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Environmental Analysis of the Bayo Canyon (TA-10) Site, Los Alamos, New Mexico

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

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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ENVIRONMENTAL ANALYSIS OF THE BAYO CANYON (TA-10) SITE, LOS ALAMOS, NEW MEXICO

by

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

ABSTRACT

The radiological survey of the old TA-10 site in Bayo Canyon found low levels of surface contamination in the vicinity of the firing sites and subsurface contamination in the old waste disposal area. The three alternatives proposed for the site are (1) to take no action, (2) to restrict usage of the area of subsurface contamination to activities that cause no subsurface disturbance (minimal action), and (3) to remove the subsurface contamination to levels below the working criteria. Dose calculations indicate that doses from surface contamination for recreational users of the canyon, permanent residents, and construction workers and doses for workers involved in excavation of contaminated soil under the clean up alternative are only small percentages of applicable guidelines. No environmental impacts are associated with either the no-action or minimal action alternatives. The impact associated with the cleanup alternative is small, especially considering that the area already has been affected by the original TA-10 decommissioning action, but nevertheless, the preferred alternative is the minimal action alternative, where 0.6 hectare of land is restricted to surface activities. This leaves the rest of the canyon available for development with up to 400 homes. The restricted area can be used for a park, tennis courts, etc., and the ^{90}Sr activity will decay to levels permitting unrestricted usage in about 160 yr.

1.0 INTRODUCTION AND BACKGROUND[1]

1.1 The FUSRAP Program

In 1976, the Energy Research and Development Administration (ERDA) identified the Bayo Canyon Site as one of the locations to be reevaluated as part of the Formerly Utilized Sites Remedial Action Program (FUSRAP). The sites identified in the FUSRAP program were to be resurveyed for radiological contamination using modern instrumentation and analytical methods. The resurveys are the bases for determining whether any further remedial action is necessary. The Bayo Canyon resurvey was performed by the Los Alamos Scientific Laboratory under contract to ERDA and, subsequently, to the DOE.

The results of the survey[1] indicated low-level surface (<1-m) contamination with ^{90}Sr and uranium. Subsurface (6- to 8-m) contamination was found in the vicinity of the old waste disposal area. Because of the residual contamination located by the resurvey, a set of alternatives for remedial action for Bayo Canyon has been identified. An engineering evaluation of the proposed alternatives has been prepared by Ford, Bacon & Davis Utah.[2] This document describes the environmental consequences associated with the proposed alternatives.

1.2 Preferred Alternative

The range of alternatives being considered for Bayo Canyon includes no action, minimal action, and decontamination with restoration and disposal. The minimal action alternative requires demarcation and control of the area of subsurface contamination to prevent disturbance. Decontamination with restoration and disposal involves exhumation and disposal of the subsurface contamination, followed by rehabilitation of the disturbed area.

The most reasonable alternative for Bayo Canyon appears to be the minimal action alternative. This alternative requires control and surveillance of the 0.6-hectare plot of land encompassing the former solid and liquid waste disposal areas. This action would preclude any subsurface disturbance that could intrude into the region of subsurface contamination. The remainder of the canyon would be available for unrestricted use. This alternative is discussed in detail in Section 3.1.

The basis for selecting this alternative is that the additional impact and cost of removal of the subsurface contamination provide little additional benefit. Under the minimal action alternative, there is virtually no environmental impact, the cost is low, and only 0.6 hectare is unavailable to the County for residential development or for other uses. The New Mexico State Environmental Improvement Division (EID) concurs that the contaminated soil presents no radiological hazard if kept at depth.[3] The environmental impact and cost of exhuming the subsurface contamination provide only an additional 0.6 hectare of land for development or other use.

2.0 THE BAYO CANYON SITE

2.1 Summary History and Description of Site

2.1.1 Description of Site. Bayo Canyon is adjacent to the townsite of Los Alamos in northcentral New Mexico, about 100 km NNE of Albuquerque and 40 km NW of Santa Fe by air (Fig. 1). Bayo Canyon is one of many canyons cut into the Pajarito Plateau (Fig. 2). The Technical Area 10 (TA-10) site in Bayo Canyon is located about 5 km east of the community of Los Alamos and 8 km northwest of the community of White Rock at T20N, R6E, Sections 12 and 13. The area encompassing the site is legally described as the Bayo Canyon Parcel, as shown on the Walsh Survey Plat thereof, which survey plat was filed for record with the Clerk of Los Alamos County, New Mexico, on August 16, 1965, Plat Book 1 Page 59, Document No. 4552.

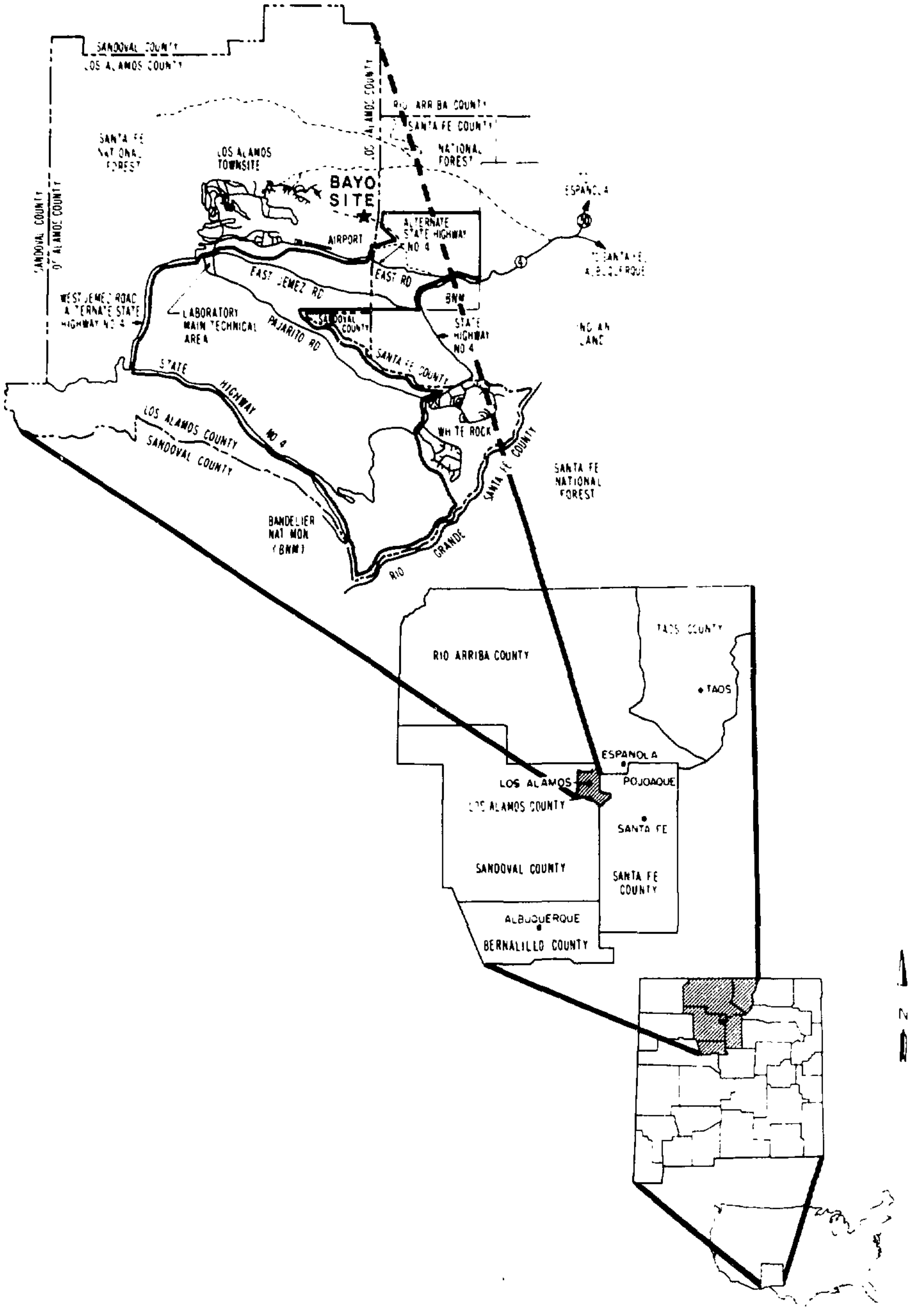

Fig. 1. Location of former Bayo Site.

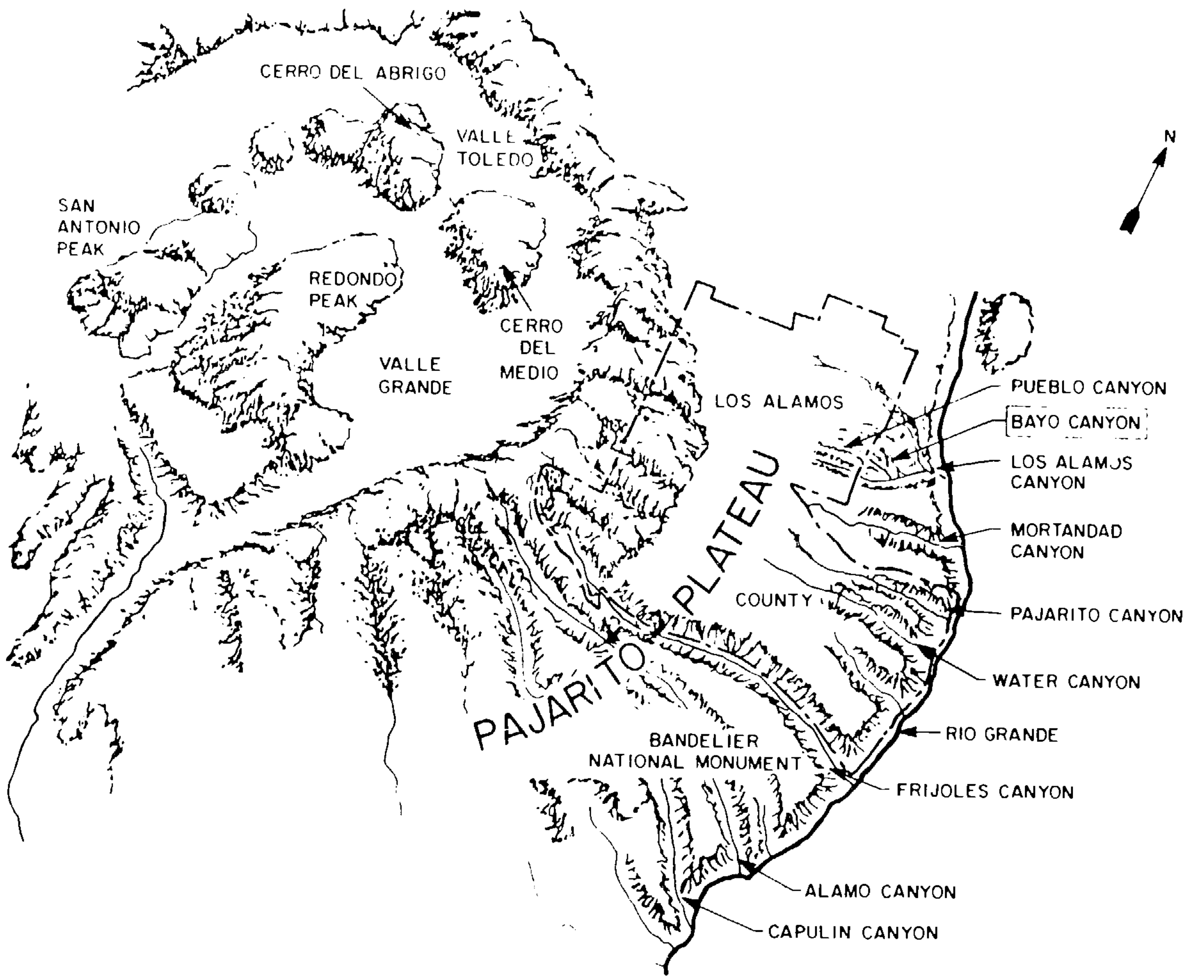

Fig. 2. Physiographic setting of Bayo Canyon.

The facilities associated with the former test site, TA-10, were built in the bottom of Bayo Canyon, where now only a few remnants remain. Bayo Canyon trends generally in an east-west direction. The north boundary of the site is considered to be on a generally east-west line along the top of Otowi Mesa (Fig. 3). The south boundary, similarly, is an east-west line along the top of Kwage Mesa. The east boundary is a north-south line approximately 150 m east of the former radiochemistry laboratory, and the west boundary lies approximately 300 m to the west of the former firing site area. Access to the site is from New Mexico State Road 4 onto a dirt road leading west across DOE property into Pueblo Canyon and then into Bayo Canyon.

2.1.2 History of Site.[1] Facilities for conducting experiments with high explosives were constructed in Bayo Canyon in 1943 for Project Y of the Manhattan Engineer District (MED). The facilities were used until 1961 for experiments relating to the development of nuclear weapons at the Los Alamos Scientific Laboratory, operated by the University of California under contract to the Atomic Energy Commission (AEC). In 1963, the Bayo Site, alternatively referred to as TA-10, was decontaminated to detection limits of available instrumentation and demolished. The land was turned over to Los Alamos County by quitclaim deed in 1967.

The principal structures comprising TA-10 (Fig. 3) included a radiochemistry laboratory (TA-10-1), two assembly buildings (TA-10-10 and TA-10-12), an inspection building (TA-10-8), a personnel building (TA-10-21), and structures at two detonation control complexes, particularly the control buildings (TA-10-13 and TA-10-15) and adjacent firing pads. Ancillary facilities included sanitary and radioactive liquid waste sewage lines, manholes, septic tanks and seepage pits, and solid radioactive waste disposal pits.

Radioactivity was released into the environment in Bayo Canyon primarily by (1) the explosive shots, which contained radioactive materials, and by (2) the disposal of radioactive wastes from radiochemistry operations. Secondary sources included airborne exhausts from laboratory hoods, accidental spills, and redistribution during decommissioning operations.

The explosive test assemblies usually included components made from natural or depleted uranium and a radiation source for blast diagnostics. The sources contained several hundred to several thousand curies of ^{140}La (half-life 40.2 h) and a small portion of ^{90}Sr (half-life 28.1 yr). The sources were prepared in the radiochemistry lab (TA-10-1) at Bayo Site by radiochemically separating the ^{140}La from a solution containing the radioactive parent ^{140}Ba (half-life 12.8 days), the stable daughter ^{140}Ce, and other impurities, including ^{90}Sr. The separated ^{140}La and an unavoidable proportion of ^{90}Sr were precipitated onto a filter medium and encased in foil to form a source. (Separation, precipitation, and encapsulation were performed at TA-10-1 between 1944 and 1950. Subsequently, only the precipitation

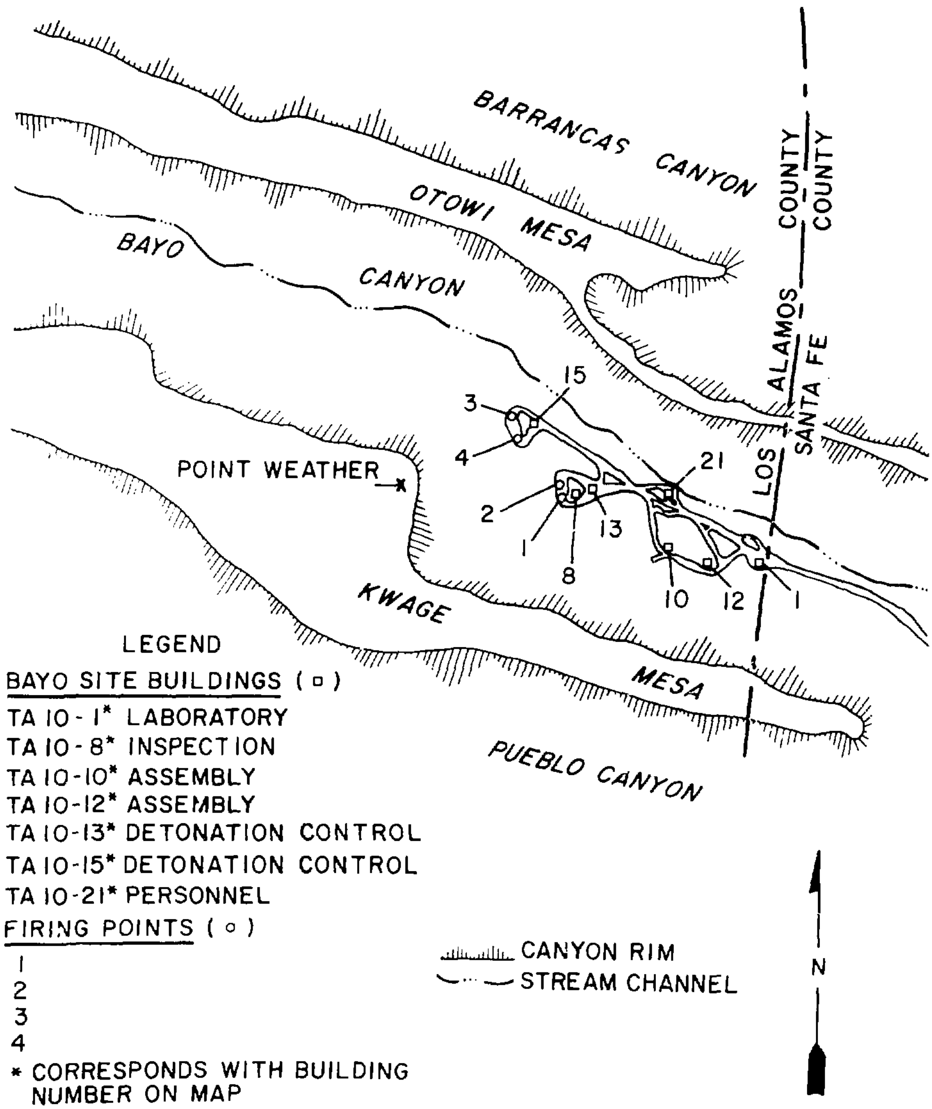

Fig. 3. Layout of former Bayo Site.

and encapsulation operations were performed there, and the radiochemical separations were done at another laboratory still on DOE land.) Other components of test devices were assembled in buildings TA-10-13 and TA-10-15, inspected in building TA-10-8, and placed on one of the shot pads. Once the source was inserted, the experiment was remotely detonated from one of the control buildings, TA-10-13 or TA-10-15.

