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*P. R. Fresquez**
*D. R. Armstrong***
*M. A. Mullen**
*L. Naranjo, Jr.**

**Environmental Soil Scientist, Biostatistician, and Environmental Health Technician, respectively, Environment, Safety and Health Division, Ecology Group (ESH-20).*

***Health Physicist, Environment, Safety and Health Division, Air Quality Group (ESH-17).*

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

RADIONUCLIDE CONCENTRATIONS IN PINTO BEANS, SWEET CORN, AND ZUCCHINI SQUASH GROWN IN LOS ALAMOS CANYON AT LOS ALAMOS NATIONAL LABORATORY

by

P.R. Fresquez, D.R. Armstrong, M.A. Mullen, and L. Naranjo, Jr.

ABSTRACT

Pinto beans (*Phaselous vulgaris* var. Idaho 111), sweet corn (*Zea mays* var. early sunglow), and zucchini squash (*Cucurbita pepo* var. black beauty) were grown in a randomized complete-block field/pot experiment at a site that contained the highest observed levels of surface gross gamma radioactivity within Los Alamos Canyon (LAC) at Los Alamos National Laboratory. Soils as well as washed edible and nonedible crop tissues were analyzed for various radionuclides (^{3}H, ^{137}Cs, ^{90}Sr, ^{238}Pu, ^{239}Pu, ^{241}Am, ^{tot}U, and gross α, β and γ) and heavy metals (As, Hg, Sb, Cd, Cr, Pb, and Zn). Most radionuclides, with the exception of ^{3}H and ^{tot}U, in soil from LAC were detected in significantly higher concentrations ($p < 0.01$) than in soil collected from regional background (RBG) locations. Similarly, most radionuclides in edible crop portions of beans, squash, and corn were detected in significantly higher ($p < 0.01$ and 0.05) concentrations than RBG. Most soil-to-plant concentration ratios for radionuclides in edible and nonedible crop tissues from LAC were within the default values given by the Nuclear Regulatory Commission and Environmental Protection Agency. All heavy metals in soils, as well as edible and nonedible crop tissues grown in soils from LAC, were within RBG concentrations. Overall, the total maximum net positive committed effective dose equivalent (CEDE)--the CEDE plus two sigma for each radioisotope minus background and then all positive doses summed--to a hypothetical 50-year resident that ingested 160 kg [352 lb.] of beans, corn, and squash in equal proportions, was 74 mrem y^{-1}. This dose was below the International Commission on Radiological Protection permissible dose limit (PDL) of 100 mrem y^{-1} from all pathways; however, the addition of other internal and external exposure route factors may increase the overall dose over the PDL. Also, the risk of an excess cancer fatality, based on 74 mrem y^{-1}, was 3.7×10^{-5} (37 in a million), which is above the Environmental Protection Agency's (acceptable) guideline of one in a million.

I. INTRODUCTION

Los Alamos National Laboratory (LANL), a nuclear weapons research, development, and testing facility, is situated on a series of finger-like mesas separated by approximately 19 east-to-west canyon drainage systems (USDOE 1979). Although the Laboratory makes great effort to minimize the release of radioactive materials to the environment, some of these canyon ecosystems have received either directly and/or indirectly varying types and amounts of radioactivity (Hakonson et al. 1981, Fresquez et al. 1995a, Bennett et al. 1996, Conrad et al. 1995). Direct and indirect releases include treated radioactive liquid waste effluents and operations within the canyons themselves and transport of contaminated sediments by surface water runoff processes from the surface of the mesa tops. Measurable amounts of ^{3}H, ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{241}Am, and U, for example, have been detected within Los Alamos Canyon (LAC) (ESR 1996)—a major drainage system that originates from the Jemez Mountains and passes through approximately 10.3 km (6.4 mi.) of LANL and 6.4 km (4 mi.) of Pueblo of San Ildefonso lands to the Rio Grande (Figure 1).

The possibility of some radionuclide contamination within LAC on Pueblo of San Ildefonso lands, combined with the fact that the Pueblo community has expressed concerns about the adequacy of standard exposure assessment assumptions in determining past, present, and future risks from LANL operations (Dorries et al. 1996), have prompted the Laboratory to develop human health risk assessment scenarios that reflect traditional/ceremonial Native American activities (e.g., adobe making, ranching, hunting, wood gathering, pot making, ceremonial body painting, ingestion of indigenous plants and animals, and subsistence farming) (Dorries et al. 1996, Dorries and Lewis 1996). Consumption of domestic crop plants, for example, constitutes a significant pathway by which radionuclides can be transferred to humans (Wicker and Schultz 1982), and site-specific plant uptake factors for known contaminants have been identified as being a major driver of a Native American risk scenario (Naranjo

