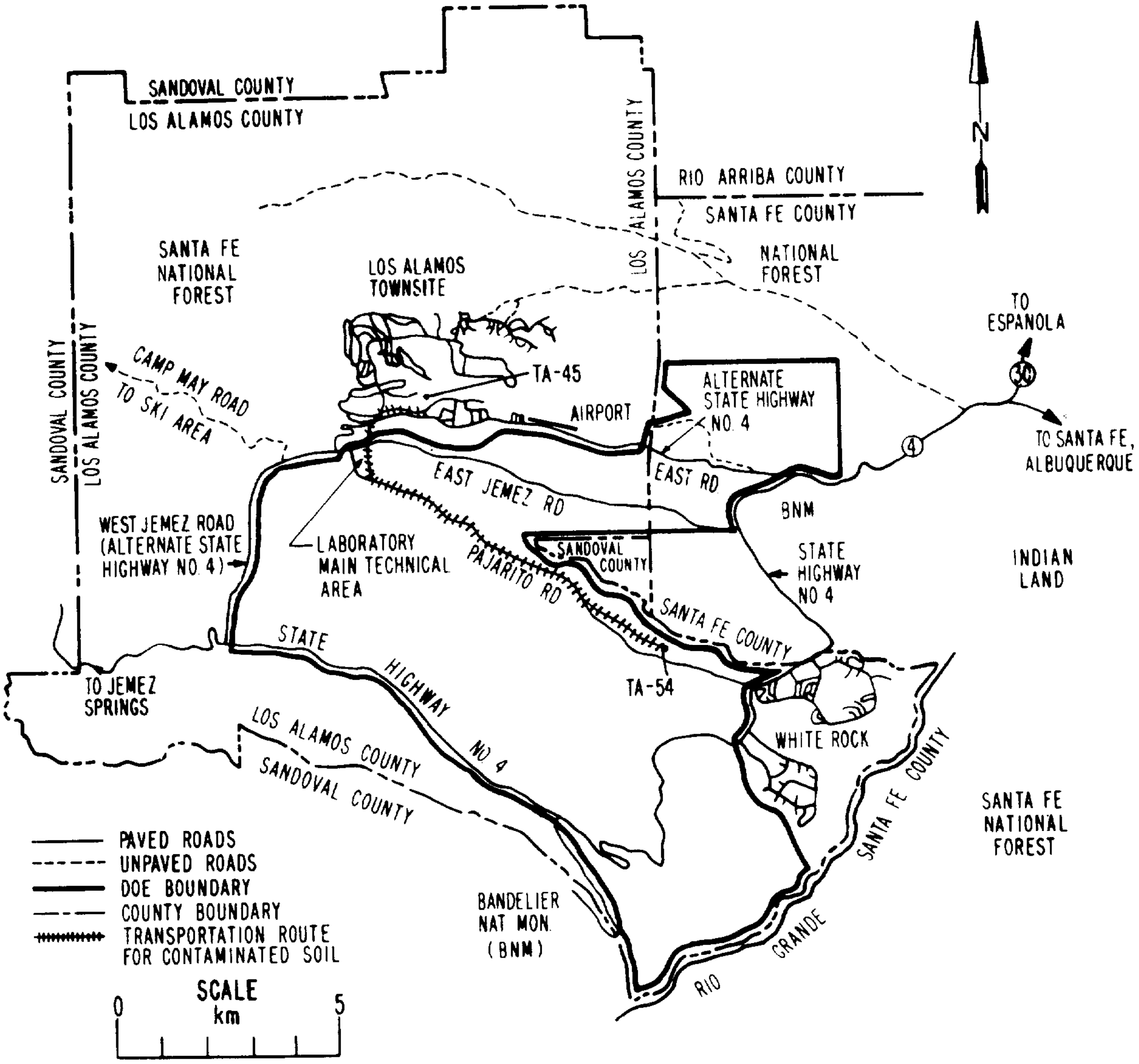

Fig. 7. Location of TA-54 and transportation route from former TA-45 site.

New Mexico State Highway Department and Los Alamos County, taken in the years 1980 and 1982, indicate that the daily traffic along Diamond Drive between Canyon Road and Trinity Drive averages around 8500 to 9500 one-way trips. The section of Diamond Drive from the Los Alamos Canyon bridge to Pajarito Road and all of Pajarito Road theoretically could be closed to the public, because they are entirely on DOE property.

4.2 Socioeconomics

4.2.1 Demography.[19] Los Alamos County has a population estimated by the preliminary 1980 census at 17 599. Two residential and related commercial areas exist in the County. The Los Alamos townsite, the original area of development (and now including residential areas known as the Eastern Area, the Western Area, North Community, Barranca Mesa, and North Mesa), has an estimated population of 11 039. The White Rock area (including residential areas known as White Rock, La Senda, and Pajarito Acres) has about 6 560 residents. Population estimates for 1980 place 112 000 people within an 80-km radius of Los Alamos.

Los Alamos County is a relatively small county, 280 km^2 in area, which was formed from portions of Santa Fe and Sandoval Counties in 1949. At the present time, slightly under 90% of County land is federally owned by the Los Alamos National Laboratory, the National Park Service, and the US Forest Service.[19] Almost all of the privately owned land already is developed. Potential residents of the County are frequently forced to reside in surrounding communities, such as Espanola and Santa Fe, both because of the shortage of residentially developable land and because of the high housing costs resulting from this shortage.

No documented information is available on the public attitude toward residual radioactivity associated with the Acid/Pueblo Canyon system and the former TA-45 site. The County is aware of the existing problem and is awaiting DOE action.

4.2.2 Economy.[20] The economy of Los Alamos is based primarily on governmental operations, with that sector directly accounting for about three-fourths of the employment within the County. This employment is associated with the federally funded operations of the Los Alamos National Laboratory and the associated activities of the Zia Company, Los Alamos Constructors, Inc. (LACI), EG&G, and the Los Alamos Area Office of DOE (LAAO). The direct federally funded employment of the Laboratory, Zia, LACI, EG&G, and LAAO has averaged around 70% of total employment since 1967. This has a large impact on the area surrounding Los Alamos County, because about 35% of the federally supported workers live outside of the County. Within Los Alamos, unemployment is extremely low, averaging around 5%. The underemployed groups consist primarily of women and adolescents.

4.2.3 Institutional.[20] As the only H-class county in the state, the powers of the Los Alamos County government are granted by the State Legislature. The County coordinates planning activities with the North Central New Mexico Economic Development District and the State Planning Office. In 1973, the New Mexico State Legislature passed a law giving the counties responsibility for managing subdivision of land, and Los Alamos County has since enacted subdivision regulations. The County Comprehensive Plan was adopted in 1964 and revised in 1976. In 1977, the County Zoning Ordinance was revised and adopted.

The Los Alamos County Charter was adopted in 1967. The County is governed by a seven-member County Council, elected at large. Other elected officials include the County Judge, the County Clerk, the County Assessor, and the County Sheriff. The County Council appoints the chief administrative officers, such as the County Manager, Attorney, and Utilities Manager. The County Council also appoints a five-member Utilities Board, a three-member Board of Equalization, and a nine-member Planning and Zoning Commission.

DOE has administrative control of all of the Laboratory reservation. The responsibilities of the security force, operated under contract to the Laboratory by the Mason and Hanger-Silas Mason Co., Inc., include policing activities, generally to prevent the entry of unauthorized persons into restricted areas. An agreement with the Los Alamos County Police Department authorizes them to ticket traffic violators on the public access roads across DOE lands. The State Police have authority over state highways, such as State Road 4. The Indian Tribal Police have authority over roads that cross tribal lands. In certain situations, this results in overlapping authorities.

Other federal agencies having resource management responsibilities in the region include the Forest Service and Farmer's Home Administration of the US Department of Agriculture, the US Geological Survey and National Park Service of the US Department of the Interior, the US Army Corps of Engineers, the Bureau of Reclamation, the Bureau of Indian Affairs, the Fish and Wildlife Service, the Soil Conservation Service, and the Agricultural Stabilization and Conservation Service.

Many state agencies have jurisdiction over particular aspects of the County. The State Environmental Improvement Division (EID) has jurisdiction over environmental matters. The State Engineer Office and the New Mexico Water Quality Control Commission are responsible for water rights and water quality management. The two interstate compacts affecting water use in the region are the Rio Grande Compact of 1938, amended in 1948, and the Costella Creek Compact. There also is one international treaty, the Rio Grande Convention of 1906. Los Alamos County is a part of the declared Rio Grande Underground Basin. Other important state agencies include the National Resource Conservation Commission, the Department of Game and Fish, and the Parks and Recreation Commission.

The large percentage of federally owned lands in the region affects the institutional structure of the County. Only Congress is authorized to pass laws affecting the administration of federal property. The Multiple Use and Sustained Yield Act of 1960 and the Classification and Multiple Use Act of 1964 have changed the administration of lands in the region and affected the regional economy.

4.2.4 Community Services. Sewage treatment for the community of Los Alamos is provided by two sewage treatment plants. One is located near the junction of Acid and Pueblo Canyons. The effluent from this plant is discharged into Pueblo Canyon during most of the year but is used to water the municipal golf course during the summer. A larger treatment plant is located just off the eastern end of Kwage Mesa in lower Pueblo Canyon. It discharges continuously into lower Pueblo Canyon. The community of White Rock is served by a County sewage treatment plant that discharges into a tributary of the Rio Grande. There are 10 small treatment plants on Laboratory property, which discharge into canyons on Laboratory property.

Water for Los Alamos County is supplied by a series of wells that penetrate a deep aquifer underlying the Pajarito Plateau at depths ranging from 60 m at the western edge of the plateau to 180 m at the eastern edge of the plateau.[20] The water supply system is operated and maintained for DOE by the Zia Company. The County purchases water from DOE and distributes it to users throughout the County. The water supply system and characteristics are described in a recent report.[21]

Electricity for Los Alamos townsite is purchased from DOE by the County and distributed to users throughout the community of Los Alamos. Electricity is supplied to the community of White Rock by the Public Service Company of New Mexico.

Natural gas for Los Alamos townsite is purchased from DOE by the County and distributed to users throughout the community of Los Alamos. Natural gas service is supplied to the community of White Rock by the Gas Company of New Mexico.

Telephone service to the entire county is provided by the Mountain Bell Telephone Company.

4.2.5 Archaeology. The only portion of the Acid/middle Pueblo Canyon system where archaeology is a concern is middle Pueblo Canyon itself. A survey of this canyon has revealed only one group of caveate ruins as an archaeological resource.[22] No archaeological ruins are associated with the former TA-45 site.

In general, evidence exists of sporadic Indian use of the Pajarito Plateau for some 10,000 years. One Folsom point has been found, as well as many other archaic varieties of projectile points. Indian occupation of the area occurred principally from late Pueblo III (late 13th century) until early Pueblo IV (middle 16th century). Continued use of the region well into the historic period is indicated by pictographic art that portrays horses.

Consequently, the plateau and canyons are dotted with hundreds of pre-Columbian Indian ruins. Many of the ruins on the southern part of the plateau are encompassed by Bandelier National Monument. Ruins on Laboratory property have been surveyed by Frederick C. V. Worman and, more extensively, by Charlie R. Steen,[23] former Chief Archaeologist of the Southwest Region of the National Park Service and subsequently a consultant to the Los Alamos National Laboratory on archeological matters. Portions of the Pajarito Plateau not included in Bandelier National Monument or the Los Alamos National Laboratory have been surveyed more recently by J. N. Hill of the University of California. His findings are not yet published.

There are three major ruins on Laboratory property: Tsirege, Cave Kiva, and Otowi Ruins. These sites are being considered for nomination to the National Register of Historic Places in 1973. This nomination is still pending. The Otowi Ruins, comprising two large, unexcavated pueblos, are located in lower Pueblo Canyon, at a point where the canyon wall between Pueblo Canyon and Bayo Canyon is partially broken down.

There are hundreds of small ruins on Laboratory property; these also have been submitted for consideration for nomination to the National Register of Historic Places.[24]

4.3 Soil and Geology

4.3.1 Soils. The soils in the vicinity of Acid/Pueblo Canyon are clay on the mesa tops, with more sandy soils occurring in the canyon bottoms along the stream beds. The soils are derived from volcanic tuff and, thus, tend to be alkaline in nature, which is unusual for coniferous forest soils. The stream channel consists of granules and sand-sized particles derived from weathering and erosion of the volcanic material. The alluvium is thin in the upper reaches of the canyon and thickens toward the east, becoming 3 to 5 m thick in the lower part of the canyon.

A recent soil survey[25] discusses many of the canyons and mesas in Los Alamos County. On the basis of information given in that survey, some inferences can be drawn concerning the soils at the former TA-45 site and in Acid/Middle Pueblo Canyon.

The soil at the former TA-45 site probably falls into the Pogna series, which is described as follows.[25]

"The Pogna series consists of shallow, well-drained soils that formed in material weathered from tuff on gently to strongly sloping mesa tops. Included with this soil in mapping are rock outcrop and Carjo, fine Typic Eutroboralf, and Tocal soils; the inclusions make up about 10% of this mapping unit. Commonly found vegetation includes ponderosa pine, mountain mahogany, and Kentucky bluegrass.

"Typically, the soil is a light brownish-gray fine sandy loam, or sandy loam, over tuff bedrock at 25 to 50 cm. The available water capacity of this moderately rapid permeable soil is low, and the effective rooting depth is 25 to 50 cm. Runoff is medium, and there is a moderate water erosion hazard.

"The representative profile of the Pogna fine sandy loam (3 to 12% slope) is described as follows:

A1 0-13 cm, light brownish-gray fine sandy loam, very dark grayish-brown moist; weak fine granular structure; slightly hard and very friable moist; many medium roots; many interstitial pores; neutral; clear smooth boundary.

C 13-30 cm, light brownish-gray fine sandy loam, grayish-brown moist; weak fine granular structure; slightly hard and very friable moist; many medium and coarse roots; many interstitial pores; slightly acid.

R 30+ cm, tuff bedrock."[25]

Acid Canyon and the upper part of middle Pueblo Canyon could be described as steep rock outcrop. "This land type has slopes greater than 30% on steep to very steep mesa breaks and canyon walls and consists of about 90% rock outcrop. The rocks are mainly tuff, except at the lower end of some of the canyons where there is basalt. The inclusions in this mapping unit are very shallow undeveloped soils on tuff, mesic rock outcrop (5 to 30% slope), and frigid rock outcrop (5 to 30% slope). The south-facing canyon walls are steep and have little or no soil material or vegetation, but the north-facing walls have areas of very shallow dark-colored soils. Vegetation is ponderosa pine, spruce, and fir."[25]

With progression down Pueblo Canyon, the steep rock outcrop gives way to a Typic Ustorthents-Rock Outcrop complex, which occupies most of the lower portion of middle Pueblo Canyon.

"The Typic Ustorthents in this complex are deep, well-drained soils that weathered from dacites and latites of the Puye Conglomerate. This complex is found on very steep to extremely steep mountain sideslopes vegetated with a pinon-juniper woodland, interspersed with ponderosa pine.