The explosive detonation resulted in the dispersion of radioactive materials (uranium, ^{140}La, and ^{90}Sr), as well as nonradioactive materials (copper, lead, aluminum, etc.), in the form of aerosols and solid debris. Depending on wind conditions, aerosols were dispersed to varying degrees both within Bayo Canyon and beyond the adjacent mesas. Standard procedures required a southwesterly wind at the time of detonation; however, routine postshot surveys out to about 5 miles did at times find ^{140}La contamination in the vicinity of State Road 4 and on Otowi and Kwage Mesas. On one occasion, an aircraft was able to track airborne ^{140}La activity eastward across the Rio Grande Valley. Solid debris, including fragments of uranium and other metal components, was scattered around the firing points, largely within 90 to 125 m. Some large fragments were found 300 to 600 m away. Some radioactivity was dispersed around the firing pads by water from postshot cleanup. Radiation levels around the pads were frequently in the range of a few tenths to a few roentgens per hour.

The disposal of liquid and solid radioactive wastes resulted in the deposition of radioactivity below the surface. Radioactive liquid wastes from the radiochemistry building (TA-10-1) were collected in so-called acid waste lines and subsequently flowed to holding tanks, pits, and a leaching field to the north. Liquids placed or flowing into the pits drained through an outlet pipe at the bottom into the earth. Liquid wastes from the storage tanks were periodically discharged directly into the stream channel. The basic components of the waste disposal system are depicted in Fig. 4. Sanitary sewage lines, septic tanks, the TA-10-1 outfall line, and the TA-10-21 disposal pit, also shown in Fig. 4, may have received some contaminated liquid waste. Solid radioactive wastes were disposed into two of the six pits located as shown in Fig. 4.

Other smaller quantities of radioactivity may have been released with the unfiltered exhausts from fume hoods used for the routine radiochemical processing carried out in building TA-10-7. This resulted in the accidental dispersal of some α activity, evidenced by contamination on the roof of the building. Some cleanup was undertaken, and α activity remaining on the roof was stabilized by mastic.

Bayo Site was decommissioned starting in 1960 with the demolition or burning of several buildings. In 1963, the rest of the buildings were demolished or burned, the sewer systems removed, the contaminated waste pits excavated, and surface debris picked up out to a radius of about 760 m from the detonation control buildings. All debris was removed for disposal in the contaminated waste burial site at TA-54,

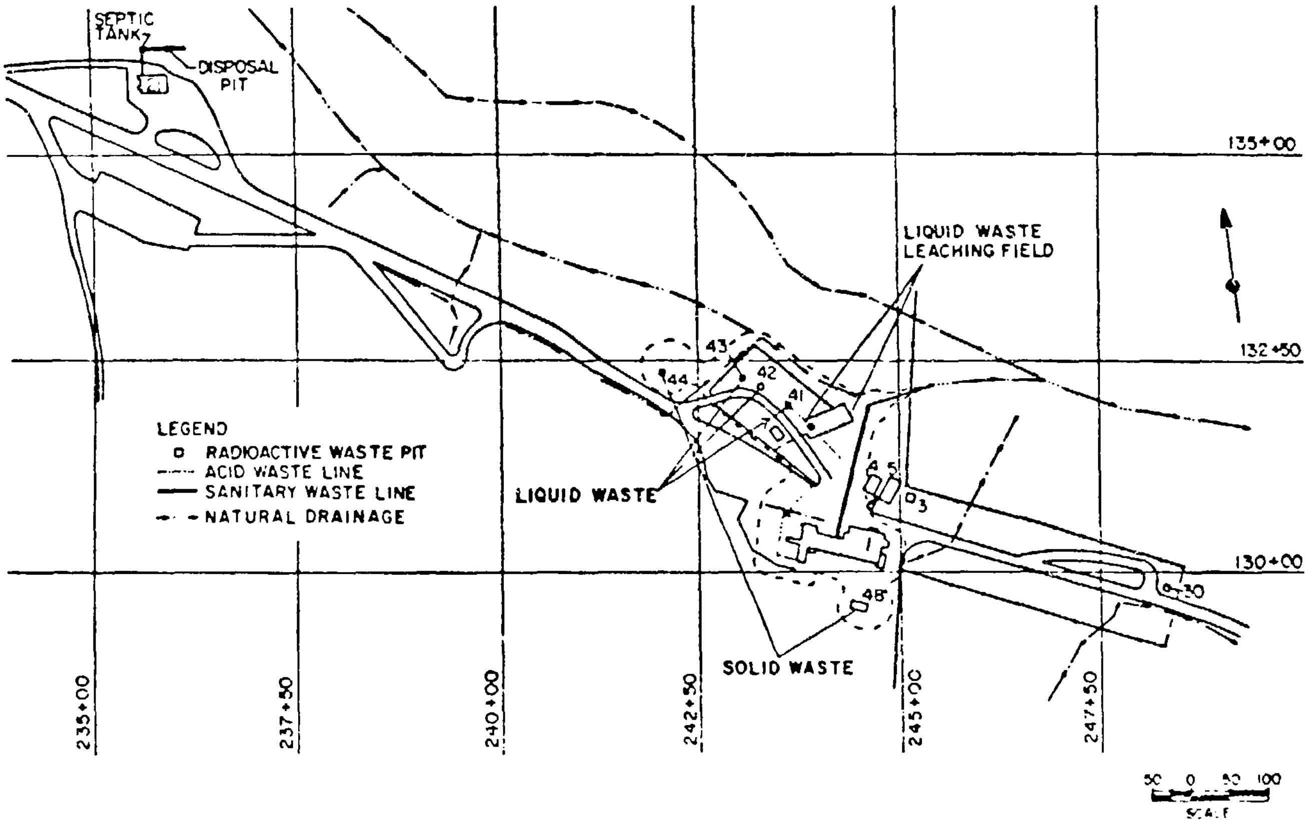

Fig. 4. Waste handling facilities at Bayo Canyon.

which remains within the present Laboratory boundary. A decommissioning summary is presented in Table I. Some contamination may possibly have been deposited on the surface soil as a result of the burning and excavation operations. However, once decommissioning was completed in 1963, no surface contamination could be detected in Bayo Canyon with portable instruments then in use. (Such survey meters should have been able to detect from roughly 2 nCi at contact to roughly 20 nCi at 1 m of ^{90}Sr spread uniformly on a smooth, dry surface of low atomic number. Any departure from such ideal conditions, as would be the case in field situations, would raise the detection limit appreciably.)

During the decommissioning, the highest levels of radioactivity were found associated with the acid sewer lines and waste disposal pits, while low levels were found around the shot pads and some buildings. An attempt was made to remove all materials, including soil, that showed detectable contamination. Radiation levels encountered during excavation of waste pit TA-10-48 and the tank farm area ranged as high as 35 mrad/h. Some subsurface contamination was left in the excavations of waste pit TA-10-48 (excavated to 8 m deep) and the tank farm (excavated to 6 m deep). The bottom of the TA-10-48 excavation read 1.5 mrad/h, and samples from the first 1.2 m below the bottom (9 m below ground) ranged from 0 to 300 pCi ^{90}Sr per gram of soil. The bottom of the tank farm excavation also read 1.5 mrad/h. Both excavations were backfilled with uncontaminated soil from other parts of the canyon.

Because of the wide dispersal of debris by the tests and continuing natural erosion processes, a reasonable probability exists that some high-explosive and some potentially radioactive materials remained in the canyon after decommissioning. Thus, periodic surface surveys and searches were conducted in 1966, 1967, 1971, 1973, 1975, and 1976. During such surveys, a number of additional pieces of debris were located, with only a few of them being contaminated with ^{90}Sr or including normal or depleted uranium.

2.2 Need For Action

2.2.1 Radiological Risk.

2.2.1.1 Method of Estimating Risk. Using the data from the radiological survey,[1] which is reviewed in Section 4.7, the radiological risk from residual contamination in Bayo Canyon was evaluated for the three proposed alternatives (Section 3.0). These alternatives were considered in light of two potential uses of the Bayo Site: (1) undeveloped County land open to recreational use (status quo) and (2) development as a residential area for as many as 400 homes. Groups of people considered at risk from exposure to radioactive material in Bayo Canyon were identified. Exposure pathways by which each group could receive radiation doses were analyzed, and maximum radiation doses were calculated.

TABLE I

SIGNIFICANT STRUCTURES DECOMMISSIONED AT BAYO SITE

Structure Number	Structure Nomenclature	Date Removed	Potential Contamination	Disposition
TA-10-1	Radiochemistry laboratory	1963	^{140}Ba, ^{140}La, ^{90}Sr uranium	Burned, debris to Area G disposal pit; TA-54
TA-10-2	Source storage	1963	^{140}Ba, ^{140}La, ^{90}Sr	Burned, debris to Area G disposal pit, TA-54
TA-10-3 TA-10-4 TA-10-5 TA-10-6	Storage	1960	^{140}Ba, ^{140}La, ^{90}Sr uranium	Burned, debris to Area G disposal pit, TA-54
TA-10-7	Tractor shed (plutonium, spill)	1963	^{140}Ba, ^{140}La, ^{90}Sr, uranium, 239Pu	Burned, debris to Area G disposal pit; TA-54
TA-10-21	Personnel building	1963	^{140}La, ^{90}Sr, uranium	No record of disposal
	Acid waste system	1963	^{140}Ba, ^{140}La, ^{90}Sr	Removed to Area G pit, TA-54
	Sanitary waste system	1963	^{140}Ba, ^{140} La, ^{90}Sr	Removed to Area G pit, TA-54
	Waste pits	1963	^{140}Ba, ^{140}La, ^{90}Sr	Removed to Area G pit, TA-54

The largest health risk resulting from residual Bayo Canyon contamination is to potential residents of the area. The added lifetime risk is estimated to be one chance in 11 000 000 of dying from cancer for a year of exposure at the maximum dose levels. For comparison, the added lifetime cancer risk to potential residents incurred from each year of exposure to naturally occurring background whole body radiation is one chance in 63 000. These risks are summarized in Table II, which also contains a list of other risks encountered during everyday life.

Two types of radiation exposure were considered: lifetime chronic exposure and shorter term exposure limited in time. For chronic exposure, such as that caused by living in the contaminated area, a continuous intake of ^{90}Sr and ^{238}U-^{234}U was assumed to occur for a 70-yr lifetime. The highest annual dose received during this 70-yr period was calculated and compared with DOE Radiation Protection Standards (RPS),[4] which limit annual radiation doses to members of the public. These doses were then used for the risk estimate.

Shorter term exposures could occur to groups such as construction workers building homes or installing utilities in the area. Typically, adults would be involved in these activities. During the exposure period, individuals would inhale or ingest radioactive material, but intake would cease after termination of the particular activity. The ^{238}U-^{234}U and ^{90}Sr absorbed by the body during the exposure, however, would continue to irradiate the organs in which they were deposited. To account for this extended irradiation period, the 50-yr dose commitment was used in calculating the dose. This dose commitment is the total dose resulting from an intake of radioactive material that an organ would receive in the 50 yr following the exposure.

If the limited exposure scenario were to last longer than a year, the 50-yr dose commitment per year of exposure was calculated. This dose was used in estimating the health risk from the shorter term exposures and was compared with the DOE RPS. Because the 50-yr dose commitment is larger than the actual dose received in a year, use of the dose commitment for comparison with the RPS is a conservative procedure protective of public health.

Health risks from radiation exposure were calculated from risk factors published by the International Commission on Radiological Protection (ICRP).[5] These factors give the lifetime risk of radiation-induced cancer mortality in various organs per unit radiation dose. For leukemia and bone and lung cancer, which are the principal health risks corresponding to exposure to residual Bayo Canyon contaminants, the ICRP recommends age- and sex-averaged risk factors of 2×10^{-5}/rem, 5×10^{-6}/rem, and 2×10^{-5}/rem, respectively. The risk of radiation-induced cancer mortality from uniform whole body radiation is 1×10^{-4}/rem. Multiplication of an organ dose calculated above by the appropriate risk factor gives the added lifetime risk of a particular cancer induced by that exposure.

TABLE II

RISK COMPARISON DATA

Maximum Estimated Added Lifetime Risk of Cancer Mortality from Annual Radiation Exposure

Group	Source	Additional Lifetime Cancer Risk/Year of Exposure
Potential resident of Bayo Canyon	Bayo Canyon residual contamination	9.0×10^{-8}
Potential resident of Bayo Canyon	Natural background radiation (whole body)	1.6×10^{-5}

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

Activity	Increased 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 1 Yr Due to Selected Causes[a]

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[a]

Contracting cancer from all causes	- 0.25
Mortality from cancer	- 0.20

[a] Taken from DOE/EV-0005/30 (May 1981).

Risks are calculated for the various groups of individuals exposed to radiation from Bayo Canyon. For perspective, the annual health risk from natural background radiation and selected risks commonly encountered in everyday activities are also presented (Table II).

2.2.1.2 Results of Dose Calculations. Survey results at Bayo Canyon showed traces of ^{90}Sr and uranium contamination in surface soil (0-30 cm) over approximately a 1.4×10^6 m^2 area and low-level subsurface contamination, generally at depths greater than 100 cm, in a more limited area within approximately 10 m of TA-10-1 and its waste handling facilities (Section 4.7).[1] This section reports results of dose calculations for exposure scenarios associated with the surface and subsurface contamination. A detailed description of the dose calculation procedures and assumptions used for each scenario is given in Appendix B. Results of the pathway analysis are summarized in Table II.

Two principal uses of Bayo Canyon have been considered.

(1) Undeveloped Land. If Bayo Canyon remains in its current undeveloped state, the potentially exposed groups in the general public are (1) the occasional recreational users of the canyon and (2) the residents in Los Alamos townsite who live on mesas adjacent to Bayo Canyon.

The occasional recreational users who venture into Bayo Canyon for such activities as hiking, picnicking, and trail riding could be exposed to increments of external penetrating radiation or to increments of airborne contamination above natural background because of residual surface contamination from strontium and uranium. Typically, these users are present in the canyon for only a few hours at a time on an infrequent basis. Thus, potential exposures to such users would be considerably less than those that could be received by permanent residents should Bayo Canyon be developed. Because measurements of airborne radioactivity from ^{90}Sr and uranium showed no elevation in the vicinity of Bayo Canyon, no significant increment of dose to present mesa residents is attributable to residuals of Bayo operations.

(2) Developed Land. If Bayo Canyon is developed for residential and light commercial use, the potentially exposed groups in the general public are (1) residents, (2) construction personnel, and (3) persons employed in the commercial establishments. These exposures are typically chronic exposures rather than occasional exposures common to recreational use. Residents and employees other than the construction workers will be present in the canyon 8 or more hours a day for 50 weeks or more per year and possibly for

many years. Construction workers will be present for perhaps 8 yr during development.

2.2.1.2.1 Doses from Surface Contamination.

2.2.1.2.1.1 External Penetrating Dose. Most of Bayo Canyon, including the portion used or affected by experimental operations, has a higher natural background of external penetrating radiation than typical in the townsite areas of Los Alamos or White Rock or on mesa tops. This is due in part to higher concentrations of naturally occurring radionuclides in the geologic formations surrounding the former operations site. It is also due in part to differences in the geometry of the canyon situation, whereby radiation is received from the canyon walls as well as the floor. The available data[1] indicate that average penetrating radiation in the canyon bottom is 21 ± 2 μR/h, with somewhat higher values observed on the talus slopes. The level of external penetrating radiation at the operational area does not show a statistically significant, instrumentally measurable difference from other parts of the canyon. The canyon as a whole exhibits levels about 13% greater than observed in the townsite areas. Theoretical estimates can be made of penetrating radiation caused by strontium and uranium debris deposited on soil in the old operational areas. These estimates show that the increments of exposure rate attributable to the residual contaminants are less than the spatial and temporal variation in natural background. The dosimetric consequences of external exposure from the experimental debris remaining in Bayo Canyon are shown in Table III.

