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Ground-water supplies for Los Alamos, New Mexico

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By

Harold T. Stearns

Consulting Geologist

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Introduction

An investigation of the geology and ground-water resources of the Los Alamos area, Sandoval County, New Mexico, was made at the request of Black and Veatch, Consulting Engineers, for the United States Atomic Energy Commission. Field work, including the supervision of test borings, was done from May 29 thru. July 8, 1948. The field work was limited to the Jemez Mountains west of Los Alamos, including the upper parts of the Valle Grande and the San Antonio Valley, both of which drain westward. No investigation was requested regarding ground-water conditions in the Rio Grande Valley and adjacent tributaries east of Los Alamos as drilling was underway in that area when the writer arrived, and some wells had already been completed. The writer is indebted to Mr. Berkeley Johnson, District Engineer, U. S. Geological Survey, Santa Fe, New Mexico, for the surface water measurements.

Geologic mapping.

No geologic map accompanies this report as the topographic base map has not been finished and no other base map sufficiently accurate for recording the geology exists. The rock names used in the geologic history and elsewhere in the report are based on megascopic determinations as no equipment was available for making thin sections for petrographic classification by microscopy.

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Outline of Geologic History

Sometime during the Miocene (?) a volcano was born about 10 miles west and a little north of the present town of Los Alamos on a terrane of older folded and eroded rocks. It erupted sticky massive andesite and latite lavas for a period long enough to build up a volcano, herein called the Jemez Volcano, with the typical conical form of Popocatepetl in Mexico or Mt. Hood in Oregon. Explosions during and between lava eruptions laid down a few ash beds which are now found interbedded with the andesites. The volcano probably reached a height of about 14000 feet and had a diameter at the base of about 30 miles.

At the close of this eruptive period, the Rio Grande and its tributaries laid down the Santa Fe formation of gravel, sand, and clay. This formation was locally warped and folded in some places, but seems to have been disturbed very little near the Jemez Volcano. Late in this period streams cut deeply into the volcano and great canyons radiated from the summit-like spokes of a wheel. The detritus carried from these canyons formed extensive fans on the Santa Fe formation.

Next, there occurred widespread flows of basalt from small vents and fissures thruout the Rio Grande Valley. One such vent lies in Frijoles Canyon just below the headquarters building for Bandelier National Monument. Basalt entered a small shallow lake near the present mouth of Los Alamos Canyon and formed pillow lavas. A few thin beds of basaltic tuff were laid down. The basalts did

not come from the hearth of the Jemez Volcano, but from the basaltic substratum, and lie among the Jemez volcanics by coincidence only.

In the late Pliocene or early Pleistocene the summit of Jemez Volcano began to collapse and gradually a great caldera was formed about 16 miles across and many hundred of feet deep. The collapse beheaded the radial canyons leaving them short and wide with wind-gaps at their heads.

Concomitant with collapse, rhyolitic eruptions occurred on the floor and a few adjacent to the walls of the caldera on the outer slopes. They began with violent explosions of rhyolitic pumice and ash and culminated with stiff, pasty, thick lava flows and bulky fragmental cones. About 15 cones were formed during the Quaternary, some of which reached a height of 3000 feet above the caldera floor. Lava blocked drainage in places and gave rise to local lakes in Jemez and San Antonio Valleys. In these valleys lake-bed clays, probably bentonitic, accumulated to depths of as much as 300 feet, as well as thick deposits of alluvial pumice and sand.

Erosion proceeded between eruptions so that the older cones and flows were gullied and the caldera wall was cut back making the original fault scarp less steep. The ash ejected during the explosions fell far and wide, but chiefly to the leeward where it now forms the extensive Pajarito Plateau (pl.2).

Ash and pumice which accumulated thickly on the steep valley walls and sharp divides of the ancient andesitic volcanic mass, were washed into the canyons and there moved downstream as great mud flows.

Some of these mud flows appear to have been as much as 500 feet thick before they debouched upon the plain below and thinned out fanwise. Some ash fell hot and welded to a firm rock resembling lava, now used for building stone.

During the epoch of ash deposition a long curved fault (pl.1) extending from the east side of the San Miquel mountains northward past Los Alamos to Santa Clara Valley threwdown the entire Pajarito Plateau about 300 feet. The scarp forms a prominent feature of the landscape in the Los Alamos area and constitutes the western boundary of the Pajarito Plateau and the eastern edge of the Jemez Mountains. In places along this scarp, the dip of the tuff beds has been increased from 5-10 degrees to 25-55 degrees, due to drag at the time of faulting. A secondary fault trace is exposed at the top of the abrupt grade on New Mexico Highway #4, just west of the south gate of Los Alamos reservation.

Tuffaceous mudflows and erosion followed the epoch of faulting as the fault does not break the thick tuff deposit forming the north side of Los Alamos Canyon. Instead the mudflow shows a monoclinal structure resulting from the deposit mantling the pre-existing steep scarp. Likewise, the tuffs north of Los Alamos Canyon are not disturbed by the fault and are therefore chiefly later.

Concurrent with and following the deposition of the tuffs and associated mud-flows, erosion removed large quantities of these deposits from the ancient canyons and ridges of the Jamez Mountains and cut narrow gorges in the Pajarito Plateau. Remnants of the mud-flow and tuff deposits form high-level terraces in Los Alamos,

Frijoles and other canyons in the area. The divide between the north fork of Los Alamos Canyon and the caldera is formed of bedded tuff in which box-headed canyons have been cut from both the east and west sides. The ancient andesite-latite group of lava flows has been re-exposed in the major canyon floors and over a large area northwest of Los Alamos residential section. At Guaje Canyon they form the abutments of the dam. The lakes in the caldera were drained during this erosional period.

The erosion period was interrupted either by uplift or by a change in climate and alluvium accumulated in the canyon floors all the way to the Rio Grande. Subsequently streams cut into the alluvium leaving terraces 10 to 50 feet above the present channels. In some canyons an interruption in the down-cutting is indicated by two terraces at different levels, one above the other. The main valleys are floored with recent alluvium, which is probably largely older alluvium reworked. Extensive talus fans mantle the caldera wall and the bases of the canyon cliffs. Since the beheading of the canyons by the collapse of the summit to form the great caldera, the drainage has been so reduced that streams are not able to keep their walls free of talus and boulder-talus trains clog the heads of the canyons.

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Recent	Talus	5 to 50	Forms aprons at the foot of cliffs. Consists largely of jumbled blocks of rocks and some are bare of vegetation on the cliffs bordering San Antonio and Jemez Valleys.	Very permeable, but chiefly valuable as an intake formation.
	Younger alluvium	5 - 1004	Sand, gravel, and bouldery deposits derived from the erosion of pre-existing rocks, confined to valley floors. That in Jemez and San Antonio Valleys is largely pumiceous.	Very permeable and usually contains considerable water in the upper stretches of the main valleys.
Local erosional unconformity				
	Lake beds	5 - 300	Dark adobe clays deposit behind lava dams in San Antonio Valley and Valle Grande.	Impermeable and forming the caprock of artesian structures.
Recent and latest Pleistocene	Older alluvium	504	Forms terraces 10 to 100 feet above the major streams. Sand, gravel and bouldery deposits. Contains much pumice in places, especially along Jemez and San Antonio Creeks.	Highly permeable, but generally lies above the water table in the major valleys.
Great erosional unconformity				
Pleistocene	Rhyolite flows, pumice cones, pumiceous mud flows, and pumice and ash deposits.	Flows 50 to 500	Massive short flows of rhyolite in places pumiceous and glassy (obsidian) confined chiefly to the caldera floor.	The brecciated tops of the flows are very permeable and form important recharge areas in the caldera. The largest springs in the area issue from them. The lower parts are dense, but fractured.
		Cones 1000 to 3000	Bulky cones of rhyolitic pumice and loose blocks of rock, chiefly pumiceous and glassy rhyolite. Confined chiefly to the caldera floor and north wall.	Highly permeable and important recharge areas. Practically no run-off from them.
		Mud-Flows 50-500	Consolidated and partly consolidated tan-colored mud-flows consisting of quartz grains, rhyolitic pumice sand, lump pumice and scarce fragments of lava rock.	The consolidated type has relatively low permeability, but the unconsolidated type is very permeable.
		Pumice, Ash and Tuff 20 - 500	Widespread subaerial, white to tan deposits of rhyolitic ash, pumice, and tuff lying in thin and thick beds. Welded tuffs are present in places.	The tuffs have relatively low permeability, but the ash and pumice is very permeable. The fractured welded tuff gives rise to important springs.
Erosional Unconformity				
Pleistocene	Basalt flows	20 - 200	Columnar-jointed basalt flows adjacent to the Rio Grande Valley. Pillow lava and a thin layer of basaltic tuff in the lower part of Los Alamos Canyon, and basaltic cinders and tuff in Frijoles Canyon and in adjacent arroyos.	Permeable, but above the zone of saturation; hence do not carry water.
Pleistocene and Pliocene (?)	Fanglomerates	50 - 300	Partly consolidated bedded angular subangular, and rounded volcanic boulders, gravel, and sand, chiefly andesitic, laid down as fans at mouths of canyons on the Jemez Mountains.	Fairly permeable, but mostly above the zone of saturation; hence do not generally carry water.
Local unconformity and deformation				
Pliocene (?)	Santa Fe formation	300 +	Weakly consolidated tan-colored sand, gravel and locally clays, containing rocks derived from ancient sedimentary and igneous rocks.	Permeable, but carry water only below the zone of saturation of the Rio Grande Valley.
Profound erosional unconformity				
Miocene (?)	Andesite-latite flows and associated tuffs.	5000 ±	Grayish and reddish massive lava flows usually brecciated at top and bottom and commonly porphyritic, due to the presence of feldspar phenocrysts ¼ to ½ inch across. The associated tuff beds are usually indurated.	Carry water in the fractures and brecciated parts and give rise to important high-level springs where they have baked underlying tuff beds. The tuff beds are rarely permeable.
Profound erosional and deformational unconformity				

Present sources of gravity water

The gravity water supplying Los Alamos is derived from the five canyons lying in the western part of the reservation. From north to south they are Guaje, Los Alamos, Pajarito, Valle, and Water Canyons. The surplus water from Pajarito, Valle, and Water Canyons is piped to Los Alamos Canyon where the main distributing reservoir lies.

The springs in the canyons mostly can be classed as perched springs; that is springs which issue from a permeable bed overlying an impermeable stratum. The chief aquifers are fractured andesite and welded tuff overlying baked tuff beds which serve as the perching members. Some springs issue from friable pumice beds resting on compact and nearly impermeable tuffs. Other springs issue from bouldery alluvium on valley floors, but these also appear to be supplied by similar structures. The older tuffs, interbedded with the andesites, form the important perching structures. The area is so dissected by erosion that tunnelling along these structures for additional water does not seem justified.