"The surface layers of the Typic Ustorthents are generally a pale brown stony or gravelly sandy loam about 5 cm thick. The substratum is about 150 cm thick and generally consists of a very pale brown or light gray gravelly loamy sand or sand. The effective rooting depth is about 50 cm, and the depth to dacite-latite bedrock is greater than 155 cm. The Typic Ustorthents have moderately rapid to very rapid permeability and a very low available water capacity.

"A typical profile of Typic Ustorthent, sandy-skeletal, mixed, mesic (64% slope) is described as follows:

A1 0-6 cm, pale brown gravelly sandy loam, dark brown moist; strong very fine and fine granular structure; nonsticky and friable moist, nonsticky and nonplastic wet; 30% gravel, 20% cobble, 10% stone; abundant very fine and fine roots, plentiful medium roots, few coarse roots; abundant very fine and fine interstitial pores; neutral; clear wavy boundary.

C1 6-18 cm, very pale brown, very gravelly loamy sand, yellowish brown moist; massive structure; slightly hard and friable moist, nonsticky and nonplastic wet; 50% gravel; few very fine, fine, medium and coarse roots; plentiful very fine and fine interstitial pores; neutral; abrupt wavy boundary dry, clear wavy boundary moist.

C2 18-29 cm, light gray gravelly sand, pale brown moist; massive structure, nonsticky and friable moist, nonsticky and nonplastic wet; weakly cemented; 30% gravel, 10% cobble; few very fine, fine, and coarse roots, plentiful medium roots; plentiful fine and medium interstitial pores; neutral; abrupt wavy boundary dry, clear wavy boundary wet.

C3 29-52 cm, very pale brown gravelly sand, yellowish brown moist; massive structure; hard and friable moist, nonsticky and nonplastic wet; weakly cemented; 30% gravel; few very fine, fine, and medium roots, plentiful coarse roots; plentiful fine and medium interstitial pores; neutral; clear wavy boundary dry, gradual wavy boundary moist.

C4 52-82 cm, very pale brown very gravelly sand, light yellowish brown moist; massive structure; hard and friable moist, nonsticky and nonplastic wet; weakly cemented; 60% gravel; plentiful fine and medium interstitial pores; mildly alkaline; clear wavy boundry, moist, gradual wavy boundary dry.

C5 82-102 cm, very pale brown very gravelly sand, light yellowish brown moist; massive structure; hard and friable moist, nonsticky and nonplastic wet; weakly cemented; 70% gravel; abundant fine and medium interstitial pores; mildly alkaline; gradual wavy boundary.

C6 102-122 cm, light gray very gravelly sand, light yellowish brown moist; massive structure; hard and friable moist, nonsticky and nonplastic wet; weakly cemented many thick clay films on coarse fragments; 50% gravel; abundant fine and medium interstitial pores; moderately alkaline; gradual wavy boundary.

C7 122-153+ cm, white very gravelly loamy sand, light yellowish brown moist; massive structure; nonsticky and friable moist, nonsticky and nonplastic wet; weakly cemented; 40% gravel; abundant very fine and fine interstitial pores; moderately alkaline."[25]

Toward the lower part of middle Pueblo Canyon, where the canyon bottom begins to widen out, the soils most likely to be found are Puye soils, giving way to Totavi soils in lower Pueblo Canyon. Descriptions of these soils are as follows.

"The Puye series consists of deep, well-drained soils that formed in alluvium in level to gently sloping canyon bottoms near the mountains. Individual areas of Puye soils are 2 to 40 acres in size and occur as long slender bodies. Included with this soil in mapping are areas of this soil with up to 10% slope on the side of the canyons, and a few intermingled areas of Totavi soils adjacent to the north canyon walls; the inclusions make up about 10% of this mapping unit. Vegetation commonly found in this soil type includes Kentucky bluegrass, western wheatgrass, mountain muhly, ponderosa pine, oak species, and annual grasses and forbs.

"Typically, the surface soil is a dark grayish brown sandy loam, fine sandy loam, or loam, to 150 cm or more. Permeability is moderately rapid, the available water capacity is high, and the effective rooting depth is 150 cm or more. Runoff is very slow, and the erosion hazard is low.

"A typical profile of Puye sandy loam (0 to 5% slope) is described as follows:

A1 0-15 cm, dark grayish brown sandy loam, very dark grayish brown moist; weak fine granular structure; soft and very friable moist; many fine and very fine roots; neutral; clear smooth boundary.

C 15-152+ cm, dark grayish brown sandy loam, very dark grayish brown moist; massive; soft and very friable moist; common fine and very fine roots; neutral.

"The Totavi series consists of deep, well-drained soils that formed in alluvium in canyon bottoms in the central and eastern portion of the soil survey area. Individual areas are 2 to 60 acres in size and occur as long slender bodies. Native vegetation is blue grama, pinon pine, one-seed juniper, and annual grasses and forbs.

"The surface soil is a brown gravelly loamy sand, or sandy loam, to 150 cm or more, with 15 to 20% gravel. Permeability is very rapid, runoff is very slow, and the erosion hazard rating is low. The available water capacity is low, but the effective rooting depth is 150 cm or more.

"A typical pedon of Totavi gravelly loamy sand (0 to 5% slope) is described as follows:

> AC 0-152 cm, brown gravelly loamy sand, brown moist; single grain; loose dry and moist; few fine roots; 15% fine gravel; neutral."[25]

4.3.2 Geology.[1] 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 (Fig. 8). 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.

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.

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.

The Puye formation consists of two members. The lower member is a poorly consolidated, channel-fill deposit, which 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.

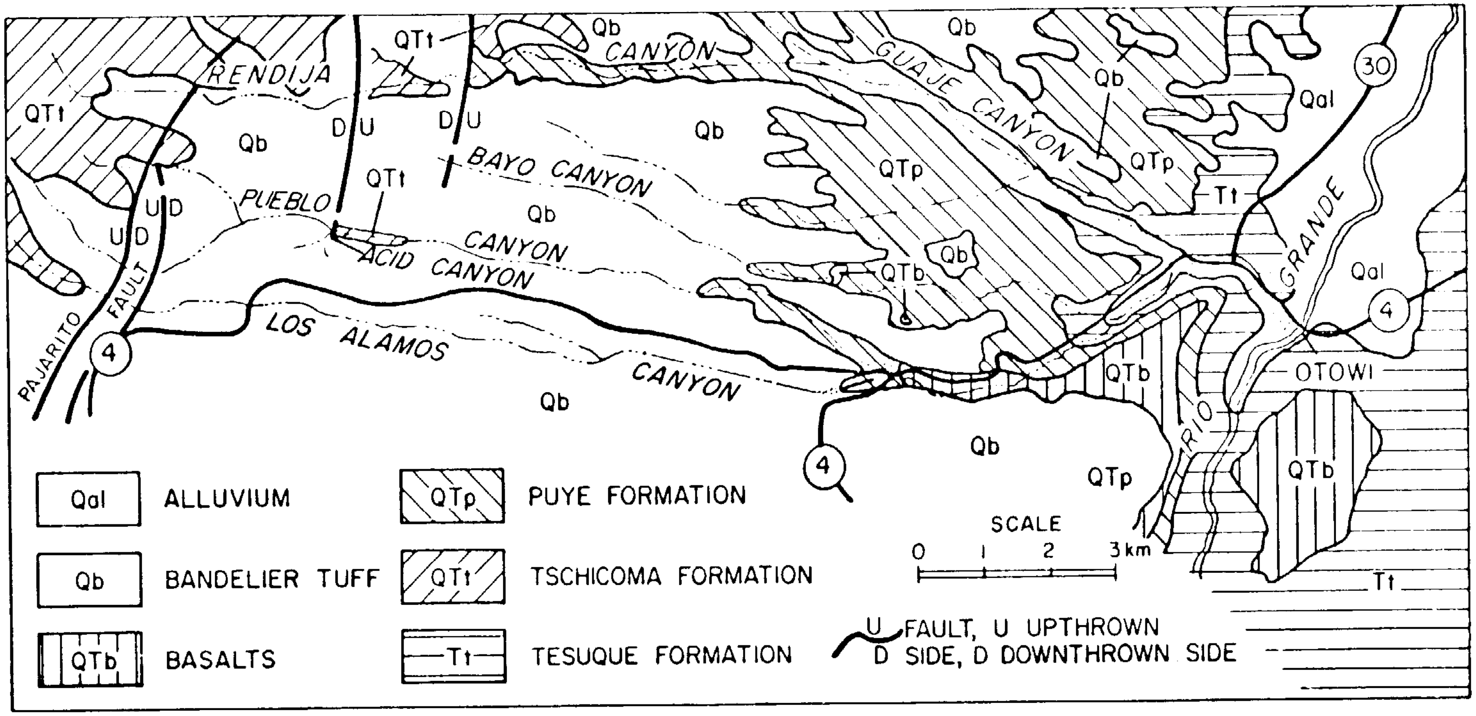

Fig. 8. Geologic map of a part of the Pajarito Plateau in the Los Alamos area.

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.

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. 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. The Bandelier Tuff is composed chiefly of ashfall and 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 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 farther 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. It is a part of the complex fault system that formed the Rio Grande depression. 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. The displacement, estimated from the fault scarp, is 120 to 150 m north of Los Alamos and east of the Pajarito Fault. Two normal faults cut the Bandelier Tuff, the Puye Formation, and the Tschicoma Formation. 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. 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.

Further information on the geology of the Jemez Mountains can be found in a recent Los Alamos National Laboratory report.[26]

4.4 Climatology

4.4.1 General Climate.[19] Los Alamos has a semiarid, continental mountain climate. The average annual precipitation of 45 cm is accounted for by warm-season convective rain showers and cold-season migratory storms. Forty per cent of the annual moisture total falls during July and August, primarily from afternoon thundershowers. Winter precipitation falls primarily as snow, with heavy annual accumulations of about 130 cm. Heavy localized thundershowers can at times cause severe runoff events through canyons, with attendant scouring of canyon bottoms.

Summers are generally cool and pleasant. Maximum temperatures are usually below 32°C. The high altitude, light winds, clear skies, and dry atmosphere allow night temperatures to drop into the 12° to 15°C range. Winter temperatures are typically in the range from -10° to 5°C. Many winter days are clear, with light winds, so that strong solar radiation makes conditions quite comfortable even when air temperatures are cold.

Major spatial and diurnal variations of surface winds in Los Alamos are caused by the complex terrain. Under moderate and strong atmospheric pressure differences, flow is channeled by the major terrain features. Under weak pressure differences, a distinct daily wind cycle exists: a light westerly drainage wind during nighttime hours and a light easterly upslope wind during daytime hours. Interaction of the strong and weak pressure patterns gives rise to westerly flow predominance over the Laboratory and a more southerly predominance at the east end of the mesas.

4.4.2 Air Quality. No major emission sources exist in the Los Alamos area, although there are routine small releases of radionuclides and other chemicals by the Laboratory. Data from routine monitoring systems indicate that, although radiation and radioactivity levels above-background can be detected, no concentration guidelines (CGs) or other applicable standards are being violated.[19]

Air quality regulation compliance at the Laboratory, a small (50 MW) gas-fired power plant, the Zia Company asphalt plant, other unit operations, and the general status of air quality recently were reviewed.[27] The review indicated that emission standards and ambient air quality standards are not being violated in the Los Alamos area. Air quality in the Los Alamos area should continue to be very good because of the proximity of Bandelier National Monument, the Wilderness Area of which is mandated as a Class I area under the Prevention of Significant Deterioration (PSD) provisions of the Clean Air Act.[28]

4.5 Hydrology and Water Quality[1]

The Rio Grande, the master stream in northcentral New Mexico, flows southwestward along the eastern edge of the Pajarito Plateau (Fig. 7). 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 x 10^3 km^2 in southern Colorado and northern New Mexico. The surface water discharge of the Rio Grande is measured at the US Geological Survey gauging station at Otowi, located east of Los Alamos County on State Road 4. The average discharge for 71 yr 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 x 10^8 to 6.86 x 10^9 kg with an annual average of 2.2 x 10^9 kg for the 28-yr period of record. The annual volume of flow for this period has ranged from 4.65 x 10^8 to 1.88 x 10^9 m^3 with an annual average of 1.03 x 10^9 m^3.

Pueblo Canyon heads on the flanks of the Sierra de los Valles. Acid Canyon is tributary to Pueblo Canyon near the western edge of the plateau. Surface flow in sections of Pueblo Canyon occurs because of the release of sanitary effluents. As the effluents move downgradient, the surface flow is depleted by infiltration into the alluvium of the stream channel and by evapotranspiration. Thus, the surface flow in the lower reaches of the canyon is intermittent, and only during periods of heavy precipitation does surface flow reach the Rio Grande.

The storm runoff and sanitary effluents infiltrate from the stream channel to recharge small perennial bodies of ground water perched on underlying tuff or volcanic sediments in the alluvium. The volume of water in these stream-connected alluvial aquifers is largest during the spring from snowmelt and in the early summer from storm runoff. In late summer, fall, winter, and early summer, the volume of water declines. As the water in the alluvium moves downgradient in the canyon, part of it 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. The perched aquifer is of limited extent. The Bandelier Tuff does not contain any perched ground water in the Acid-Pueblo 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. The main aquifer is separated from water in the alluvium by over 180 to 300 m of unsaturated tuff and volcanic sediments. It is separated from the 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. The aquifer extends into the rocks of the Tschicoma Formation beneath the western edge of the plateau. 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 part is discharged to the river from seeps and springs. 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.

4.6 Biotic Environmental Factors

4.6.1 General Ecology. Community types on the Pajarito plateau range from pinon-juniper woodland with 25 to 30 cm of rain annually at the eastern, lower part of the plateau to ponderosa pine forest with 45 to 50 cm annual precipitation at the western, higher edge. The canyons serve as cold air drainage channels from the mountains to the Rio Grande Valley and, thus, tend to be cooler and more moist than the mesa tops above. This allows vegetation typically characteristic of higher elevations to extend farther eastward along the canyon bottoms. The steep-sided and narrow upper portions of the canyons support a pine-fir community, which gives way to ponderosa pine and subsequently to piñon-juniper with progression down the canyons.

4.6.2 Plants.

4.6.2.1 Characterization. The mesa top at the head of Acid Canyon and at the former TA-45 site is within the ponderosa pine (*Pinus ponderosa*) forest. Acid Canyon and the upper portion of middle Pueblo Canyon are steep sided and narrow. This relatively moist and cool environment supports a pine-fir (*Pinus ponderosa*, *Pinus flexilis*, *Pseudotsuga menziesii*, *Abies concolor*) forest. Lower in middle Pueblo Canyon, the pine-fir forest gives way to a ponderosa pine (*Pinus ponderosa*) forest and finally begins to change to a pinon-juniper (*Pinus edulis*, *Juniperus monosperma*) woodland toward the lower portion of Pueblo Canyon, where the canyon begins to widen out.

Vegetation near the lower portion of middle Pueblo Canyon was recently surveyed.[29] A tabulation of the plants found in this survey is given in Appendix B. The most common shrubs and herbs are listed in Table VI. There is no comprehensive survey of either the Acid/upper-middle Pueblo Canyon area or the mesa top around the head of Acid Canyon and the former TA-45 site. A preliminary survey[30] of these areas resulted in the list of species given in Table VII.