The largest incremental contribution to penetrating dose attributable to the former Bayo Site is from residual uranium debris. This contribution is about 0.2% of the penetrating dose that would be received by residents in the area had Bayo Site never existed.

2.2.1.2.1.2 Dose from Internal Emitters. Bayo Canyon soil is a reservoir that could permit some radioactivity to make its way through various pathways to human tissues. The difference between the mean soil concentration of either ^{90}Sr or uranium and fallout strontium or naturally occurring uranium, respectively, gives the expected mean concentration of Bayo debris used in this evaluation. The values used are shown in Table IV. The values for debris in the surface layers 0 to 5 cm, 0 to 10 cm, and 0 to 30 cm are representative of the area within a 450-m radius of the center of the firing site and of the canyon floor from 900 m upstream beyond the center of the firing sites to 850 m downstream. The values for debris in the 0 to 122-cm layer, however, are only representative for an area 1 by 10^4 m^2 surrounding the laboratory building, its associated waste disposal facilities, and its contaminated storage buildings. The maximum gross β value at or above 244 cm is 4400 pCi/g at 244 cm.

These values were used to make exposure evaluations in relation to potential human interaction with each soil layer. All ^{90}Sr values are presumed to be associated with ^{90}Y in secular equilibrium. The

TABLE III

DOSE EVALUATION FOR BAYO CANYON

Group Receiving Estimated Dose	Contributing Soil Depth (cm)	Dose (mrem)[a] Bone Lining	Lung	Red Marrow
Permanent residents[b]				
Soil resuspension	0 to 5	0.01	0.28	[illegible]
Garden produce	0 to 30	2.41	---	[illegible]
External dose[c]	0 to 30	0.43	0.43	[illegible]
Total[d]		2.85	0.71	[illegible]
Construction Workers[e]				
Excavation, landscaping[f]				
Inhalation	0 to 30	<0.01	0.19	[illegible]
External dose	0 to 30	0.10	0.10	[illegible]
Total[d]		0.10	0.29	[illegible]
Foundations, utilities[g]				
Inhalation	0 to 122	0.01	<0.01	<0.01
External dose	0 to 122	0.02	0.02	[illegible]
Total[d]		0.03	0.02	[illegible]
Sewer installation[h]				
Inhalation	122 to 244	0.01	<0.01	<0.01
External dose	122 to 244	<0.01	<0.01	<0.01
Total[d]		0.01	<0.01	<0.01
Radiation protection standard[i]		1500	1500	500
Per cent of RPS (worst case)		0.19	0.05	0.41
Per cent of background (worst case)		1.60	0.45	1.2[illegible]

[a]For permanent residents, the maximum annual dose during 70 yr of exposure. All other internal doses are 50-yr dose commitments: the dose accumulated over 50 yr as a result of exposure during the first year.

[b]Hypothetical residents of Bayo Canyon assuming development occurs.

[c]Based on 8766 h/yr exposure (resident).

[d]Summation of internal plus external doses.

[e]Hypothetical construction workers in Bayo Canyon assuming development occurs.

[f]Based on 2000 h/yr exposure.

[g]Based on 360 h exposure.

[h]Based on 60 h exposure.

[i]Taken from Ref. 4.

TABLE IV

ABOVE-BACKGROUND SOIL CONCENTRATIONS (pCi/g)

Soil Layer (cm)	^{90}Sr	^{238}U	^{235}U	^{234}U
0 - 5	1.0	0.530	0.016	0.334
0 - 10	0.6	0.066	0.002	0.042
0 - 30	0.5	0.298	0.009	0.188
0 - 122	10.3	---	---	---

gross β value at 244 cm is presumed to be associated with ^{90}Sr and ^{90}Y. No likely exposure scenario was thought to be associated with the single maximum sample showing 24 000 pCi/g gross β at a depth of 4.3 to 5 m.

The highest radiation dose was estimated for a potential resident in the canyon. The maximally exposed resident was assumed to spend 100% of his time for 70 yr in the contaminated area. During that time, he would be exposed to elevated ^{90}Sr and uranium levels in the dust in the air while at home, during outdoor recreation, and outdoors at work. In addition, he would obtain one-half of his vegetables and one-third of his fruit from his home garden, located in contaminated soil. Radionuclides and concentrations for the 0- to 5-cm soil layers were used for the inhalation exposure, and from the 0- to 30-cm layer for garden produce. The highest annual radiation dose for the 70-yr exposure time was calculated for both the inhalation and ingestion pathways and is presented in Table III. Bone lining is the organ receiving the highest dose, which is some 2.85 mrem/yr, or 0.18% of the RPS.

General exposure of construction crews to Bayo debris would be expected during construction, which could last several years. Exposure would come from aerosols generated by excavation work. Because surface deposited Bayo debris is most prevalent in the top 30 cm, it would be disturbed by essentially all excavation work.

Doses to construction workers were calculated using an average dust loading of 400 μg/m^3 and a breathing rate (43 ℓ/min) typical of relatively demanding physical work. The annual exposure time was 2000 h/yr (40 h/wk for 50 wk/yr). The airborne dust was assumed to be contaminated with ^{90}Sr and uranium at levels found in the 0- to 30-cm soil layer, resulting in inhalation of these radionuclides by the workers and in a resultant dose. Fifty-year dose commitments per year of exposure were calculated for this scenario. The organ whose dose is the highest fraction of the RPS is the lung, which receives 0.19 mrem/yr, or 0.01% of the RPS.

2.2.1.2.2 Doses from Subsurface Contamination. Limited areas have elevated ^{90}Sr-^{90}Y concentrations below a 30-cm depth. The area potentially involved is restricted to that which could have been affected by subsurface deposition.

Doses were calculated for two scenarios: excavation at 122 cm (4 ft), where average ^{90}Sr concentrations are 17 pCi/g, and at 244 cm (8 ft) at 1100 pCi/g. Uranium is at background levels at these depths. Exposure times were 360 h and 60 h, respectively, corresponding to the times needed to construct foundations and utilities for six small homes and to install sewer lines and manholes (Appendix B). The breathing rate and dust loading were the same as those used for construction workers.

Calculated 50-yr dose commitments are presented in Table II. The highest dose is to bone lining, 0.03 mrem or 0.002% of the RPS.

Under Alternative 2 (Section 3.0), contaminated subsurface soil would be removed and replaced by clean fill so that cleanup limits of 100 pCi/g ^{90}Sr would be met. This would reduce the inhalation doses calculated for excavation at 8 ft by at least a factor of 100/1100. The actual reduction would depend on how far below the 100 pCi/g limit the "as left" soil concentrations would be.

Dose pathways involving resuspension of contaminated soil by wind, or growing of contaminated produce, do not apply to subsurface contamination. While wind and water erosion may eventually expose this soil, above-background ^{90}Sr concentrations would have decayed to negligible levels in the time needed for the erosion to occur.

2.2.1.3 Health Risks from Residual Bayo Canyon Contamination. The highest risk resulting from calculated doses occurs to the potential resident, who receives a maximum annual dose of 2.4 mrem to the bone, 1.6 mrem to red marrow, 0.3 mrem to the lung from ingestion and inhalation, and 0.4 mrem to the whole body during 70 yr of exposure. Using the ICRP risk factors, these doses correspond to a one in 11 000 000 additional lifetime risk of dying from a radiation-induced cancer for each year of exposure to Bayo Canyon residue. Risks associated with other exposure scenarios, such as those involving construction workers, are appreciably lower.

This risk can be compared to the risk of dying from cancer induced by exposure to background radiation. Background external penetrating radiation in Bayo Canyon is 183 mrem/yr,[1] of which 66 mrem/yr is cosmic and 117 mrem/yr terrestrial. The background external radiation dose to a potential resident is 134 mrem/yr, where cosmic radiation has been reduced by 10% to account for shielding by structures, terrestrial radiation by 20% because of shielding by structures, and an additional 20% to account for self-shielding by the body.[6] Internal radiation is approximately 24 mrem/yr.[6] Residents in Bayo Canyon would then receive approximately 158 mrem/yr whole body background radiation. The total risk of dying from a cancer induced by natural background whole body radiation is one chance in 63 000 for each year of exposure.

Additional perspective is offered by comparison of the radiation risk to a potential Bayo Canyon resident with other risks normally encountered in everyday life. A list of the risks is presented in Table II. The annual cancer risk to a maximally exposed individual in Bayo Canyon is on the order of his being struck by lightning.

2.2.2 Criteria upon Which Cleanup Action is Based. Alternative 2 would require cleanup of contaminated soil containing above-background soil concentrations of ^{90}Sr and ^{238}U-^{234}U to at least 100 pCi/g and 40 pCi/g, respectively. These levels apply when either ^{90}Sr or ^{238}U-^{234}U is present singly. When both ^{90}Sr and ^{238}U-^{234}U are present, the critera would be reduced proportionately.[2] These cleanup criteria, derived by Healy, Rodgers, and Wienke,[7] were calculated by determining what levels in soil of ^{90}Sr or ^{238}U-^{234}U could result in a member of the public receiving an annual dose to any organ greater than 500 mrem during a 70-yr lifetime. This 500 mrem/yr dose for any organ is based on recommendations of the National Council on Radiation Protection and Measurements[8] for dose limits for members of the public.

Representative pathways by which individuals could receive radiation doses from exposure to Bayo Canyon debris were analyzed. Parameters describing the exposure were chosen to reasonably estimate the minimum concentration that would result in this dose. These included assuming that the maximally exposed individual lived and worked in the contaminated area for 100% of the time for 70 yr, and that during this time he obtained 50% of his vegetables and 33% of his fruit from a garden located in the contaminated zone.

A detailed description of the methods used in arriving at these criteria is given in Appendix B. The dose calculation procedures and assumptions used in their derivation also were used in arriving at the pathway dose estimates in the previous section.

2.3 Other Agencies Involved in Implementation of the Proposed Action

The land in Bayo Canyon where the former TA-10 site was located is owned by Los Alamos County. Although the land presently is used only for recreational purposes, the ultimate use probably will be residential development.[9] Therefore, there must be interaction and cooperation between DOE and the County to implement the selected alternative.

3.0 ALTERNATIVES

There are five basic alternatives that can be modified to produce a range of alternatives for a given site. Modification or elimination of alternatives is based on site-specific conditions. The five basic 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 contamination to make site available for unrestricted use.

On the basis of these basic alternatives and the conditions in Bayo Canyon, Ford, Bacon & Davis Utah has proposed three working alternatives.[2] These alternatives are discussed in the following sections, and a summary of the actions associated with each option and the advantages and disadvantages associated with each option is presented in Table V.

3.1 Alternative I (Preferred Alternative)--Minimal Action

This alternative is derived from basic alternative 2. In this alternative, a 0.6-hectare area encompassing the old radiochemistry laboratory and solid and liquid waste disposal sites will be set aside as a restricted area and retained under County ownership. The rest of the canyon will be available for recreational purposes or residential development. Thus, the area of subsurface contamination will be isolated. County use of the restricted area will be confined to park land, tennis courts, etc., which will preclude disturbance of the subsurface contamination. Based on a half-life of 28 yr for ^{90}Sr, approximately 160 yr will be required for the activity level to decay to below 100 pCi/g, at which time the restricted area can be released for unrestricted use.

See Table V for a tabulation of the required actions associated with this alternative and the advantages and disadvantages associated with it.

3.2 Alternative II-Decontamination and Restoration with Disposal

This alternative is derived from basic alternative 5. It requires subsurface decontamination. In the area of subsurface contamination, excavation would continue to the depth necessary to reduce contamination to working criteria levels. Based on the radiological survey data, the depth of excavation could extend down to about 12 m. According to the Ford, Bacon, & Davis Utah report,[2] the maximum volume of contaminated soil to be removed is about 1160 m^3. Some soil would have to be removed and then replaced to gain access to the contaminated soil. The contaminated soil would be hauled to the Los Alamos National Laboratory radioactive solid waste disposal site (TA-54), and the resulting pit would be refilled with the uncontaminated material that was excavated and with clean fill material.

After restoration, the site could be released for unrestricted use, and consequently, restricted use of the 0.6-hectare area of subsurface contamination by Los Alamos County would be unnecessary. Periodic surveillance and monitoring would not be required.

See Table V for a tabulation of the required actions and the advantages and disadvantages associated with this alternative.

TABLE V

ALTERNATIVES, ASSOCIATED ACTIONS, AND ADVANTAGES AND DISADVANTAGES

Alternative	Associated Actions	Advantages	Disadvantages
I Minimal Action	1) Maintain County ownership of restricted area for 160 yr. 2) Install monument markers on restricted area. 3) Provide surveillance during monument installation; annual radiological monitoring and quarterly surveillance thereafter.	1) Low cost. 2) Accomplished quickly. 3) Administrative control (County ownership) of restricted area limits likelihood of access to subsurface contamination. 4) Essentially no environmental impact.	1) Subsurface contamination remains with potential for disturbance. 2) Contaminated area use restricted for about 160 yr. 3) Surveillance and monitoring required. 4) County must maintain title to restricted area. 5) Cost of long-term monitoring and surveillance.
II Decontamination and Restoration	1) Remove subsurface contamination as necessary to meet guideline criteria. 2) Provide clean backfill. 3) Dispose of contaminated soil. 4) Rehabilitate impacted area. 5) Provide radiological survey support and surveillance. 6) Obtain DOE certification of decontaminated area.	1) Permanent solution to problem. 2) No ongoing surveillance required. 3) County ownership of restricted area not required. 4) Entire Bayo Canyon site available for restricted use.	1) Highest cost option. 2) Greatest short-term environmental impact. 3) Highest potential for accidents.
III No Action	None	1) No cost. 2) No new environmental impacts. 3) Accomplished immediately.	1) Subsurface contamination remains with potential for spread of contaminants. No restricted use. 2) Strontium-90 contamination does not decay to 100 pCi/g for 160 yr.

3.3 Alternative III--No Action

In this alternative, no action would be taken at the Bayo Canyon Site, which means that the property would remain unchanged and no costs would be incurred. Implementation of this alternative must be considered so that the impacts of the current conditions can be compared with impacts that would result from implementation of other alternatives.

See Table V for a tabulation of the required actions and the advantages and disadvantages associated with this alternative.

4.0 AFFECTED ENVIRONMENT

4.1 Land Use

4.1.1 Bayo Canyon. The section of Bayo Canyon where the old TA-10 site was located lies between Otowi Mesa to the north and Kwage Mesa to the south (Fig. 3). This area is owned by Los Alamos County, which hopes to eventually develop the canyon as a residential area.[9] Kwage Mesa is presently designated as a recreational area and thus should not be subject to development. Otowi Mesa is too narrow for development. The upper part of Bayo Canyon, above the old TA-10 site, is narrow, steep-sided, and dark. This area, also owned by Los Alamos County, is probably not suitable for residential development. It is bordered on the north by Barranca Mesa and on the south by North Mesa. North Mesa is the location of the rodeo grounds and horse stables. Barranca Mesa is residentially developed. Bayo Canyon presently is used as a recreational area by hikers, horseback riders, picknickers, etc.

4.1.2 TA-54 (Radioactive Solid Waste Disposal Site). Contaminated soil removed from Bayo Canyon would be taken to TA-54, the radioactive solid waste disposal facility at the Los Alamos National Laboratory, for disposal. TA-54 is located on Mesita del Buey and is entirely on Laboratory property, as shown in Fig. 5. At TA-54, the contaminated soil would be handled according to standard disposal procedures.[10] A general description of the TA-54 site is given in a 1977 Los Alamos report on waste disposal sites at the Laboratory.[11]

4.1.3 Transportation Route. The contaminated soil would be transported by truck along the route outlined in Fig. 5. The distance from Bayo Canyon to TA-54 is about 20 km. The transportation route proceeds for most of the way along State Road 4, Alternate State Road 4, and Pajarito Road. These roads are heavily used from 7:00 to 8:30 a.m. and from 3:30 to 5:30 p.m. by Laboratory employees commuting from White Rock, Española, Santa Fe, and other communities in the area. Pajarito Road is located entirely on DOE property and theoretically could be closed to the public. However, this would be of little value because State Road 4 and Alternate State Road 4 could not be closed.