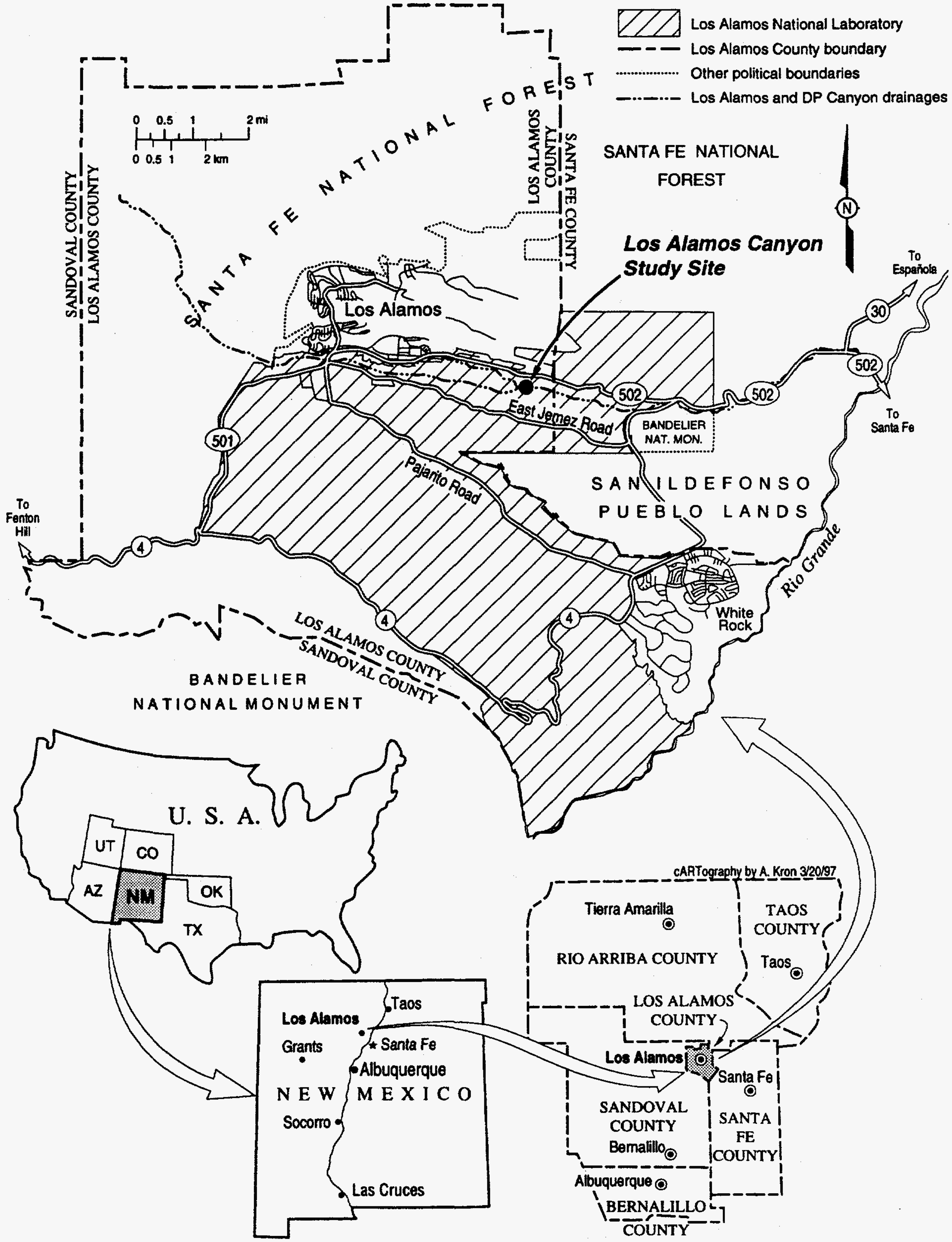

Figure 1. Location of Los Alamos Canyon Study Site with respect to surrounding areas.

et al. 1996, Dorries et al. 1996).

The objectives of this study were to determine (1) the uptake of various radionuclides and heavy metals by commonly cultivated Native American crop plants--pinto beans, sweet corn, and zucchini squash--grown in (contaminated) soils within LAC at LANL, and (2) the committed effective dose equivalent (CEDE) along with the corresponding risk of excess cancer fatalities (RECF) to a hypothetical 50-year resident who may consume these products.

II. METHODS AND MATERIALS

In April of 1996, the Environmental Restoration (ER) project, as part of the Canyons Pilot Study at LANL (LANL 1995), surveyed several reaches of LAC for radioactivity using field instrumentation. A site--an alluvial embankment measuring 1.5 m (5 ft) high by 6.7 m (22 ft) wide by 14.2 m (47 ft) long and located in middle LAC approximately 7.6 m (25 ft) away from the ephemeral stream channel--was identified as containing the highest observed levels of surface gross gamma radioactivity within the immediate survey area downstream from a known contaminant source (Reneau 1996) (Figure 1). On May 16, 1996, the site was cleared of debris and plant material, and a randomized complete-block design comprised of four plots spaced evenly apart across the length of the study site was established. At each plot, soil was excavated from a 1.2-m- (4-ft-) diameter area to a depth of 0.3 m (1 ft) and placed onto a large plastic sheet. The soil was thoroughly mixed and approximately 500 g and 125 g of this homogenized soil was collected for radionuclide and heavy metal analysis, respectively. A hard plastic children's pool was then placed into the excavated area (this secondary containment system was used to prevent the leaching of radionuclides to deeper possibly uncontaminated areas, to prevent surface water run off, and to protect deeper water sources), followed by placing 10 three-gallon plastic pots that were 23 cm (9 in.) tall and 25 cm (10 in.) in diameter. The pots were then filled to the top with homogenized soil that had been removed from the excavation.