Guaje Canyon. - The flow of Guaje Stream is impounded by a concrete dam about 15 feet high at an altitude of 8018 feet, in a narrow gorge cut into porphyritic andesite. The andesite is considerably fractured and there is probably some seepage thru the abutments, but it is the best intake on any of the streams. The drainage area is approximately 5.6 square miles and the quantity of water from this source is greater

than in any of the other canyons altho the drainage area of the Los Alamos Canyon is larger. During the drought year of 1947, Guaje Stream averaged 167 gallons per minute and reached a low flow of 5,416,400 gallons during the month of June. A traverse was made of this canyon on June 3, 1948. The flow of the main stream is derived from three main sources in addition to accretions in the channel proper. On this date, the largest spring was flowing about 100 gallons per minute from two vents in andesite talus at an altitude of 8580 feet (determined by barometer). The spring heads a short tributary to the main stream. The source of the water is believed to be from porphyritic andesite overlying baked tuff as andesite crops out a short distance upstream. At an altitude of 8700 feet (bar.) the canyon forks and about one third of the flow comes from a large canyon running northwest. The main stream heads in a group of small springs issuing from an outcrop of fine-grained white pumice, at an altitude of 8855 feet (bar.). The northwest branch rises in a swampy flat at an altitude of 8820 feet (bar.) with no rocks exposed. Probably the swamp is supplied with water by the same pumice bed as in the main fork because the altitude of the swamp is nearly the same as that of the springs in the main canyon. Both canyons head in a massive vitric-crystal tuff above the springs.

The stratigraphy 1.3 miles below the dam is well exposed and there 50 feet of tan tuff overlies 100 feet of bouldery fanglomerate which is separated by a profound erosional unconformity from the underlying porphyritic andesite. This tuff obviously is much later than

the andesite and the fanglomerate.

Los Alamos Canyon. - The flow of Los Alamos Stream is impounded by a rock-fill dam about 25 feet high with a capacity of 13,000,000 gallons at an altitude of 7659 feet. The south abutment is highly fractured andesite with dirt in the seams. The north abutment is blocky talus and talus forms the flow line. Considerable seepage must take place thru this loose material. About 100 feet downstream from the north abutment is an outcrop about 100 feet high of much disturbed tuff. It is possible that this tuff fills an ancient canyon north of the present one.

The drainage area of Los Alamos Canyon is 6.3 miles, being the largest of any in the reservation. The yield of the Los Alamos Stream, where metered, was computed to be 3,492,500 gallons in 1947, or only 6.6 gallons per minute. This amount does not give a true picture of the situation as it was calculated from the difference between the water piped into the reservoir from other sources and the discharge thru the meter on the outflow pipe. No record has been made of wastage over the dam during periods when snow is melting or during flash run-off. Also all seepage from the reservoir is charged against this stream. A gage installed on Los Alamos stream above the reservoir would give the flow of the stream and show the seepage loss from the reservoir.

A traverse was made of the main Los Alamos Canyon on June 4, 1948. At an altitude of 9125 feet (bar.) a spring, yielding 2 gallons per minute, is piped to a stock watering trough. No rocks are exposed

nearby. About 500 feet downstream, at an altitude 9065 feet (bar.) is a spring yielding about 25 gallons per minute, but it soon sinks. The permanent head of the creek is at an altitude of 8850 feet (bar.) in a box-headed canyon. About 100 gallons per minute was issuing from very fractured andesite resting on baked tuff, chiefly along the contact in the south bank. At 8680 feet (bar.) the canyon is in blocky tuff, consisting of two distinct beds. At 8520 feet (bar.) a heavy andesitic lava crops out. At 8202 feet (U.S.G.S.profile) the Camp May fork enters. On June 4, the flow of that fork was about 100 gallons per minute and the main stream was about 150 gallons per minute. Andesite flow breccia crops out at this place. At 8025 feet (bar.) about 30 gallons per minute was entering from the tributary known as Quemazon Canyon. At 7970 feet (bar.) the andesite walls narrow and about 10 gallons per minute was rising from the alluvium in the floor of the canyon. At 7840 feet (bar.) the steep-walled canyon ends and the floor is covered with bouldery alluvium downstream. The stream gains and loses as it flows along this alluvium to the reservoir at altitude 7659 feet. Below the dam there are high walls of tuff. The tuff seems to have been emplaced as a pumiceous mud flow and to have filled an ancient canyon of Los Alamos a little north of the present one. The stream cut the present canyon at the south contact of the mud-flow with the older tuffs.

It is recommended that wier measurements be made to determine whether Los Alamos Stream loses appreciably in the $\frac{1}{4}$ mile upstream from the reservoir.

Pajarito Canyon. - The flow of Pajarito Stream is diverted at a low sand-bag dam at an altitude of 7850 feet (bar.) with huge boulders of andesite as abutments. The visable seepage past the intake was 10 gallons per minute on June 8, and 2 gallons per minute on July 8, 1948. Just upstream from the diversion dam is an overhanging cliff of porphyritic andesite. Tuff overlies the andesite in the north wall. A traverse of this canyon, made on June 8, 1948, showed that the stream rises in two springs issuing from bouldery alluvium on the valley floor at an altitude of 8680 feet (bar.). On that day there appeared to be a loss in the stream, not far above the intake. Heavy andesite crops out along most of the canyon walls with tuff above it. The drainage area of the stream is approximately 2 square miles and the diversions, in 1947, were 11,500,000 gallons. However, for three months in the winter the water was not diverted because the pipe line freezes. The yield for the 240 days in use was 33.2 gallons per minute. The flow in September, 1947, was only 142,000 gallons. Pajarito Spring issues from loose gravel and sand half a mile upstream from New Mexico Highway 4. On July 9, 1948, it was flowing about 25 gallons per minute. This spring is probably supplied by seepage thru the alluvium from the upper canyon.

Valle Canyon. - The flow of Valle Stream is diverted at a low dam of sand-bags and concrete built on loose andesite blocks (talus) at an altitude of 8390 feet (bar.). About 100 yards downstream at the same altitude is a spring box on the north wall from which a 2-inch pipe

line diverts water. On July 8, 1948, the flow of the stream at the intake was estimated to be 10 gallons per minute and 100 yards upstream to be 15 gallons per minute. It goes dry farther upstream, and reappears again still farther up.

Valle Stream drains 1.5 square miles and in 1947, was diverted during 184 days and yielded 2,387,800 gallons during that time, or an average of 9 gallons per minute. It was not diverted for a period of five months because the pipe line is not protected against freezing.

A traverse was made of the canyon on June 7, 1948. The divide between it and the Valle Grande is 9525 feet (U.S.B.M.). Springs were noted at 9400 feet, 9330 feet, and 9235 feet (bar.), but it is reported that these springs dry up later in the summer. The real head is at 8955 feet (bar.) where a spring flowing 15 gallons per minute was issuing 50 feet above the north bank from the contact of fractured andesite and tuff. At 8800 feet (bar.) two springs issue from tuff in the south bank. At 8550 feet (bar.) considerable water was rising from among boulders on the north side of the stream. The entire flow was disappearing in alluvium at 8440 feet (bar.).

Water Canyon. - Water Canyon has two forks. The northern one is a spring cove less than one quarter of a mile long shown as Big Spring on Plate 1. It heads in a cliff in which 50 feet of rock, believed to be welded tuff, overlies a friable pumice deposit. The pumice deposit was baked to a depth of about 10 feet by the hot tuff, thereby forming an impermeable sheet of rock at the base of the tuff. A recently excavated tunnel about 25 feet long tapped a spring at the

base of the welded tuff. The welded tuff is fractured and jointed and closely resembles a lava flow in permeability. The spring formerly discharged from the talus apron at the foot of the cliff. The tunnel had been walled up with brick on July 8, 1948, and the water, after passing over a weir was flumed to the former intake, a small diversion dam at the mouth of the canyon. The intake has an altitude of about 7740 feet and on the north bank near the dam is an outcrop of porphyritic andesite. The spring is about 150 feet higher than the intake. It yielded 58,840,300 gallons in 1947 or an average of 112 gallons per minute. This flow includes a few gallons per minute from American Spring. The flow ranged from a low of 2,940,100 gallons in January to a high of 6,144,000 gallons in December, 1947. This record includes surface run-off in addition to the spring flow, but the spring averaged about 5,000,000 gallons per month during the summer when there was no run-off. It is the best spring in the reservation. The welded tuff dips slightly north near the spring and it is probable that the tuff filled a former shallow valley or swale in the underlying pumice. It is improbable that additional water can be developed here as all the water in the tuff seems to discharge from the tunnel. The short box-headed canyon is the typical erosional work of such a spring and indicates its long existence at this place. During the early part of July a pipe line was laid up the shallow south fork for two miles to a spring reported to be yielding 40 gallons per minute. The intake is in a box-shaped excavation in the south bank. Reddish clayey material containing small pebbles was excavated. Not far downstream, on the north bank is an exposure of alluvial pumice.

Only alluvium is exposed in this fork of Water Canyon.

American Spring is a small spring reported to yield a few gallons per minute in dry weather. It is on the high slope south of Water Canyon. The spring was excavated by the CCC and so thoroughly sealed that no rock exposures can be seen. Bedded tuffs form the slope, however, and it is probable that the water issues from a permeable bed in the tuff series.

Apache Spring, not far south and at about the same horizon in one of the tributaries of Frijoles Canyon yields 2 gallons per minute (July 5, 1948) from a fractured welded tuff. American Spring may issue from the same tuff bed.

Conclusion regarding the five canyons. - The five canyons listed above all contain perched springs which, before diversion, flowed down to the Pajarito Plateau where they sank in the valley fills of coarse debris. The water-bearing structures are different in each canyon due to the nature of volcanics, most of which extend down the mountain in fan-shaped bodies, hence do not have great lateral extent. In addition the canyons have been cut by the five spring-fed streams and dissection is so prevalent that most perched ground water in the upper area now finds a visible outlet in the canyons.

The Los Alamos Fault (pl.1) threw down the andesite beds about 300 feet on the east side and brought permeable pumice and tuff beds into contact with their truncated ends. No springs are known along this fault; hence any water moving eastward below the floors of the canyons probably sinks into the tuffs at the fault. Thus no ground-water dam has been created by the faulting. The andesites, altho

supplying small quantities of water from their fractures, have low permeability as a mass. Furthermore, over large areas in the Jemez Mountains they are roofed by perching sheets of baked tuff which prevent recharge. It is therefore concluded that development of water from wells drilled into these rocks does not seem promising, but a test hole in Los Alamos or Valle Canyon 500 to 1000 feet deep, west of the fault and in the andesite, might be drilled to determine whether water exists in quantities sufficient to justify development.