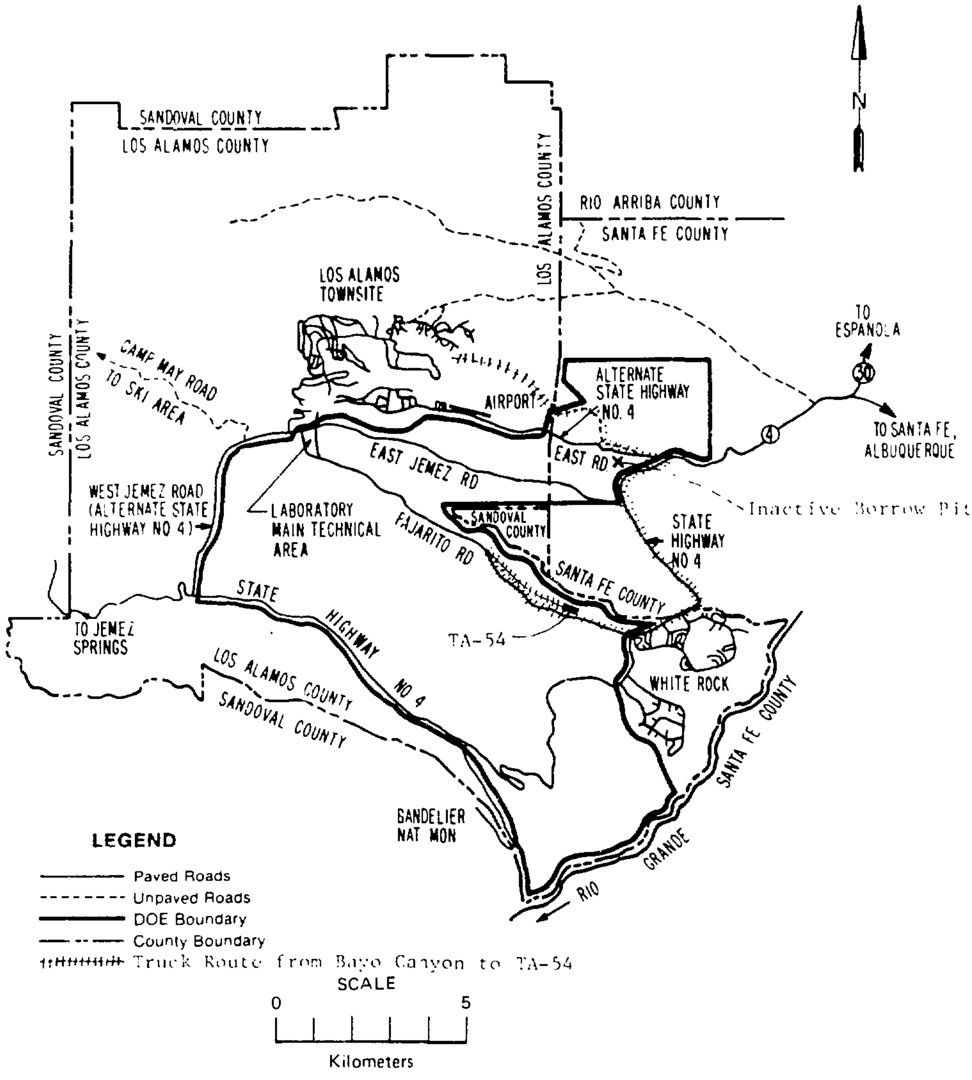

Fig. 5. Location of TA-54 and transportation route from Bayo Canyon.

4.1.4 Borrow Area. A specific borrow area has not been designated. Any borrow area selected would almost certainly be located on Laboratory property at a site where little reclamation would be necessary. There is an inactive borrow pit in Los Alamos Canyon close to Alternate State Road 4 (Fig. 5), which possibly could be reactivated to provide fill for any Bayo Canyon excavation. This pit is located about 7 km from the old TA-10 site.

4.2 Socioeconomics

4.2.1 Demography.[12] Los Alamos County has a population estimated by the preliminary 1980 census count at 17 586. 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 11 038. The White Rock Area (including residential areas known as White Rock, La Senda, and Pajarito Acres) has about 6 548 residents. About one-third of those employed in Los Alamos commute from other counties. 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 under Federal ownership by the Los Alamos National Laboratory, the National Park Service, and the US Forest Service.[13] Almost all of the privately owned land is already developed. Potential residents of the County are frequently forced to reside in surrounding communities, such as Española and Santa Fe, both because of the shortage of residentially-developable land and because of the high housing costs resulting from this shortage. The County is, thus, interested in any land with potential for residential development, and Bayo Canyon, which is owned by the County, is presently the most likely source of further development.

There is no documented information available on the attitude of the general public toward residential development of Bayo Canyon, with or without cleanup. The County is aware of the existing contamination problem and is awaiting DOE action before pursuing the matter of residential development any further.

4.2.2 Economy.[13] The economy of Los Alamos is based primarily on governmental operations, with the governmental 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 Contractors, 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 Los Alamos County. Within Los Alamos, unemployment is extremely low, averaging around 5%. The underemployed groups consist primarily of women and adolescents.

4.2.3 Institutional.[13] 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 Planning Commission.

DOE has administrative control of all of the Laboratory reservation. The responsibilities of the security force include policing activities, generally to prevent the entry of unauthorized persons into restricted areas. There is an agreement with the Los Alamos County Police Department authorizing 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.

There are many State agencies that have jurisdiction over particular aspects of the County. 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 declared part of the Rio Grande Underground Basin. Other important State agencies include the National Resource Conservation Commission, the Department of Game and Fish, the Parks and Recreation Commission, and the Environmental Improvement Division.

The large percentage of federally owned lands in the region affects the institutional structure. 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 head of Pueblo Canyon. 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, at the point where the road crosses from Pueblo Canyon into Bayo Canyon. This plant is about 1 km southeast of the old TA-10 site. It discharges continuously into middle Pueblo Canyon. There are a few small treatment plants on Laboratory property, which discharge into canyons on Laboratory property. The community of White Rock is served by a sewage treatment plant that discharges into a tributary of the Rio Grande.

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.[13] 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.[14]

Electricity for Los Alamos County is purchased from DOE 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 County is purchased from DOE 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. Cursory searches of Bayo Canyon in the 1950s through 1970s turned up no sites on the canyon floor, although Museum of New Mexico records show several sites on the north side of the canyon that were reported during the early days of the Laboratory.[15] A recent, more thorough search of the canyon resulted in the finding of only one small site west of the vicinity of the Otowi ruins.[16]

In general, there are evidences of sporadic Indian use of the Pajarito Plateau for some 10 000 yr. 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.

The plateau and canyons consequently 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,[17] former Chief Archeologist 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 have not yet been published.

There are three major ruins on Laboratory Property. These are Tsirege, Cave Kiva, and Otowi Ruins. These sites were submitted for consideration for nomination to the National Register of Historic Places in 1973. This nomination is still pending. The Otowi Ruins, a large, unexcavated pueblo, are located about 1.5 km east of the old TA-10 site, at a point where the canyon wall between Pueblo Canyon and Bayo Canyon is partially broken down.

There are hundreds of other small ruins on Laboratory property, and these also have been submitted for consideration for nomination to the National Register of Historic Places.[18]

4.3 Soil and Geology

Soils in the vicinity of Bayo Canyon are clay soils 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 tens of feet thick in the lower part of the canyon.

Within Bayo Canyon, weathering has produced a rocky talus slope facing south from Otowi Mesa, whereas a sandy soil has developed on the talus slope facing north from Kwage Mesa. Soil analysis of both the surface and 30- to 45-cm soil layers indicates that the soil is reasonably fertile.[19] (See Appendix A.)

A soil survey[20] of canyons similar to Bayo Canyon on the Pajarito Plateau indicates that the Bayo Canyon soil would fall into the Puye Series. The description of the Puye Series is as follows.[20]

"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 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 on 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 soils referred to in this description are more gravelly soils, with less organic matter, and tend to support pinon-juniper rather than ponderosa pine communities. The descriptions of the Puye and Totavi soils fit well with the observed vegetational patterns in Bayo Canyon, although much of the old TA-10 site and firing areas are presently inhabited by chamisa (Chrysothamnus) and other disturbed habitat species.

The floor of Bayo Canyon is about 2040 m above sea level at the location of the old TA-10 site, and the canyon slopes southeastward at a 3% grade. The mean elevation for Kwage and Otowi Mesas is about 2160 m.

In general, canyons and mesas in the Laboratory area are formed by Bandelier Tuff, composed of the ashfall, ashflow pumice, and rhyolite tuff that form the surface of the Pajarito Plateau. The tuff ranges from nonwelded to welded and is in excess of 300 m thick in the western part of the Pajarito Plateau, thinning to about 80 m toward the east above the Rio Grande. It was deposited as a result of a major eruption of a volcano in the Jemez Mountains to the west about 1.1 to 1.4 million years ago.

The tuffs lap onto older volcanics of the Tschicoma Formation, which form the Jemez Mountains along the western edge of the plateau, and are underlain by the conglomerate of the Puye Formation in the central and eastern edge along the Rio Grande. Chino Mesa basalts interfinger with the conglomerate along the river. These formations overlie the siltstone/sandstone Tesuque Formation, which extends across the Rio Grande valley and is in excess of 1000 m thick.[12]

4.4 Climatology

4.4.1 General Climate.[12] Los Alamos has a semiarid, continental mountain climate. The average annual precipitation of 45 cm is from 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 attendent 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°C to 15°C range. Winter temperatures are typically in the range from -10°C 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. Routine monitoring systems and procedures indicate that, although radiation and radioactivity levels above background can be detected, no concentration guidelines (CGs) or other applicable standards are being violated.[12]

The TA-3 power plant, the Zia Company asphalt plant, other unit operations, and the general status of air quality and Laboratory compliance with air quality regulations recently were reviewed in a series of internal memoranda.[21] The basic finding of this review was 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.[22]

4.5 Hydrology and Water Quality[12]

In Bayo Canyon, water runoff is intermittent and drains eastward through the canyon. There is water in the canyon only after heavy rainfall or heavy snowmelt. However, although the stream is intermittent, a flood plain above the stream channel occupies a significant portion of the canyon bottom.

The alluvium within the canyon is underlain by volcanic tuff. Many of the canyons support perched aquifers on the tuff within the alluvium, but no such aquifer exists in Bayo Canyon. The main aquifer is located below the tuff, at a depth of about 250 m. There is no hydrologic connection between surface water in Bayo Canyon and the main aquifer.

There also is no hydrologic connection between Bayo Canyon and Pueblo Canyon, although the wall between the two canyons is broken down at a point east of the old TA-10 site, in the vicinity of the sewage treatment plant and the Otowi Ruins.

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 characteristic of higher elevations to extend farther eastward along the canyon bottoms.

In Bayo Canyon, the narrow, steep-sided upper part of the canyon is populated with a pine-fir community that is normally located at an elevation above the ponderosa pine forest. The portion of the canyon where the old TA-10 site was located supports the remnants of a ponderosa pine community, in contrast to the pinon pine-juniper woodland found on the mesa tops above and on the drier northern slopes of the canyon. The old firing sites, where the ponderosa pine forest was removed, support a brushy, disturbed habitat community.

4.6.2 Plants.

4.6.2.1 Characterization. The steep-sided and narrow upper part of Bayo Canyon is relatively moist and cool and supports a pine-fir (Pinus ponderosa, Pseudotsuga menziesii, Abies concolor) forest. As the canyon widens into the section where the old TA-10 site was located, the pine-fir overstory thins and is relegated to the north-facing slope of Kwage Mesa. The canyon bottom supports many large ponderosa pine trees (Pinus ponderosa) scattered throughout the old TA-10 site, except in the vicinity of the old firing sites, where all vegetation was removed during the time period of active site operation. The ponderosa pine gives way to a pinon-juniper woodland (Pinus edulis, Juniperus monosperma) on the drier south-facing slope of Otowi Mesa.

The vegetation in Bayo Canyon has never been characterized. However, a study of the vegetation in Pueblo Canyon recently was completed.[23] Pueblo Canyon is located one canyon south of Bayo Canyon, and so the vegetation in the two canyons should be similar, particularly because the wall between the canyons is broken down for a considerable distance between the sewage treatment plant at the end of Kwage Mesa and the eastern end of the Big Otowi Ruins. The more mesic vegetation found in Pueblo Canyon because of the sewage treatment plant effluent may not be present in Bayo Canyon, which is drier. Appendix C gives a tabulation of the total plant survey of Pueblo Canyon. The most common shrubs and herbs are listed in Table VI.

4.6.2.2 Rare and Endangered Species. A recent study by Foxx and Tierney[24] has dealt with the status of the flora found on Laboratory property. Some inferences concerning the Bayo Canyon flora can be drawn from this report.

There appear to be no plant species from the Federal Endangered and Threatened Species List present in Bayo Canyon. A species that is being considered for this list, the grama grass cactus (Pediocactus papyracanthus), can be found in Los Alamos, but it is not likely to be found in Bayo Canyon as it preferentially inhabits mesa tops.

Table VII lists those plants that could be found in Bayo Canyon and that are protected under New Mexico Statute 45-11. Although this statute does not have any penalties associated with it, per se, destruction of plants covered by it can result in court action if anyone wishes to bring suit.

None of the 350 plant species submitted by the New Mexico Heritage program for consideration for protection under the Federal Endangered and Threatened Species List are likely to be found in Bayo Canyon, although 27 species on this list have been found in or around Los Alamos County.

4.6.3 Animals.

4.6.3.1 Characterization. Little quantitative information concerning the fauna of the Los Alamos area is available. Species lists were presented in the Environmental Impact Statement[13] for the Los Alamos Scientific Laboratory site. These lists are

TABLE VI

COMMON HERBS AND SHRUBS OF THE BAYO 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 PROTECTED BY NEW MEXICO STATE LAW THAT MIGHT BE FOUND IN BAYO CANYON

Asclepia tuberosa - butterflyweed

Castilleja integra - Indian paintbrush

Clematis pseudoalpinus - alpine clematis

Heuchera parvifolia - alumroot

Pulsatilla ludoviciana - pasqueflower

Ribes cereum - wax currant

Ribes montigenum - gooseberry currant

included as Appendix D of this report. The lists are, however, somewhat uncertain. Occurrence of some species has not been verified, although sightings have been reported, and other species that are not on the list may be present.

A biotic survey conducted by Miera et al.[25] 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 by the New Mexico State Game Commission for northcentral New Mexico.[13] Although several of these species have been documented in Los Alamos County, the only one known to be present in proximity to Bayo Canyon is the peregrine falcon (*Falco peregrinus*). There is a peregrine falcon aerie in Pueblo Canyon, adjacent to Bayo Canyon, which has been in existence at least since the early 1960s. Bayo Canyon is used as a hunting area by the falcons.

There is no reason to suspect the presence of other species from Table VI in Bayo Canyon, although the habitat probably would be suitable for animals such as the black-footed ferret, pine marten, red-headed woodpecker, and zone-tailed hawk, if these animals were present in large numbers in Los Alamos County.

4.7 Summary of Radiological Conditions

4.7.1 Background Radiation and Radioactivity. Soil in the Bayo Canyon area contains, like soil anywhere, trace levels of naturally occurring radioactivity. Uranium soil concentrations range from 0.5 to 8.1 μg/g, thorium from 9.2 to 22.7 μg/g, and ^{40}K from 29.5 to 37.3 pCi/g.[1] These levels are typical of salic igneous materials, which generally have slightly higher naturally occurring radionuclide contents than other soils.[6] Soil concentrations of ^{90}Sr from fallout vary with depth. Background soil levels for ^{90}Sr and uranium are summarized in Table X.

External penetrating radiation in the canyon and surrounding area has high spatial variation for three principal reasons. (1) The soil concentrations of naturally occurring radionuclides discussed above vary over relatively wide ranges. (2) The local topography from one location to the next can be quite different. (A site located in the canyon would receive radiation from the canyon walls as well as the floor, while a location on a mesa top would only receive radiation from the material beneath it.) (3) The 120-m change in elevation between canyon floor and mesa top would affect the level of cosmic radiation. In addition, there is temporal variation from the solar cycle and climatic conditions such as soil moisture and snow cover. In this report, the background external penetrating radiation in the canyon from charged particles and photons is taken to be 172 ± 13

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 - piñon 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 sp. - cottontail rabbit

Thomomys bottae - valley pocket gopher

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]

[a]Not documented in Los Alamos County.

TABLE X

CONCENTRATIONS OF ^{90}Sr AND URANIUM IN SOIL

Depth (cm)	^{90}Sr (pCi/g)			Uranium (μg/g)		
	Mean	Fallout	Bayo Debris	Mean	Naturally Occurring	Bayo Debris
0 - 5[a]	1.4	0.4	1.0	4.9	3.4	1.6
0 - 10[a]	0.9	0.3	0.6	3.6	3.4	0.2
0 - 30[a]	0.7	0.2	0.5	4.3	3.4	0.9
0 - 122[b]	10.3	<0.1	10.3			

[a]General Bayo site.

[b]Limited to approximately 90-m^2 area around disposal pits.

mrem/yr. Annual cosmic neutron radiation is approximately 11 mrem, so that the total external radiation level is 183 mrem/yr.