4.6.2.2 Rare and Endangered Species. A recent study by Foxx and Tierney[31] has dealt with the status of the flora found on Laboratory property. Inferences concerning the flora in the areas of interest on the mesa top and in Acid and middle Pueblo Canyons were drawn from their report.

There are no species from the Federal Endangered and Threatened Species List present on Laboratory property. The grama grass cactus (*Pediocactus papyracanthus*), which is found on Laboratory property, has been proposed for inclusion in this list. The grama grass cactus prefers drier mesa tops at lower elevations, however, and so it is not likely to be found in the areas of interest in this report.

Appendix C lists plants found in Los Alamos County and protected under New Mexico Statute 45-11. This statute has no penalties associated with it, per se, but destruction of plants covered by it can result in court action if anyone wishes to bring suit.

A list of 350 plant species was submitted by the New Mexico Heritage Program for consideration for protection under the Federal Endangered and Threatened Species List. Twenty-seven species from this list have been found in or around Los Alamos County, but only pasque flower (*Pulsatilla ludoviciana*) has definitely been found in moist canyon areas in the vicinity of the Laboratory. Other species, such as woodlily (*Lilium umbellatum*), perhaps could be found.

TABLE VI

COMMON HERBS AND SHRUBS OF THE LOWER MIDDLE PUEBLO CANYON AREA

Grasses and Forbs

Andropogon scoparius	little bluestem
Bouteloua gracilis	blue grama
Bromus tectorum	cheatgrass
Koelaria cristata	Junegrass
Taraxicum Officinale	dandelion
Verbascum thapsis	woolly mullein

Shrubs and Subshrubs

Artemisia tridentata	big sagebrush
Atriplex canescens	saltbush
Chrysothamnus nauseosus	chamisa or rabbitbrush
Fallugia paradoxa	Apache plume
Forestiera neomexicana	New Mexico olive
Gutierrezia microcephala	snakeweed
Prunus virginiana, var. *melanocarpa*	chokecherry
Quercus gambelii	Gambel oak
Quercus undulata	scrub oak
Rhus trilobata	squawbush
Robinia neomexicana	New Mexico locust

Disturbed Habitat Plants

Artemisia frigida	wormwood
Chenopodium fremontii	lambsquarters
Chrysopsis villosa	goldenweed
Croton texensis	doveweed
Cryptantha jamesii	James cryptantha
Erodium circutarium	filaree
Helianthus petiolaris	prairie sunflower
Lupinus caudatus	lupine
Mirabilis multiflora	wild four o'clock
Salsola kali	Russian thistle or tumbleweed
Viguiera multiflora	crownbeard

TABLE VII

PLANTS OF TA-45/ACID/MIDDLE PUEBLO CANYON

Sites:
1. TA-45 Treatment Plant Site
2. Mesa Top Adjacent to Head of Acid Canyon
3. East Facing Slope of Upper Acid Canyon
4. Acid Canyon Bottom and Stream Channel
5. Upper Portion of Middle Acid Canyon, Broad Section
6. Middle Pueblo Canyon Stream Channel
7. Upper Portion of Middle Pueblo Canyon, Narrow Section

	Location[a]						
Species	1	2	3	4	5	6	7
Abies concolor - white fir		o	o	●		o	●
Acer glabrum - New Mexico maple							●
Agrostis alba - redtop	o					o	
Allium Cernuum - wild onion						o	
Amaranthus retroflexus - pigweed	o						
Andropogon scoparius - little bluestem	o	●	●	o	●	o	●
Antennaria parvifolia - pussytoes		o	o	o	o	o	
Arctostaphylos uva-ursi - bearberry		o	o				●
Artemisia dracunculus - false terragon	●	o					
Artemisia ludoviciana - wormwood		o	o	o	o	o	
Aster novae-angliae - aster	o			o			
Berberis fendleri - barberry		●	●	o	o	o	●
Betula occidentali8s - birch				o		o	o
Blepharoneuron tricholepis - pine dropseed				o	●	o	
Brickellia spp. - brickelbush		o	o				o
Bromus spp. - bromegrass, cheatgrass	o	o		●		●	
Castilleja integra - Indian paintbrush					o		
Cercocarpus montanus - mountain mahogany			o		●	o	
Chenopodium spp. - lambsquarters		o					
Chrysopsis villosa - golden aster	o	o	o		o		o
Circium spp. - thistle					o		
Clematis pseudoalpina - Rocky Mt. clematis		o	o				o
Conyza canadensis - horseweed	o						
Cornus stolonifera - dogwood							o
Dactylis glomerata - orchard grass						●	o

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[a] Bullet (●) denotes dominant species.

TABLE VII (cont)

Species	Location[a]						
	1	2	3	4	5	6	7
Elaeagnus angustifolia - Russian olive	o			o		o	●
Elymus canadensis - wild rye	o						
Erigeron spp. - fleabane		o			o	o	
Erodium circutarium - heronbill	o						
Eupatorium herbaceum - throughwort					o		
Fallugia paradoxa Apache plume					o		
Fragaria bracteata - wild strawberry							o
Franseria confertifolia - bursage	o						
Grindelia aphanactis - gumweed	o						
Helianthus annuus - sunflower	o						
Helianthus petiolaris - prairie sunflower	o						
Hymenoxys richardsoni - pinque					o		
Ipomopsis longiflora - blue skyrocket	o						
Iva spp. - marsh-elder				o			
Jamesia americana - cliffbush		●	●	●		o	●
Juniperus monosperma - one-seed juniper					o		o
Kochia scoparia - summer cypress	●						
Koeleria cristata - Junegrass					o		
Liatris punctata - gayfeather				o			
Monotropa latisquama - pinesap		o					
Muhlenbergia montana - mountain muhly		●	o	●		o	●
Oenothera spp. - evening primrose	o				o		
Pachystima myrsinites - myrtle boxleaf							●
Panicum capillare - witchgrass	●			o			
Parthenocissus inserta - woodvine							o
Penstemon barbatus - scarlet bugler		o	o				
Picea pungens - blue spruce						o	
Pinus flexilis - limber pine		●	●	●	●	o	●
Pinus ponderosa - ponderosa pine	o	●	●	o	●	o	●
Phleum pratensis - Timothy						o	
Polygonum ramosissimum - knotweed	o						
Populus tremuloides - quaking aspen						o	
Potentilla pulcherrima - cinquefoil		o			o	o	
Pseudotsuga menziesii - Douglas fir		●	●	●	●	o	●

TABLE VII (cont)

Species	Location[a] 1	2	3	4	5	6	7
Quercus gambelii - Gambel oak		●	●	●	○	●	●
Rhus radicans - poison ivy				○	○		
Ribes cereum - wax currant	○		○	○	○		
Rosa spp. - wild rose						●	
Rubus strigosus - raspberry							●
Rumex spp. - dock				○		○	
Salix spp. - willow						●	
Salsola kali - Russian thistle, tumbleweed	○	○					
Senecio spp. - groundsel		○	○				
Sitanion hystrix - squirreltail	○				○		
Solidago spp. - goldenrod		○	○		○		
Sphaeralcea spp. - globe mallow	○						
Sporobolus spp. - dropseed	○						
Tragopogon dubius - goatsbeard, salsify		○					
Ulmus spp. - elm	○						
Valeriana acutiloba - valerian							○

4.6.3 Animals.

4.6.3.1 Characterization. Little quantitative information concerning the fauna of the Los Alamos area is available. Species lists are presented in the Environmental Impact Statement[20] for the Los Alamos Scientific Laboratory site. These lists are included as Appendix D of this report. The lists are, however, uncertain. Occurrence of some species is unverified, although sightings have been reported, and other species that are not in the list are suspected to be present.

A biotic survey conducted by Miera et al.[32] in Acid-Pueblo Canyon and other liquid-effluent receiving areas noted the presence of 14 small mammal species, verified by trapping or sighting. These species are listed in Table VIII.

4.6.3.2 Rare and Endangered Species. Table IX gives a list of endangered and threatened species developed for northcentral New Mexico by the New Mexico State Game Commission.[20] Although several of these species have been documented in Los Alamos County, the only one known to be present in proximity to Acid/middle Pueblo Canyon is the peregrine falcon (*Falco peregrinus*). There is a peregrine falcon aerie in lower Pueblo Canyon, and the falcons use middle Pueblo Canyon as a hunting area.

TABLE VIII

MAMMALS TRAPPED OR SIGHTED IN ACID/PUEBLO CANYON

Eutamius minimus	least chipmunk
Microtus pennsylvanicus	meadow vole
Mus musculus	house mouse
Neotoma mexicana	Mexican woodrat
Peromyscus maniculatus	deer mouse
Peromyscus truei	pinon mouse
Reithrodontomys megalotis	western harvest mouse
Sciurus aberti	tassel-eared squirrel
Sigmodon hispidus	hispid cotton rat
Sorex nanus	dwarf shrew
Spermophilus lateralis	golden-mantled squirrel
Spermophilus variegatus	rock squirrel
Sylvilagus spp.	cottontail rabbit
Thomomys bottae	valley pocket gopher

Another species that may very likely be present in Pueblo Canyon, at least in the upper reaches, is the Jemez Mountain salamander (*Plethodon neomexicanus*). Although this species never has been documented in Pueblo Canyon, it is known to be present in Los Alamos Canyon, which is one canyon south of Pueblo Canyon. The moist environment in Pueblo Canyon caused by sewage treatment plant effluent makes the canyon an ideal habitat for the salamander. A faunal survey of Pueblo Canyon to ascertain whether the salamander is there has never been conducted.

No other endangered or threatened species are suspected of being present in the Acid/middle Pueblo Canyon area.

4.7 Summary of Radiological Conditions[1]

4.7.1 Radioactivity in Soils and Sediments.

4.7.1.1 *Present Conditions*. The data for the Acid/Pueblo Radiological Survey[1] were taken in 1976-1977. Since that time, the routine soil and sediment sampling program conducted by the Environmental Surveillance Group at the Los Alamos National Laboratory has included radiochemical analyses of soil and sediment samples from the Acid/Pueblo Canyon system. These data have been reported in the annual surveillance reports.[19,33-36] A summary of the results of the more recent radiochemical sediment analyses of samples from Acid Canyon is presented in Table X. The annual data from the

TABLE IX

STATE-LISTED ENDANGERED ANIMAL SPECIES FOR NORTHCENTRAL NEW MEXICO

	Group 1 Endangered	Group 2 Threatened
Mammals	Black-footed ferret[a] River otter[a]	Pine marten[a] Mink[a]
Birds	Peregrine falcon Whooping crane White-tailed ptarmigan[a] Sage grouse[a] Mexican duck[a] Bald eagle[a]	Osprey Red-headed woodpecker Zone-tailed hawk
Amphibians		Jemez Mountain salamander
Fish	Shovelnose sturgeon[a] (exterminated) Bluntnose shiner	Suckermouth minnow[a]

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[a] Not documented in Los Alamos County.

TABLE X

SEDIMENT ANALYSES FROM ACID CANYON

	^{137}Cs (pCi/g)	^{241}Am (pCi/g)	^{90}Sr (pCi/g)	^{238}Pu (pCi/g)	^{239}Pu (pCi/g)	Gross α (pCi/g)	Gross β (pCi/g)	Total U (μg/g)
1981	1.0 ± 0.2			0.085 ± 0.032	14.9 ± 1.00	11 ± 4.0	3.9 ± 1.0	
1980	0.8 ± 0.20	0.449 ± 0.032	1.23 ± 0.28	0.039 ± 0.008	6.46 ± 0.32	7.7 ± 3.2	4.2 ± 1.2	2.1 ± 0.4
						17 ± 8.0	9.2 ± 2.0	
1979	1.03 ± 0.18		0.68 ± 0.20	0.068 ± 0.012	10.6 ± 0.60	12 ± 4.0	6.0 ± 1.4	2.7 ± 0.6
1978	0.68 ± 0.06	0.351 ± 0.024		0.034 ± 0.018	5.62 ± 2.39	7.5 ± 3.2	4.5 ± 1.2	
1977					1.24 ± 0.658	2.8 ± 0.8	2.9 ± 1.6	1.6 ± 0.1
1976-77[a]								
Acid Canyon								
Channel Average	1.9 ± 4		1.0 ± 1.4		31 ± 29			1.3 ± 1
Range	(0.2 - 12.1)	(0.33 - 43.4)	(0.4 - 4.5)	(0 - 3.13)	(5.2 - 629)	(20 - 580)	(1-9)	(2.8 - 10)

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[a] Data taken from Ref. 1.

surveillance reports generally fall into the lower end of the range of values reported in the radiological survey. The data show no particular trend. The apparent drop in some concentrations from the averages reported in the radiological survey (see Table X) is explained by noting that, during the survey, radiochemical analyses were performed only on samples for which high-gross alpha and/or beta counts were recorded.

Sections 4.7.1.2 and 4.7.1.3 summarize the data from the radiological survey.[1]

4.7.1.2 Concentrations. The distribution pattern of ^{239}Pu* on sediments and soils is displayed in Fig. 9. Quantitative data summaries are also presented in Table XI. The most important features of the pattern include the following.

- The highest concentrations are associated with the untreated waste outfall (Treatment Plant Site Surface, Figs. 5 and 9).
- Some subsurface residual radioactivity is present in the immediate area of the former waste treatment plant location and along part of the alignment of the former industrial waste line (Treatment Plant Site Subsurface, Figs. 5 and 9).
- 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 (Fig. 9).
- Concentrations in the channels and banks generally decline with increasing distance from the discharge points (Fig. 9).
- 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 (Fig. 9).

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 having subsurface residual radioactivity in the vicinity of the former waste treatment plant site is generally within a rectangle about 55 m by 60 m and within about 2 m depth from the surface (Fig. 5 and Table XI). Another smaller area along the alignment of the former waste line is about 40 by 3 m and within about 1.5 m depth from the surface.