On May 17, 1996, seeds from pinto beans (*Phaseolus vulgaris*, var.

Idaho 111), sweet corn (*Zea mays*, var. early sunglow), and zucchini squash (*Cucurbita pepo*, var. black beauty), were planted according to a random number table and subreplicated accordingly to obtain adequate sample materials for analysis. All pots were watered to field capacity with water from the Rio Grande using a 200-gallon polybottle/trailer. Plants were irrigated every other day until germination, beans and corn were thinned to two plants per pot (squash to one plant per pot), and watered every fourth day thereafter until maturation.

Soil samples from the LAC study along with background soil samples collected from seven regional background (RGB) locations around the Laboratory (Fresquez et al. 1996a) were submitted under full chain-of-custody to the Environmental Chemistry Group (CST-9) at LANL for the analysis of various radionuclides and radioactivity (^{3}H, ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{tot}U, and gross alpha, beta and gamma) and heavy metals (As, Cd, Cr, Hg, Pb, Sb, and Zn). Methods of soil radionuclide and heavy metal analysis can be found in Purtymun et al. (1987) and Fresquez et al. (1996a), and Fresquez et al. (1996b), respectively. Also, a composite sample was submitted to the Colorado State University Soil Testing Laboratory for the analysis of other chemicals (N, P, K, Ca, Mg, Na, pH, EC, CEC, OM) and physical (% sand, silt, and clay) properties (Table 1). Results were expressed on an oven-dry weight basis (dry gram) and can be found in Appendices A and B; summarized results can be found in the appropriate tables.

In early September, all edible crop tissues were harvested along with representative (composite) samples of nonedible crop materials. Edible bean tissues from each plot were also composited. Samples were placed into individual Ziplock® plastic bags, marked for identification, and transported to the Laboratory in locked ice chests at 4°C. Background samples of similar crops were collected from the Espanola (Rio Chama and Santa Cruz River basins), Farmington, and Jemez, New Mexico areas. At the Laboratory, all samples were washed thoroughly with tap water, towel-dried, sliced into 2.5- to 5-cm (1- to 2-in.) pieces, and divided into three subsets to provide analysis material for ^{3}H, heavy metals, and other radionuclides.

Subsamples (~100 wet g) for ^{3}H analysis were placed into 1-L beakers and heated to collect distillate (water) for ^{3}H analysis. Material for heavy metal analysis was dried at 75°C for 48 h before being ground in a Wiley mill (40-mm screen). The rest of the subsample (~500 to 1500 wet g) was placed into tared 2-L beakers and weighed. The beaker contents were oven-dried at 75°C for 120 h, weighed, and ashed incrementally to 500°C for 120 hr. The sample(s) ash was weighed, pulverized, and homogenized before being submitted with the distillate (water) sample(s) and the dried sample(s) to CST-9 for the analysis of ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu, and ^{tot}U, and ^{3}H, and As, Cd, Cr, Hg, Pb, Sb and Zn, respectively. All methods of radiochemical and heavy metal analysis of produce have been described previously (Fresquez et al. 1995b, Fresquez et al. 1996b). All results, expressed as pCi mL^{-1} of tissue moisture for ^{3}H, and on an oven-dry weight basis (dry gram) for heavy metals and uranium (ug g^{-1}) and the other radionuclides (pCi g^{-1}), can be found in Appendices C and D; summarized results can be found in the appropriate tables.

The mean radionuclide content in soils and produce (with the exception of beans) collected from the LAC garden study was compared with soils and produce collected from the regional background areas at the 0.01 and 0.05 probability level using a nonparametric Wilcoxon Rank Sum test (Gilbert 1987).

The CEDE was calculated following procedures recommended by the Department of Energy (DOE) (USDOE 1991) and Nuclear Regulatory Commission (NRC 1977) for a hypothetical 50-year resident. Public dose conversion factors used for ingestion calculations are those recommended by the DOE (USDOE 1988) and are based on factors in the International Commission on Radiological Protection (ICRP) Publication 30 (ICRP 1978). When more than one ingestion factor is given, the most conservative factor was chosen to maximinze the CEDE for comparison with the ICRP permissable dose limit (PDL) of 100 mrem y^{-1} (USDOE 1990). Radionuclide concentrations for each crop species were multiplied by the estimated consumption rate of 53 kg (117 lb.) (one-third of the maximum consumption rate for all produce per person per year of 160 kg [352 lb.]) to obtain an adjusted intake for a particular radionuclide. Multiplication of this intake rate by the appropriate radionuclide dose conversion factor for a particular organ gives the estimated committed dose equivalent to organs, and similarly the CEDE to the entire body (USDOE 1988). To determine Laboratory impacts, the maximum CEDE (i.e., CEDE + 2 sigma) for each radionuclide detected in each of the three food crops grown in LAC was subtracted from the maximum CEDE for each radionuclide measured in similar produce collected from regional background locations. All negative dose equivalents were set to zero and only the net positive CEDEs were used. This radionuclide-specific maximum net positive CEDE was summed over all the monitored radionuclides to obtain the total maximum net positive CEDE for each crop species seperately and together for comparison to the ICRP's PDL. Morevoer, the total maximum CEDE and the total maximum net positive CEDE were multiplied by 5×10^{-7} excess cancer fatalities per person-mrem (NCRP 1993, USEPA 1994a and b) to calculate the RECF from whole-body radiation from the consumption of beans, corn, and squash separately or in combination.