4.7.2 Surface Soil Conditions.

4.7.2.1 Probability of Surface Contamination Exceeding the Working Criteria. Statistical analysis of the surface soil data for ^{90}Sr and uranium concentrations indicates that there is little probability of undetected surface concentrations exceeding the working criteria.

The statistical analysis was undertaken because the proposed alternatives do not consider surface cleanup. Surface cleanup was not considered because the radiological survey[1] did not report any ^{90}Sr or uranium concentrations above the working criteria. The statistical techniques used were kriging analysis[26] and a linear regression of ^{90}Sr concentration against gross β concentration.

Kriging provides isopleths of concentrations as well as isopleths of the upper 95% confidence bound for these predicted values. Thus, the probability that repeated sampling of the area would show concentrations greater than the upper 95% confidence bound is 0.025 (because there is also 0.025 probability that concentrations may be less than the 95% confidence lower bound). Such confidence bound isopleths are shown in Figs. 6 and 7. The kriging analysis was based on concentration averaging over a 1.5-m (5-ft) radius circle.

Figure 6 presents the kriging results for gross β concentrations. In the central, roughly circular, area, there is a 95% probability that the gross β concentration would not exceed 0.9 pCi/g if another sample were taken. Beyond that is an area with a 95% probability where the gross β concentration would not exceed 1.4 pCi/g, and so forth. Figure 8 shows similar results for gross α concentrations.

Concentrations increased with progression away from the center of the firing site area for two reasons. (1) The central portion of this area was more heavily sampled, allowing the prediction of a lower concentration at the 95% confidence level. (2) The central portion of the firing area received more attention during the original cleanup and demolition activities.

As a follow-up to the kriging analysis, a linear regression of ^{90}Sr concentration against gross β concentration was performed, using the data from Tables D-II, D-III, D-IV, D-V, D-VII, D-XII, D-XIV, D-XVI, D-XVIII, D-XX, D-XXII, D-XXIV, and D-XXVI of the radiological survey.[1] At low gross β concentrations, no correlation existed between the two sets of data because of β contributions from naturally occurring radioisotopes other than ^{90}Sr. At higher gross β concentrations, however, the ^{90}Sr concentrations were found to be approximately twice the gross β concentrations with a correlation coefficient of 0.98.

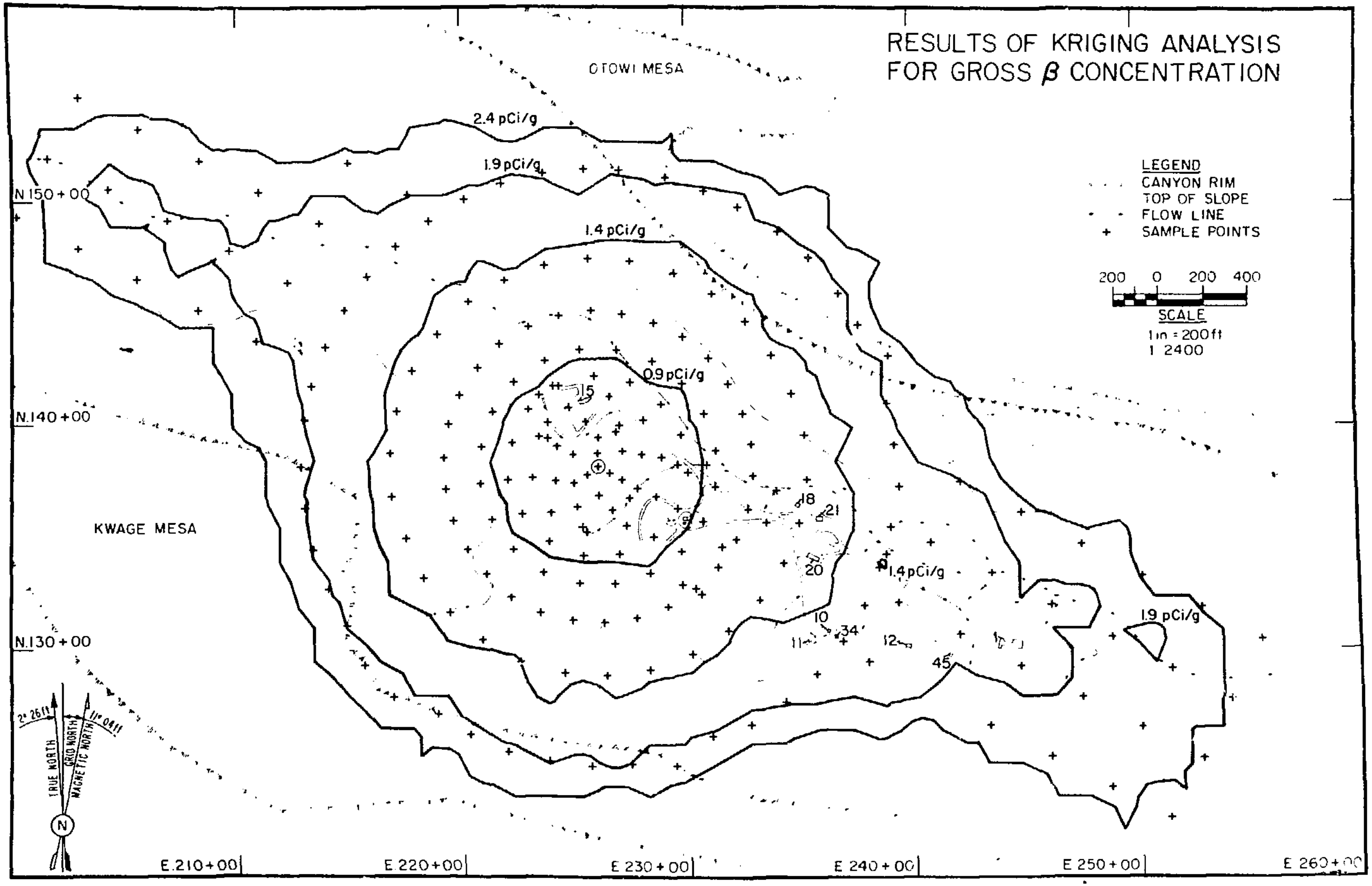

Fig. 6. Surface debris from Bayo Canyon.

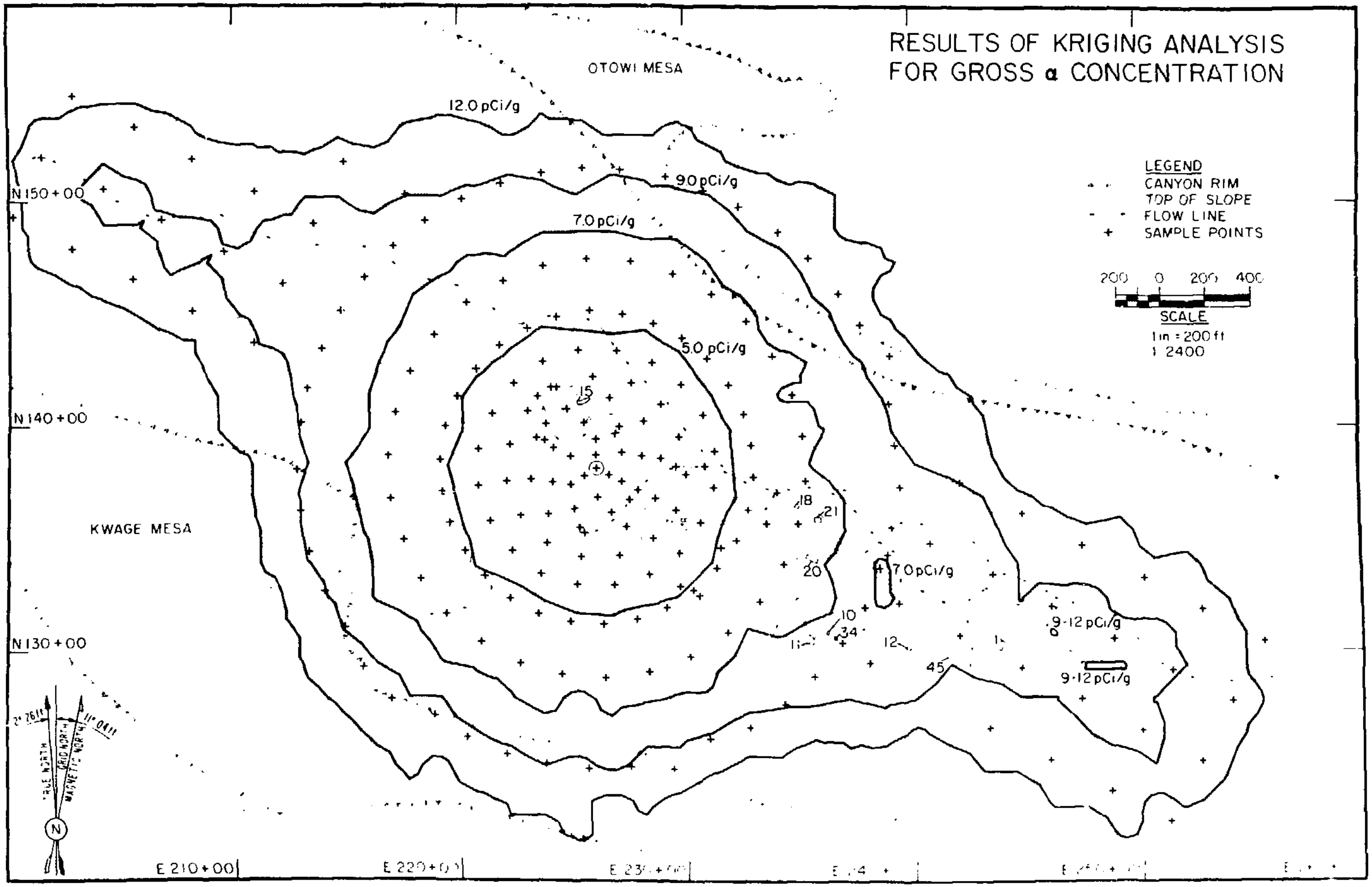

Fig. 7. Confidence boundary isopleths for gross β concentrations.

Thus, some certainty can be attached to the following conclusions.

1. Strontium-90 concentrations are not likely to be much more than twice gross β concentrations.

2. Because the highest gross β concentration predicted by the kriging analysis, at 95% probabil. y, is 2.4 pCi/g, the highest ^{90}Sr concentration likely to be found should be around 5 pCi/g.

3. Even if a higher ^{90}Sr concentration does exist, the probability that the working criteria of 100 pCi/g will be exceeded is very small.

The kriging analysis was not performed directly on the ^{90}Sr data because insufficient ^{90}Sr data were available. All of the sample locations, indicated by +'s in Fig. 6, were tested with portable instruments that gave gross β values. However, only those samples with high gross β concentrations were further analyzed for ^{90}Sr concentrations. The ^{90}Sr analysis is a complicated and time-consuming wet chemical analysis, and the gross β measurement, which is a very crude measurement, was used to screen samples for ^{90}Sr analysis. The crudeness of the instrumental gross β analysis also is the reason why the ^{90}Sr concentrations appear to be higher than the gross β concentrations.

4.7.2.2 <u>Existing Conditions</u>. The 1977 survey[1] detected traces of ^{90}Sr and uranium debris in the 0- to 30-cm layer of soil. This contamination was principally found within the 1.4 x 10^6 m^2 area covered by the firing site and canyon floor grids.

The 0- to 5-cm layer appears slightly more burdened with debris than other layers of the 0- to 30-cm surface zone, so it is taken as illustrative of them. The mean ^{90}Sr concentration was 1.4 pCi/g, which is about three times the level of local ^{90}Sr from fallout. Of the 50 representative samples from this layer analyzed for ^{90}Sr, 1 exceeded 9 pCi ^{90}Sr/g, and 17 exceeded 1.0 pCi ^{90}Sr/g. The highest level sample contained 132 pCi ^{90}Sr/g.

The mean uranium level among these 50 samples was 4.9 μg/g, which is 44% greater than the naturally occurring uranium concentration of 3.4 μg/g. One sample exceeded 10 μg/g, and twenty-one exceeded 4 μg/g.

Uranium and ^{90}Sr soil concentrations from the 0- to 10-cm layer and the 0- to 30-cm layer tend toward lower mean values and less divergence from the mean than those from the 0- to 5-cm layer. Radionuclide soil levels are summarized in Table X.

Both the vertical and horizontal distributions of the radionuclides are uneven. As expected, most surface radioactivity was found around the firing pads. Results from some 1973 data[1] indicated that no elevated levels of ^{90}Sr were present in stream channel alluvium 2 km downstream from the firing sites.

With the exception of the highest ^{90}Sr sample, radiological surveys[1] have indicated that surface soil concentrations of ^{90}Sr and uranium are below the cleanup criteria. The area in which the high ^{90}Sr sample of 132 pCi/g was taken was resampled, and the high analysis was not duplicated. Several supplementary samples taken within 2 m, as well as an adjacent core sample and another portion of the high sample, showed only normal levels of activity.

Eighteen years have elapsed since the last thorough sweep of the old TA-10 site in 1963,[27] although biennial inspections with some attendant debris collection were continued until 1975. Undoubtedly, debris will continue to be uncovered in Bayo Canyon with further weathering. That is, the canyon will never be completely free of debris from TA-10 testing. On the other hand, the use of the area by people has left its mark in cans, broken glass, broken clay pigeons from skeet shooting, etc. At some point in time, recreational debris will exceed TA-10 debris. If developed for housing, construction debris will be added.

Based on previous cleanup efforts, several truck loads of weathered surface debris are scattered over a 30-hectare area. Most of this debris is jagged and twisted metal shrapnel wire and cable pieces from explosive tests, although some structural debris also remains. Figure 8 is a photograph of representative pieces of debris collected in October, 1979, in 15 min in dense vegetative cover near the old firing sites. None of the pieces had measurable radioactive contamination.

To evaluate the radiological impact of the above-background ^{90}Sr and uranium levels in the surface soil, air concentrations of ^{90}Sr, uranium, and external penetrating radiation were monitored in Bayo Canyon and the surrounding area. Concentrations of airborne ^{90}Sr were statistically indistinguishable from fallout levels measured at regional northern New Mexico sites and at other North American locations. Uranium levels in air were not statistically different from the concentration expected locally from naturally occurring uranium. Air concentration measurements are summarized in Tables XI and XII.

Measured external penetrating radiation levels at Bayo Canyon are within the range expected for the Pajarito Plateau area. Measurements made with gamma spectroscopy able to identify the radionuclides generating external terrestrial radiation found no detectable levels of radionuclides present in above-background concentrations. Because external radiation levels from Bayo debris are below sensitive instrument detection limits, they were theoretically calculated from the soil concentrations to be 0.43 mrem/yr. Results of both the measurements and the calculations are presented in Table XIII.

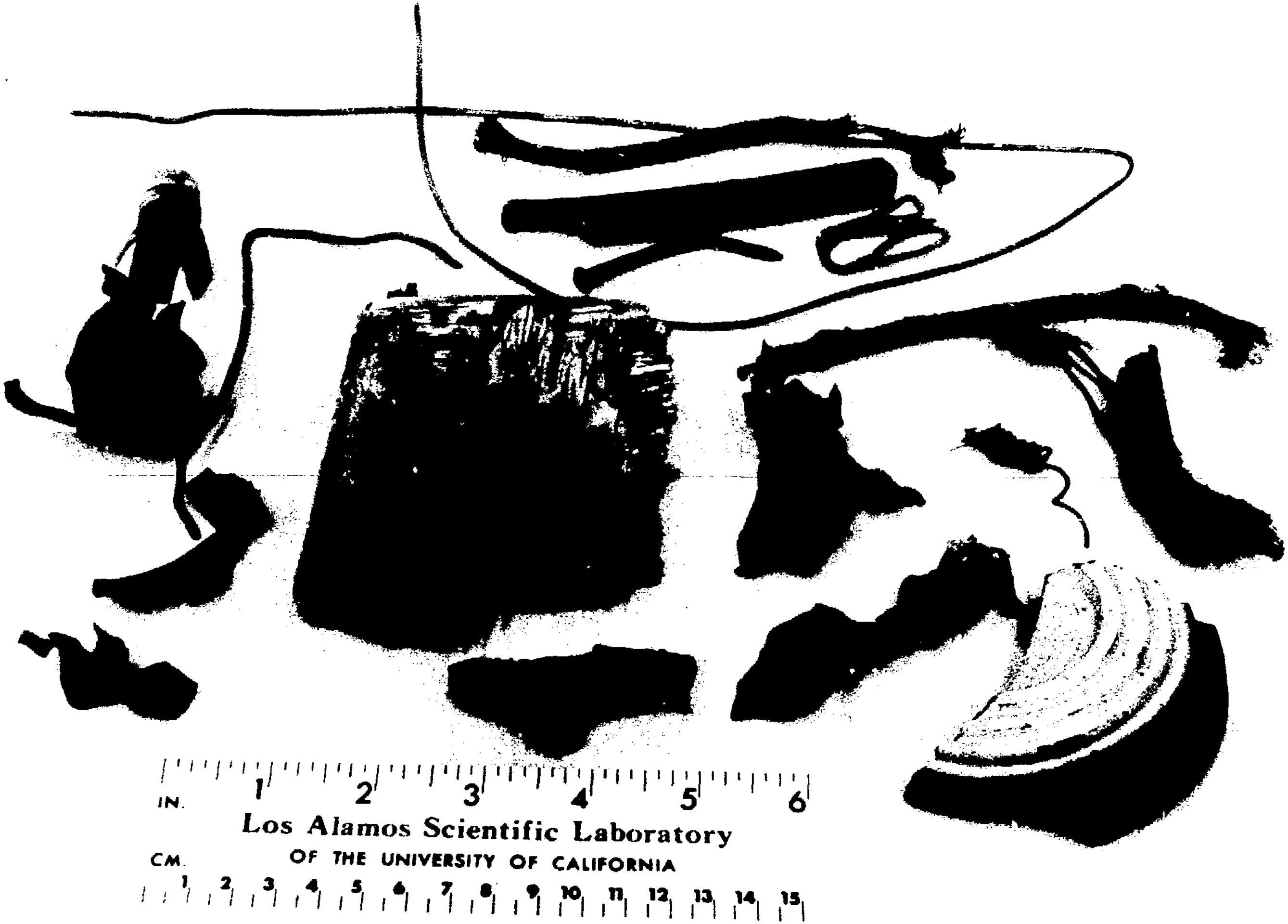

Fig. 8. Confidence boundary isopleths for gross α concentrations.