The highest concentrations of surface residual radioactivity (depths to about 30 cm) in the vicinity of the Treatment Plant site are adjacent to the

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

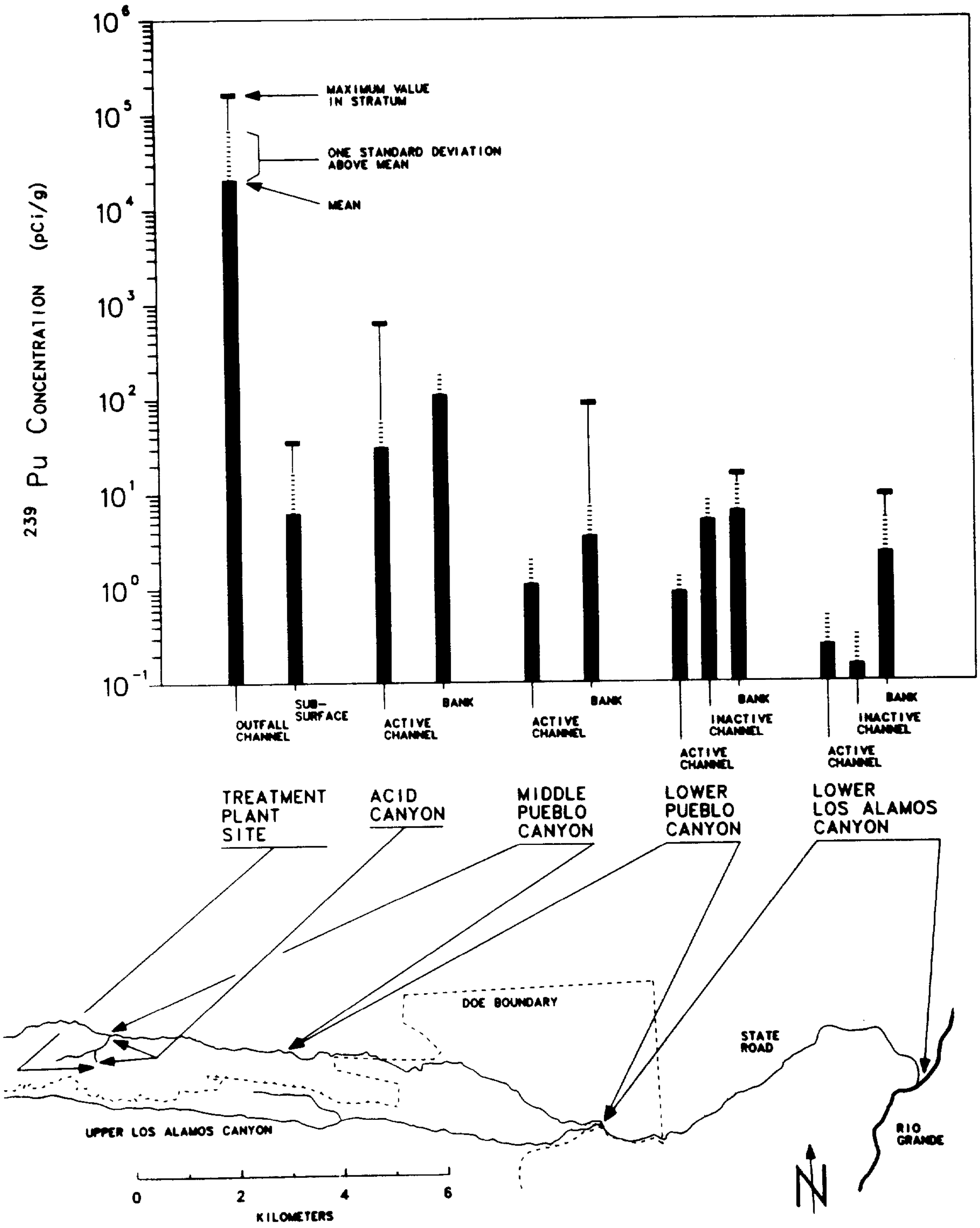

Fig. 9. Concentration of ^{239}Pu on soils and sediments by location.

TABLE XI

SUMMARY OF DATA[a]

STRATUM:	Treatment Plant Site		Acid Canyon	Mid-Pueblo Canyon	Lower Pueblo Canyon	Lower Los Alamos Canyon	Northern New Mexico Background Concentrations
	Subsurface	Surface					
Radioactivity Concentrations ($\bar{x} \pm s$)[b]							
^{239}Pu (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.[c]	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}Pu Inventory Estimate							
Stratum inventory (mCi, $x \pm 2s_x$)[d]			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 (m^2)	~3500	~500	~1750	~50 000	~200 000	~260 000	

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[a] Taken from Ref. 1.

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

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

[d] $s_{\bar{x}}$ denotes the standard error of the calculated estimate; in this line, $\bar{x} \pm 2s_{\bar{x}}$ represents an approximate 95% confidence interval of the estimate.

natural drainage channel that received the untreated effluent (Fig. 5). This area is about 30 m long and no more than 5 m wide. Within it, maximum concentrations occur within a band of elevated activity about 30 to 70 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 toward the canyon edge. This area is roughly 10 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 Table XI). Throughout the canyons the activity is largely confined to depths of about 30 cm.

Transuranic radioactive isotopes present in addition to ^{239}Pu include ^{238}Pu, ^{241}Pu, and ^{241}Am. They are accounted for in the evaluation by using ratios of their activities to the activity of ^{239}Pu, as shown in Table XII. 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/or 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 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 XI. The values given are the statistically significant increment above regional background values. Where there was no significant increment (significance level α = 0.05), the entry in the Table is "N.S."

Even though a large number of samples were collected and analyzed, the physical areas involved and the complex natural processes involved in the dispersion of the radioisotopes from the discharge points made representative sampling extremely difficult. This is reflected clearly in the standard deviations of the concentrations presented in Table XI. 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 are 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 sediments within the channels, measurements made during this study are compatible with values obtained during previous special and monitoring studies (Ref. 1).

The standard deviations of the concentration data are given in Table XI 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.

Preliminary evaluations of the data were performed using geometric means, because physical processes such as hydrologic transport often have 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 used 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.

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

4.7.1.3 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. 10. Quantitative estimates are summarized in Table XI. Two major features of the pattern are evident.

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

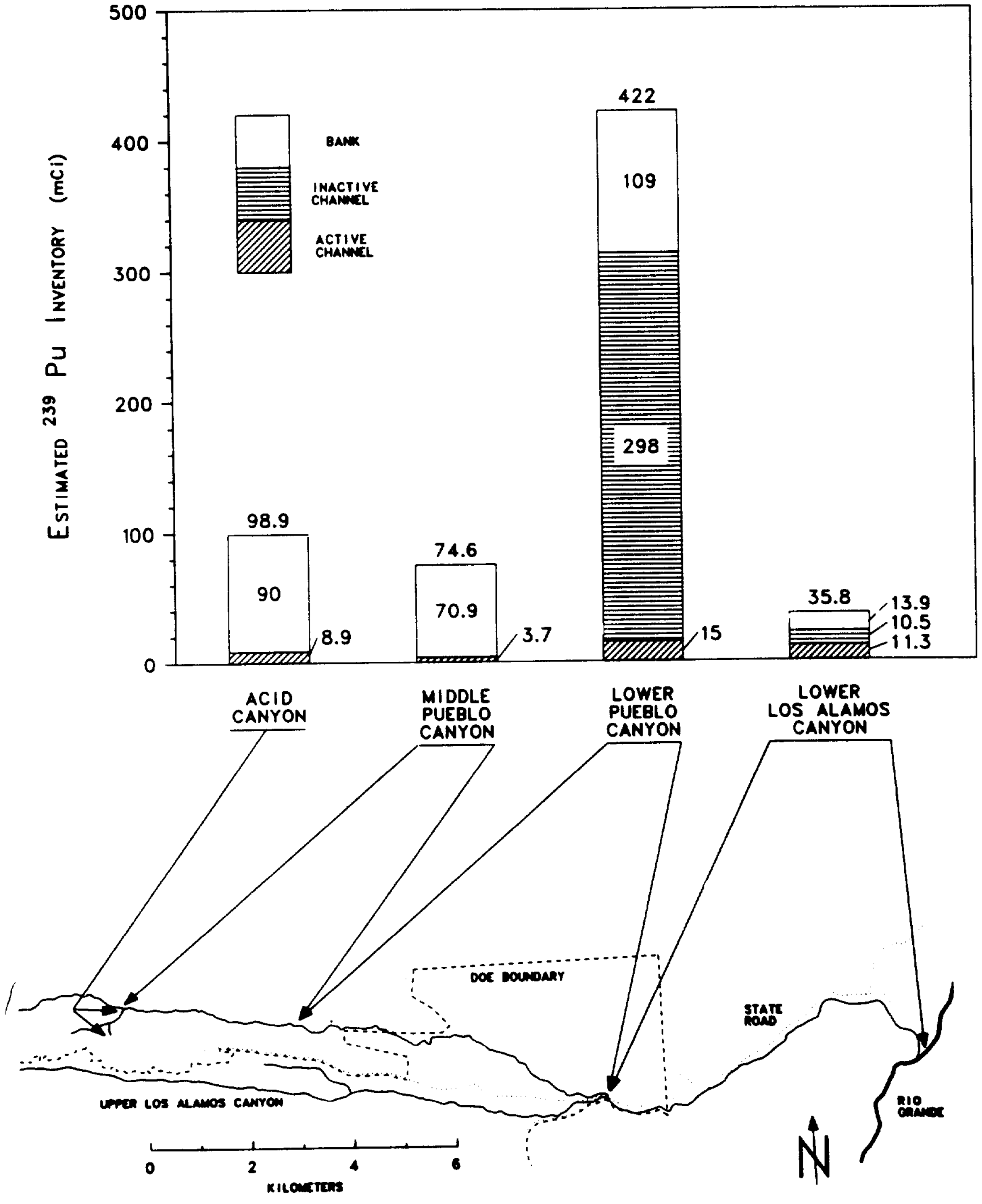

Fig. 10. Estimated inventory of ^{239}Pu on soils and sediments by location.

The total estimated inventory, based on arithmetic means, is about 630 ± 300 mCi (approximate 95% confidence interval), or 7.9 ± 3.8 g. This is about 3 times the total of estimated and measured releases into Acid Canyon and the still-onsite DP Canyon, which discharges into Los Alamos Canyon. This is reasonable agreement given the uncertainties discussed in this section.

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

4.7.2 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 analyzing actual measurements of airborne radioactivity in the vicinity of Los Alamos and by applying a simple theoretical model to the canyon sediment and soil radioactivity data.

4.7.2.1 Present Conditions. Information for the Acid/Pueblo Radiological Survey[1] was assembled from data collected by the air sampling network maintained as part of the routine environmental surveillance program at the Los Alamos National Laboratory. Data from 1974 through 1978 were used in the radiological survey. The same air sampling network still is in operation, and Table XIII presents data from the network for 1979-1981,[19,35-36] along with the 1974-1978 data used in the radiological survey.

The stations for which data are presented include four on mesa tops at various distances from the TA-45/Acid/Middle Pueblo site. These are Cumbres School, TA-21, Los Alamos Airport, and Bandelier stations, in order of increasing distance from the TA-45/Acid Canyon site. The Bayo Sewage Plant station is near the midpoint of lower Pueblo Canyon, and the Santa Fe station is located about 40 km to the southeast.

Although there appear to be large fluctuations in the data presented in Table XIII, these fluctuations generally are within the uncertainties of the analyses and represent year-to-year fluctuations rather than variation among stations. There is no indication that any of the stations are being influenced by resuspension from TA-45/Acid/middle Pueblo Canyon.

Sections 4.7.2.2 and 4.7.3.3 summarize the data from the radiological survey.[1]

4.7.2.2 Measurements. The basic conclusions presented in the radiological survey[1] on the basis of analysis of the 1974-1978 data include the following.

TABLE XII

RELATIONSHIP OF ^{239}Pu AND OTHER TRANSURANIC CONCENTRATIONS[a]

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

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[a] Taken from Ref. 1.

[b] Plutonium-241 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 XIII

ANNUAL AVERAGE ^{239}Pu AIR CONCENTRATIONS (aCi/m^3) (10^{-12} μCi/m^3)

Location	1974	1975	1976	1977	1978	1979	1980	1981
Bayo Sewage Plant (Bottom of Lower Pueblo Canyon)	27 ± 3	19 ± 2	5.1 ± 1.0	65 ± 240	27 ± 61	4.8 ± 6.3	3.5 ± 3.4	12 ± 13
Cumbres School (North Rim, Middle Pueblo Canyon)	31 ± 4	15 ± 2	4.0 ± 0.9	13 ± 39	24 ± 47	25 ± 91	4.0 ± 2.7	14 ± 15
Los Alamos Airport (South Rim, Lower (Pueblo Canyon)	25 ± 2	24 ± 4	6.8 ± 1.1	18 ± 28	20 ± 41	4.8 ± 5	9.8 ± 16	14 ± 8
Technical Area 21	23 ± 2	18 ± 2	6.2 ± 1.1	21 ± 32	23 ± 51	6.1 ± 10	1.2 ± 2.0	4.6 ± 4.2
Bandelier	32 ± 3	23 ± 2	6.2 ± 1.2	28 ± 58	40 ± 66	6 ± 10	0.8 ± 1.8	19 ± 14
Santa Fe	21 ± 2	16 ± 2	3.8 ± 0.8	16 ± 23	24 ± 46	3.6 ± 2.2	0.1 ± 0.9	7.2 ± 9.6
New York City	39	20	6.0	21	32 (1st quarter only)			

- Measurements of annual average ^{239}Pu concentrations found in Pueblo Canyon showed the same temporal pattern as locations representative of only worldwide fallout.
- Possible, but generally not statistically significant, differences in individual airborne plutonium concentration measurements during 6- to 8-wk sampling periods during 1976 and 1977 at various locations in Los Alamos apparently were unrelated to proximity to Acid and Pueblo Canyons or to measurements of total airborne particulates.
- Measurements during 1 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 (CG) or 0.3% of the proposed EPA derived air concentration limit.

The most useful data of the 5 yr 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 as 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. 11. In general, all three locations display the same pattern throughout the year, in most cases differing by less than 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 (12/12/75 to 2/2/76 and 9/13/76 to 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 to 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 of the second, third, fourth, eighth, and ninth sampling periods, when no significant differences in plutonium concentrations occurred. Thus, there are only marginal differences between airborne concentrations of ^{239}Pu in Pueblo Canyon and worldwide fallout levels measured elsewhere. No clear relation exists 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

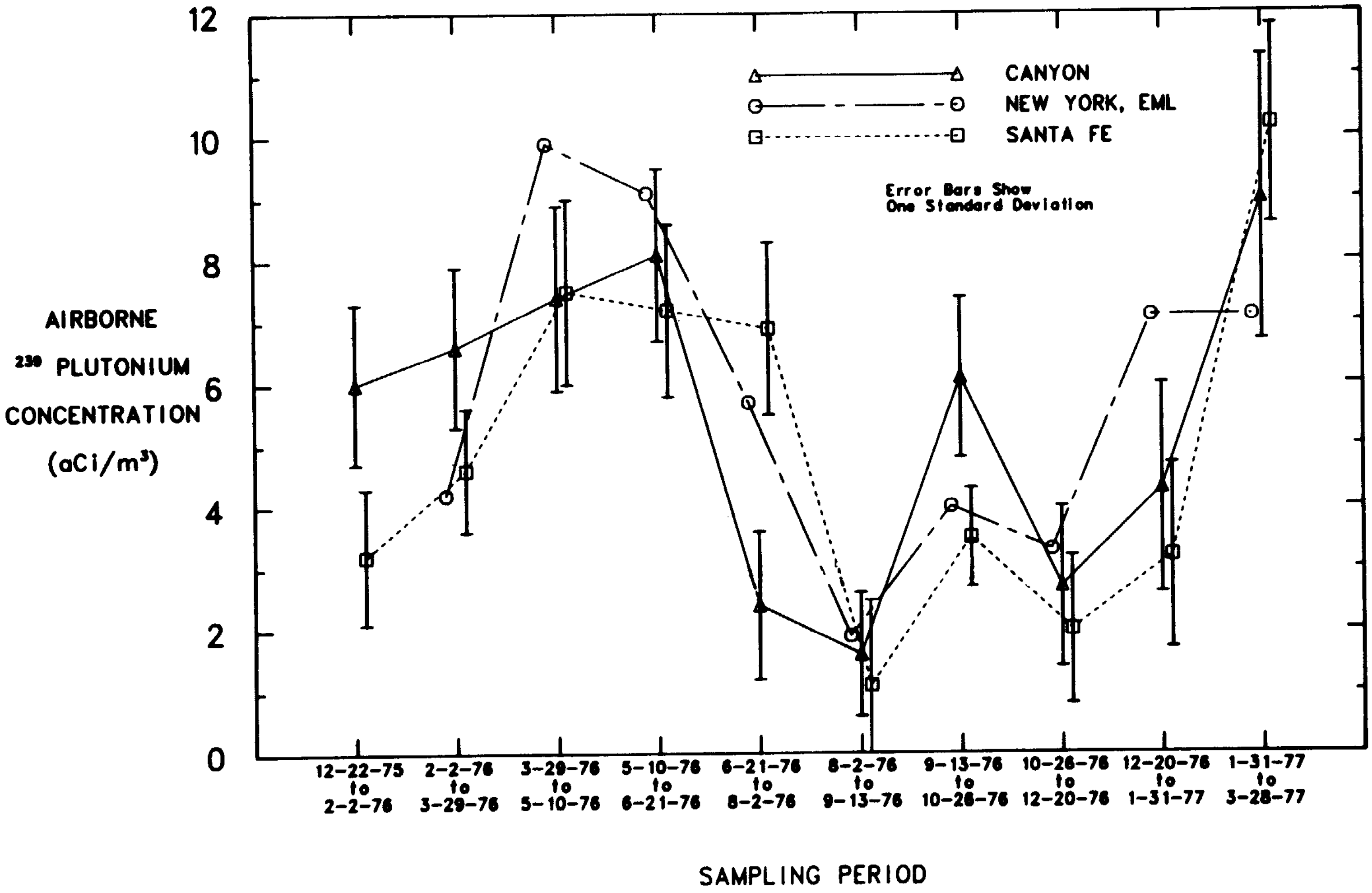

Fig. 11. Concentrations of airborne ^{239}Pu at three locations during 1976-1977.