Upper San Antonio and Jemez Valleys.

This report deals only with that part of the San Antonio Valley above an altitude of 8500 feet (Pl.3) and the East Fork of Jemez Valley (Valle Grande) above 8400 feet (Pl.4). These valleys lie in a unit of private land known as Baca Location No. 1.

The Rocks and their water-bearing properties. - San Antonio and Jemez Streams drain the moat-shaped depression between the caldera wall and the later rhyolites on the caldera floor. The geology is shown on Plate 1. The talus on the caldera wall mantles the ancient andesite-latite lava flows and their associated tuffs, which dip away from the rim. A few outcrops of these lavas exist which are too small to show on this map. Much of the talus is highly permeable and forms a large recharge area.

The area labelled tuff, forming the head of the north fork of Los Alamos Stream is later than the andesite-latite lava flows and fills a former valley. It has low permeability.

Six bulky pumice cones strewn with rhyolite blocks lie on the north side of San Antonio Valley (Pls.1 and 2). They reach heights of 9500 to 10500 feet or more; hence receive heavy precipitation. The five cones at the head of the valley bury the caldera rim and two are eroded. The others, including the one downstream, have virtually no gullies on them, indicating high permeability and important areas of recharge.

The rhyolite flows on the caldera floor issued from several vents, two of which are within the area mapped. (Pl. 1). These rhyolites were erupted chiefly from bulbous domes. The bottom of the rhyolite is not exposed, but it is probably 200 to 500 feet thick over much of the area. It was erupted as stiff pasty lava with an obsidian and pumiceous crust. Most of the crust was smashed into blocks when cooled, by the movement of the still pasty lava below. When the eruptions ceased these rhyolitic flows were left with indescribably rough brecciated tops. Weathering has reduced the roughness of the lavas, but their fissured tops still have little run-off because of their high permeability. All large springs in the area issue from fissured rhyolite (Pls. 1 and 5).

Two lakes existed in the area shown on Plate 1. San Antonio Stream was dammed by the tongue of rhyolite shown on Plate 1 at Spring 1. The lake was about two miles long and a mile wide. The lake was finally drained by the overflow cutting a gorge thru the rhyolite dam. The drainage from the adjacent slopes laid down extensive fans of gravel and pumice sand in the basin. These deposits now form terraces along the former lake shore. Test hole 1 encountered sticky

lake-bed clays between 31 and 81 feet and Test hole 2, near the center of the lake bed, encountered about 30 feet of sticky lake-bed clay below 41 feet of alluvium. These clay beds confine water in the underlying pumiceous sands and gravels thereby forming an artesian basin (Pl. 6).

San Antonio Valley, just west of the area mapped, has been occupied by another lake. Its basin has a similar geologic structure, but is more extensive than the one described above.

The East Fork of Jemez Stream was dammed by a rhyolite flow just west of the edge of the map (Pl. 1) and a lake about 6 miles long, about 2½ miles wide and about 350 feet deep was formed. The dam was finally cut in two and the lake drained leaving the smooth valley called Valle Grande (Pl. 4). During the existence of the lake great quantities of pumice and detritus were washed into it. Sticky clay accumulated in the bottom to a depth of at least 288 feet, as shown by Test hole 8, before the lake was drained.

The heads of the Valle Grande and San Antonio Valley consist of coalescing fans of alluvium. Test hole 5 in San Antonio Valley indicates that the alluvium is not deep there, but is underlain at a depth of 26 feet by at least 335 feet of lapilli tuff with relatively low permeability. Whether this tuff extends into the head of the Valle Grande is unknown.

The lake-bed clays have no permeability, but are valuable as they confine water under artesian pressure. The pumiceous sandy and gravelly alluvium, talus, and rhyolite are highly permeable and form valuable recharge areas.

Surface water. - San Antonio Stream drains the northern part of the caldera. In dry weather it heads in Spring 2 (Pl. 1). During the latter part of June, 1948, water was standing in pools supplied by small seeps in the upper stretches and about a quarter of a mile east of Test hole 5 there is a stock-watering hole that has long been in use and probably carries water most of the year. Spring 3 issues from the foot of a rhyolite point and during the latter part of June sank about 100 yards downstream. The main flow of the stream comes from Spring 1 in the north bank of a small gorge cut in rhyolite where 1,257,120 gallons per day (June 28, 1948) issue from fissures in the rock.

The stream crosses an extensive lake bed west of this place and finally enters a rocky gorge where a warm spring flowing about 200 gallons per minute issues from the east side of the canyon wall from a late lava flow. At the bridge on highway 126, not far below where San Antonio Stream leaves the canyon, the flow on June 29, 1948, was at the rate of 3,771,300 gallons per day. Below this point it picks up the flow of Redondo Creek (see table) and enters a deep gorge where it leaves the caldera. The flow at the mouth was at the rate of 4,192,560 gallons per day on June 29, 1948, which is exactly the sum of the flow of Redondo Creek plus the flow at the highway bridge. This means that there are no springs entering the stream from the terminal margins of the lava flows in the caldera truncated by this gorge.

The East Fork of Jemez Stream drains the southern part of

the caldera. In dry weather it heads in Spring 5, the largest spring in the caldera. Its flow, on June 28, was at the rate of 1,445,140 gallons per day. Spring 4, about 1½ miles upstream yields only about 25 gallons per minute and sinks a short distance downstream. Jemez Stream picks up the flow of Jaramillo Creek in the ancient lake-bed flat. This creek heads in Springs 6,7 and another west of the map (Pl.1). This creek is reported by Mr. Davenport, manager of the Baca Ranch, to have gone dry during the drought in 1947. Jemez Stream gains water from numerous small springs on its way thru the caldera. At its mouth, the flow on June 29, 1948, was at the rate of 4,199,040 gallons per day or the same as San Antonio Stream altho the latter has a larger surface drainage basin.

The following table summarizes the available data regarding surface water:

Measurements of San Antonio and Jemez Streams
(See Plate 1 for location of measuring points & springs.)

	Drainage basin	Altitude (feet)	Discharge (sec-ft.) c/	Discharge (gals pr.day	Date (1948)	Remarks
Rito de los Indios	San Antonio	b/8560	- -	b/200,000	June 14	(All melt water had drained
Meas. pt. A	Do	Do	2.80	1,445,140	June 28	away so that all measure-
B	Do	8585	0.86	557,280	Do	ments indicate gain from
C	Jemez	8520	2.23	1,445,040	Do	springs.)
D	Do	b/8470	1.37	887,760	Do	
E	Do	b/8460	3.21	2,080,080	Do	
d/E.F.Jemez Stream at mouth	Do	6755	6.48	4,199,040	June 29	Indicates total drainage from Jemez Caldera when added to flow of San Antonio Stream at mouth.
d/Redondo Creek below Sulphur Springs Creek	San Antonio	7730	0.64	414,720	Do	
d/San Antonio Stream at crossing Highway 126	Do	7687	5.82	3,771,360	Do	
d/San Antonio Stream at mouth	Do	6755	6.47	4,192,560	Do	
Spring 1	Do	b/ 8570	1.94	1,257,120	June 28	Difference between measurements at A & B. Issues from rhyolite
2	Do	8732	-	b/500,000	June 28	Issues at foot of rhyolite point
3	Do	8768	-	b/ 21,600	June 10	Do
4	Jemez	8600	-	b/ 21,600	Do	Issues from alluvium near rhyolite point
5	Do	8524	2.23	1,445,140	June 28	Issues from fissured rhyolite
6	Do	a/ 8640	-	b/ 21,600	June 10	Issues from rhyolite 30 feet above Jaramillo Creek
7	Do	a/ 8700	-	b/ 40,000	Do	Issues from alluvium next to rhyolite.

a/ Determined with an aneroid barometer. b/ Estimated. c/ Measured by U.S.G.S.
d/ Not shown on Plate 1. See U.S.G.S. Jemez Springs topographic sheet for location.

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Results of test borings. - A contract was made with Livingston and Wilson for 1000 feet of core borings in the Jemez and San Antonio Valleys in Baca Location No. 1, (private property.). A Failing rotary rig was used, but only a few feet of core were recovered due to the unconsolidated character of much of the material encountered and the type of equipment used. Eight sites were selected, but only seven of the sites were drilled and holes at two of these sites were abandoned by the driller before completion. The drilling was started on June 18, and was completed on June 30. Samples are stored at the office of Black and Veatch, Los Alamos.

The drilling proved the existence of artesian basins in San Antonio and Jemez Valleys consisting of a caprock of sticky clay 10 to 288 feet thick, underlain with unconsolidated coarse pumiceous sands and gravel saturated with water. Test hole 5 encountered lapilli tuff fairly well consolidated to a depth of 361 feet and altho saturated in its lower part, it has a low yield. It is possible that a permeable rock exists at a greater depth.

A sample of water from Test hole 2 was analyzed by the Los Alamos hospital laboratory with the following result:

	p.p.m.
Hardness - - - - - -	30
Ph - - - - - - - - -	7.2
Total alkalinity - -	42.0

Samples have been collected for complete chemical analyses.

Data for the 7 holes are summarized in the following table and are given in detail in the subsequent pages.

Summary of test hole data (Locations shown on Plate 1)
All levels run by Black & Veatch, surveyors from U.S.C.& G. bench marks.

Test hole (No.)	Altitude top of casing (feet)	Depth (feet)	Depth to water (feet)	Altitude of water table (feet)	Altitude of stream nearby (feet)	Simplified log
1	8598.8	100	10	8588.8	8583.9	Hillwash 0-11; sticky clay 11-81; sand & gravel 81-98; rock 98-100.
2	8649.9	100	+ 2	8652	8635.3	Sand & gravel 0-41; sand & clay 41-91; gravel & sand 91-100
3	8741.3	31	4.5	8736.8	8732.0	Rocks & soil 0-16; sand & gravel 16-31
4	8874.8	--	--	--	8768.1	Not drilled
5	8929.7	361	128.8	8800.9	--	Gravel 0-26; lapilli tuff 26-361.
6	8589.8	140	7.7	8582.1	8603.0	Gravel 0-10; clay 10-18; gravel and sand 18-91; clay and gravel 91-124; sand and gravel 124-140
7	8532.3	40	6.0	8526.3	8523.9	Fissured rhyolite 0-40.
8	8506.6	299	2.6	8504.0	--	Sticky clay 0-288; pumice sand 288-299

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Test hole #1.

Location - San Antonio Valley, N. M.
Drilled - June 19, 1948
Altitude - 8598.8 feet (top of tile)
Depth - 100 feet
Depth to water - 10 feet, after 15 minutes bailing and 10 minute rest. Hole filled up to 73 feet with sand while bailing. Abundant water.