TABLE XI

COMPARISON OF ^{90}Sr IN SURFACE AIR
(fCi/m^3)

	Range	$\bar{X} \pm \sigma$	No.
Moosonee, Ontario	0.09 - 0.15	0.13 ± 0.03	3[a]
Helena, Montana	0.17 - 0.18	0.18 ± 0.01	3[a]
New York, New York	0.19 - 0.24	0.21 ± 0.03	3[a]
Rocky Flats, Colorado	0.14 - 0.27	0.21 ± 0.04	6[a]
Richmond, California	0.14 - 0.22	0.19 ± 0.04	3[a]
Group summary	0.09 - 0.27	0.18 ± 0.07	18
Española, New Mexico		0.17	1[b]
Pojoaque, New Mexico		0.14	1[b]
Santa Fe, New Mexico		0.14	1[b]
Group summary		0.15 ± 0.02	3
Bayo Canyon floor		0.13	1[b]
Mesa top (townsite)		0.09	1[b]
Group summary		0.11 ± 0.03	2

[a]EML-339 Department of Energy, Environmental Measurements Laboratory, 4th Quarter 1975.

[b]Los Alamos Scientific Laboratory Surveillance Net, 4th Quarter 1976.

TABLE XII

COMPARISON OF TOTAL URANIUM IN SURFACE AIR
(pg/m^3)

Station Location	Range	$\overline{X} \pm \sigma$	No. of 12-14 Wk Samples
Perimeter Stations (0 - 4 km)			
Arkansas Avenue	27 - 105	66 ± 4	4
Golf course	40 - 64	54 ± 3	4
Diamond Drive	50 - 179	111 ± 6	3
48th Street	39 - 63	53 ± 4	4
Fuller Lodge	64 - 109	80 ± 6	4
LA Airport	40 - 68	49 ± 4	4
Gulf station	51 - 102	72 ± 4	3
Acorn Street	9 - 134	75 ± 4	4
Royal Crest	-7 - 35	23 ± 4	2
White Rock S.T.P.	47 - 77	56 ± 2	4
Pajarito Acres	32 - 56	45 ± 3	4
Bandelier	24 - 55	34 ± 4	4
Group summary	7 - 179	59 ± 14	44
Bayo Canyon Stations			
Canyon floor	37 - 61	45 ± 5	4
Mesa top (townsite) 1	2 - 134	67 ± 6	3
Mesa top (townsite) 2	4 - 77	43 ± 4	3
Group summary	2 - 134	52 ± 9	10

TABLE XIII

EXTERNAL EXPOSURE
(μR/h)

Measured Total Exposure Rates

Background	Ion Chamber	GeLi
Mesa top (1.61 km SW of Bayo Site)	22.9	23.9
Mesa top (3.22 km W of Bayo Site)	19.1	20.4

Bayo Site	Ion Chamber			GeLi		
	Range	$\bar{X} \pm \sigma$	No.	Range	$\bar{X} \pm \sigma$	No.
Canyon floor	17.7 - 24.3	20.6 ± 1.6	45	20.6 - 26.1	22.6 ± 2.5	4
Talus slope	19.3 - 26.1	23.2 ± 1.6	21	---	---	---
Mesa top	17.8 - 20.3	19.1 ± 0.9	12	---	---	---
Group summary	17.7 - 26.1	21.0 ± 2.1	3	---	---	---

Calculated Exposure Rates[a] Attributable to Bayo Debris

Debris Contribution	$^{90}Sr-^{90}Y$	4.1×10^{-3}
	Total uranium	4.3×10^{-1}

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[a]DOE 77-24, Table B-8.

4.7.3 Subsurface Soil Conditions (Below 30 cm). Subsurface soil contamination is mostly low level and within 10 m of TA-10-1 and its acid waste system. The ^{90}Sr levels in the 30- to 122-cm layer, obtained from 18 samples having high gross β levels, had a mean concentration of 10.3 pCi ^{90}Sr/g and a range of 0.1 to 67.2 pCi ^{90}Sr/g. In all, 378 subsurface samples were taken from 30 to 200 cm and screened for gross β activity, and of these, 68 were analyzed for ^{90}Sr. Of these 68 samples, 12 exceeded 20 pCi ^{90}Sr/g and 8 exceeded 100 pCi ^{90}Sr/g. The maximum ^{90}Sr activity detected was 4310 pCi/g, which was measured in a sample taken from the 460- to 600-cm layer. The highest level sample contained 24 000 pCi gross β/g and came from between 430 and 490 cm below the surface. The maximum gross β sample at or above 244 cm was 4400 pCi/g at 244 cm.

Soil sampling has indicated that soil concentrations of ^{90}Sr below 244-cm depth in a limited area around TA-10-1 exceed the cleanup criteria. Soil containing these levels would be removed under alternative 2. Uranium levels in subsurface soil were found to be at background concentrations.

Studies indicate that ground water has not been affected by the ^{90}Sr and uranium concentrations in Bayo Canyon. The runoff volume in the canyon is so low that there is no apparent water in the alluvium. The intermittent runoff is not a source of recharge to the main aquifer.

5.0 ENVIRONMENTAL CONSEQUENCES

5.1 Minimal Action Alternative (Alternative I)--Preferred Alternative

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 chance of exposure to the subsurface contamination will be effectively eliminated because of constraints placed on the use of the area where the subsurface contamination is located.

5.1.2 Ecological Consequences. The ecological consequences associated with this alternative will be essentially zero. The placing of monuments to delineate the area of restricted use will involve some field work, but the associated ecological impact will be insignificant. No endangered species will be threatened. No alteration of the landscape will occur. No impact on the present natural succession of plant species will occur. There is no potential for surface or ground water contamination.

5.1.3 Land Use Impacts. Essentially, no land use impacts are associated with this alternative. The removal of 0.6 hectare of land from availability for residential development in the canyon is inconsequential. The restricted plot can be used for a playground, tennis court, park, or other recreational facility, and such a facility probably would be included in the plans for the canyon anyway. The most likely alternative to residential development will be continued use of the canyon for recreational purposes.

5.1.4 Socioeconomic Effects. No direct demographic, institutional, archaeological, or economic effects are associated with the minimal-action alternative. The placing of monuments and radiological surveillance can be carried out as part of the routine activities of County employees and Environmental Surveillance Group employees from the Los Alamos National Laboratory.

Because no actual cleanup is involved in this alternative, adverse public reaction could result from the perceived risk of surface contamination remaining in the canyon. The issue of contamination and debris could undergo considerable scrutiny with attendant publicity should the County decide to permit development of the land. Failure to implement any cleanup action could leave some question in the public mind as to the safety of developing the land for residential use.

5.1.5 Risk to Individual Health and Safety. Because little action is associated with this alternative, the direct risk resulting from its implementation is negligible. There remains, however, the potential for injury to the public from residual blast debris, as discussed in Sections 2.2 and 4.7.

5.2 Decontamination and Restoration Alternative (Alternative II)

5.2.1 Radiological Consequences. As only subsurface contamination above the working criteria will be removed, radiological risk and radiological conditions associated with surface contamination remain the same as described in Sections 2.2 and 4.7. The removal of the subsurface contamination eliminates the risk associated with its presence. This reduced risk, along with risks to cleanup workers, truck drivers, and in the event of an accident en route to the waste disposal site, is examined further in Section 5.2.5 on "Risk to Individual Health and Safety."

5.2.2 Ecological Consequences. Ford, Bacon & Davis Utah has estimated that the removal of 1160 m^3 of contaminated soil would require the removal and temporary storage of 12 200 m^3 of uncontaminated soil, which presently covers the contaminated material. Allowing for the backslope necessary to prevent cave-ins, 2790 m^2 of surface area would be disturbed by the excavation itself, and another 4180 m^2 would be required for stockpiling of uncontaminated soil.[2] This represents a total of 0.7 hectare that would be disturbed by the cleanup action.

As noted in Section 4.6.1, the old TA-10 site, exclusive of the firing sites, supports the remnants of a ponderosa pine forest. These trees are estimated, on the basis of trunk diameter, to be 100 to 200 yr old and, thus, are irreplaceable within one or two human lifetimes. They are a valuable natural asset to utilization of the land as a park, for a recreational area, or for residential development. Because the old waste disposal area is located in the middle of this stand of trees, efforts should be made to arrange the backslope on the excavation pit so as to minimize damage to the trees. The uncontaminated cover material should be stockpiled to the west on the old firing sites, from which trees were removed during the period of site activity, so that damage to the ponderosa pine trees is minimized.

In Section 4.3, the soil was described as being reasonably fertile, so that revegetation should require little effort. However, the 0.7 hectare of land directly impacted by the excavation, plus other land incidentally disturbed, represents only a small fraction of the portion of the canyon bottom already disturbed both by the site operation and by the original decommissioning action. No effort was made after the decommissioning to rehabilitate the area, and thus, this section of the canyon is already in a state of natural succession. The firing sites, in particular, are still quite brushy and have not yet reverted to the grassland found elsewhere in the canyon. Revegetation of one small area in the midst of a larger disturbed area seems futile. Furthermore, if the canyon ultimately is to be used for residential development, as seems likely (Section 4.1.1), there is little point in a revegetation effort.

Although the portion of Bayo Canyon disturbed under this alternative is relatively small, a possibility exists that the area could contain some of the plants listed in Table VII as protected under New Mexico Statute 45-11 (Section 4.6.2.2). These plants, although protected by law, are not necessarily rare or endangered species. Thus, even if a small amount of damage to any of the species were to occur during the cleanup action, the consequences would be insignificant. However, any amount of damage would be sufficient for initiation of a lawsuit, if any person or organization were inclined to do so.

The peregrine falcons that nest in adjacent Pueblo Canyon have been observed to hunt in Bayo Canyon (Section 4.6.3.2). However, the falcons are known to range over a large part of Los Alamos County, and there is much open land south of Pueblo Canyon on Los Alamos National Laboratory property. Therefore, the loss of Bayo Canyon as a hunting area should be inconsequential.

Noise associated with the excavation process (or with subsequent development of the canyon as a residential area) also is likely to have little effect on the falcons, because they already are tolerant of noise associated with the airport and industrial park located across Pueblo Canyon from the aerie.

The actual amount of contaminated soil that would require removal and disposition presently is estimated at about 1160 m^3. This amount is an increase of 15 to 20% over the anticipated annual solid waste disposal at TA-54 for the next couple of years. Furthermore, if the Bayo Canyon cleanup occurrs within that time, it may be superimposed on additional disposal demands, such as an acid-sewer line cleanup and cleanup of two old burial sites. Thus, although the Bayo Canyon cleanup would not be unmanageable at the TA-54 operation, it would represent a significant increment and would place an additional strain on operations and on the limited burial space available.[28]

Eleven hundred and sixty cubic meters of clean fill to replace the excavated, contaminated soil probably can be removed from an existing borrow pit without undue impact. The inactive pit in Los Alamos Canyon (Section 4.1.4) does not appear to have been rehabilitated after previous use was terminated, so reactivation of the pit probably would not have a great effect on the environment.

5.2.3 Land Use Impacts. As discussed in Section 4.1.1, the most probable future use of Bayo Canyon is for residential development. The impact of the decontamination alternative is that the additional 0.6-hectare site of subsurface contamination would be available for unrestricted use. However, there is some question as to whether this area would be structurally suitable for residential construction because of the large volume of fill. Some period of time for compaction might be necessary before it could be so used.

The likelihood of increased potential for erosion is small, even though the area of excavation is on the floodplain of the intermittent stream that flows through Bayo Canyon, because of the small amount of runoff that normally occurs. An extraordinarily large runoff event would be required to have a significant erosive effect. This conclusion is reinforced by noting that the firing sites, which were stripped of vegetation during site operation, do not show any signs of significant erosion.

5.2.4 Socioeconomic Effects. There are no direct demographic, institutional, or archaeological effects associated with the decontamination and restoration alternative. As noted in Section 4.2.5, a recent search of the canyon located only one small archaeological site west of the Otowi Ruins, and this is not in the area that would be impacted by the excavation of the contaminated soil.

Economic effects associated with this alternative would be minimal. Ford, Bacon & Davis Utah estimates that the required remedial action could be completed by a crew of 10 people in 55- to 65-working days at a total cost of $461,000.[2] If the Zia Company, a private company under contract to DOE in Los Alamos, were to undertake this cleanup, the operation would represent about 0.8% of their annual budget and less than 0.15% of total annual man hours for the company. Thus, regardless of whether Zia or some other company undertakes the cleanup, the economic impact on Los Alamos and the region will be insignificant.

Transportation of contaminated soil to TA-54 should have a negligible impact on local traffic if it is not scheduled during peak commuter traffic hours.

5.2.5 Risk to Individual Health and Safety. The risks to mesa-top residents, casual recreational users of the canyon, or permanent residents of the canyon from surface contamination remain as discussed in Section 2.2.

Because subsurface contamination in the area around TA-10-1 and its waste pits will be removed, potential radiation doses from exposure of hypothetical residential construction workers to ^{90}Sr levels elevated above the cleanup limit of 100 pCi/g would be reduced. This would principally affect individuals, involved in projects such as installing sewer lines, who are working at depths greater than 122 cm. Estimates of maximum individual 50-yr dose commitments from inhalation would be reduced from 0.01 mrem to at least 0.001 mrem (to bone lining). The actual value would depend on how far below the 100 pCi ^{90}Sr/g limit the "as left" soil concentrations are.

Doses to cleanup workers and truck drivers carrying contaminated soil to TA-54, the waste disposal facility at the Laboratory, are summarized in Table XIV. The maximum 50-yr dose commitments to these two groups were estimated to be 0.10 and 0.89 mrem, respectively, to bone lining. These doses are 0.01 and 0.06% of the RPS to bone for members of the public. The doses were calculated using the same assumptions discussed in Section 2.2 for construction excavation at 2.4 m (8 ft) and an exposure time of 40 h per week for 12 weeks.

The risks associated with accidents during the cleanup process are small because of the small size of the operation, but some risk is associated with transport of contaminated soil to TA-54. The estimated 1160 m^3 of soil to be removed from Bayo Canyon represents 200 to 250 truckloads of material, which will be hauled from Bayo Canyon to TA-54 (Fig. 5). Based on Interstate Commerce Commission statistics of 5.24×10^{-8} accidents per ton-mile and 5.14×10^{-9} fatalities per ton-mile,[29] there is a 0.0016 probability of an accident and a 0.00015 probability of a fatality occurring during the course of the soil transportation.

In the unlikely event of an accident, the soil transported by truck may spill in a place, such as the vicinity of the community of White Rock, where there is potential for some radiation exposure to the public. Inhalation of material resuspended by wind would be the principal exposure route. A maximum 50-yr dose commitment to persons near the accident was evaluated and found to be 0.02 mrem to the bone, 0.001% of the RPS.

Doses are summarized in Table XIV. Details of the dose calculations are given in Appendix B.

TABLE XIV

DOSE EVALUATION FOR BAYO CANYON CLEANUP

Group Receiving Estimated Dose	Contributing Soil Depth (cm)	Dose (mrem)[a] Bone	Dose (mrem)[a] Lung	Red Marrow
Decontamination worker[b]				
Inhalation	122 to 244	0.08	<0.01	0.07
External dose	122 to 244	0.02	0.02	0.02
Total[e]		0.10	0.02	0.09
Truck Drivers[c]				
Inhalation		0.04	<0.01	0.03
External dose		0.85	0.85	0.85
Total[e]		0.89	0.85	0.88
Maximally exposed member of public due to accident		0.02	<0.01	0.01
Radiation Protection Standard[d]		1500	1500	500
Per cent of RPS (worst case)		0.06	0.06	0.18

[a]Internal doses are 50-yr dose commitments.