III. RESULTS

a. Radionuclide and Heavy Metal Concentrations in Soils

1. Most radionuclides, with the exception of ^{3}H and ^{tot}U, were significantly higher ($p < 0.01$) in soils collected from LAC than from RBG locations (Table 2). They also exceed long-term regional statistical reference levels (RSRL) (the upper limit background [mean + 2 std dev]) developed from data collected over a 20-year period (Fresquez et al. 1996a).

2. ^{137}Cs and ^{90}Sr concentrations in soils from LAC exceeded LANL screening action levels (SALs), albeit they were developed for mesa top soils using residential exposure assumptions and a 10-mrem y^{-1} dose limit (FIMAD 1997); ^{137}Cs, in particular, was over nine times greater (Table 2).

3. Concentrations of heavy metals in soils from LAC were statistically similar to background soils (Table 3). Accordingly, all heavy metals in soils from LAC were within LANL SALs.

b. Radionuclide and Plant:Soil Concentration Ratios (CRs) in Edible Crop Tissues

1. Most radionuclide concentrations, with the exception of ^{238}Pu and ^{tot}U, were significantly higher ($p < 0.05$) in edible portions of corn and squash from LAC than from RBG (Table 4).

2. Although beans collected from LAC and RBG were not subjected to a statistical test because they were composited, all results appear similar to the values obtained with the other two crop species as described in #1.

3. Squash grown in LAC were significantly higher in ^{137}Cs, ^{90}Sr, ^{239}Pu, and ^{241}Am than corn grown in LAC (Table 4).

4. Plant:soil concentration ratios from LAC ranged from 10^{-6} to 10^{-3} for Pu and Am isotopes, from 10^{-4} to10^{-3} for ^{tot}U, from 10^{-2} to 10^{-1} for ^{137}Cs and ^{3}H, and from 10^{-1} to 10^{1} for ^{90}Sr (Table 5). Most CRs were within the range of (default) values reported for the Nuclear Regulatory Commission (NUREG) (Kennedy and Strenge 1992) and Environmental Protection Agency (EPA) (Baes et al. 1984).

5. Squash from LAC consistently exhibited higher CRs for most radionuclides than beans or corn (Table 5).

c. Heavy Metal and Plant:Soil Concentration Ratios in Edible Crop Tissues

1. Many elements (As, Cd, Cr, Hg, and Sb) in edible crop tissues for all three vegetable crops growing in both LAC and RBG were below the limit of detection (i.e., less than values) (Table 6). Lead and Zn were the only two elements in edible crop tissues that were reported at concentrations above the limit of detection; and of the two, only Zn was found to be significantly higher in the edible portion of corn grown in LAC as compared to RBG. These data do not correlate very well with the Zn levels in the soil, as Zn concentrations in soil collected from LAC was lower than Zn concentrations in soil collected from RBG locations.

2. Corn (and probably beans) from LAC contained significantly higher concentrations of Pb than squash from LAC (Table 6).

3. Because many of the elements in edible crop tissues, with the exception of Pb and Zn, were reported below the limit of detection, the plant:soil CRs for these elements were probably overestimates and their use in risk assessments is not recommended (Table 7). Instead, the reader is referred to the values reported by NUREG and EPA for these elements, which are much lower. Although, Pb and Zn also appear high, as compared to the NUREG and EPA values, the confidence in these values is high because the estimates are not based on less than values.

4. Beans grown in LAC contained a higher CR for Pb than corn or squash, and corn contained a higher CR for Zn than beans or squash (Table 7).

d. Radionuclide and Plant:Soil Concentration Ratios in Nonedible Crop Tissues

1. Most radionuclides, with the exception of ^{tot}U, were generally higher in nonedible crop tissues grown in LAC than in nonedible crop tissues from RBG locations (Table 8); this trend was consistent with that observed with the edible crop tissue results (Table 4).

2. Beans and squash from LAC contained generally higher radionuclide concentrations in nonedible plant tissues than corn (Table 8).

3. Most nonedible crop tissues from LAC exhibited CRs much higher than the CRs reported by the NUREG and EPA (Table 9). Beans and squash nonedible tissue exhibited higher CRs for all radionuclides than the nonedible plant tissue of corn.

e. Heavy Metal and Plant:Soil Concentration Ratios in Nonedible Crop Tissues

1. Mercury, Pb, and Sb in all three nonedible plant tissues from LAC and RBG were reported below the limit of detection (i.e., less than values) (Table 10). Arsenic, Cd, Cr, and Zn in nonedible crop tissue of all three species from LAC were generally higher than RBG (Table 10).