Log

	Feet
Hillwash containing loose rhyolitic rocks	0- 11
Hillwash and sticky clay	11- 21
Clay containing quartz and feldspar grains	21- 31
Sticky brown clay	31- 81
Sand containing much quartz, some rhyolitic grains and a few obsidian grains	81- 91
Pea- to nut-sized rhyolitic gravel, mostly angular and subangular	91- 98
Rhyolite (core obtained)	98-100

Test hole #2.

Location - San Antonio Valley, N. M.
Drilled - June 21, 1948
Altitude - 8750 feet (top of tile 6" above ground)
Depth - 100 feet
Depth to water - Hole flows at rate of 37½ gallons per minute.

Log

	Feet
Sand and rhyolitic gravel up to 3 inches, some well water-worn	0- 11
Pumiceous gravel and sand (white) containing many quartz grains	11- 21
Yellowish pumice, sand and a few obsidian grains, some pea- to nut-sized gravel	21- 41
Sand similar to that above, but with streaks of silt and a little clay	41- 61
Brown clay with a little sand	61- 66
Brown clay with a little pumice	66- 81
Brown clay and sand	81- 91
Fine gravel and sand (no sample)	91-100

Test hole #3.

Location - San Antonio Valley, N. M.
Drilled - June 23, 1948
Altitude - 8741.3'(top of tile)
Depth - 31 feet (abandoned by driller)
Depth to water - 54 inches. This hole was planned for 100 feet, but driller failed due to running sand.

Log

	Feet
Loose rocks (rhyolite) and soil	0- 16
Sand, predominantly quartz, fragments of rhyolite, pumice and obsidian, some of gravel size.	16- 21
Gravel, like above, with a little sand.	21- 31

No test hole was drilled at site #4.

Test hole #5.

Location - Upper end of San Antonio Valley, N. M.
Drilled - June 25, 1948
Altitude - 8929.7' (Top of tile)
Depth - 361 feet
Depth to water - 128 feet, 10 inches
Note - Some water entered hole at depth of 15 feet.

Log

	Feet
Sand and gravel, up to ½ inch across, of angular and sub-angular rhyolite (white), and pumice and darker volcanic rocks including obsidian.	0- 11
Some cuttings like above, but with much more pumice and a brown soil containing partly decomposed pumice	11- 16
Lump pumice with a few fragments of lava ½ to 1 inch. . . .	16- 21
Rhyolite and obsidian fragments with much less pumice and many quartz grains.	21- 31
(Note. No waterworn fragments noted below 26 feet, the bottom of water-laid sediments.)	
Dirty cuttings similar to above, possibly indicating a decomposition zone.	31- 36
White rhyolite, mainly pumiceous, some obsidian, some pumice, mixed with dark lava fragments and sand	36- 51
The same, but with more pumice fragments	51- 61
The same with more dark fragments, apparently rhyolite . . .	61-361

The whole deposit at this place was sufficiently compacted to stand up without casing, but was not firm enough to core. From 26 to 361 feet is apparently a lapilli rhyolitic tuff, weakly consolidated.

An andesite fragment was recovered at 91-101 feet. The only core fragment recovered was a piece of rhyolitic pumice, 2 inches across, from 181-191 feet. The white fragments in the cuttings are from this material. Increase in pumice noted from 241-251 feet. Dark fragments, apparently finely banded semi-glassy rhyolite noted from 281-361, and a marked decrease in pumice.

Test hole #6.

Location - Valle Grande, Sandoval Co., N. M.
Drilled - June 28, 1948
Altitude - 8589.8'(top of tile)
Depth - 140 feet. Hole filled up to 70 feet after bailing.
Depth to water - 10 feet. Bailed at rate of 30 gallons per minute without lowering water level. July 1, 1948 = 7.7 ft.

Log

	Feet
Rhyolitic gravel and some clay.	0- 10
Sticky brown clay.	10- 18
Rhyolitic gravel and sand with pumice thruout, much obsidian in places and nut-sized fragments of rock common.	18- 91
Sticky brown clay with some gravel.	91-124
Sand and rhyolitic gravel up to 6 inches across	124-140

Test hole #7.

Location - Valle Grande, N. M.
Drilled - June 28-29, 1948
Altitude - 8532.3 ft. (top of tile)
Depth - 40 feet. Hole abandoned by driller because his core barrel bearing broke.
Depth of water - 6 feet, 10 inches from top of tile casing. July 1 = 6 ft.
Tile casing set 1 foot, 4 inches above ground.
Spherulitic rhyolite containing pellets of obsidian. 0 - 40 ft.

Test hole #8.

Location - Valle Grande, N. M.
Drilled - June 30, 1948
Altitude - 8506.6 ft. (top of tile)
Depth - 299 feet
Depth to water - 3 feet, 6 inches (below top of tile at ground)
Bailing lowered water. D. to W. July 1, 1948 - 2.6 ft.
Drilling rate - 100 feet per hour.

Log

	Feet
Sticky brown lake-bed clay.	0-288
White pumice sand with many quartz grains	288-299

Ground-water conditions. - The water table in San Antonio Valley has a gradient of 66 feet per mile in the $2\frac{1}{4}$ mile stretch between Test holes 1 and 3. This compares with a gradient of 39 feet per mile for the 2-mile stretch between holes 6 and 8 in Jemez Valley. This points to a higher permeability for the aquifers in Jemez Valley. The lapilli tuff encountered in Hole 5 has low permeability. No pumping test was possible at the time of drilling. A test was made by pouring water down the hole. The depth to water before the test was 128.8 feet. The 4-inch hole took water at the rate of 21 gallons per minute. However, with no casing and fairly permeable gravel in the upper 26 feet; it is believed that most of the water was absorbed by the upper gravel. The depth to water a day later was 101 feet, indicating that drainage thru the tuff is very slow.

The sand and gravel encountered in holes 1, 2, 3, 6, and 8 yielded water freely as far as could be determined by bailing. Hole 8 contained water under 285 feet of pressure and, had not the drilling contract terminated at 299 feet, it is probable that an additional 50 feet of drilling would have brought in a flowing well. At no time did a test hole penetrate the water-bearing sands and gravels except in Hole 1, where it entered rhyolite which is known to be highly permeable, as shown by the discharge of Spring 1, nearby.

Insufficient data are available to draw a water-table map of the area, but it is believed that a zone of saturation extends under the whole caldera floor, but with dense masses of rhyolites near the vents

and with local bodies of tuff standing as nearly impermeable islands in this zone. The San Antonio and Jemez (Valle Grande) artesian basins are recharged thru detritus fans and the lavas which pass under the lake bed clays.

Quantity of ground-water. - The quantity of ground-water available can be estimated only from the flow of springs and from precipation on the basin because no wells exist in the area. Gaging stations should be established at the narrows on San Antonio and Jemez Streams below the basins to determine the run-off. At least one precipitation station should be established in the area. The total ground-water inflow to San Antonio Stream on June 28, 1948, was at the rate of 1,445,140 gallons per day. The flow of the Rito de los Indios just downstream from measuring point A (pl. 1) could bring the total discharge to about 1,650,000 gallons per day. The total flow of Jemez Creek, at measuring point E (pl. 1) was at the rate of 2,080,080 gallons per day on June 28, 1948. It is reported that the flow of these streams was appreciably less during the drought of 1947.

The drainage basins of the two streams above the measuring points is about 65 square miles. The average precipitation, much of which falls as snow, is estimated to be from 24 to 30 inches per year over this area, due to its high altitude. From the time the snow starts melting until about the end of June the valleys are very swampy, indicating that all aquifers are fully recharged. The surplus is discharged as run-off. The swamps slowly dry up by

evaporation, transpiration, and drainage. The loss by evaporation and transpiration is considerable during the summer.

Assuming that 10 percent of the precipitation could be recovered by wells, the supply would range from about 7 to 10 million gallons per day, depending upon whether the precipitation was 24 or 30 inches per annum. It is believed that properly spaced wells which would lower the water table each fall, to allow ample room for recharge when the snow melts, would have a safe yield of 3 to 6 million gallons per day in the Valle Grande and 2 to 4 million gallons per day in San Antonio Valley in the area shown on Plate 1. Considerable additional water, perhaps up to 4 million gallons per day, could be obtained by additional wells west of the area mapped in San Antonio Valley.

Methods for developing water. - The water in San Antonio and Jemez Valleys can be developed by drilled wells 100 to 500 feet deep with screens or perforated casing set in the water-bearing sands and gravels. Test hole 8 demonstrated that the wells should be placed on the margin of the Jemez Valley floor rather than in the center to avoid deep deposits of non water-bearing clay. The two artesian basins should be operated somewhat like surface reservoirs. The water-table can be safely lowered about 50 feet or more during the fall season, in order to leave space for recharge when the snow melts in the spring. Considerable water, now lost to the atmosphere by evaporation and transpiration can be conserved by drying up the swampy tracts.

The water table is the adjacent rhyolite will probably decline with pumping from wells on the valley floor, but, if the springs did not dry up soon, it would be advisable to drill 50-foot wells adjacent to the springs in the rock and utilize this supply. The drilling mud used in Test hole 7 soon discolored the nearest spring showing that the water is moving thru fissures in the rock.

The altitude of the water table in San Antonio Valley ranges from 8570 to 8768 feet and in the Valle Grande from 8500 to 8582 feet. The altitude of Los Alamos is 7300 feet, thus the water is 1200 feet or more higher. However, the Jemez Mountains separate the two areas. The lowest pass near the Valle Grande is at the head of the Valle Canyon where the altitude is 9525 feet (USGS plane-table elevation). The pass at the head of Los Alamos Canyon is about 9515 feet (bar.), the nearest point to San Antonio Valley. The lift would be of the order of 1000 feet to pump water over these passes, but about 2000 feet of head would be gained in dropping the water to the Los Alamos reservoir at an altitude of 7657 feet. This head might be used to generate electric power to run the pumps on the other side of the divide.

If the water in the Valle Grande or in San Antonio Valley is to be developed for use at Los Alamos, alternate consideration should be given to a tunnel thru the head of either Los Alamos Canyon or Valle Canyon to carry the water to Los Alamos by gravity and to do away with wells, pumping and power lines. In other areas, where

tunnelling is cheaper, long tunnels of this sort have proven practicable to save maintenance on pipelines over rugged terranes, pumping costs, freezing hazards during winter months, and other factors. It is beyond the scope of this report to discuss the economics of the various methods of transporting the water, but it is fitting here to point out some of the geologic and hydrologic problems that a tunnel to tap the underground waters of the San Antonio or Valle Grande would encounter.

Tunnelling on tuff beds is much easier than in andesite and long stretches of a tunnel in tuff will not need to be lined for either support or leakage. It is believed that layers of tuff, interbedded with the andesite, could be located for the purpose of easy tunnelling.