[b]Based on 480-h exposure.

[c]Based on 230-h exposure on site and 125-h exposure in transit to the radioactive solid waste disposal facility.

[d]Taken from Ref. 4.

[e]Summation of internal plus external doses.

5.3 No-Action Alternative (Alternative III)

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

5.3.2 Ecological Consequences. The ecological consequences of this action are zero. No endangered species will be threatened; no alteration of the landscape will occur; and no impact on the present natural succession of plant species will occur. No potential for surface or ground water contamination exists. Conditions will remain as described in Sections 4.3 and 4.6.

5.3.3 Land Use Impacts. Failure to implement any cleanup action very likely will have little impact on the decision to go ahead with residential development of Bayo Canyon. Developable land is scarce in Los Alamos County (Section 4.2.1), and so, because the State has concurred that the residual surface contamination remaining poses no significant health hazard (Section 2.2), residential development probably will occur under any circumstances. Should residential development not occur, the most likely alternative is continued use of the canyon for recreational purposes (hiking, Boy Scouts, skeet shooting, horseback riding, etc.).

5.3.4 Socioeconomic Effects. No direct demographic, economic, institutional, archaeological, or other socioeconomic factors will be affected under the no-action alternative. Such effects will occur secondarily if subsequent residential development occurs. However, the fate of the site will be decided by the owner, Los Alamos County, and actions taken at the site will be beyond control of the DOE.

Failure to implement any remedial action in Bayo Canyon will undoubtedly leave some question in the public mind as to the safety of developing the land for residential use. Residual contamination and debris could conceivably become an issue should the County decide to permit development of the land.

5.3.5 Risk to Individual Health and Safety. There will be no human risk from remedial actions, because no action occurs. Risks to recreational users, residents, or construction workers will remain as discussed in Section 2.2.

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APPENDIX A

BAYO CANYON SOIL FERTILITY DATA

COLLEGE OF AGRICULTURE AND HOME ECONOMICS

DEPARTMENT OF AGRONOMY
Box 3Q/Las Cruces, New Mexico 88003
Telephone (505) 646-3405

NEW MEXICO STATE UNIVERSITY

May 29, 1980

Dr. Roger W. Ferenbaugh
Group H-8, MS 490
Environmental Surveillance
Los Alamos Scientific Laboratory
P. O. Box 1663
Los Alamos, New Mexico 87545

Dear Roger:

Enclosed are the results of the soil analysis. Listed below are approximate levels indicating fertility level from the Colorado Extension publication - reference included.

Nitrogen	less than 1 ppm add 50 lbs/acre unless manure (o.m.) is added then reduce amount of N.
Potassium	anything greater than 60 ppm is high - K is not needed - could add 40 lbs/acre as a starter.
Phosphorus	0-7 ppm add 40 lbs/acre P_2O_5 8-14 ppm add 20 lbs/acre P_2O_5 and would plan on adding 40 lbs/acre.
Iron	greater 4.0 ppm is adequate - if Fe is added it would be best to add foliar - but it isn't going to be necessary. Note control.
Manganese	greater 1.0 ppm is adequate - note control is fairly high but it is not toxic at these pH values.
Copper	greater than 0.2 ppm is adequate. The middle 0-6 is high but copper additions are not needed nor should they be toxic.
Zinc	greater than 0.25 ppm is adequate - Zn levels are fine.

Texline is easy to work; one would expect good drainage, minimum crusting actually couldn't be better. The salts are very low, Ca-Mg ratios are good and SAR is very low. SAR of 4 begins to limit some plants. The pH is just about ideal. I would like the organic matter to be erased some by either adding manure or straw and nitrogen. Add about 10 tons/acre manure.

The Colorado publication is listed below. If you have trouble getting a copy, I could xerox our copy for you. It should be available from Colorado State.

Guide to Fertilizer Recommendations in Colorado, Soil Analysis and Computer Process. Cooperative Extension Service Colorado State. Jan. 1978. P.N. Soltanpour, A. Ludwick, and J. O. Reuss.

Let me know if you need anything concerning these, and send the bill to the person on the purchase request, Charles Justis.

Sincerely,

Bruce Buchanan

Bruce Buchanan
Assistant Professor

BB:mmc

Enclosure

COLLEGE OF AGRICULTURE AND HOME ECONOMICS

DEPARTMENT OF AGRONOMY
Box 3Q/Las Cruces, New Mexico 88003
Telephone (505) 646-3405

NEW MEXICO STATE UNIVERSITY

May 9, 1980

To: Univ. Of Cal. at Los Alamos
Charles Justis Lp11
P.O. Box 990 Mail stop 274
Los Alamos, NM 87544

From: Soil & Water Testing Lab.
NMSU Box 3Q
Las Cruces, NM 88003

Subject: Soil analysis to be interpreted by Dr. Buchanan

	mmhos/cm		---- meq/L ----				%	-------- ppm --------		
Sample	E.C.	pH	Na	Ca	Mg	SAR	OM	1:5 NO_3	NH_4OAc K	$NaHCO_3$ P
Control 0-6	.159	6.79	.21	.81	.23	.29	1.39	3.40	168	6.6
Lower 12-18	.266	6.80	.72	1.00	.36	.87	.81	1.05	156	10.0
Waste 12-18	.386	7.79	.46	2.45	.59	.37	.48	.55	123	2.6
South 0-6	.165	7.13	.17	.80	.22	.24	1.50	1.20	143	15.0
Middle 0-6	.249	6.97	.19	1.25	.18	.22	1.24	.35	268	13.4
Waste 0-6	.261	7.51	.35	1.55	.38	.36	.48	.65	158	5.8
Lower 0-6	.248	7.02	.42	1.11	.35	.49	.98	2.65	113	10.6
South 12-18	.268	6.84	.51	1.09	.33	.60	1.29	2.50	94	4.0
Middle 12-18	.411	7.07	1.34	1.37	.45	1.40	.77	2.15	232	4.0

	---------- ppm ---------- DTPA				------ % ------			
	Fe	Mn	Cu	Zn	Sand	Silt	Clay	Texture
Control 0-6	10.06	11.92	.36	.96	62.8	26.6	10.6	Sandy loam
Lower 12-18	4.40	6.32	.56	.80	72.8	18.4	8.8	Sandy loam
Waste 12-18	1.68	1.68	.14	.16	61.0	28.2	10.8	Sandy loam
South 0-6	8.36	9.34	9.38	4.20	64.8	24.6	10.6	Sandy loam
Middle 0-6	7.06	16.58	15.12	4.38	50.4	32.8	16.8	Loam
Waste 0-6	3.20	4.86	.42	.68	59.0	28.4	12.6	Sandy loam
Lower 0-6	6.46	6.38	.98	1.48	68.4	22.8	8.8	Sandy loam
South 12-18	5.24	6.52	1.16	.58	56.8	30.6	12.6	Sandy loam
Middle 12-18	4.82	4.74	2.22	1.12	44.8	36.6	18.6	Loam

APPENDIX B

DOSE CALCULATION PROCEDURES

Recommendations in this report incorporate assessments of the radiation risk to members of the public caused by residual radioactive contamination in Bayo Canyon. In this appendix, an outline of the dose calculation procedures is presented, from which the soil limits were derived, and on which these risk estimates are based. The outline follows the methodology used by Healy, Rodgers, and Wienke[1] in deriving the soil limits. Refer to Ref. 1 for a more detailed description of their procedures and underlying rationale.

Results of pathway analysis are given in the second section of this appendix. Radiation doses resulting from measured ^{90}Sr and uranium soil concentrations in Bayo Canyon are evaluated for scenarios corresponding to different uses of the contaminated area.

1.0 DERIVATION OF SOIL LIMITS

Interim limits for natural uranium and ^{90}Sr were calculated by Healy, Rodgers, and Wienke[1] so that no individual would receive any organ dose during any year in a 70-yr lifetime greater than 0.5 rem. This dose limit is based on the recommendations of the National Council on Radiation Protection and Measurement (NCRP).[2] Assumptions tending to maximize the dose from soil contamination were used throughout the calculations to assure that the dose limits would not be exceeded. Three exposure pathways, inhalation and ingestion of contaminated material and external radiation, were evaluated in deriving these limits.

Annual dose rates for lung and bone were calculated for inhalation of ^{238}U-^{234}U, and annual dose rates to bone were calculated for inhalation of ^{90}Sr and ingestion of ^{238}U-^{234}U and ^{90}Sr, per unit intake of activity during a 70-yr lifetime of continuous exposure.

In calculating these dose rates, contributions from intake of the uranium decay products ^{234m}Pa, ^{234}Pa, and ^{234}Th and from intake of the ^{90}Sr decay product ^{90}Y were negligible. Calculations for doses from intake of these radionuclides are not presented. Doses from these radionuclides are included in the dose calculations if the radionuclides are produced inside the body from decay of the parent. The contribution from the intake of ^{234}U with ^{238}U is included.

The inhalation dose calculation was based on the Task Group Lung Model of the International Commission on Radiological Protection (ICRP).[3,4] Parameters used for the calculation are summarized in Table B-I, adapted from Ref. 1. They include the use of Y and W solubility classifications for uranium and strontium, respectively, and an activity medium aerodynamic diameter of 1 µm.

Dose estimates due to ^{90}Sr intakes are based on ^{90}Sr/calcium ratios. For ^{90}Sr, 30% of the inhaled material that reaches the

TABLE B-I

PARAMETERS USED IN CALCULATION OF DOSE RATE FACTORS

	$^{238}U-^{234}U$	Strontium
Solubility class	Y	W
Activity median aerodynamic diameter	1 μm	1 μm
Biological half-life		
Lung	400 days	90 days
Bone	500 days	
Organ transfers		
Nasopharyngeal to blood	0.01	0.10
Tracheobronchial to blood	0.01	0.10
Pulmonary to blood	0.05	0.15
Pulmonary to lymph	0.15	0.05
Lymph to blood	0.9	1.0
GI to blood	0.2	0.3
Blood to bone	0.20	
Radiological Factors		
Quality factor	10	
Dose distribution factor	5 (U only)	
Alpha energy deposited in organ per disintegration		
Lung	8.96 MeV	
Bone	8.96 MeV	
Organ mass		
Lung	1000 g	
Bone	5000 g	

gastrointestinal (GI) tract is absorbed by the blood. The assumption is that the ^{90}Sr absorbed through either the lung or GI tract mixes with the daily calcium intakes, and that ^{90}Sr/calcium in bone is 0.14 of that in blood. Dose conversion factors of 1.4 mrad/yr per pCi ^{90}Sr/g calcium to the bone marrow and 1.9 mrad/yr per pCi ^{90}Sr/g calcium to the bone surface were used.

In calculating dose rate to bone for inhalation and ingestion of uranium, uranium absorption in the GI tract was conservatively set at 20%.[1] The authors felt that this value, although probably overestimating the dose, provided a reasonable upper limit on dose rate until the question of gut uptake of uranium is resolved.

Annual dose rates corresponding to constant radionuclide intake of 23 pCi/day (inhalation) and 1 pCi/day (ingestion) over a 70-yr lifetime were calculated using these parameters. The only exception was for ingestion of ^{90}Sr, for which the dose was calculated in terms of the ^{90}Sr/calcium ratio in the diet. In Table B-II (taken from Ref. 1), the annual doses are listed for select years for both ingestion and inhalation.

Inhalation exposure was estimated using a mass loading approach, based on the amount of respirable dust in the air. The maximally exposed individual was assumed to spend 100% of his time in the contaminated area for 70 yr. For 8 h/day, 5 days/week, he would work outdoors, during which time he would inhale one-half of his total daily air intake of 23 m^3 and be exposed to dust levels of 400 $\mu g/m^3$. For 10 h/day, 7 days/week, he would be inside where dust levels are 50 $\mu g/m^3$. The remaining time would be spent outdoors under ambient dust loading of 100 $\mu g/m^3$. The weighted average air concentration, taking into account time spent under each condition and breathing rates, would be 200 $\mu g/m^3$.

Given this dust loading, a standard breathing rate of 23 m^3 day, and the dose rates per amount inhaled described above, the soil concentration corresponding to the 0.5 rem/yr dose limit was calculated for the inhalation pathway.

Consumption of food grown in soil containing above-background ^{238}U-^{234}U and ^{90}Sr was considered to be the most important ingestion pathway. Estimates were developed for the home gardener diet; the gardener would grow one-third of his fruit and one-half of his vegetables, totaling some 80 kg of plant-derived foods each year.

A uranium concentration ratio, which is the uranium activity (pCi)/wet weight of food (g), per uranium activity (pCi)/dry weight of soil (g) of 1×10^{-3} was used to relate uranium concentration in plants to soil contamination. Uranium intake per unit soil concentration was calculated from the home gardener vegetable and fruit consumption rate and the uranium concentrations in plants. In a final step, the uranium intake and the derived ingestion dose rates were used to estimate the dose per unit uranium activity in soil and the soil concentration that corresponded to the 0.5 rem/yr dose limit for the ingestion pathway.

TABLE B-II

DOSE RATES (rems/yr) AND TOTAL DOSES (rems) FROM:[a]

1. Inhalation of 23 pCi/day (1 pCi/m^3)

	^{238}U-^{234}U	
Time (yr)	Lung	Bone
5	3.1	0.27
50	3.3	0.62
70	3.3	0.62
Total (rem)	230	40

2. ingestion of 1 pCi/day

	^{238}U-^{234}U
Time (yr)	Bone
5	0.044
50	0.048
70	0.048
Total	3.3

[a]Adopted from Ref. 1.

The ^{90}Sr soil limit ingestion pathway was derived by estimating the ^{90}Sr/calcium ratio in plants due to surface ^{90}Sr contamination and the consequent ^{90}Sr/calcium ratio in bone from consumption of the plants. This allowed calculation of the expected bone dose and also the soil concentration giving a 0.5 rem/yr dose.

External radiation from ^{238}U also was based on 100% occupancy of the contaminated area. Radiation from ^{90}Sr-^{90}Y, primarily β radiation emitters whose critical organ would be skin, was not considered.

For both ^{90}Sr-^{90}Y and ^{238}U-^{234}U, the ingestion pathway was the most limiting. The final soil limit for each radionuclide was calculated from the inverse of the sum of the reciprocals of the limit for the inhalation, ingestion, and external radiation pathways.

In deriving these limits, ^{238}U was assumed to be in equilibrium with its decay products, ^{234}Th, ^{234}Pa, and ^{234}U. Equilibrium between ^{238}U and its decay products is characteristic of natural uranium. In depleted uranium, which comprises some 60% of the uranium released at the Bayo Canyon site, ^{234}U is in approximately 50% equilibrium with ^{238}U. The ^{234}U-^{238}U activity ratio, taking into account both the natural and depleted uranium released at the site, is 63%. Use of the 40-pCi ^{238}U/g limit for Bayo Canyon should be additionally protective of public health because it assumes more ^{234}U to be present than is actually there.

No correction was made in the derivation of the soil criteria for the decay of ^{90}Sr. Because the ^{90}Sr radioactive half-life is 28 yr, the ^{90}Sr soil levels would decay to 18% of their original value during the 70-yr exposure time. Not taking into account the ^{90}Sr decay is a conservative procedure because the estimated maximum annual dose would be less than the 0.5-rem limit for the 100-pCi ^{90}Sr/g soil criteria.

2.0 CALCULATION OF RADIATION DOSES

Doses are estimated for three activity categories: permanent residence in Bayo Canyon, construction activities involving working with the contaminated soil, and cleaning up the residual contamination. The first two categories would typify maximum doses under the no-action alternative, whereas the third would set an upper limit on doses to workers and members of the public if cleanup were to occur. Where applicable, doses were estimated using the procedures taken from Ref. 1, discussed above.

The largest calculated doses correspond to the development of Bayo Canyon as a residential area. This would involve year-long occupancy of the canyon by members of the public and some use of the canyon for gardening. Doses estimated for these activities would be larger than those incurred by the occasional users of canyon facilities, such as hikers or horseback riders. The doses calculated for full-time residence in the canyon are presented here as indicative of the maximum exposures to members of the public under the no-action alternative.

Some organ doses resulting from exposure to ^{90}Sr and uranium, such as those to bone, occur over relatively long time periods after the exposure because these radionuclides are only slowly removed from those organs. Depending on the situation, this extended exposure period is accounted for in one of two ways in this dose assessment:

1. the use of the maximum annual dose occurring for any year during a 70-yr lifetime of continuous exposure at constant levels; or

2. the use of the 50-yr dose commitment, which is the total dose received by an organ during the 50 yr following the exposure.