2. Because Hg, Pb, and Sb in nonedible crop tissues from LAC were reported below the limit of detection, the CRs for these elements are probably

overestimates and should not be used for risk calculations. CRs for As, Cd, Cr and Zn, on the other hand, were based on values above the limit of detection and are given with confidence; and in fact, the CRs for Zn for all of the nonedible tissues studied are close to those values reported in the NUREG and EPA reports (Table 11).

f. Radionuclide and Heavy Metal Concentrations in Edible verses Nonedible Crop Tissues

1. Levels of ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{241}Am, and ^{tot}U in nonedible crop tissues (all three crops combined) were detected in significantly higher ($p < 0.05$) concentrations than in edible crop tissues (all three crops combined) (Table 12).

2. ^{239}Pu was over 160 times higher in nonedible tissues as compared to edible tissues.

3. Only a few elements--Cd and Cr--in nonedible plant tissues were significantly higher ($p < 0.05$) than edible crop tissues (Table 13).

g. Committed Effective Dose Equivalent

1. The total CEDE estimated for the ingestion of 53 kg (117 lb.) (one-third of the maximum consumption rate for all produce per person per year of 160 kg [352 lb.]) each of beans, corn, and squash from LAC was 25, 4.6, and 30 mrem y^{-1}, respectively (Table 14). The total CEDE estimated for the ingestion of 160 kg (352 lb.) of beans, corn, and squash in equal proportions per person per year from LAC was 60 mrem y^{-1}.

2. The total maximum (CEDE + two sigma) net positive CEDE (i.e., the radionuclide-specific net positive CEDE summed over all radionuclides) estimated for the ingestion of 53 kg (117 lb.) (one-third of the maximum consumption rate for all produce per person per year of 160 kg [352 lb.]) each of beans, corn, and squash from LAC was 28, 6.9, and 39 mrem y^{-1}, respectively (Table 15). The total maximum net positive CEDE estimated for the ingestion of 160 kg (352 lb.) of beans, corn, and squash in equal proportions per person per year was 74 mrem y^{-1}. The ICRP PDL for all pathways above that received from natural background is 100 mrem y^{-1}.

3. The majority of the CEDE was due to ^{90}Sr (beans = 83%, corn = 59%, and squash = 90%) and ^{137}Cs

(beans = 12%, corn = 41%, and squash = 10%) activity (Table 15).

h. Risk of Excess Cancer Fatalities

1. The total maximum net positive CEDE (74 mrem y^{-1}) from the consumption of 160 kg of beans, corn, and squash in equal proportions corresponds to a RECF of 3.7×10^{-5} (37 in a million) and is above the EPA 40 CFR 300.430 (acceptable) value of 1 in a million (EPA 1994) (Table 15).

IV. CONCLUSIONS

Pinto beans, sweet corn, and zucchini squash grown in a contaminated reach within LAC at LANL translocated significantly higher quantities of ^{137}Cs, ^{90}Sr, ^{239}Pu, and ^{241}Am to edible and nonedible crop portions as compared to similar materials collected from RBG locations. Most plant:soil CRs in edible and nonedible crop tissues for pinto beans, sweet corn, and zucchini squash grown within LAC were more or less within the default CRs given by NUREG and EPA; these values reported here, however, were radionuclide specific for seven radioisotopes and plant specific for three crop species and should provide greater confidence for use in dose/risk assessments at LANL above that which would have been normally employed. Zucchini squash exhibited higher CRs for most of the radionuclides as compared to pinto beans or sweet corn. The total maximum net positive CEDE estimated from the ingestion of 160 kg (maximum annual consumption rate for all produce per person per year) of pinto beans, sweet corn, and zucchini squash in equal proportions was 74 mrem y^{-1}. Although this dose is below the ICRP PDL of 100 mrem y^{-1} for all pathways, the addition of other internal and external exposure route factors, at conservative levels, may increase the overall dose to over 100 mrem y^{-1}, however. Also, based on the total maximum net positive CEDE of 74 mrem y^{-1}, the RECF was 3.7×10^{-5} (37 in a million) which exceeds the EPA (acceptable) guideline of one in a million.

IV. ACKNOWLEDGMENTS

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Table 1. Soil chemical and physical properties of the study site in Los Alamos Canyon.

Water-soluble cations				Phoshorus and Nitrogen								
Na	Ca	Mg	K	P	NH_4-N	NO_3-N	TKN[1]	Organic Matter	EC[2]	CEC[3]	pH	Texture
mg kg^{-1}								g kg^{-1}	dS m^{-1}	cmol kg^{-1}		
2	190	20	45	20.3	22.7	2.2	500	12.0	0.8	4.8	7.1	sand

[1]Total Kjeldahl Nitrogen
[2]Electrical Conductivity
[3]Cation Exchange Capacity

Table 2. Mean (± 1 SD) radionuclide concentrations in soils from Los Alamos Canyon (LAC) and regional background (RBG).