A tunnel penetrating the saturated zone under either valley would waste tremendously valuable ground-water storage if driven at one time. It is the usual practice not to drive the tunnel on a contract basis, but to lengthen it when water is needed. This constitutes "mining" water. When the tunnel is finally completed and yielding the flow needed, it is then essential to install bulkheads, equipped with gate valves, at rock barriers to store surplus water in the aquifers when demand declines during the winter months. If such a tunnel is planned additional field work and test borings will be necessary. The present investigation was limited to the assumption that water, if obtained in the Valle Grande or San Antonio Valley, would be pumped from wells.

It is reported that all water in the Jemez and San Antonio Valleys

belongs to water users in the irrigated areas downstream. Development of ground-water in these valleys would certainly reduce the stream flow. According to Mr. Berkeley Johnson, District Engineer, U. S. Geological Survey, Santa Fe, water rights can be purchased at the rate of 3-acre feet per acre at a reasonable cost by buying water-logged marginal lands in the Middle Rio Grande Conservancy District at Albuquerque and transferring these rights to the Valle Grande and San Antonio Valley.

Summary

This report deals only with the area west of Los Alamos and not with the deep-well field now being developed by the A.E.C. near the Rio Grande. The writer was requested to look for an underground supply of 10,000,000 gallons of water per day to meet the growing needs of Los Alamos.

A brief synopsis of the geologic history is given together with a stratigraphic table and the water-bearing character of each formation. Geologic and hydrologic traverses were made of each canyon behind Los Alamos. It was found that most of the springs issue either from fractured andesite lava or from welded tuff overlying baked tuff beds. The springs are perched and do not indicate a thick zone of saturation at high levels. The prospects for developing additional water in these canyons is poor, especially for the large quantities desired.

The search for ground-water led to the upper parts of the valleys of Jemez and San Antonio Streams. Test holes revealed an artesian basin in each of these valleys. Nearly all the rocks there

are permeable and recharge is heavy because the precipitation has been estimated to average about 27 inches per annum. The water table is close to the surface thrucut the year and the area is uninhabited, hence pollution can be controlled. The quality of the water, as determined by preliminary tests, is excellent with a hardness of only 30 parts per million. The quantity of ground-water recoverable is estimated to be 5 to 10 million gallons per day. Drilled wells 100 to 500 feet deep are recommended to recover this water from highly permeable pumiceous sands and gravels. The water lies 1200 feet or more above Los Alamos, but, due to a mountain ridge intervening, the water would have to be pumped up about 1000 feet and then dropped 2000 feet. Sufficient power might be generated from the drop to pump the water over the divide. The water could be obtained by gravity by tunnelling thru the divide into the zone of saturation. The Jemez Valley offers a better site for such a tunnel because a mass of tuff with low permeability lies at the head of San Antonio Valley.

Harold T. Stearns

Harold T. Stearns
Consulting Geologist
Hope, Idaho

July 15, 1948

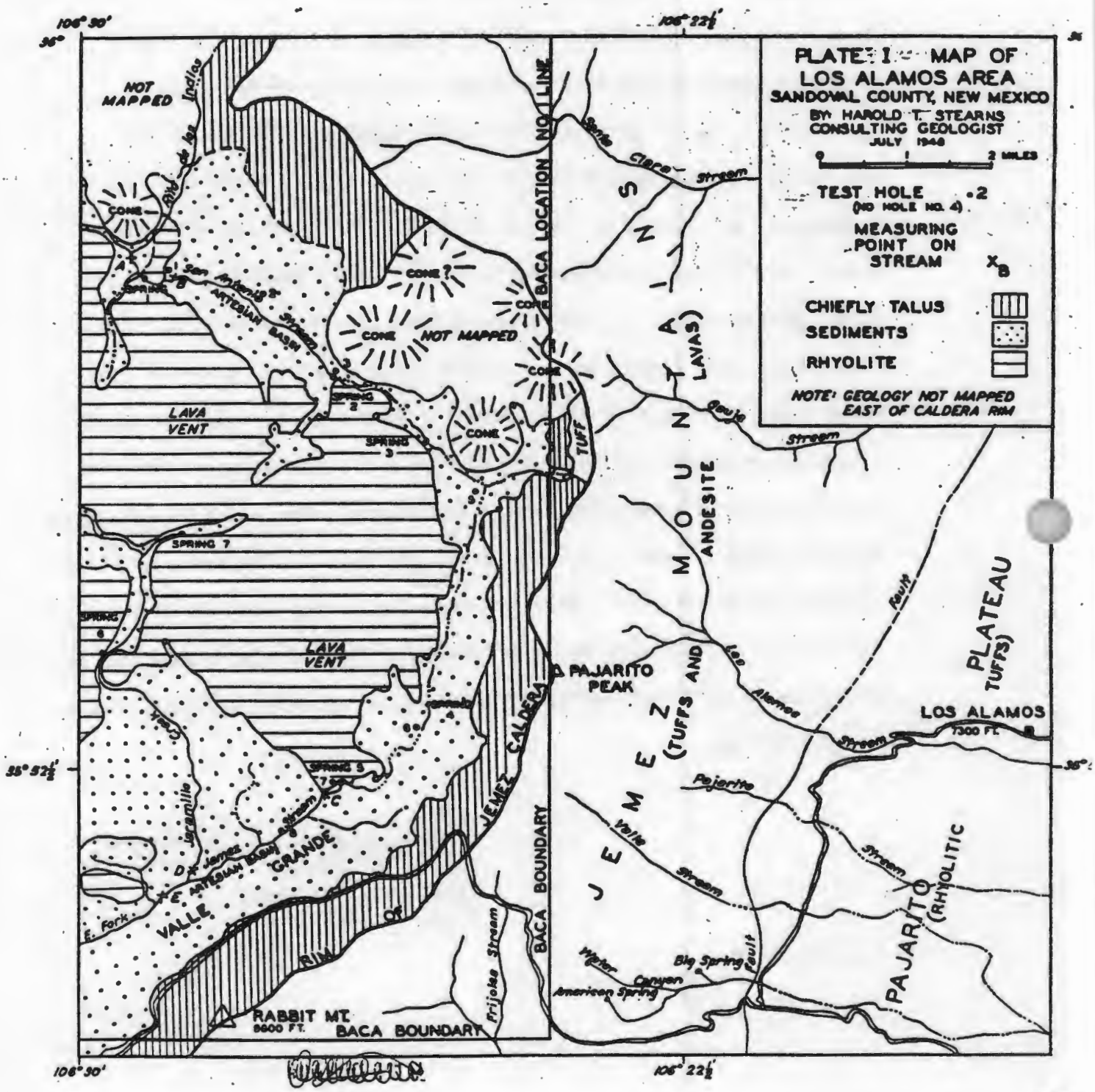
PLATE I MAP OF
LOS ALAMOS AREA
SANDOVAL COUNTY, NEW MEXICO
BY HAROLD T. STEARNS
CONSULTING GEOLOGIST
JULY 1948
0 1 2 MILES
TEST HOLE •2
(NO HOLE NO. 4)
MEASURING POINT ON STREAM X_B
CHIEFLY TALUS
SEDIMENTS
RHYOLITE
NOTE: GEOLOGY NOT MAPPED EAST OF CALDERA RIM
106° 30'
106° 22½'
36°
35° 52½'
NOT MAPPED
Rio de los Indios
CONE
A
B
SPRING 1
San Antonio Stream
ARTESIAN BASIN
CONE ?
CONE NOT MAPPED
CONE
SPRING 2
SPRING 3
LAVA VENT
SPRING 7
SPRING 6
LAVA VENT
Jemez
SPRING 5
C
Jaramillo
D
James
E
ARTESIAN BASIN
Stream
GRANDE
VALLE
E. Fork
RIM OF
JEMEZ CALDERA
Frijoles Stream
RABBIT MT.
8600 FT.
BACA BOUNDARY
BACA LOCATION NO. 1 LINE
Santa Clara Stream
SANGRE DE CRISTO MOUNTAINS
(LAVAS)
Guaje Stream
TUFF
ANDESITE
PAJARITO PEAK
Los Alamos Stream
Fault
PLATEAU TUFFS)
LOS ALAMOS
7300 FT.
JEMEZ (TUFFS AND
Pajarito
Valle Stream
Stream
PAJARITO (RHYOLITIC
Water Canyon
Big Spring Fault
American Spring

Plate 2. Looking up Pueblo Canyon from Los Alamos highway, showing tuffs making up the Pajarito Plateau and the Jemez Mountains in the background.

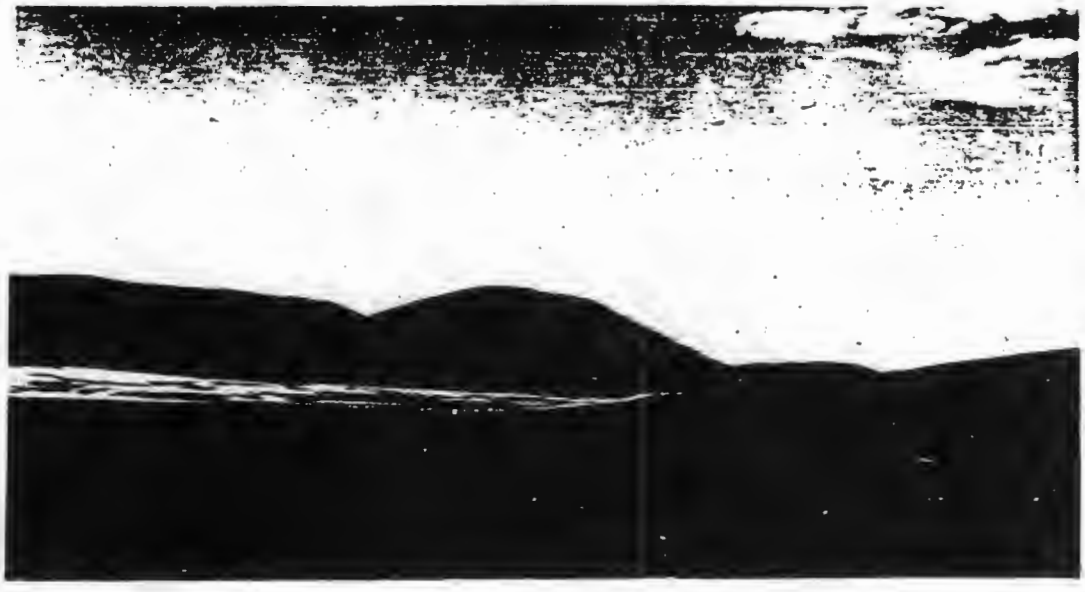

Plate 3. Looking up the San Antonio Valley from near Test Hole 1. The round hill is a rhyolitic pumice cone. The flat in the foreground is an old lake bed.