Maximum annual doses during a 70-yr exposure are calculated from the dose rate factors given in Table B-II. The 50-yr dose commitments for a given intake of ^{90}Sr or uranium are derived from the 50-yr dose commitment conversion factors (DCFs) presented in Table B-III.

These DCFs were calculated from Healy et al.,[1] using the fact that the dose rate for the 50th yr of continuous exposure to an annual intake of 1 μCi is equal to the 50-yr dose commitment due to a single intake of 1 μCi.[5] The dose rates at 50 years were calculated by Healy et al. for continuous intake of 23 pCi/day (inhalation) and 1 pCi/day (ingestion). The annual intake was found for inhalation and ingestion, and the DCFs derived by dividing the 50-yr dose by the annual intake.

Dose in bone was calculated as dose to the bone lining cells. This involved modifying the ^{238}U and ^{234}U dose factors. The dose factors for uranium were calculated through use of S factors from Dunning et al.[6] The S factors used here, S(bone lining from bone) and S(bone from bone), give the dose in the bone lining cells and bone, respectively, per μCi-day of uranium deposited in bone. The uranium dose rate and 50-yr dose commitment factors for bone were multiplied by the ratio of the S factors, S(bone lining from bone)/S(bone from bone). These ratios are 0.0806 and 0.0889 for ^{238}U and ^{234}U.

For the inhalation and ingestion pathways for potential residents, the maximum annual dose for a 70-yr continuous exposure is calculated because lifelong occupation of the contaminated area is involved. For other situations, in which the exposures are of shorter duration, the 50-yr dose commitment is used because this is more representative of the exposure situation.

Soil concentrations used in the dose calculations are taken from the radiological survey results.[7] Complete equilibrium was assumed between ^{90}Sr and ^{90}Y, and 63% equilibrium between ^{238}U and ^{234}U. However, as in Section B.1, doses from intake of ^{90}Y, ^{234}Th, ^{234}Pa, and ^{234m}Pa were negligible.

TABLE B-III

CONVERSION FACTORS USED IN CALCULATING RADIATION DOSE

Maximum Annual Dose in 70-Yr Exposure [rem/(μCi/yr) intake]

Mode of Exposure	Lung	Bone Lining
Inhalation		
^{238}U	183.6	2.85
^{234}U	209.2	3.42
^{90}Sr		0.155
Ingestion		
^{238}U	--	5.10
^{234}U	--	6.14

50-Yr Dose Commitment Factors (rem/μCi intake)

Inhalation	
^{238}U	2.85
^{234}U	3.42
^{90}Sr	0.155

2.1 Inhalation of Contaminated Soil (0- to 5-cm soil layer)

Inhalation of resuspended surface contamination could result in radiation doses, principally to the lungs and bone. The above-background ^{90}Sr and ^{238}U-^{234}U concentrations in the 0- to 5-cm soil layer, from Table B-III, are multiplied by 200 $\mu g/m^3$ to obtain the radionuclide air concentrations, by 8395 m^3/yr to get the annual intake of each radionuclide, and by the 70-yr conversion factors to obtain the dose.

The calculated doses (Table B-II) are the maximum annual doses during 70 yr of exposure to these air concentrations. The calculations assume 100% occupancy of the contaminated area throughout the year.

2.2 Ingestion of Homegrown Produce (0- to 30-cm soil layer)

Vegetables and fruits grown in residential areas developed in Bayo Canyon may absorb residual ^{90}Sr and ^{238}U-^{234}U from the soil, resulting in a dose to man. Following Healy, et al.,[1] the assumption was made that a home garden would supply 80 kg/yr of vegetables and fruits to the maximum exposed individual. The 0- to 30-cm soil concentration results were used in the calculations because this soil depth is representative of root zones of many garden plants.

Uranium. From the concentration ratio of 1×10^{-3} and the uranium soil concentrations, the activity of each uranium isotope per plant wet weight was determined. Multiplication by 80 kg/yr and the uranium ingestion conversion factors gives the maximum annual dose during 70 yr of continuous exposure. The maximum annual ingestion dose from uranium is 2.53 mrem to bone. This corresponds to 0.21 mrem to bone lining.

Strontium. Calculation of the ^{90}Sr/calcium ratio in fruits and vegetables grown in the garden depends on the ^{90}Sr surface contamination. The calculation presented here follows that of Healy et al.,[1] who use a 20-cm soil depth. Using a density of 1.4 gm/cm^3 (Ref. 7) and an above-background ^{90}Sr soil concentration of 0.5 pCi/g, the ^{90}Sr surface contamination is 140 mCi/km^2. Concentration M (in pCi ^{90}Sr/g calcium) in the diet from an initial deposit of ^{90}Sr in the soil, F (in mCi/km^2), is given by[1]

$$M_1 = 1.03\ F \text{ for vegetables}$$

$$= 144 \text{ pCi } ^{90}Sr/g \text{ calcium and}$$

$$M_2 = 0.90\ F \text{ for fruit}$$

$$= 126 \text{ pCi } ^{90}Sr/g \text{ calcium.}$$

Vegetable and fruit consumption is expected to provide 8.9% and 3.9% of the calcium in the diet, respectively. The calcium provided by food grown on the contaminated area is 4.5% (1/2 x 8.9%) and 1.3%

(1/3 x 3.9%) of the total. The resulting weighted ^{90}Sr/calcium ratio in the diet would be

$$(0.045)(144) + (0.013)(126) = 8.12\text{-pCi } ^{90}Sr/g \text{ calcium}.$$

The ^{90}Sr/calcium ratio in bone is 0.14 that in the diet,[8] or 1.14 pCi ^{90}Sr/g calcium. (This is a conservative assumption because ^{90}Sr reaches equilibrium in bone slowly.) Using dose conversion factors of (1.4 mrad/yr)/(pCi ^{90}Sr/g calcium) for bone marrow and (1.9 mrad/yr)/(pCi ^{90}Sr/g calcium) for bone surfaces, the bone marrow and bone surface doses are 1.60 and 2.2 mrem/yr, respectively.

This dose calculation does not take into account evidence showing ^{90}Sr to be less biologically mobile the longer it is in the environment, which would result in less uptake by plants and lower doses to man.[1] Because the ^{90}Sr has been present at Bayo Canyon for at least 19 yr, the actual dose could be significantly less than this estimated dose.

The estimated maximum total annual ingestion dose of 4.73 mrem is lower than that calculated previously.[6] The dose estimate presented here agrees with the current understanding of the radiological and environmental behavior of ^{90}Sr, the radionuclide that accounted for the greatest part of the dose estimated in the previous report.[7]

To illustrate the compatibility of this dose estimate with other assessments, the ^{90}Sr ingestion dose can be compared with the fallout-deposited ^{90}Sr dose calculated by the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).[7] This committee estimated the ^{90}Sr population weighted deposition density from fallout to be 85.1 mCi/km^2. Measurements of ^{90}Sr to calcium ratios in adult vertebrae generally lie between 1 and 2 pCi ^{90}Sr/g calcium. This corresponds to a bone surface dose of 1.9 to 3.8 mrad/yr. The above-background Bayo Canyon ^{90}Sr concentration of 140 mCi/km^2 is slightly larger than the fallout value, whereas the consumption rate of Bayo Canyon fruits and vegetables is smaller than the total diet consumption rate that would apply for the fallout situation. Ingestion doses from above-background Bayo Canyon ^{90}Sr levels would be expected to be approximately the same as those calculated for fallout. The 2.73 mrem/yr estimated here for the ^{90}Sr ingestion dose is in reasonable agreement with that from UNSCEAR for similar levels of ^{90}Sr intake. Revision of the previous estimate of maximum ingestion dose to the present value, therefore, is thought to be appropriate.

2.3 Doses to Construction and Cleanup Workers

Doses to workers were calculated using the 50-yr dose commitment factors from Table B-III. A dust loading of 400 µg/m^3 and breathing rate of 43 ℓ/min, typical of a man engaged in physical work,[9] were used. Radionuclide soil concentrations depended on the soil layer being disturbed, which, in turn, depended on the activity being performed. These are summarized in Table B-IV.

Doses due to inhalation of dust containing ^{90}Sr contamination are less than those estimated in Ref. 7. As discussed above, for ^{90}Sr ingestion, these present estimates agree with data summarized by UNSCEAR. In addition, the value used for dust loading was reduced from 10 mg/m^3 to 400 μg/m^3, which is more representative of the average dust loading under these conditions.

2.4 Doses Resulting from Transportation of Bayo Soil to TA-54

2.4.1 Dose to the Driver of a Truck Hauling Contaminated Soil. The driver can receive radiation doses from external radiation emitted by the contaminated soil and from inhalation of contaminated material resuspended from the soil carried by the truck. Two types of external radiation are expected from the contaminated soil: β radiation emitted by the ^{90}Sr and ^{90}Y nuclei and photon bremsstrahlung, or "braking," radiation resulting from β particles losing energy in interactions with nuclei in either the soil or the truck walls.

2.4.1.1 Beta Dose. Beta radiation would be totally absorbed by the truck walls. The maximum β energy is 2.27 MeV, which is the maximum energy of the β particles emitted by ^{90}Y. The range of this particle is 1.1 g/cm^2.[10] Given the density of iron as 7.86 g/cm^3, this β range is 0.14 cm, or 0.055 in. Because this is less than the 0.125-in. thickness typical of truck bed walls, no β radiation would penetrate to the driver.

2.4.1.2 Bremsstrahlung Dose. An upper limit to the radiation dose from bremsstrahlung was estimated by calculating the photon intensity at the surface of an infinite half-space of soil having a ^{90}Sr concentration of 1100 pCi/g. The actual dose to the driver would be less than this dose because of the finite size of the load and the average soil concentration probably being considerably lower than 1100 pCi/g. The bremsstrahlung dose is calculated from this photon intensity, attenuated by the 5 g/cm^2 thickness of the truck bed and cab walls. Attenuation from material inside the cab, as well as self-shielding by the body, was ignored.

At equilibrium, the ^{90}Sr and ^{90}Y soil concentrations, C_i, would both be 1100 pCi/g. Following Cember,[11] the fraction f_i of incident β energy converted into photons in a material of atomic number Z is given by

$$f_i = 3.5 \times 10^{-4} Z E_i ,$$

where E is the maximum β particle energy in a million electron volts (MeV) for $^{90}Sr (i = 1)$ or $^{90}Y (i = 2)$. Assuming soil to have the composition given in Table B-IV, the effective Z is calculated to be 9.65. Because E = 0.546 MeV for ^{90}Sr and 2.2 MeV for ^{90}Y, the values of f are 0.0018 (^{90}Sr) and 0.0077 (^{90}Y).

Next, a virtual photon emission rate is assigned to each volume element V. This emission rate is assumed to be uniform throughout the infinite half-space. This is a valid assumption except near the edge

TABLE B-IV

WORK PARAMETERS FOR EXCAVATION SCENARIOS

Activity	Soil Layer	Exposure Time
Excavation, landscaping	0-30 cm	2000 h/yr
Foundations, utilities	0-122 cm	360 h
Sewer installations	122-244 cm	60 h
Cleanup crews	122-244 cm	480 h

TABLE B-V

SOIL COMPOSITION BY WEIGHT USED IN DETERMINING EFFECTIVE ATOMIC NUMBER AND SOIL-TO-BREMSSTRAHLUNG DOSE CONVERSION FACTOR[a]

Al_2O_3	0.135
Fe_2O_3	0.045
SiO_2	0.675
CO_2	0.045
H_2O	0.10

[a]Taken from Ref. 12.

of the space, where it would be conservative. The volume element would contain activity C_i DV each of ^{90}Sr and ^{90}Y, where D is the soil density. Then the β energy produced by each radionuclide per unit time, W_i, in V is

$$W_i = E_i C_i DV/3 \quad .$$

This expression uses the fact that the average β energy is approximately one-third the maximum β energy.

The photon activity from each radionuclide, Q_i, in V is

$$Q_i = f_i W_i / E_i \text{ and}$$

$$Q_i = f_i E_i C_i DV/3E_i$$

$$= f_i C_i DV/3 \quad ,$$

where it is assumed conservatively that all photons have an energy equal to the maximum β energy. The photon activity from each radionuclide per gram of soil is

$$\left(\frac{Q}{m}\right)_i = \left(\frac{Q}{DV}\right)_i = f_i C_i/3 \quad .$$

For 1100 pCi/g = 40.7 dps/g, this activity per gram is equal to 0.0244 and 0.1041 photons/s/g for ^{90}Sr and ^{90}Y, respectively.

Exposure rates were determined from interpolating conversion factors from Beck et al.[12] For 0.546 and 2.27 MeV photons, the conversion factors used are 15.88 and 70.12 (μR/h)/(gamma/s/g), respectively. These factors were calculated for a radiation field at 1 m above the surface of contaminated soil occupying an infinite half-space. They include contributions from photons scattered by air and soil as well as unscattered photons.

Using the photon activity per gram previously calculated for ^{90}Sr and ^{90}Y and the above conversion factors, the photon exposure levels at 1 m are

$$(15.88)(0.0244) = 0.39 \ \mu R/h \text{ and}$$

$$(70.12)(0.104) = 7.30 \ \mu R/h \quad .$$

Shielding by the cab or truck walls would reduce this exposure level. Both the truck bed and cab walls were assumed to be 0.125-in.-thick steel, providing some 0.25 in. of shielding in all. Mass attenuation coefficients in iron for 0.546- and 2.27-MeV photons are approximately 0.0769 and 0.0410 cm^2/g, respectively.[10] The relaxation lengths μx are 0.384 and 0.205. Interpolated estimates of build-up factors for these values of μx are 1.41 and 1.14.[10] The exposure rates would then be

$$X = (0.39)(1.41)e^{-0.384} = 0.38\ \mu R/h \text{ and}$$

$$X = (7.30)(1.14)e^{-0.205} = \underline{6.79}\ .$$

$$\text{TOTAL}\quad 7.17$$

Total dose to the driver was estimated assuming that the driver would haul contaminated soil for 125 h. The total exposure would be

$$7.17\ \frac{\mu R}{h}\ (125\ h) = 0.90\ mR = 0.85\ mrem\ ,$$

where 1 R equals 0.95 rad and the photon quality factor equals one.

Doses from bremsstrahlung due to β particle deceleration in the truck walls also were calculated. While the fraction f of β energy changed to bremsstrahlung radiation was higher than that for soil because of the higher atomic number of the iron, the overall dose was lower than that estimated above because of the smaller number of β particles involved. A procedure similar to that used above estimated this dose to be less than 0.01 mrem.

The total dose of 0.85 mrem is 0.2% of the 500 mrem/yr allowed members of the public and 0.02% of the 5 rem/yr occupational radiation dose limit.

2.4.1.3 Inhalation Dose. The soil will be covered while being transported, so that a negligible amount of material would be available for wind transport and eventual inhalation by the driver. Doses resulting from this exposure mechanism would be correspondingly small.

While the driver was not in transit to the waste disposal site and back, he was assumed to be in Bayo Canyon with the cleanup crew. Of the estimated 480 h to remove the contaminated soil, the driver would spend 250 h going and coming from TA-54 and 230 h at Bayo Canyon. His dose while at the work site was calculated like that for other workers (Section 2.3) but with a 230-h exposure time.

2.4.2 Doses Resulting from an Accidental Spill of Contaminated Soil. To evaluate the radiological impact of an accidental spill, the assumption was made that an entire truckload of contaminated soil, some 5.4 m^3 (7 yd^3), was deposited in a populated area. The soil was removed 24 h later. Doses from longer or shorter exposure times can be approximated by scaling the 24-h value calculated here.

The principal exposure route is through inhalation of resuspended material. Inhalation doses were based on the maximum predicted air concentration of 4.29 mg/m^3. This air concentration was based on the following meteorological assumptions.

1. Eight hours each of D, E, and F atmospheric stability
2. A constant wind speed of 2 m/s
3. A constant wind direction toward the receptor location

A maximum upper limit on the source term was estimated by assuming that all particles less than 20 µm were resuspended by wind and mechanical forces. This was approximately 14% of the total mass.[7] The resulting average 24-h dust loading is an order of magnitude higher than those usually encountered. It is used here to estimate the maximum dust loading over a short 24-h period, which would be higher than the average for longer time periods. It also ignores dust control measures that would be taken to prevent the spread of spilled material, such as covering the soil to prevent wind erosion, or watering down the soil while it is being removed to reduce wind and mechanical resuspension.

The airborne dust concentration was multiplied by a breathing rate of 23 m^3/day and a soil concentration of 1100 pCi/g to obtain a ^{90}Sr intake of 107.8 pCi. Doses corresponding to this intake were calculated from the 50-yr dose commitment conversion factors given in Table B-III.

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APPENDIX C

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

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

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 priarie 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[a] 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[a] 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	

[a]This category only covers 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 flammeolus	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	Black-chinned	x	x					
alexandri	hummingbird	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					
Gymnorninus 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		
Pooecetes 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

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