Location	^{3}H pCi g^{-1} dry	^{137}Cs pCi g^{-1} dry	^{90}Sr pCi g^{-1} dry	^{238}Pu pCi g^{-1} dry	^{239,240}Pu pCi g^{-1} dry	^{241}Am pCi g^{-1} dry	^{tot}U μg g^{-1} dry	gross α pCi g^{-1} dry	gross β pCi g^{-1} dry	gross γ pCi g^{-1} dry
LAC	0.028	47.45**[1]	6.45**	0.051**	1.745**	0.708**	2.15	0.00	31.09**	62.10**
	(0.010)	(2.84)	(3.10)	(0.004)	(0.258)	(0.068)	(0.33)	(6.76)	(8.42)	(7.99)
RBG	0.026	0.26	0.20	0.002	0.011	0.005	2.26	4.39	4.87	2.64
	(0.020)	(0.11)	(0.24)	(0.001)	(0.005)	(0.001)	(0.46)	(1.06)	(0.82)	(0.55)
RSRL[2]	0.704	1.13	0.82	0.008	0.028	0.208	4.05	35.25	13.62	7.33
SAL[3]	260.000	5.10	4.40	27.000	24.000	22.000	29.00			

[1]* and ** denote significantly different from background at the 0.05 and 0.01 probability level, respectively, using a Wilcoxon Rank Sum (one-sided) Test.
[2]Regional Statistical Reference Level; this is the upper limit background (mean + 2 std dev) from Fresquez et al. (1996a).
[3]Los Alamos National Laboratory Screening Action Level for mesa top soils from FIMAD (1997).

Table 3. Mean (± 1 SD) heavy metal concentrations ($\mu g\ g^{-1}$) in soils from Los Alamos Canyon (LAC) and regional background (RBG).[1]

Location	As	Cd	Cr	Hg	Pb	Sb	Zn
LAC	1.10 (0.60)	0.14 (0.08)	4.16 (2.28)	0.03 (0.00)	11.65 (5.56)	0.13 (0.02)	26.98 (10.52)
RBG	3.31 (1.53)	0.13 (0.00)	8.24 (1.81)	0.03 (0.00)	9.44 (2.71)	0.14 (0.03)	31.47 (6.04)
RSRL[2]	5.85	0.25	14.55	0.03	15.18	0.20	47.64
SAL[3]	5.85	80.00	400.00	24.00	500.00	32.00	2.30×10^4

[1]There were no significant differences in any of the elements in soils collected from LAC verses background at the 0.05 probability level using a Wilcoxon Rank Sum (one-sided) Test.

[2]Regional Statistical Reference Level; this is the upper limit background (mean + 2std dev) from Fresquez et al. (1997).

[3]Los Alamos National Laboratory Screening Action Level for mesa top soils from FIMAD (1997).

Table 4. Mean (± 1 SD) radionuclide concentrations in edible crop tissues grown in soils from Los Alamos Canyon (LAC) and regional background (RBG).

Location	^{3}H pCi mL^{-1}	^{137}Cs 10^{-3} pCi g^{-1} dry	^{90}Sr 10^{-2} pCi g^{-1} dry	^{238}Pu 10^{-5} pCi g^{-1} dry	$^{239,240}Pu$ 10^{-5} pCi g^{-1} dry	^{241}Am 10^{-5} pCi g^{-1} dry	^{tot}U ng g^{-1} dry
LAC Beans[1]	1.62 (0.15)	1700.0 (145.0)	507.0 (31.0)	0.0 (1.5)	6.0 (3.0)	21.5 (4.5)	1.0 (0.5)
RBG Beans[1]	0.11 (0.14)	7.5 (11.0)	6.5 (1.0)	-0.5 (0.2)	1.0 (1.0)	7.0 (3.0)	2.5 (0.5)
LAC Corn	0.64 (0.24)*[2]	1905.0 (1023.6)**	172.4 (22.3)**	4.9 (2.0)	9.0 (5.2)*	27.8 (7.5)**	2.1 (2.1)
RBG Corn	0.09 (0.37)	9.7 (3.7)	1.6 (1.2)	2.8 (3.2)	3.1 (3.5)	4.1 (5.5)	1.0 (0.2)
LAC Squash	0.45 (0.20)*	5490.0 (2459.5)**‡	2651.9(352.9)**‡	12.0 (21.0)	81.5 (33.6)**‡	182.5 (66.7)**‡	2.8 (1.0)
RBG Squash	-0.11 (0.44)	46.0 (57.9)	3.2 (1.1)	3.3 (8.4)	12.1 (7.3)	27.1 (10.2)	6.6 (0.6)

[1]Composite of four samples (± 1 counting uncertainty; values are the uncertainty in the analytical results at the 65% confidence level); and, therefore, no statistics could be accomplished. The average dry/wet and ash/dry weight ratio for beans was 0.64 and 0.05, respectively.

[2]* and ** denote significantly different from background for corn and squash at the 0.05 and 0.01 probability level, respectively, using a Wilcoxon Rank Sum (one-sided) Test.

[3]‡denotes significantly different (LAC corn verses LAC squash) at the 0.05 probability level using a Wilcoxon Rank Sum (two-sided) test.