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Plate 4. Valle Grande, the site of an ancient lake, from highway 4, showing the caldera wall (right). The mountain covered with grass on the caldera rim is Pajarito and the gap in front is the head of Valle Canyon. The trees on the left grow on rhyolite.

Plate 5. Spring No. 5 discharging 1,500,000 gallons per day from fissured rhyolite in the Valle Grande. Note wave-cut terrace just above the spring.

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Plate 6. Water flowing at the rate of 37½ gallons per minute from 4-inch Test Hole #2 in San Antonio Valley.

Classification cancelled (~~or changed to~~ _____
(Insert appropriate Classification)

by authority of Edwin B. Eisenhart
(Person authorizing change in classification)

by Edwin B. Eisenhart 1/26/65
(Signature of person making the change, and date thereof)

White et al. 1981

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Factors Affecting Radionuclide Availability to Vegetables Grown at Los Alamos

G. C. WHITE, T. E. HAKONSON, AND A. J. AHLQUIST

Factors Affecting Radionuclide Availability to Vegetables Grown at Los Alamos[1]

G. C. WHITE, T. E. HAKONSON, AND A. J. AHLQUIST[2]

ABSTRACT

A field study was conducted in 1977 on ^{238,239}Pu and ^{137}Cs availability to zucchini squash (*Curcurbita melopepo*, hybrid seneca) and green bush beans (*Phaseolus vulgaris*, Landreths stringless) grown under home-garden conditions in an area at Los Alamos National Laboratory used for treated radioactive liquid waste disposal. Radionuclide concentrations were measured as a function of tissue type, height above the soil, fertilization regime, and for the squash, food-cleansing procedures. Analysis of variance procedures were used to analyze the data.

Ratios of the concentration of a radionuclide in oven-dried vegetation to dry soil ranged from 0.0004 to 0.116 for the Pu isotopes, and from 0.051 to 0.255 for ^{137}Cs. Fertilization with cattle manure reduced the Pu concentration ratios by 30% and ^{137}Cs by 50%. Vegetative parts sampled within 20 cm of the ground surface were contaminated about four times as much as those parts growing further from the ground surface. About 65% of the contamination was removed by washing, indicating the presence of surficial contamination. The 50-year radiation dose commitment to humans consuming vegetables from the garden plot would be less than 0.05 mrem and would be due almost entirely to ^{137}Cs.

Additional Index Words: **radiation, fertilizer, soil splash-up.**

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The need for information on transuranic element transfer into human food chains has prompted many studies on plutonium (Pu) uptake by agricultural plants. Most studies have been conducted under controlled laboratory or greenhouse conditions using known chemical forms of Pu (Price, 1973; Schreckhise and Cline, 1980; Schulz, 1977). Fewer studies deal with contaminated field sites where Pu transport to vegetation is likely a function of the contaminant source and local environmental factors (Adriano et al., 1980; Hakonson, 1975; Watters et al., 1980; Little and Whicker, 1978). Studies dealing with a wide variety of contaminant sources and ecological settings are required to identify the generic and site-specific attributes of environmental Pu behavior.

This paper presents the results of a field study conducted in 1977 on Pu and ^{137}Cs availability to zucchini squash (*Curcurbita melopepo*, hybrid seneca) and green beans (*Phaseolus vulgaris*, Landreths stringless) grown in Mortandad Canyon, an area at Los Alamos used for treated radioactive liquid waste disposal. The study was designed to simulate a home vegetable garden. Concentrations of radionuclides were determined in the two vegetable crops as a function of tissue, height above the ground surface, fertilization with steer manure, and food preparation treatment. The radiation doses to humans from eating the vegetable crop were calculated to assess the potential hazard from agricultural use of the area.

MATERIALS AND METHODS

Industrial liquid wastes generated by the Los Alamos National Laboratory are collected at a central location, treated to reduce the levels of radioactive contaminants to below Federal guidelines for drinking water, and then released to the local environs (USDOE, 1979).

Mortandad Canyon has been used for disposal of this liquid waste since 1963. The quantities of ^{238}Pu, ^{239,240}Pu (denoted as ^{239}Pu in this paper), and ^{137}Cs released to the canyon from 1963 through 1977 were 0.051, 0.039, and 0.85 Ci, respectively (USDOE, 1979). Prior to 1968 the isotopic composition of Pu in the waste was predominately ^{239}Pu. Subsequently, more ^{238}Pu than ^{239}Pu was processed so that the ^{238}Pu inventory is now greater than the ^{239}Pu inventory.

A 9- by 13-m plot was established in Mortandad Canyon about 2,500 m downstream from the liquid effluent outfall on an alluvial floodplain formed from storm runoff. The plot was fenced and commercial garden preparation (6%N–12%P–6%K) was applied just prior to cultivation of the soil. The soil is an unnamed member of the Typic Ustorthents group. One-half of the plot received an additional amendment of cattle manure (hereafter referred to as the fertilization treatment) applied at the rate of 5 kg/m^2 (dry weight). A garden rototiller was used to cultivate the plot to a 15-cm depth. The plot was seeded with zucchini squash and green beans.

The term "plant" as used in this paper refers to the above-ground vegetative parts. The term "fruit" refers to the edible reproductive parts. Plant roots were not sampled during this study. Green beans were sampled at maturity by pooling beans from four randomly selected plants within each plot. A total of 13 samples of bean fruit was collected. Green bean plants were also collected and bagged separately.

Squash fruits were collected at maturity from individual plants. Squash plants were sampled as a function of height above the ground surface with a 1-m^2 template divided into four equal quadrants; the heights from which samples were taken were 0–20 cm and >20 cm above the ground surface. Bean plants were not collected as a function of height above the ground.

To evaluate the effect of washing on radionuclide concentrations, squash plants and fruit from two of the quadrants in a particular height strata were pooled together for a wash treatment, while the samples from the remaining two quadrants were analyzed for radionuclide content without the wash treatment. All squash fruit and plant samples designated for the wash treatment were thoroughly washed with water in an attempt to remove surficially attached soil particles. Although the wash treatment appeared to be effective in removing coarse particles, it may not have effectively removed the smaller sized particles. All bean plant and fruit samples were washed before the radionuclide analyses.

Soil (minus roots) was collected for chemical, physical, and radionuclide analyses from the rooting zone of individual plant samples. Thus, the depth to which soil samples were taken varied depending on the depth of root penetration by the two vegetable species.

Samples were dried at 100°C and then ashed at 400°C. Samples were analyzed for ^{137}Cs on 10- by 20-cm NaI(Tl) detector coupled to a multichannel analyzer. The samples were then subjected to wet chemical techniques followed by alpha spectroscopy to quantify the Pu content (USDOE, 1979). Most of the chemical and physical analyses on garden-plot soils were conducted by Colorado State University's Soil Testing Laboratory in Fort Collins, Colo (Soltanpour et al., 1979). Soil particle size analyses were performed in our laboratory using mechanical sonic sieving methods (Nyhan et al., 1976).

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[2] Biometrician, radiation ecologist, and health physicist, respectively.

STATISTICAL ANALYSIS

Analysis of variance (ANOVA) procedures involving nested factors were used to analyze the vegetable crop data. Calculations were made with the multivariate ANOVA (MANOVA) procedure (Cohen and Burns, 1977) of SPSS (Nie et al., 1975). Because nested factors are random effects, e.g., the ANOVA model is a mixture of fixed and random effects, the F ratios are not constructed with a common error term in the denominators. Rather, the F ratios utilize different error terms depending on the nesting structure. The complexity of the linear models used necessitates the following complete descriptions.

Bean data were analyzed as a three-factor experiment (Winer 1971:361–363, 514–539) with plants nested within fertilization plots. The linear model utilized was

$$y_{ijk} = \mu + \alpha_i + \beta_{j(i)} + \gamma_k + \alpha\gamma_{ik} + \beta\gamma_{j(i)k} + e_{ijk}, \qquad [1]$$

where

y_{ijk} is the radionuclide concentration for the ijk^{th} cell;
μ is the overall mean;
α_i with $i = 1, 2$ is the fertilizer effect;
$\beta_{j(i)}$ with $j = 1, \ldots, 13$ is the plant effect nested within fertilizer plots;
γ_k with $k = 1, 2$ is the tissue effect, e.g., stem and leaves or fruit; and
e_{ijk} is the error term for the ijk^{th} cell.

Squash plant data were analyzed as a four-factor design (Winer 1971:539–559) with plants nested within fertilization plots. The linear model utilized was

$$y_{ijkl} = \mu + \alpha_i + \beta_{j(i)} + \gamma_k + \delta_l + \alpha\gamma_{ik} + \alpha\delta_{il} + \gamma\delta_{kl} + \alpha\gamma\delta_{ikl} + \beta\gamma_{j(i)k} + \beta\delta_{j(i)l} + \beta\gamma\delta_{j(i)kl} + e_{ijkl}, \qquad [2]$$

where

y_{ijkl} is the radionuclide concentration for the $ijkl^{th}$ cell,
α_i with $i = 1, 2$ is the effect either with or without fertilizer,
$\beta_{j(i)}$ with $j = 1, \ldots, 8$ is the plant effect nested within fertilizer plots,
γ_k with $k = 1, 2$ is either the lower or upper portions of plant (height),
δ_l with $l = 1, 2$ is either the washed or unwashed tissue effect, and
e_{ijkl} is the error term for the $ijkl^{th}$ cell.

Squash fruit were also analyzed with a four-factor hierarchial design. The linear model utilized was

$$y_{ijkl} = \mu + \alpha_i + \beta_{j(i)} + \gamma_{k(j)} + \delta_l + \alpha\delta_{il} + \beta\delta_{j(i)l} + \gamma\delta_{k(j)l} + e_{ijkl}$$

where

y_{ijkl} is the radionuclide concentration for the $ijkl^{th}$ cell,
α_i with $i = 1, 2$ is the effect either with or without fertilizer,
$\beta_{j(i)}$ with $j = 1, \ldots, 8$ is the plant effect nested within fertilizer plots,
$\gamma_{k(j)}$ with $k = 1, \ldots, 3$ is the fruit effect nested within plants,
δ_l with $l = 1, 2$ is the fruit peel or meat effect, and
e_{ijkl} is the error term for the $ijkl^{th}$ cell.

Each of the radionuclides was analyzed separately for each of the above designs, and was also analyzed for MANOVA for each of the above designs where the observed concentration is a vector of concentration:

$$y = [^{238}\mathrm{Pu}, {}^{239}\mathrm{Pu}, {}^{137}\mathrm{Cs}].$$

The multivariate tests give overall tests of the various hypotheses for each of the models above, and provide a means of evaluating the three radionuclides simultaneously rather than trying to interpret them separately. Significance levels of multivariate tests utilized Pillai's method (Morrison, 1976).