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. Most important, additional data from many more sampling locations, as reported annually by the Los Alamos National Laboratory environmental monitoring program, have shown no statistically discernible 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 sediment and soil resuspension 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 of suspended airborne particulates was slightly higher than normal (37.6 $\mu g/m^3$ compared to 35 $\mu g/m^3$). These conditions all would be expected to maximize resuspension. The largest increment above worldwide fallout in ^{239}Pu concentration measured during the year was 2.8 aCi/m^3 in Pueblo Canyon (as compared to Santa Fe). This value, rounded to 3 aCi/m^3, was used in subsequent analyses 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. 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 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. 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 were 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.

4.7.2.3 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-resuspendible particles (enrichment factor) and for the small proportion of the area containing residual radioactivity along the channels (area modification). Details of the assumptions and calculations are presented in Ref. 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. 37. 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 to contain residual radioactivity 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 XIV presents 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 give the relation of the estimated concentration increments and background to the DOE CG and to the proposed EPA derived concentration limit. The DOE CG (60 000 aCi/m^3) is that for ^{239}Pu in Uncontrolled Areas, that is, accessible to the public, with continuous occupancy, and the lung is considered the critical organ. The EPA value (1000 aCi/m^3) 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..."[38] 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-yr average for fallout. The estimated maximum short-term value for Pueblo Canyon is about 10 times the 5-yr average.

The activity ratios from Table XII 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.

4.7.3 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 residual radioactivity 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 (Ref. 1). These measurements represented total doses without discrimination between the contribution from the residual radioactivity and that from natural cosmic and terrestrial sources. Accordingly, they can be compared to measurements made in areas representing only natural sources and to estimates of potential residual radioactivity contributions. Such estimates are subject to considerable uncertainty because of large temporal and spatial variation in natural background.

Natural background external penetrating radiation variations are well documented in the Los Alamos area. Most of the variation is due to differences in the terrestrial component because 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 μrem/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, that 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 resulted 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 μreh/h between 1976 and 1978. These stations are located on the mesas in the townsite and at 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-yr average of 13.4 μrem/h, as shown in Table XV. The TLD measurements in the four canyon areas averaged 12 to 19 μrem/h. 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. The apparent differences of 4 to 7 μrem/h for middle Pueblo Canyon and Acid Canyon are probably due largely 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 due primarily to measurements made in small areas in the vicinity of the untreated waste outfall and the vehicle decontamination facility, where maximum levels of surface residual radioactivity were found (Fig. 5).

TABLE XIV

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

	^{239}Pu Concentration (aCi/m^3)	Percent of DOE Concentratation Guide (%)	Percent of Proposed EPA Derived Limit (%)
Theoretical Contributions of Resuspension to ^{239}Pu Airborne Concentrations			
Acid Canyon	71	0.1	7
Middle Pueblo Canyon	25	0.04	2.5
Range of ^{239}Pu from Worldwide Fallout 1974-1978 at Santa Fe, NM			
Low (1976)	3.8	0.006	0.4
5-yr average	16	0.03	1.6
High (1978)	24	0.04	2.4

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[a] Taken from Ref. 1.

TABLE XV

EXTERNAL PENETRATING RADIATION MEASUREMENTS AND ESTIMATES OF CONTRIBUTIONS FROM RESIDUAL RADIOACTIVITY[a]

(μrem/h)

Location	Measurement by TLD First Quarter 1978	Theoretical Contribution From Above-Background Radioactivity
Middle Pueblo Canyon	16 ± 1	<0.01
Acid Canyon	19 ± 3	1.1[b]
TA-45 Site	19 ± 3	
Untreated Waste Outfall	16-18	50[c] (maximum)
Vehicle Decontamination Facility	22-26	40[b] (maximum)
Los Alamos Surveillance Program Perimeter Group[d]		
First Quarter 1978	12 ± 1	
4-yr Group Average	13.4 ± 1	
Range of Separate Station Values	9.4 - 17.4	

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[a] Taken from Ref. 1.

[b] Cesium-137 main contributor.

[c] Americium-241 and ^{137}Cs main contributors.

[d] Not affected by Los Alamos operations.

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}Am. The method assumed doses were from an infinite plane, with the radioactivity distributed vertically, and accounted for absorption and scattering in the soil.[1] The estimated total contributions to doses from these isotopes are presented in Table XIII. 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 residual radioactivity in the 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 results mainly from ^{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 residual radioactivity occurs in areas of a few meters, the 40 μrem/h estimate also is overstated.

During the course of the field work, many measurements were made with portable instruments. The readings observed with the 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.[1] The purpose of the instrumental surveys was to increase the confidence that no major areas of activity were overlooked.

5.0 ENVIRONMENTAL CONSEQUENCES

5.1 Alternative I--Minimal Action

5.1.1 Radiological Consequences. There will be no cleanup under this alternative. The radiological risks and radiological conditions, as described in Sections 2.2 and 4.7, respectively, will remain the same. However, the likelihood of exposure to surface residual radioactivity exceeding the proposed criteria will be effectively eliminated by fencing the areas where it exists.

5.1.2 Ecological Consequences. Ecological consequences associated with this alternative will be minimal. Some disturbance will be associated with the fence installation, but this should have little long-term impact on the area, because it is naturally rather barren and rocky. No trees need be disturbed, only the sparse herbaceous and shrubby vegetation. The fence will restrict large animal movement into the 0.45 hectare enclosed plot, but large animal movement in this area is minimal anyway, if not nonexistent, because of its location in the middle of the Los Alamos townsite. No endangered species will be affected, because access to the area is not through Pueblo Canyon where the peregrine falcons and perhaps the Jemez Mountain salamander are found. Only temporary alteration of the landscape will occur, and actions associated with the fence installation will not increase erosion potential. No ecological impact on lower Acid Canyon and middle Pueblo Canyon will result from this alternative.

5.1.3 Land Use Impacts. Fencing the area around the head of Acid Canyon will not affect the land use potential because this part of the site is rocky and steep. Recreational use of this area is negligible. The only portion of the site suitable for any kind of a building is the former waste treatment facility location where construction would be difficult because of the metal and concrete debris within the landfill (Sec. 4.1.1). This location is outside of the proposed fence and is used by the County as a landfill area. Alternative I does not affect the land use potential of lower Acid Canyon or middle Pueblo Canyon. The most likely use of these canyons is for recreational purposes, as discussed in Sec. 4.1, because they are not suitable for residential development.

5.1.4 Socioeconomic Effects. No direct demographic, institutional, or archaeological effects are associated with this alternative. The 0.45-hectare plot to be fenced is not in an area associated with any archaeological ruins.

The economic effect will be negligible. Ford, Bacon & Davis Utah estimated that acquisition of the land and fencing could be completed by a crew of four in 10 to 12 days at a cost of $96,000.[2] This cost may be an underestimation because of the extremely rugged nature of the area to be fenced and the inflated cost of land in Los Alamos Canyon, but, nevertheless, it represents only a small economic impact. If the Zia Company, a private company under contract to DOE in Los Alamos, were to perform the cleanup, it would represent about 0.15% of their annual budget and less than 0.015% of total annual company man hours.

5.1.5 Risk to Individual Health and Safety. The risk associated with installing the fence is negligible, even considering the rugged terrain that the fence traverses. The radiological risk to the fencing crew also is negligible because of the low level of radioactivity present and the short time required for fence installation. In addition, the fencing crew will not be working directly in the small areas where radioactivity exceeds the proposed criteria. After fencing, radiological risk to recreational users of either the mesa top area at the head of Acid Canyon or of Acid/middle Pueblo Canyon remains as discussed in Sec. 2.2.

5.2 Alternative II--Remedial Action (Preferred Alternative)

5.2.1 Radiological Consequences. Only two small areas, about 0.2 hectare in extent, will be affected by this alternative. Removal of the soil containing residual radioactivity from the former treatment plant site will reduce the potential dose and risk associated with it. Lower Acid Canyon and middle Pueblo Canyon will remain as discussed in Secs. 2.2 and 4.7. The reduced risk in cleanup areas, along with risks to cleanup workers, truck drivers, and to the general public in the event of an accident en route to the waste disposal site, is discussed in Sec. 5.2.5 on "Risk to Individual Health and Safety."

5.2.2 Ecological Consequences. About 0.2 hectare of surface area will be impacted directly by the cleanup operation. Some additional impact will result from the movement of vehicles to the cleanup sites. However, this will be a minimal additional impact considering the short distance from the main road and the already disturbed landfill area, especially if the existing fence is removed to provide easier access to the former untreated waste outfall site west of Acid Canyon.

The amount of vegetation that will be removed is small because the area is rather barren, rocky, and sparsely vegetated. Removal of only a few large trees should be necessary. Primarily, only herbaceous vegetation and shrubs should be affected, although some root damage to surrounding large trees could occur. The likelihood of any plant protected by state law (Sec. 4.6.2.2) existing on this particular small plot of ground is very small. The peregrine falcons in Pueblo Canyon are not threatened, nor are any Jemez Mountain salamanders that may reside there, because access to the cleanup areas is by way of Canyon Drive on the mesa top.

The Ford, Bacon & Davis Utah engineering evaluation called for replacement of the excavated soil and revegetation of the impacted area. However, any attempt to do so would probably be wasted effort. Because the area is rocky and steep, any soil and seed used in a revegetation attempt would probably wash down the canyon with the first rainstorm. Sparseness of existing vegetation indicates that allowing natural succession to re-establish the vegetation is the most logical approach. In addition, no revegetation is being undertaken in the immediately adjacent active landfill area. Erosion potential may be slightly increased in the short term as a result of the cleanup action, but any erosive effect should be small because of the shallow soil depth at the site.

The amount of excavated soil requiring disposal is estimated to be about 230 m^3 (Ref. 2). This is a relatively small quantity and should have a negligible impact on operations at the radioactive solid waste disposal site (TA-54), amounting to about 5% of current annual operation.

5.2.3 Land Use Impacts. The cleanup alternative will not affect continued use of lower Acid Canyon and middle Pueblo Canyon as recreational areas (Sec. 4.1). The effect on the area around the head of Acid Canyon will be negligible because this terrain is rocky and rough. The only portion of the mesa top at the former TA-45 site suitable for construction is the site of the old treatment plant itself. This area, currently used by Los Alamos County for landfill, will not be affected by the cleanup action. As discussed in Sec. 5.1.3, construction there would be difficult because of the metal and concrete debris within the landfill. Aesthetic effects beyond the cleanup operation itself will be minimal because of the location of the site, which is between a County landfill and a County equipment storage yard.

5.2.4 Socioeconomic Effects. No direct demographic, institutional, or archaeological effects are associated with this alternative. The small area around the head of Acid Canyon affected by the cleanup operation contains no archaeological ruins.

The economic effect associated with the cleanup will be small. The cleanup operation is estimated to require 10 to 12 days by a crew of six at a cost of $55,500.[2] This does not include the cost of backfill and revegetation. The cost of backfill and revegetation was subtracted from the Ford, Bacon & Davis Utah estimate because it seems unnecessary and also probably is futile (Sec. 5.2.2). If the cleanup operation were carried out by the Zia Company, it would represent about 0.1% of their annual budget and less than 0.02% of total annual company man-hours.

Transport of soil containing residual radioactivity to TA-54 should have a negligible impact on local traffic if it is scheduled to avoid peak commuter traffic hours. Two hundred and thirty cubic meters of soil represent 40 to 45 truckloads of material to be transported from the former TA-45 site to TA-54. Compared to an average daily weekday traffic load of 8500 to 9500 trips (one-way) (Section 4.1.4), this is insignificant. With proper precautions, closure of Diamond Drive and Pajarito Road should not be necessary (Sec. 4.1.4).

5.2.5 Risk to Individual Health and Safety. As a result of cleanup activities, cleanup workers, truck drivers, and the general public may receive some radiation dose. The maximum incremental lifetime risks of dying from cancer as a result of these doses were estimated for these three groups. These risks are summarized in Table II.

Cleanup workers would incur an additional lifetime risk of bone cancer mortality of 8.4×10^{-7} (1 chance in 1 200 000). This is the highest risk encountered among these groups. For comparison, the lifetime risk of cancer mortality from a 1-yr exposure to natural background radiation is 1.5×10^{-5} (15 chances in 1 000 000). The risk for 50 yr of exposure is 8×10^{-4} (8 chances in 10 000).

5.3 Alternative III--No Action

5.3.1 Radiological Consequences. If no fencing or cleanup action is undertaken, radiological risks and conditions will remain the same as discussed in Sections 2.2 and 4.7.

5.3.2 Ecological Consequences. No new ecological consequences are associated with the no-action alternative. No endangered species will be threatened. No further alteration of the landscape will occur. Conditions will remain the same as discussed in Secs. 4.3 and 4.6.

5.3.3 Land Use Impacts. The use of lower Acid Canyon and middle Pueblo Canyon as recreational areas (Sec. 4.1) will not be affected. The present use of the former treatment plant site as a landfill will continue. Location of a building there in the future is a possibility because the site is level. However, construction would be difficult because of metal and concrete debris within the landfill (Sec. 4.1.1). Should this occur, there will then be greater potential for exposure of the building occupants to the surface residual radioactivity around the head of the adjacent Acid Canyon.

5.3.4 Socioeconomic Effects. No direct demographic, economic, institutional, archaeological, or other socioeconomic effect will occur under the no-action alternative.