Table 5. Mean plant:soil concentration ratios (dry basis) for various radionuclides in edible crop tissues grown in soils from Los Alamos Canyon (LAC).[1]

Location	^{3}H	^{137}Cs	^{90}Sr	^{238}Pu	^{239,240}Pu	^{241}Am	^{tot}U
LAC Beans	0.83	0.036	0.79	0.000000	0.000034	0.000304	0.00047
LAC Corn	0.33	0.040	0.27	0.000961	0.000052	0.000393	0.00098
LAC Squash	0.23	0.116	4.11	0.002353	0.000467	0.002578	0.00130
NUREG[2]		0.049	0.81	0.000200	0.000200	0.000410	0.01400
EPA[3]		0.030	0.25	0.000045	0.000045	0.000250	0.00400

[1]Calculated from the mean radionuclide concentration (pCi g^{-1} dry or µg g^{-1} dry) in edible crop matter (Table 4) to the mean radionuclide concentration (pCi g^{-1} dry or µg g^{-1} dry) in the associated soil collected within the root zone (Table 2).
[2]Kennedy and Strenge (1992).
[3]Baes et al. (1984).

Table 6. Mean (± 1 SD) heavy metal concentrations (µg g^{-1}) in edible crop tissues grown in soils from Los Alamos Canyon (LAC) and regional background (RBG).

Location	As	Cd	Cr	Hg	Pb	Sb	Zn
LAC Beans[1]	0.10[2]	0.12[2]	0.08[2]	0.05[2]	13.0	0.15[2]	33
RBG Beans[1]	0.10[2]	0.12[2]	0.08[2]	0.05[2]	5.1	0.15[2]	27
LAC Corn	0.10 (0.00)[2]	0.12 (0.00)[2]	0.29 (0.4)[2]	0.05 (0.00)[2]	8.4 (2.8)‡[3]	0.15 (0.0)[2]	64 (32.3)**[4]
RBG Corn	0.10 (0.00)[2]	0.12 (0.00)[2]	0.08 (0.0)[2]	0.05 (0.00)[2]	7.6 (4.5)	0.15 (0.0)[2]	30 (6.6)
LAC Squash	0.23 (0.30)[2]	0.21 (0.10)[2]	0.12 (0.10)[2]	0.05 (0.00)[2]	1.2 (0.0)[2]	0.15 (0.0)[2]	45 (3.5)
RBG Squash	0.10 (0.00)[2]	0.12 (0.00)[2]	0.08 (0.00)[2]	0.05 (0.00)[2]	1.2 (0.0)[2]	0.15 (0.0)[2]	36 (22.7)

[1]Composite of four samples, and therefore no statistics were performed.
[2]Less than values were reduced by one-half concentration.
[3]‡denotes significantly different (LAC corn verses LAC squash) at the 0.05 probability level using a Wilcoxon Rank Sum (two-sided) test.
[4]* and ** denote significantly different from background at the 0.05 and 0.01 probability level, respectively, using a Wilcoxon Rank Sum (one-sided) Test.

Table 7. Mean plant:soil concentration ratios (dry basis) for various heavy metals in edible crop tissues grown in soils from Los Alamos Canyon (LAC).[1]

Location	As	Cd	Cr	Hg	Pb	Sb	Zn
LAC Beans	0.09[2]	0.86[2]	0.019[2]	1.67[2]	1.120	1.150[2]	1.22
LAC Corn	0.09[2]	0.86[2]	0.070[2]	1.67[2]	0.720	1.150[2]	2.35
LAC Squash	0.21[2]	0.71[2]	0.029[2]	1.67[2]	0.100[2]	1.150[2]	1.66
NUREG[3]	0.006	0.15	0.0045	0.20	0.003	0.001	0.59
EPA[4]	0.006	0.15	0.0045	0.20	0.009	0.030	0.90

[1]Calculated from the mean metal concentration (μg g^{-1} dry) in edible crop matter (Table 6) to the mean metal concentrations (μg g^{-1} dry) in the associated soil collected within the root zone (Table 3).
[2]Calculated from less than values in tissue and are probably overestimates of actual values.
[3]Kennedy and Strenge (1992).
[4]Baes et al. (1984).

Table 8. Radionuclide concentrations in composite nonedible crop tissues grown in soils from Los Alamos Canyon (LAC) and regional background (RBG).[1]

Location	^{3}H pCi mL^{-1}	^{137}Cs 10^{-3} pCi g^{-1} dry	^{90}Sr 10^{-2} pCi g^{-1} dry	^{238}Pu 10^{-5} pCi g^{-1} dry	^{239,240}Pu 10^{-5} pCi g^{-1} dry	^{241}Am 10^{-5} pCi g^{-1} dry	^{tot}U ng g^{-1} dry
LAC Beans	0.66 (0.14)	7875.0 (690.0)	15502.5 (945.0)	258.0 (34.5)	7206.0 (240.0)	5235.0 (270.0)	60.0 (6.0)
RBG Beans	0.42 (0.14)	9.0 (4.5)	6.0 (0.5)	3.0 (2.0)	8.0 (2.5)	0.5 (1.5)	2.0 (0.5)
LAC Corn	0.37 (0.14)	5994.0 (495.0)	977.4 (59.4)	15.3 (9.9)	253.8 (36.9)	337.5 (58.5)	4.5 (0.9)
RBG Corn	0.19 (0.13)	0.7 (16.8)	12.6 (0.7)	4.2 (3.5)	9.8 (4.2)	1.4 (2.8)	10.5 (1.4)
LAC Squash	0.79 (0.14)	14004.0 (1152.0)	15476.4 (943.2)	163.8 (25.2)	8661.6 (250.2)	3492.0 (237.6)	12.9 (1.8)
RBG Squash	0.12 (0.13)	8.0 (12.0)	23.2 (1.6)	0.8 (0.8)	11.2 (3.2)	16.8 (12.8)	9.6 (0.8)