Radionuclide concentrations were analyzed both untransformed and with logarithmic transformations. Conclusions from the two analyses were identical for the effects of interest, and so only the analyses for untransformed data are presented.

RESULTS AND DISCUSSION

Study plot soils receiving the fertilization treatment differed significantly ($p < 0.01$, *t-test*) in chemical composition from those receiving no fertilizer treatment (Table 1). Of the parameters measured, only Ca, Cu, and pH remained unchanged in soil after addition of the fertilizer.

Table 1—Chemical and physical characteristics of soils from Mortandad Canyon garden plot in 1977.

Constituent	Soil treatment: Fertilization‡	Soil treatment: None	Significance
	mean (SD)†		
Ca, meq/liter	4.9 (2.2)	3.6 (0.91)	NS
Mg, meq/liter	1.7 (0.66)	0.93 (0.22)	<0.01
Na, meq/liter	3.9 (1.3)	1.1 (0.12)	<0.01
K, meq/liter	5.3 (0.91)	0.27 (0.05)	<0.01
Sodium absorption ratio	2.2 (0.59)	0.75 (0.15)	<0.01
pH	8.1 (0.20)	7.9 (0.10)	NS
Conductivity, mmhos/cm	1.6 (0.49)	0.60 (0.10)	<0.01
Organic matter, %	1.4 (0.29)	0.60 (0.07)	<0.01
P, ppm	52 (6.1)	16 (4.9)	<0.01
K, ppm	557 (71)	66 (4.9)	<0.01
NO_3-N, ppm	16 (7.1)	7.3 (3.7)	<0.01
Zn, ppm	2.6 (0.22)	1.9 (0.22)	<0.01
Fe, ppm	15 (0.93)	12 (1.9)	<0.01
Cu, ppm	2.2 (0.27)	2.1 (0.20)	NS
Mn, ppm	4.2 (0.39)	2.8 (0.59)	<0.01

† means based on sample size of six.
‡ Fertilized with cow manure.

Table 2—Radionuclide concentrations in oven-dry soil and soil size fractions from Mortandad garden plot.

	<43 μm	53–100 μm	100–500 μm	0.5–0.1 mm	1.0–2.0 mm	2.0–23 mm
	mean (SD)†					
% Soil weight	9.0 (5.0)	14 (5.0)	22 (4.0)	19 (4.0)	21 (4.0)	16 (6.1)
pCi ^{137}Cs/g	217 (43)	196 (47)	125 (36)	69 (35)	54 (30)	114 (67)
% ^{137}Cs in fraction	17	23	23	11	10	16
pCi ^{238}Pu/g	14 (2.4)	17 (3.4)	10 (6.1)	8.1 (5.6)	5.4 (3.9)	6.8 (4.1)
% ^{238}Pu in fraction	12	22	32	14	10	10
pCi ^{239,240}Pu/g	2.6 (0.52)	3.7 (3.2)	2.8 (0.87)	1.7 (0.83)	0.95 (0.46)	1.3 (0.55)
% ^{239,240}Pu/g in fraction	11	25	30	15	10	10

† Mean and SD based on sample size of 26.

Table 3—Effect of soil fertilization on concentrations of Pu and ^{137}Cs in plants (above-ground biomass minus fruits) and fruits of bush beans (mean ± one SD of 13 determinations).

Radionuclide	Unfertilized	Fertilized†
	pCi/g oven-dry tissue	
	Plant	
^{238}Pu	0.92 ± 0.41	0.52 ± 0.23
^{239}Pu	0.14 ± 0.06	0.08 ± 0.04
^{137}Cs	17.3 ± 3.7	8.0 ± 3.7
	Fruit	
^{238}Pu	0.26 ± 0.60	0.31 ± 0.72
^{239}Pu	0.04 ± 0.09	0.05 ± 0.11
^{137}Cs	5.9 ± 4.1	2.8 ± 1.2

† Fertilized with cow manure.

Table 5—Effects of soil fertilization, washing, and height of material sampled on concentrations of Pu and ^{137}Cs in the above-ground biomass of squash plants (minus fruits) (mean ± one SD of eight determinations).

Radionuclide	Unfertilized		Fertilized	
	0–20 cm	20 cm	0–20 cm	20 cm
	pCi/g oven-dry tissue			
	Washed			
^{238}Pu	1.34 ± 0.40	0.34 ± 0.25	0.81 ± 0.31	0.17 ± 0.09
^{239}Pu	0.19 ± 0.04	0.05 ± 0.04	0.12 ± 0.05	0.02 ± 0.01
^{137}Cs	24.9 ± 7.5	1.9 ± 1.4	10.5 ± 5.4	4.5 ± 3.3
	Unwashed			
^{238}Pu	3.3 ± 1.4	0.63 ± 0.50	2.26 ± 0.76	0.44 ± 0.22
^{239}Pu	0.56 ± 0.25	0.10 ± 0.88	0.36 ± 0.13	0.07 ± 0.04
^{137}Cs	66 ± 36	22 ± 11	33.5 ± 7.7	10.5 ± 4.0

Radionuclide concentrations in soils (Table 2) did not differ significantly ($p > 0.05$) between treatments (fertilizer vs. no fertilizer) and, overall, averaged 85 pCi ^{137}Cs/g dry weight, 10 pCi ^{238}Pu/g, and 1.9 pCi ^{239}Pu/g. The soil was sandy with over 90% of the soil mass consisting of particles > 53 μm. In addition, over 80% of the radionuclide inventories were present in sand size fractions. Relatively little of the radionuclide inventory was present in the silt-clay (< 53 μm) fraction; these particles contained only about 10% of the radionuclide inventory (Table 2), even though the radionuclide concentrations in this fraction were relatively high (Table 3).

Treatment Effects

The fertilization treatment had no significant effect ($p > 0.26$, Table 4) on Pu concentrations in beans (Table 3), although it decreased ^{137}Cs concentrations. Bean fruits had lower concentrations ($p < 0.001$, Tables 3 and 4) of all three radionuclides than bean plants did.

The differences for tissue effects (e.g., fruits vs. plants) are explainable due to the differential times of the material being available for contamination by soil from wind or water movement, and to the fruits usually having lower radionuclide concentrations (Schulz, 1977; Schreckhise and Cline, 1980). The leaves and stems had been exposed to raindrop splash-up and/or wind erosion for the full growing season, while the fruits appeared late in the growing season and were soon harvested. The potential for the fruits to become contaminated by physical processes was much less than for the remainder of the plant.

The differences between the effect of fertilization (Table 4) for Pu ($p = 0.26$) and ^{137}Cs ($p < 0.001$) is attributed to the increase of K, a biological analog of Cs. The increased K concentrations in the soil (8.4 times greater in fertilized soil, Table 2) decreased the uptake of ^{137}Cs by 55% (Table 3). The significant ($p = 0.004$, Table 4) fertilization × tissue effect for ^{137}Cs further indicates the importance of biological uptake for this radionuclide.

The three main effects (fertilizer treatment, washing, and height above the ground; Table 5) were each significant (Table 6) for all three radionuclides. The fact that washing significantly reduced radionuclide concentrations by about 65% (Table 5) indicates that much of the measured radioactive materials must have been associated with the plant surface. Likewise, because the lower portions of the plant had about four times higher concentrations than the upper portions (Table 5), surface contamination of the plant by soil is further supported. The lower radionuclide concentrations ($p = 0.066$, Tables 5 and 6) on the fertilized plot (35% for Pu, 50% for Cs) is attributed to the increase in organic matter, which stabilizes the soil and decreases mobility from wind- and water-driven processes. This hypothesis is further substantiated by the significant interaction term ($p = 0.055$, Table 6) for fertilization × height. Fertilization

Table 4—Analysis of variance table for the beans.

Source	Radionuclide	Sum of squares	Degrees of freedom	F	Significance	Multivariate significance
Fertilization	^{238}Pu	0.397	1	1.306	0.264	
	^{239}Pu	0.009	1	1.329	0.260	< 0.001
	^{137}Cs	503.332	1	47.367	< 0.001	
Plants within fertilization	^{238}Pu	7.304	24			
	^{239}Pu	0.165	24			
	^{137}Cs	255.023	24			
Tissue	^{238}Pu	2.459	1	9.980	0.004	
	^{239}Pu	0.054	1	9.847	0.004	< 0.001
	^{137}Cs	904.890	1	71.932	< 0.001	
Fertilization × tissue	^{238}Pu	0.621	1	2.521	0.125	
	^{239}Pu	0.014	1	2.558	0.123	0.014
	^{137}Cs	125.800	1	10.000	0.004	
Tissue × plants within fertilization	^{238}Pu	5.914	24			
	^{239}Pu	0.132	24			
	^{137}Cs	301.917	24			

Table 6—Analysis of variance for squash plants.

Source	Radionuclide	Sum of squares	Degrees of freedom	F	Significance	Multivariate significance
Fertilization	^{238}Pu	3.677	1	5.813	0.030	
	^{239}Pu	0.110	1	6.970	0.019	0.066
	^{137}Cs	3064.038	1	9.783	0.007	
Plants with fertilization	^{238}Pu	8.855	14			
	^{239}Pu	0.220	14			
	^{137}Cs	4384.757	14			
Washing	^{238}Pu	15.688	1	37.832	<0.001	
	^{239}Pu	0.471	1	38.993	<0.001	<0.001
	^{137}Cs	8075.943	1	34.273	<0.001	
Fertilization × washing	^{238}Pu	0.247	1	0.597	0.453	
	^{239}Pu	0.017	1	1.399	0.257	0.254
	^{137}Cs	1014.343	1	4.305	0.057	
Washing × plants within fertilization	^{238}Pu	5.806	14			
	^{239}Pu	0.169	14			
	^{137}Cs	3298.900	14			
Height	^{238}Pu	37.305	1	157.885	<0.001	
	^{239}Pu	0.966	1	111.601	<0.001	<0.001
	^{137}Cs	9097.583	1	74.877	<0.001	
Fertilization × height	^{238}Pu	1.434	1	6.069	0.027	
	^{239}Pu	0.043	1	4.989	0.042	0.055
	^{137}Cs	1406.906	1	11.579	0.004	
Height × plants within fertilization	^{238}Pu	3.308	14			
	^{239}Pu	0.121	14			
	^{137}Cs	1701.010	14			
Washing × height	^{238}Pu	8.042	1	23.311	<0.001	
	^{239}Pu	0.254	1	24.250	<0.001	0.006
	^{137}Cs	1403.345	1	12.605	0.003	
Fertilization × washing × height	^{238}Pu	0.219	1	0.633	0.439	
	^{239}Pu	0.016	1	1.482	0.244	0.286
	^{137}Cs	12.311	1	0.111	0.744	
Washing × height × plants within fertilization	^{238}Pu	4.830	14			
	^{239}Pu	0.149	14			
	^{137}Cs	1558.684	14			

reduced the accumulation of contaminants more on the upper parts of the plant than it did on the lower portions (Table 5).