5.3.5 Risk to Individual Health and Safety. There will be no human risk from remedial actions because none are occurring. Risks to recreational users will remain as discussed in Sec. 2.2.

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APPENDIX A
DOSE CALCULATIONS FOR TA-45/ACID CANYON CLEANUP

1.0 SOIL CONCENTRATIONS IN THE AREAS OF CLEANUP

Two areas would be cleaned up under Alternative II. These areas, shown in Fig. A-1, have highly variable above-background soil concentrations of ^{90}Sr, ^{137}Cs, ^{234}U, ^{238}U, ^{238}Pu, ^{239}Pu, ^{241}Pu, and ^{241}Am, with ^{239}Pu predominating.[1] Soil concentrations of ^{239}Pu are included in Fig. A-1 to show the range of concentrations involved. The soil concentrations of all above-background isotopes are presented in Table A-I.

As can be seen from the table, the radionuclide having the highest activity is ^{239}Pu, for which the soil concentrations range from 0.61 to 163 000 pCi/g.[1] Maximum concentrations of total uranium, ^{238}Pu, ^{241}Pu, and ^{241}Am are 600 μg/g, 696 pCi/g, 14 900 pCi/g, and 1200 pCi/g, respectively, and were located in the same area as the highest ^{239}Pu sample near the untreated waste outfall. The maximum concentrations of ^{90}Sr (229 pCi/g) and ^{137}Cs (176 pCi/g) were found near the former vehicle decontamination facility.

To estimate doses resulting from cleanup operations, average radionuclide soil concentrations were calculated for the soil to be removed. Most samples in the areas to be excavated were collected in the sections of the untreated waste outfall with the higher activities (Fig. A-1). Sampling density in other areas was smaller. To adjust for this nonrandom distribution of sampling points, an area-weighted average was used to give the best estimate of the radionuclide concentrations present.

The untreated waste outfall area (shown in Fig. 5 of the main text) was divided into two sections, A and B, so that the more radioactive material in the northern part (Section A, which encompasses samples 2, 3, 6, 7, 8, 9, and 12) would be treated separately. Sections A, B, and C, the section to be cleaned up around the former vehicle decontamination facility (Fig. 5, main text), had estimated areas of approximately 90, 60, and 300 m^2, respectively.[1] These areas were used as weights in calculating the overall average radionuclide concentrations in the soil to be excavated. The averages are given in Table A-II.

2.0 DOSES TO CLEANUP WORKERS

Doses to cleanup workers were estimated from sampling results of previous cleanup operations performed at the Laboratory.[2,3] This calculational procedure was chosen because it gives the most realistic estimate of the expected dose. It is based on real data taken from projects similar to the present project. During the present project, dose reduction measures and health physics supervision similar to those for the previous cleanup operations[2,3] would be applied.

TABLE A-I

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

	µCi/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	52490	86900.0	326.0	7970	55.0	1.20	79.0	71
9	0.9	1.13	87890	163000.0	696.0	14900	1200.0	0.0	122.0	93
8	2.4	2.26	10010	16300.0	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
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
C-1	0.61	0.31	80	34.0	0.32	---	---	0.94	2.4	13.7
D-1	183.0	77.6	---	38.2	0.25	---	---	0.75	110.0	12.1

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[a] Plutonium-241, a beta emitter, is included here because it is a precurser of ^{241}Am, an alpha emitter.

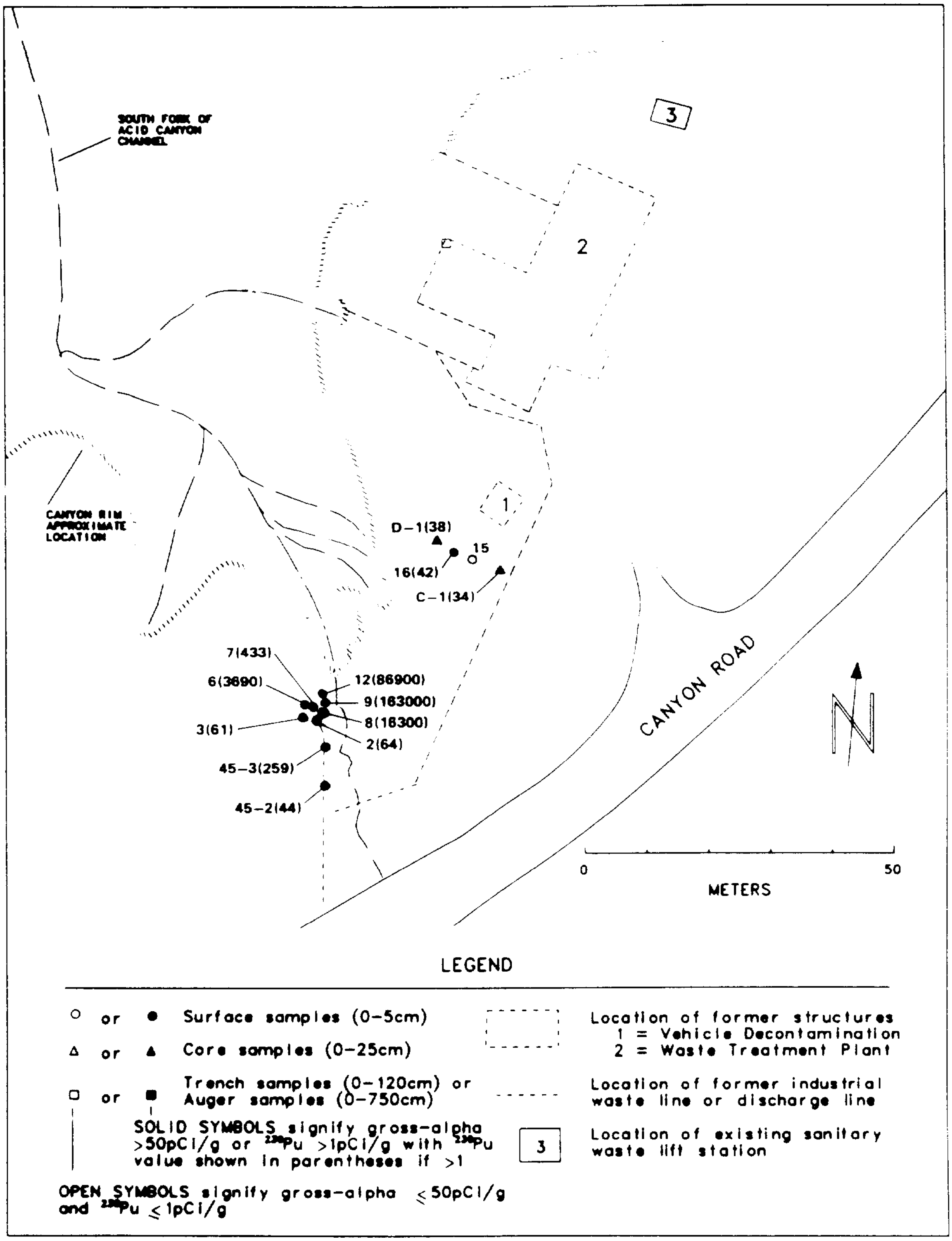

Fig. A-1. Sampling locations and summary results for areas of former treatment plant site to be cleaned up under Alternative II.

TABLE A-II

AVERAGE RADIONUCLIDE CONCENTRATIONS IN SOIL (pCi/g)
IN THE AREAS OF CLEANUP

Section	^{90}Sr	^{137}Cs	^{239}Pu	^{238}Pu	^{241}Pu	^{241}Am	^{234}U[a]	^{238}U
A	1.80	11.32	38600	160	8200	210	980	45
B	0.38	0.21	150	0.70	--	--	18	0.83
C	104	64	29	0.21	--	--	445	20
Area Weighted Average	70	45	7800	32	--	--	500	22

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[a] The ^{234}U is based on the estimate of 7 pCi of excess $^{234}U/\mu g$ of total uranium (3).

Past experience at the Laboratory has shown that dose reduction measures have been effective in keeping radiation doses low. These measures include keeping soil wet during excavation to reduce dusting and using respiratory protection equipment, in this case full-face masks, whenever resuspension of soil with high levels of residual radioactivity is a possibility.

In the cleanup of the former main technical area (TA-1) in 1975 and 1976, elevated levels of ^{239}Pu similar to those found in the Acid/Pueblo project were encountered.[1,2] Soil near buildings D and D2 at TA-1 had gross-alpha levels, mostly ^{239}Pu, in the thousands of pCi/g. Reported high concentrations included a sample with 125 000 pCi/g of ^{239}Pu, 365 pCi/g of ^{238}Pu, and 986 pCi/g of ^{241}Am. Samples were reported as having gross-alpha activities up to 89 600 pCi/g, as measured with a field gross-alpha detector. Some soil had alpha activity measured with a phoswich (a portable survey instrument designed to detect x-ray radiation, from which alpha activity is inferred) greater than 100 000 pCi/g.[2]

During the TA-1 project, air was sampled throughout the workday in the immediate vicinity of the cleanup operation, and the air filters were analyzed daily. Of 242 air samples, 33 had positive, long-lived gross alpha activity. The maximum concentration was 3.6×10^{-13} uCi/mℓ.[2]

Daily nose swipes were taken from workers in areas with residual radioactivity, but no activity was found in any of the 1705 swipes. All workers who might have been exposed to plutonium were given urinalyses. Twenty urinalyses outside the routine urinalysis program were performed for TA-1 workers. No urinalyses indicated exposure.[2]

Other radiation protection measures taken at TA-1 that would also be used at the Acid/Pueblo cleanup operation would be the wearing of personnel thermoluminescent dosimeters to measure external penetrating radiation and the use of protective clothing. If a potential for significant airborne radioactivity exists, full-face masks will be used.

The occupational health physics sampling results from the removal and cleanup of the former acid waste sewer line at the intersection of Trinity and Diamond Drive in 1977 also were reviewed.[3] Of 40 air samples taken, none had detectable gross alpha or gross beta. The lower limits of detection were 0.7% of the Radioactivity Concentration Guide (RCG) for ^{239}Pu and 0.0035% of the RCG for unknown gross-beta activity.[4]

Doses to cleanup workers for the present project, the cleanup of the site of the former waste treatment plant, were estimated using the highest TA-1 air sampling result. We used the conservative assumption that the highest air concentration of gross-alpha activity measured at TA-1 (3.6×10^{-13} µCi/mℓ, or 0.36 pCi/m^3) persisted throughout the 56 h of Acid-Pueblo site preparation and excavation. This alpha activity was assumed to be due to ^{239}Pu. We assigned air concentrations to the other radionuclides present in the soil by multiplying the ^{239}Pu air concentration (0.36 pCi/m^3) by the ratio of the activity of each radionuclide to that of ^{239}Pu. Ratios were calculated from the average concentrations of the various radionuclides from soil samples collected in the section of the untreated waste outfall area (Sec. A, Fig. A-1) having the highest concentration of residual radioactivity.

The formula $D_{ij}=(AC_j)(BR)(T)(DCF_{ij})/(PF)$ was used for 50-yr dose commitment calculations,

where

D_{ij} = 50-yr dose commitment received by organ i from radionuclide j (mrem),

AC_j = air concentration of radionuclide j (pCi/m^3),

BR = 0.043 m^3/min, the breathing rate typical of an adult doing heavy work,[5]

T = 3360 min (56 h), the estimated length of time needed for cleanup (site preparation and excavation) of the area,

DCF_{ij} = dose conversion factor giving the 50-yr dose commitment (mrem) to organ i due to inhalation of 1 pCi of radionuclide j (mrem/pCi), and

PF = protection factor: = 1 for an individual with no respirator; = 100 for an individual wearing a full face mask.[6]

Fifty-year dose commitments to whole body, bone, and lung were calculated for all radionuclides. Dose conversion factors were taken from Ref. 7. Doses are presented in Table A-III. The doses were calculated for an individual not wearing a full-face mask (PF = 1). This is a conservative assumption because full-face masks will be worn for at least part of the project when the soil having higher concentration is being removed. This would reduce by a factor of 100 the dose received during the time period when a respirator is worn.

3.0 DOSE TO A TRUCK DRIVER

Truck drivers will spend approximately 11% of their time at the cleanup site. The remaining time will be spent driving to and from the radioactive waste disposal site (TA-54) and emptying loads of soil at the site.

At the cleanup site, drivers will have the same respiratory protection as the cleanup workers. Consequently, their doses from soil inhalation and exposure to external radiation will be 11% of that incurred by workers.

While transporting soil to TA-54, drivers will be exposed to external radiation from gamma emitting radionuclides in the soil for approximately 16 h of the 56-h cleanup operation. We used external radiation dose conversion

TABLE A-III

ESTIMATED DOSES FROM CLEANUP OF FORMER WASTE TREATMENT SITE (ALTERNATIVE II)

	50-Yr Dose Commitment (mrem)		
	Bone	Lung	Whole Body
Cleanup Workers			
Inhalation	168	9.1	4.1
External exposure	0.38	0.38	0.38
Total	169	9.5	4.5
Truck Drivers			
At work site	18.4	1.1	0.50
Driving soil	0.44	0.44	0.44
Total	19	1.5	0.94
General Public			
Routine operations			
Inhalation	0.24	0.013	0.0059
External radiation	0.17	0.17	0.17
Accidents	56	3.0	1.4

factors, calculated to give the dose at 3 ft above an infinite uniformly contaminated half-space, to conservatively estimate the external dose rate in the cab from the load of soil.[8] Area averaged soil concentrations presented in Table A-II were used in applying these factors. Total estimated 50-yr dose commitments to drivers are shown in Table A-III.

4.0 DOSES TO THE GENERAL PUBLIC

4.1 Routine Operations

Inhalation doses to the general public were estimated using the highest reported environmental concentration of ^{239}Pu measured as part of the monitoring for the two previous cleanup operations at TA-1 and Diamond/Trinity Drives,[2,3] discussed in Sec. 2 of this appendix. This concentration was 463 x 10^{-18} μCi/mℓ, measured during a 2-wk period during the cleanup of TA-1. The general public was assumed to be exposed to this ^{239}Pu concentration during the entire 7 days of site-preparation and excavation. Air concentrations of ^{90}Sr, ^{137}Cs, ^{234}U, ^{238}U, ^{238}Pu, ^{241}Pu, and ^{241}Am were derived by multiplying the ^{239}Pu air concentration by the ratio of the activity of each radionuclide to ^{239}Pu activity, as found in the average radionuclide concentrations from the untreated waste outfall area (Sec. 1, Table A-II) with the highest residual radioactivity concentration. A breathing rate of 23 m^3/day, which is the daily air intake of the standard man,[5] an exposure time of 7 days, and dose conversion factors from Ref. 7 were used in the formula from Sec. 2 of this appendix to calculate the dose.

We estimated the maximum external radiation dose by assuming that a person drove a car next to a truck carrying soil containing residual radioactivity to the waste disposal site three times a day for all 5 days of excavation/hauling. The total exposure time would be 6.25 h. The dose rate in the cab of the truck, 28.8 μR/h above background, is assumed to apply in the car as well. The total whole body dose is 0.17 mrem, where a conversion of 1 mrem = 0.95 mR has been used.

4.2 Accidents

Fifty-year dose commitments to the general public from a hypothetical truck accident in which the load of 5.4 m^3 (7 cubic yards) of soil containing residual radioactivity would be spilled on open land were estimated. We assumed the truck carried soil having radionuclide concentrations equal to the average levels for soil from that zone of the untreated waste outfall area with the highest residual radioactivity concentration. The soil would be exposed for 3 h after the accident, then it would be covered until removal. Soil removal would be accomplished with mechanical equipment in one-half hour.

The dose to the general public was calculated assuming that an individual stood 100 m downwind from the spilled soil for the entire time that the soil was uncovered and being removed. During that time, his breathing rate was 20 ℓ/min, typical of an adult engaged in light activity.

The source term was calculated from dust flux terms given in Ref. 9. A flux of 150 μg/m^2/s was used for wind resuspension and 0.06 g of dust/kg of soil for mechanical resuspension. Cloud depletion through deposition was accounted for by the fallout function given in Ref. 9 for use with the source terms. The spilled soil was assumed to have an area of 17.6 m^2, which would correspond to a height of approximately 0.31 m (1 ft). As in Ref. 1, an enrichment factor of 2.3 was used to account for the higher concentrations of radionuclides on the smaller sized particles.

Air concentrations were calculated using a standard Gaussian dispersion model for plume release. A D-wind stability category and wind speed of 3 m/s were assumed throughout the scenario.

The dose estimates included a number of conservative assumptions that would result in an overestimation of the predicted dose. The exposure time for the maximally exposed individual would probably be much less than 3 h. This is because the spilled soil would be covered shortly after the accident, eliminating dusting from wind resuspension. In addition, keeping the soil wet, and, if necessary, removing the soil with hand shovels rather than heavy equipment would reduce dusting from mechanical resuspension. If the need arose, controlled access areas would be roped off around the spilled soil so that the general public would not be in areas of significant airborne radioactivity.Another conservative assumption was that the spilled soil was from the section of the cleanup site having the highest concentrations of residual radioactivity. The dose estimates are presented in Table A-III.

REFERENCES

1. "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," US Department of Energy report DOE/EV-0005/30 (May 1981).

2. A. J. Ahlquist, A. K. Stoker, and L. K. Trocki, "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).

3. US Department of Energy, "Removal of a Contaminated Industrial Waste Line, Los Alamos, New Mexico," report DOE/EV-0005/14 (April 1979).

4. US Department of Energy, "Environmental Protection, Safety, and Health Protection Program for DOE Operations," Chapter XI, "Requirements for Radiation Protection," DOE 5480.1 (April 1981).

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6. American National Standards Institute, Inc., "American National Standard Practices for Respiratory Protection," ANSI publication Z88.2-1980 (May 1980).

7. G. R. Hoenes and J. K. Soldat, "Age-Specific Radiation Dose Commitment Factors for a One-Year Chronic Intake," US Nuclear Regulatory Commission report NUREG-0172 (November, 1977).

8. H. L. Beck, J. DeCampo, and C. Gogolak, "*In Situ* Ge(Li) and NaI(TI) Gamma-Ray Spectrometry," US Health and Safety Laboratory report HASL-258 (September 1972).

9. US Nuclear Regulatory Commission, "Final Generic Environmental Impact Statement on Uranium Milling," US Nuclear Regulatory Commission report NUREG-0706 (September 1980).

APPENDIX B

PLANTS OF PUEBLO CANYON

- *Anacardiaceae*
  - *Rhus trilobata*
- *Amaranthaceae*
  - *Amaranthus retroflexus*
- *Boraginaceae*
  - *Cryptantha jamesii*
  - *Lappula* spp.
  - *Lithospermum* spp.
- *Cactaceae*
  - *Echinocereus* spp.
  - *Opuntia polycantha*
- *Capparidaceae*
  - *Polansia trachyspermum*
- *Chenopodiaceae*
  - *Atriplex canescens*
  - *Chenopodium graveolans*
  - *Chenopodium fremontii*
  - *Salsola kali*
- *Compositae* (*Asteraceae*)
  - *Antennaria parvifolia*
  - *Artemisia carruthii*
  - *Artemisia dracunculoides*
  - *Artemisia frigida*
  - *Artemisia ludoviciana*
  - *Artemisia tridentata*
  - *Aster bigelovii*
  - *Aster hesperius*
  - *Bahia dissecta*
  - *Brickellia californica*
  - *Chrysopsis villosa*
  - *Chrysothamnus nauseosus*
  - *Conyza canadensis*
- *Compositae* (cont)
  - *Cosmos parviflorus*
  - *Dyssodia papposa*
  - *Erigeron divergens*
  - *Franseria* spp.
  - *Gaillardia pulchella*
  - *Gutierrezia microcephala*
  - *Happlopappus spinulosis*
  - *Helianthus annuus*
  - *Helianthus petiolaris*
  - *Hymenopappus* spp.
  - *Hymenoxys argentea*
  - *Hymenoxys richardsonii*
  - *Lactuca serriola*
  - *Senecio multicapitatus*
  - *Thelesperma trifidum*
  - *Tragopogon dubius*
  - *Viguiera multiflorum*
- *Cruciferae*
  - *Descurainia* spp.
- *Cupressaceae*
  - *Juniperus monosperma*
  - *Juniperus scopulorum*
- *Cyperaceae*
  - *Carex* spp.
- *Euphorbiaceae*
  - *Croton texensis*
  - *Euphorbia dentata*
  - *Euphorbia serpyllifolia*
- *Fagaceae*
  - *Quercus gambelii*
  - *Quercus undulata*

- Geraniaceae
    - Erodium circutarium
    - Geranium caespitosum
- Gramineae (Poaceae)
    - Agropyron desertorum
    - Agropyron smithii
    - Andropogon scoparius
    - Aristida divaricata
    - Bouteloua curtipendulum
    - Bouteloua eriopoda
    - Bouteloua gracilis
    - Bromus spp.
    - Bromus tectorum
    - Festuca spp.
    - Koelaria cristata
    - Muhlenbergia montana
    - Munroa squarrosa
    - Oryzopsis hymenoides
    - Poa spp.
    - Sitanion hystrix
    - Sporobolus contractus
    - Sporobolus spp.
- Hydrophyllaceae
    - Phacelia spp.
- Labiatae
    - Monarda pectinata
- Leguminosae (Fabaceae)
    - Lupinus caudatus
    - Robinia neomexicana
    - Vicia americana
- Liliaceae
    - Allium cernuum
    - Yucca baccata
- Loasaceae
    - Mentzelia pumila
- Malvaceae
    - Sphaeralcea incana
- Nyctaginaceae
    - Mirabilis linearis
    - Mirabilis multiflorum
- Oleaceae
    - Forestiera neomexicana
- Onagraceae
    - Oenothera spp.
- Orobanchaceae
    - Orobanche multiflorum
- Pinaceae
    - Pinus edulis
    - Pinus ponderosa
- Plantaginaceae
    - Plantago purshii
- Polemoniaceae
    - Gilia aggregata
    - Gilia longiflora
    - Gilia spp.
- Polygonaceae
    - Eriogonum cernuum
    - Eriogonum jamesii
    - Rumex spp.
- Portulacaceae
    - Portulaca oleracea
- Ranunculaceae
    - Pulsatilla ludoviciana

APPENDIX B (cont)

Rosaceae

- *Cercocarpus montanus*
- *Fallugia paradoxa*
- *Potentilla* spp.
- *Prunus virginiana*, var. *melanocarpa*

Rutaceae

- *Ptelea angustifolia*

Salicaceae

- *Populus angustifolia*

Saxifragaceae

- *Philadelphus microcephala*

Scrophulariaceae

- *Castilleja integra*
- *Orthocarpus purpureo-albus*
- *Penstemon barbatus*, var. *torreyi*
- *Verbascum thapsis*

Solanaceae

- *Datura meteloides*
- *Physalis neomexicana*

Tamaricaceae

- *Tamarix gallica*

Urticaceae

- *Urtica gracilis*

Vitaceae

- *Parthenocissus inserta*

APPENDIX C

PLANTS ENUMERATED IN NEW MEXICO STATUTE 45-1-11 THAT ARE KNOWN TO OCCUR IN LOS ALAMOS COUNTY[a]

Family	Species	Common Name	General Habit
Araliaceae	Aralia racemosa	American spiknard	Shaded Mt Slopes 2100-2700 m (7000-9000 ft)
Asclepiadaceae	Asclepia tuberosa	butterflyweed	Gravelly Canyons 2000-2100 m (6500-7000 ft)
Cactaceae	Echinocereus triglochidiatus var: triglochidiatus	strawberry cactus	Rocky Hills 1500-1800 m (5000-6000 ft)
	Echinocereus triglochidiatus var: melanacanthus Echinocereus fendleri Echinocereus virdiflorus Mammillaria spp.		
Campanulaceae	Lobelia cardinalis	cardinal flower	Wet Ground 1700-2100 m (5500-7000 ft)
Cornaceae	Cornus stolonifera	dogwood red-osier	Wet Ground Near Streams 1700-2700 m (5500-9000 ft)
Ericaceae	Arctostaphylos uva-ursi	bearberry	Moist Woods 2100-3000 m (7000-10 000 ft)
Liliaceae	Streptopus amplexifolius	twisted-stalk	Damp Woods 2400-3200 m (8000-10 500 ft)
	Lilium umbellatum	woodlily	Open Woods 2100-2400 m (7000-8000 ft)

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[a] Taken from T. S. Foxx and G. D. Tierney, "Status of the Flora of the Los Alamos National Environmental Research Park," Los Alamos Scientific Laboratory report LA-8050-NERP, Vol. I (May 1980).

Family	Species	Common Name	General Habit
	Calochortus nuttallii	sego lily	Open Slopes 1500-2600 m (5000-8500 ft)
	Calochortus gunnisonii	mariposa lily	Meadows 2100-2600 m (7000-8500 ft)
Onagraceae	Epilobium angustifolium	fireweed	Damp Clearings 2100-3300 m (7000-11 000 ft)
Orchidaceae	Calypso bulbosa	fairy slipper	Woods 2100-3000 m (7000-10 000 ft)
	Corallorhiza maculata	spotted coralroot	Woods 2000-2700 m (6500-9000 ft)
	Corallorhiza striata	striped coralroot	Woods 2000-2900 m (6500-9500 ft)
	Epipactis gigantea	helleborine	Damp Woods 2100-2600 m (7000-8500 ft)
	Goodyera oblongifolia	rattlesnake plantain	Damp woods 2400-2900 m (8000-9500 ft)
	Habenaria sparsiflora	bog orchid	Moist Areas 2300-2900 m (7500-9500 ft)
	Malaxis soulei	adder's mouth	Woods 2400-2900 m (8000-9500 ft)
Polemoniaceae	Ipomopsis aggregata	skyrocket	Dry Hills 1500-2600 m (5000-8500 ft)

Family	Species	Common Name	General Habit
Primulaceae	Dodecatheon pulchellum Dodecatheon radicatum	shooting star	Wet Meadow 3300 m (11 000 ft)
Ranunculaceae	Aconitum columbianum	monkshood	Moist Ground 2300-3300 m (7500-11 000 ft)
	Aquilegia caerulea	Rocky Mountain columbine	Woods and Meadows 2100-3600 m (7000-12 000 ft)
	Aquilegia elegantula	red columbine	Moist Woods 2100-3000 m (7000-10 000 ft)
	Clematis drummondii	virgin's bower	Slopes and Canyons 1500 m (5000 ft)
	Clematis ligusticifolia	Western virgin's bower	Slopes and Canyons 1200-2300 m (4000-7500 ft)
	Clematis pseudoalpina	alpine clematis	Woods 2100-2700 m (7000-9000 ft)
	Pulsatilla ludoviciana	pasqueflower	Open Meadows 2100-3000 m (7000-10 000 ft)
Saxiflagaceae	Fendlera rupicola	fendlerbush	Rocky Slopes 1800-2100 m (600-7000 ft)
	Heuchera parvifolia	alumroot	Damp Woods and Rocky Places 2100-3200 m (7000-10 500 ft)
	Jamesia americana	cliffbush	Along Streams and Canyon Walls 2000-2700 m (6000-9000 ft)

Family	Species	Common Name	General Habit
	Philadelphus microphyllus	mock orange	Rocky Hillsides and Canyons 2000-2900 m (6500-9500 ft)
	Ribes cereum	wax currant	Dry Slopes and Ridges 2100-2700 m (6500-9000 ft)
	Ribes lepthanthum	trumpet gooseberry	Canyons and Woods 2000-3000 m (6500-10 000 ft)
	Ribes montigenum	gooseberry currant	Open Slopes 2300-3300 m (7500-11 000 ft)
	Ribes inerme	whitestem gooseberry	Woods 2100-2700 m (7000-9000 ft)
	Saxifraga rhomboidea	saxifrage	Moist Ground 2100-3600 m (7000-13 000 ft)
Scropulariaceae	*Castilleja integra*	Indian paintbrush	Dry Slopes 1400-2300 m (4500-7500 ft)

APPENDIX D

ANIMALS OF THE LOS ALAMOS ENVIRONS[a]

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[a] Taken from Los Alamos Scientific Laboratory, "Final Environmental Impact Statement," Department of Energy report DOE/EIS-0018 (December 1979).

TABLE D-I

MAMMALS

		Verified to Be in Area	Presence Reported or Suspected	Threatened[a] or Endangered
Cervidae				
Odocoileus hemionus	Rocky mountain mule deer	x		
Cervus canadensis	Rocky mountain elk	x		
Erethizontidae				
Erethizon dorsatum	Porcupine	x		
Sciuridae				
Tamiasciurus hudsonicus	Red squirrel	x		
Sciurus aberti	Tassel-eared squirrel	x		
Spermophilus variegatus	Rock squirrel	x		
Spermophilus spilosoma	Spotted ground squirrel		x	
Spermophilus lateralis	Golden mantled ground squirrel	x		
Eutamias dorsalis	Cliff chipmunk	x		
Eutamias quadrivittatus	Colorado chipmunk	x		
Eutamias minimus	Least chipmunk	x		
Cynomys gunnisoni	White-tailed prairie dog		x	
Leporidae				
Sylvilagus nuttallii	Mountain cottontail	x		
Lepus Californicus	Black-tailed jackrabbit	x		
Ochotonidae				
Ochotona princeps	Pika	x		
Muridae				
Mus musculus	House mouse	x		
Heteromyidae				
Dipodomys ordii	Ord's kangaroo rat		x	
Perognathus flavus	Silky pocket mouse		x	
Cricetidae				
Peromyscus leucopus	White-footed mouse		x	
Peromyscus maniculatus	Deer mouse	x		
Peromyscus boylii	Brush mouse	x		
Peromyscus truei	Pinon mouse	x		

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[a] Presently classified as Group I (Endangered Species) or Group II (Threatened Species) as defined by the State of New Mexico Game Commission Regulation No. 563, as adopted January 24, 1975.