The above explanation of the decrease in splash-up due to fertilization would also suggest that the fertilization × washing interaction should have been significant (Table 6). More material should have been washed off of the unfertilized plants than the fertilized plants because there was more material present to wash. The ^{137}Cs term was marginally significant (p = 0.057), but neither of the Pu terms were significant (Table 6). We believe this interaction term was not significantly rejected because the amount of additional material to be washed off was small in relation to detection limits, and the variation in the data obscured the interaction.

Table 7—Effect of soil fertilization on concentration of Pu and ^{137}Cs in washed fruits of squash. Three fruits were taken from each of eight plants in each fertilization plot (mean ± SD of 24 determinations).

Radionuclide	Unfertilized	Fertilized
	pCi/g oven-dry tissue	
	Peel	
^{238}Pu	0.024 ± 0.012	0.017 ± 0.031
^{239}Pu	0.006 ± 0.003	0.005 ± 0.012
^{137}Cs	9.5 ± 7.1	4.6 ± 2.3
	Meat	
^{238}Pu	0.006 ± 0.017	0.002 ± 0.001
^{239}Pu	0.006 ± 0.022	0.002 ± 0.004
^{137}Cs	6.2 ± 4.8	4.1 ± 1.8

Cesium-137 concentrations in plant material from the fertilized plot were even further reduced (Table 5) than were Pu concentrations. The greater decrease for ^{137}Cs from fertilization can be attributed to the increase in K and, hence, discrimination against ^{137}Cs by the plant, illustrating the greater biological activity of ^{137}Cs.

The reduction of radionuclide concentration in squash fruit due to fertilization (Table 7) was not significant (p >0.174, Table 8) for Pu. We attribute the lack of a fertilization effect for Pu to the short time that the squash fruits were in the garden and thus subject to surface contamination, and to the low levels of activity observed in the fruits with the effect thus obscured by the variation due to fallout background. As the fruits reached the sizes where they are normally utilized for food, they were harvested from the garden and stored until analyses. They were washed before being prepared for analyses, and thus, as illustrated in Table 5, some of the surficial contamination was removed. In addition, the greater biological activity of ^{137}Cs increased the fertilization effect, and thus a significant difference was found for ^{137}Cs but not for Pu.

For ^{238}Pu, the washing did not remove all the activity on the peel (Table 7), with the ^{238}Pu concentration in meat being only 20% of the concentration in peel. We attribute the difference to surficial contamination, although biologically active Pu could have been preferentially deposited in the peel of the fruit rather than the meat. The difference in ^{239}Pu concentration between the peel and the meat of the fruits was not significant (p = 0.48, Table 8), which suggests that there was little con-

Table 8—Analysis of variance for squash fruit.

Source	Radionuclide	Sum of squares	Degrees of freedom	F	Significance	Multivariate significance
Fertilization	^{238}Pu	8.0×10^{-4}	1	2.053	0.174	
	^{239}Pu	1.2×10^{-4}	1	0.736	0.405	0.238
	^{137}Cs	2.9×10^{2}	1	4.245	0.058	
Plants within fertilization	^{238}Pu	5.4×10^{-3}	14			
	^{239}Pu	2.2×10^{-3}	14			
	^{137}Cs	9.6×10^{2}	14			
Fruit within plants	^{238}Pu	6.0×10^{-3}	16			
	^{239}Pu	2.6×10^{-3}	16			
	^{137}Cs	2.0×10^{2}	16			
Peeling	^{238}Pu	6.5×10^{-3}	1	19.770	<0.001	
	^{239}Pu	6.0×10^{-5}	1	0.527	0.480	0.006
	^{137}Cs	8.7×10^{1}	1	10.174	0.007	
Peeling × fertilization	^{238}Pu	4.0×10^{-5}	1	0.136	0.715	
	^{239}Pu	9.0×10^{-5}	1	0.505	0.483	0.261
	^{137}Cs	4.4×10^{1}	1	3.385	0.075	
Peeling × plants within fertilization	^{238}Pu	4.6×10^{-3}	14			
	^{239}Pu	2.2×10^{-3}	14			
	^{137}Cs	1.2×10^{2}	14			
Peeling × fruits within plants	^{238}Pu	5.4×10^{-3}	16			
	^{239}Pu	2.7×10^{-3}	16			
	^{137}Cs	1.8×10^{2}	16			

tamination by Pu, and that any difference in concentration was obscured by variation due to the fallout background. Concentration of ^{239}Pu was only 20% of that for ^{238}Pu in the soil (Table 2).

In contrast, both fertilization and peeling the fruit produced significant differences (Table 8) for ^{137}Cs. The decrease in ^{137}Cs concentrations due to fertilization (Table 7) can be attributed to the increase of K in the fertilized plot, although the effect was only marginally significant ($p = 0.058$, Table 8). The greater concentration of ^{137}Cs in the peel vs. the meat (Table 7) may be explained by surficial contamination that was not removed by wash treatment. The higher concentrations of ^{137}Cs allowed smaller differences to be detected than for Pu.

Concentration Ratios

The dimensionless ratio of concentration in plant tissue to concentration in soil was calculated for the five plant tissues analyzed in this study (Table 9). Combined cell means were used for each tissue, thus the concentration ratio varied for fertilized vs. unfertilized plots, washed vs. unwashed, and lower vs. upper strata. These concentration ratios were calculated using the soil data in Table 2 and tissue data from Tables 3, 5, and 7. All of the statistical results discussed for Tables 4, 6, and 8 apply to the concentration ratios, as the only difference in the data is the constant factor, soil concentration.

In Table 9, we see that the largest concentration ratios for Pu were in squash plants, followed by bean plants. We would expect these results, as squash plants are better collectors of soil than bean plants because of their large flat leaves close to the ground surface.

The ^{137}Cs concentration ratios were always greater than those for Pu (Table 9), substantiating the fact that ^{137}Cs is biologically more active than Pu. Because greenhouse studies have shown that biological uptake is <1% of the total Pu content of vegetation (ERDA, 1976), we can use the concentration ratios in Table 9 to partition the amount of ^{137}Cs splashed up on the plant

Table 9—Concentration ratios (pCi/g dry weight vegetable ÷ pCi/g dry weight soil) for various plant tissues from the Mortandad garden plot.

Tissue	^{238}Pu	^{239}Pu	^{137}Cs
Bean plant	7.2×10^{-2}	5.8×10^{-2}	1.5×10^{-1}
Bean fruit	2.9×10^{-2}	2.4×10^{-2}	5.1×10^{-2}
Squash plant	1.2×10^{-1}	9.7×10^{-2}	2.5×10^{-1}
Squash peel	2.0×10^{-2}	2.6×10^{-2}	8.3×10^{-2}
Squash meat	4.0×10^{-4}	2.1×10^{-3}	6.1×10^{-2}

as opposed to the amount taken up biologically. The squash plant data are taken as an example to illustrate the calculations. The average concentration ratio for Pu was about 0.11, while the concentration ratio for ^{137}Cs was 0.25. Thus if no biological uptake were present for ^{137}Cs, we would expect a concentration ratio of 0.11 as for Pu. Instead, the concentration ratio of 0.25 suggests that 43% of the ^{137}Cs on the squash plant was due to splash-up, while 60% was due to biological uptake. Similar calculations for bean plants, bean fruits, squash peel, and squash meat gave the percent of ^{137}Cs splashed onto the tissue as 43, 52, 28, and 2, respectively. These values illustrate that about 45% of the ^{137}Cs on the unwashed plant material was due to splash-up. The squash fruits were washed as in normal food preparation, so the amount of ^{137}Cs remaining on the peel surface was lower than for the unwashed plants. The 2% figure for squash meat illustrates the obvious—nothing was splashed into squash meat.

Radiation Doses

Radiation doses to humans consuming vegetables from the garden plot were calculated for all vegetable combinations. Doses from zucchini squash (meat only) and for green beans from the unfertilized plot are presented in Table 10. Unfertilized plot data were chosen because contamination concentrations were higher than in the fertilized plot. Thus, calculated doses represent the upper portion of the range of calculated doses. Doses were dominated by the ^{137}Cs contamination. The

Table 10—Estimated radiation doses to humans from ingestion of garden vegetables grown in the unfertilized garden plot contaminated with $^{238,239}Pu$ and ^{137}Cs.

Vegetable	Annual ingestion†	1st-year dose‡			50-year dose commitment‡		
		Total body	Bone	Liver	Total body	Bone	Liver
	kg	mrem					
Zucchini squash	0.23	2.5×10^{-3}	2.5×10^{-3}	4.2×10^{-3}	4.0×10^{-3}	4.7×10^{-3}	6.3×10^{-3}
Green beans	0.68	1.6×10^{-2}	1.6×10^{-2}	2.8×10^{-2}	2.7×10^{-2}	4.2×10^{-2}	4.4×10^{-1}

† Ingestion rates taken from USDA, 1978.
‡ Radiation Dose Factors (mrem/μCi intake) taken from Corley et al., 1977; concentrations of ^{137}Cs and $^{238,239}Pu$ in vegetables taken from Tables 3 and 7. Calculated dose includes contributions from both ^{137}Cs and $^{238,239}Pu$.

only place where $^{238,239}Pu$ made a significant contribution (38%) was in the 50-year dose commitment to bone from green bean ingestion. As can be seen from the data, doses are extremely low and represent no hazard. The largest total body dose in the table (0.027 mrem) is equivalent to the dose received from cosmic radiation in 7 min from flying at typical jet aircraft altitude of 9,144 m (30,000 feet). This dose represents 0.23% of the estimated 138 mrem Los Alamos residents received from natural radiation in 1979 (Environmental Surveillance Group, 1979).

SUMMARY AND CONCLUSIONS

The results of this study demonstrate that a major source of contamination of green beans and zucchini squash by ^{137}Cs and $^{238,239}Pu$ was due to soil on the plant surfaces. The lower portions (0–20 cm) of zucchini and squash plants were contaminated about four times the higher portions (>20 cm). About 65% of the contamination on zucchini squash plants could be washed off with normal food preparation techniques. Fertilization of the garden plot with cattle manure reduced contamination by about 30% for Pu and even greater (about 50%) for ^{137}Cs. The reduction due to fertilization is attributed to a stabilization of the soil surface, and, in the case of ^{137}Cs, reduction in ^{137}Cs uptake in the plant was due to increased K concentrations.

Fifty-year radiation doses to humans consuming vegetables from the garden plot would be <0.05 mrem and would be due almost entirely to ^{137}Cs.

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