TABLE D-I (cont)

		Verified to Be in Area	Presence Reported or Suspected	Threatened[a] or Endangered
Cricetidae (cont)				
Reithrodontomys megalotis	Western harvest mouse	x		
Clethrionomys gapperi	Gappers red-backed vole	x		
Microtus montanus	Montane vole	x		
Microtus longicaudus	Long-tailed vole		x	
Microtus pennsylvanicus	Meadow vole	x		
Geomyidae				
Thomomys bottae	Valley pocket gopher	x		
Thomomys talpoides	Northern pocket gopher	x		
Soricidae				
Sorex nanus	Dwarf shrew	x		
Sorex vagrans	Vagrant shrew	x		
Procyonidae				
Procyon lotor	Raccoon	x		
Mustelidae				
Taxidea taxus	American badger	x		
Martes americana	Pine marten		x	
Mustela erminea	Ermine/Short-tail weasel		x	
Mustela nigripes	Black-footed ferret		x	x
Mephitis mephitis	Striped skunk	x		
Canidae				
Urocyon cinereoargenteus	Grey fox	x		
Vulpes fulva	Red fox	x		
Canis latrans	Coyote	x		
Ursidae				
Ursus americanus	Black bear	x		
Felidae				
Lynx rufus	Bobcat	x		
Felis concolor	Mountain lion	x		
Castoridae				
Castor canadensis	Beaver		x	

TABLE D-II

AMPHIBIANS AND REPTILES

		Verified to Be in Area	Presence Reported or Suspected	Threatened or Endangered
Plethodontidae				
Plethodon neomexicanus	Jemez Mountain salamander		x	x
Teiidae				
Chemidophorus spp.	Whiptail	x		
Iguanidae				
Phrynosoma spp.	Horned lizard	x		
Crotaphytus collaris	Collared lizard	x		
Sceloporus magister	Desert spiny lizard	x		
Viperidae				
Crotalus viridis	Prairie rattlesnake	x		
Colubridae				
Pituophis melanoleucas	Bull snake	x		
Thamnophis sirtalis	Common garter snake	x		
Thamnophis elegans	Western garter snake	x		
Lampropeltis getulus	Common king snake	x		

TABLE D-III

FISH

		Verified to Be in Area	Presence Reported or Suspected	Threatened or Endangered
Catostomidae				
Catostomus commersoni	White sucker	x		
Carpoides carpio	Carp-sucker	x		
Cyprinidae				
Cyprinus carpio	Carp	x		
Hybopsis spp.	Chub	x		
Salmonidae				
Salmo trutta	Brown trout	x		

TABLE D-IV

BIRDS

		Nest in Area	Summer Resident[a]	Yearlong Resident	Winter Resident	Migrant	Casual or Irregular	Uncommon
Gaviiformes								
Gavia immer	Common loon						x	
Podicipiformes								
Podicep caspicus	Eared grebe						x	
Anseriformes								
Branta canadensis	Canada goose					x		
Anas platyrhynchos	Mallard					x		
Anas strepera	Gadwall					x		
Anas acuta	Pintail					x		
Anas carolinensis	Green-winged teal					x		
Anas discors	Blue-winged teal					x		
Anas cyanoptera	Cinnamon teal					x		
Mareca americana	American widgeon					x		
Spatula clypeata	Shoveler					x		
Aythya collaris	Ring-necked duck					x		
Aythya affinis	Lesser scaup					x		
Bucephala albeola	Bufflehead					x		
Oxyura jamaicensis	Ruddy duck						x	
Mergus merganser	Common merganser	x	x					
Falconiformes								
Cathartes aura	Turkey vulture		x					
Accipiter gentilis	Goshawk			x				
Accipiter striatus	Sharp-shinned hawk			x				
Accipiter cooperii	Cooper's hawk	x	x					
Buteo jamaicensis	Red-tailed hawk			x				
Buteo albonotatus	Zone-tailed hawk[b]	x	x					
Buteo lagopus	Rough-legged hawk				x			
Buteo regalis	Ferruginous hawk[b]			x				
Aquila chrysaetos	Golden eagle	x	x			x		
Circus cyaneus	Marsh hawk				x			
Pandion haliaetus	Osprey[b]					x		
Falco mexicanus	Prairie falcon[b]			x				
Falco peregrinus	Peregrine falcon[b]			x				
Falco columbarius	Merlin (pigeon hawk)				x			
Falco sparverius	American kestrel			x				
Galliformes								
Dendragapus obscurus	Blue grouse			x				
Callipepla squamata	Scaled quail			x				
Lophortyx gambelii	Gambel's quail			x				
Melagris gallopavo	Wild turkey			x				
Gruiformes								
Grus americana	Whooping crane[c]					x		
Grus canadensis	Sandhill crane					x		
Rallus limicola	Virginia rail						x	
Porzana carolina	Sora						x	

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[a] This category covers only summer residents that nest in the area. Clearly yearlong residents also nest in the area.

[b] Presently classified as Group II (Threatened Species) as defined above.

[c] Presently classified as Group I (Endangered Species) as defined by the State of New Mexico Game Commission Regulation No. 563, as adopted January 24, 1975.

TABLE D-IV (cont)

		Nest in Area	Summer[a] Resident	Yearlong Resident	Winter Resident	Migrant	Casual or Irregular	Uncommon
Charadriiformes								
Charadrius vociferus	Killdeer					x		
Capella gallinago	Common snipe					x		
Actitis macularia	Spotted sandpiper					x		
Catoptrophorus semipalmatus	Willet					x		
Steganopus tricolor	Wilson's phalarope					x		
Recurvirostra americana	American avocet						x	
Larus delawarensis	Ring-billed gull						x	
Larus pipixcan	Franklin's gull					x		
Columbiformes								
Columba fasciata	Band-tailed pigeon	x	x					
Zenaida macroura	Mourning dove	x	x					
Cuculiformes								
Coccyzus americanus	Yellow-billed cuckoo					x		
Geococcyx californianus	Roadrunner				x		x	
Strigiformes								
Otus asio	Screech owl		x					
Otus flammcolus	Flammulated owl	x	x					
Bubo virginianus	Great horned owl	x	x					
Glaucidium gnoma	Pygmy owl			x				
Strix occidentalis	Spotted owl		x					
Aegolius acadicus	Saw-whet owl				x			
Caprimulgiformes								
Phalaenoptilus nuttallii	Poor-will	x	x					
Chordeiles minor	Common nighthawk	x	x					
Apodiformes								
Aeronautes saxatalis	White-throated swift	x	x					
Archilocus alexandri	Black-chinned hummingbird	x x	x x					
Selasphorus platycercus	Broad-tailed hummingbird	x	x					
Selasphorus rufus	Rufous hummingbird		x					
Stellula calliope	Calliope hummingbird					x		
Piciformes								
Colaptes auratus	Common flicker			x				
Melanerpes formicivorus	Acorn woodpecker			x				
Melanerpes erythrocephalus	Red-headed woodpecker[b]		x					
Sphyrapicus varius	Yellow-bellied sapsucker			x				
Sphyrapicus thyroideus	Williamson's sapsucker	x	x					
Dendrocopos villosus	Hairy woodpecker			x				

TABLE D-IV (cont)

		Nest in Area	Summer[a] Resident	Yearlong Resident	Winter Resident	Migrant	Casual or Irregular	Uncommon
Piciformes (cont)								
Dendrocopos pubescens	Downy woodpecker			x				
Dendrocopos scalaris	Ladder-backed woodpecker		x					
Asyndesmus lewis	Lewis' woodpecker					x		
Passeriformes								
Tryannus vociferans	Cassin's kingbird	x	x					
Myiarchus cinerascens	Ash-throated flycatcher	x	x					
Sayornis saya	Say's phoebe	x	x					
Empidonax traillii	Traill's flycatcher	x	x					
Empidonas hammondii	Hammond's flycatcher	x	x					
Empidonax oberholseri	Dusky flycatcher		x					
Empidonax wrightii	Gray flycatcher	x	x					
Empidonax difficilis	Western flycatcher	x	x					
Contopus sordidulus	Western wood pewee							
Nuttallornis borealis	Olive-sided flycatcher	x	x					
Eremophila alpestris	Horned lark					x		
Tachycineta thalassina	Violet-green swallow	x	x					
Iridoprocne bicolor	Tree swallow						x	
Cyanocitta cristata	Blue jay						x	
Cyanocitta stelleri	Steller's jay			x				
Aphelocoma coerulescens	Scrub jay			x				
Corvus corax	Common raven			x				
Corvus brachyrhynchos	Common crow			x				
Nucifraga columbiana	Clark's nutcracker	x	x					
Gymnorhinus cyanocephalus	Pinon jay			x				
Parus atricapillus	Black-capped chickadee					x		
Parus gambelli	Mountain chickadee			x				
Parus inornatus	Plain titmouse			x				
Psaltriparus minimus	Common bushtit					x		

TABLE D-IV (cont)

		Nest in Area	Summer[a] Resident	Yearlong Resident	Winter Resident	Migrant	Casual or Irregular	Uncommon
Passeriformes (cont)								
Sitta carolinensis	White-breasted nuthatch			x				
Sitta canadensis	Red-breasted nuthatch				x			
Certhia familiaris	Brown creeper				x	x		
Sitta pygmea	Pygmy nuthatch			x				
Cinclus mexicanus	Dipper						x	
Troglodytes aedon	House wren	x	x					
Catherpes mexicanus	Canyon wren	x	x					
Salpinctes obsoletus	Rock wren			x				
Dumetella carolinensis	Catbird					x		
Toxostoma rufum	Brown thrasher				x			
Oreoscoptes montanus	Sage thrasher				x			
Turdus migratorius	Robin			x				
Hylocichla guttata	Hermit thrush		x					
Hylocichla ustulata	Swainson's thrush		x				x	
Seiurus noveboracensis	Northern waterthrush							
Sialia mexicana	Western bluebird			x				
Sialia currucoides	Mountain bluebird			x x				
Myadestes townsendi	Townsend's solitaire			x				
Polioptila caerulea	Blue-gray gnatcatcher		x					
Regulus satrapa	Golden-crowned kinglet			x				
Regulus calendula	Ruby-crowned kinglet			x				
Anthus spinoletta	Water pipit					x		
Bombycilla garrulus	Bohemian waxwing				x			
Bombycilla cedrorum	Cedar waxwing				x			
Lanius excubitor	Northern shrike				x			
Lanius ludovicianus	Loggerhead shrike			x				

TABLE D-IV (cont)

		Nest in Area	Summer^a Resident	Yearlong Resident	Winter Resident	Migrant	Casual or Irregular	Uncommon
Passeriformes (cont)								
Sturnus vulgaris	Starling			x				
Vireo solitarius	Solitary vireo	x	x					
Vireo olivaceus	Red-eyed vireo						x	
Vireo gilvus	Warbling vireo					x		
Vermivora celata	Orange-crowned warbler					x		
Vermivora ruficapilla	Nashville warbler					x		
Vermivora virginiae	Virginia's warbler	x	x					
Dendroica petechia	Yellow warbler							
Dendroica caerulescens	Black-throated blue warbler							
Dendroica coronata	Yellow-rumped warbler			x				
Dendroica nigrescens	Black-throated gray warbler		x					
Dendroica townsendi	Townsend's warbler							
Dendroica virens	Black-throated green warbler					x	x	
Dendroica graciae	Grace's warbler		x					
Dendroica pennsylvanica	Chestnut-sided warbler						x	
Oporornis tolmiei	MacGillivray's warbler						x	
Icteria virens	Yellow-breasted chat					x		
Wilsonia pusilla	Wilson's warbler					x		
Setophaga ruticilla	American redstart					x		
Passer domesticus	House sparrow			x				
Sturnella neglecta	Western meadowlark						x	
Xanthocephalus zanthocephalus	Yellow-headed blackbird					x		
Agelaius phoeniceus	Red-winged blackbird					x		
Icterus bullockii	Bullock's oriole		x					
Euphagus carolinus	Rusty blackbird						x	
Euphagus cyanocephalus	Brewer's blackbird	x	x					

TABLE D-IV (cont)

		Nest in Area	Summer^a Resident	Yearlong Resident	Winter Resident	Migrant	Casual or Irregular	Uncommon
Passeriformes (cont)								
Quiscalus quiscula	Common grackle		x					
Molothrus ater	Brown-headed cowbird		x					
Piranga ludoviciana	Western tanager	x	x					
Piranga flava	Hepatic tanager		x					
Piranga rubra	Summer tanager	x	x					
Pheucticus ludovicianus	Rose-breasted grosbeak						x	
Pheucticus melanocephalus	Black-headed grosbeak	x	x					
Guiraca caerulea	Blue grosbeak		x					
Passerina cyanea	Indigo bunting					x		
Passerina amoena	Lazuli bunting		x					
Hesperiphona vespertina	Evening grosbeak			x				
Carpodacus cassinii	Cassin's finch		x					
Carpodacus mexicanus	House finch			x				
Pinicola enucleator	Pine grosbeak					x		
Leucosticte tephrocotis	Gray-crowned rosy finch					x		
Spinus pinus	Pine siskin	x	x					
Spinus psaltria	Lesser goldfinch			x				
Loxia curvirostra	Red crossbill			x				
Pipilo chlorurus	Green-tailed towhee	x	x					
Pipilo erythrophthalmus	Rufous-sided towhee			x				
Pipilo fuscus	Brown towhee			x				
Calamospiza melanocorys	Lark bunting					x		
Pooectes gramineus	Vesper sparrow					x		
Chondestes grammacus	Lark sparrow	x	x					
Amphispiza belli	Sage sparrow					x		
Junco hyemalis	Dark-eyed junco				x			
Junco caniceps	Gray-headed junco			x				
Spizella arborea	Tree sparrow					x		
Spizella passerina	Chipping sparrow	x	x					

TABLE D-IV (cont)

		Nest in Area	Summer^a Resident	Yearlong Resident	Winter Resident	Migrant	Casual or Irregular	Uncommon
Passeriformes (cont)								
Spizella pallida	Clay-colored sparrow							
Spizella breweri	Brewer's sparrow					x		
Spizella pusilla	Field sparrow							
Zonotrichia querula	Harris' sparrow				x			
Zonotrichia leucophrys	White-crowned sparrow					x		
Zonotrichia atricapilla	Golden-crowned sparrow							
Zonotrichia albicollis	White-throated sparrow						x	
Passerella iliaca	Fox sparrow						x	
Melospiza lincolnii	Lincoln's sparrow				x			
Melospiza georgiana	Swamp sparrow						x	
Melospiza melodia	Song sparrow			x				

TABLE D-V

INVERTEBRATES

Phylum	Class	Order	Estimated No. Species
Annelida	Oligochaeta (segmented worms)		1
Nematomorpha	Gordiaceae (round worms)		2
Arthropoda	Chilopoda (centipedes)		5
	Diplopoda (millipedes)		1
	Arachnida	Acarina (ticks and mites)	>80
		Solpugida (sun "scorpions")	1
		Chelonethida (false scorpions)	1
		Phalangida (Harvestmen)	1
		Araneida (spiders) (16 families)	74-100
	Insects	Thysanura	1
		Collembola	32-37
		Orthoptera	4-6
		Psocoptera	3-4
		Thysanoptera	4-6
		Hemiptera	28-33
		Homoptera	18-23
		Coleoptera	46-51
		Mecoptera	1
		Neuroptera	3-5
		Rhaphidioidea	1
		Trichoptera	1
		Ledidoptera	9-12
		Diptera	50-57
		Siphonaptera	2-3
		Hymenoptera (Formicidae 22-25)	54-65
		Protura	1
		Diplura	3
		Total No. Species	430-535