[1]Composite of four samples (± counting uncertainty; values are the uncertainty in the analyticl results at the 65% confidence level) per crop species.

Table 9. Plant:soil concentration ratios (dry basis) for various radionuclides in composite nonedible crop tissues grown in soils from Los Alamos Canyon (LAC).[1]

Location	^{3}H	^{137}Cs	^{90}Sr	^{238}Pu	$^{239,240}Pu$	^{241}Am	^{tot}U
LAC Beans	0.34	0.17	24.0	0.05059	0.04130	0.07394	0.0279
LAC Corn	0.19	0.13	1.5	0.00300	0.00145	0.00477	0.0021
LAC Squash	0.40	0.30	24.0	0.03212	0.04964	0.04932	0.0060
NUREG[2]		0.13	1.6	0.00039	0.00039	0.00058	0.0170
EPA[3]		0.08	2.5	0.00045	0.00045	0.00550	0.0085

[1]Calculated from the mean radionuclide concentration (pCi g^{-1} dry or μg g^{-1} dry) in edible crop matter (Table 8) to the mean radionuclide concentration (pCi g^{-1} dry or μg g^{-1} dry) in the associated soil collected within the root zone (Table 2).

[2]Kennedy and Strenge (1992).

[3]Baes et al. (1984).

Table 10. Heavy metal concentrations (μg g^{-1}) in composite nonedible crop tissues grown in soils from Los Alamos Canyon (LAC) and regional background (RBG).[1]

Location	As	Cd	Cr	Hg	Pb	Sb	Zn
LAC Beans	0.70	1.12	0.40	0.05[2]	1.3[2]	0.15[2]	78
RBG Beans	0.10[2]	0.10[2]	0.10[2]	0.05[2]	1.3[2]	0.15[2]	26
LAC Corn	0.10[2]	0.64	0.30	0.05[2]	1.3[2]	0.15[2]	57
RBG Corn	0.10[2]	0.10[2]	0.10[2]	0.05[2]	1.3[2]	0.15[2]	29
LAC Squash	0.70	1.42	0.40	0.05[2]	1.3[2]	0.15[2]	86
RBG Squash	0.20	0.10[2]	0.20[2]	0.05[2]	1.3[2]	0.15[2]	27

[1]Composite of four samples per crop.

[2]Less than values were reduced by one-half concentration.

Table 11. Plant:soil concentration ratios (dry basis) for various heavy metals in composite nonedible crop tissues grown in soils from Los Alamos Canyon (LAC).[1]

Location	As	Cd	Cr	Hg[2]	Pb[2]	Sb[2]	Zn
LAC Beans	0.64	8.0	0.10	1.7	0.11	1.2	2.9
LAC Corn	0.09	4.6	0.07	1.7	0.11	1.2	2.1
LAC Squash	0.64	10.1	0.10	1.7	0.11	1.2	3.2
NUREG[3]	0.042	0.55	0.0075	0.9	0.0058	0.00013	1.4
EPA[4]	0.04	0.55	0.0075	0.9	0.0450	0.20000	1.5

[1]Calculated from the metal concentration (μg g^{-1} dry) in composite nonedible crop matter (Table 10) to the mean metal concentration (μg g^{-1} dry) in the associated soil collected within the root zone (Table 3).
[2]Calculated with less than values in tissue and are probably overestimates of actual values.
[3]Kennedy and Strenge (1992).
[4]Baes et al. (1984).

Table 12. Comparision of mean (± 1 SD) radionuclide concentrations in edible and nonedible crop tissues grown in soils from Los Alamos Canyon (LAC).[1]

Location	^{3}H pCi mL^{-1}	^{137}Cs 10^{-3} pCi g^{-1} dry	^{90}Sr 10^{-2} pCi g^{-1} dry	^{238}Pu 10^{-5} pCi g^{-1} dry	^{239,240}Pu 10^{-5} pCi g^{-1} dry	^{241}Am 10^{-5} pCi g^{-1} dry	^{tot}U ng g^{-1} dry
Edible[2]	0.90 (0.63)	3031.7 (2131.5)	1110.4 (1345.4)	5.6 (6.0)	32.2 (42.8)	77.3 (91.2)	2.0 (0.91)
Nonedible[2]	0.61 (0.22)	9291.0 (4188.5)*	10652.1 (8378.6)	145.7 (122.4)*	5373.8 (4493.4)*	3021.5(2482.4)*	25.8 (29.9)*

[1]* and ** denote significantly different from one another at the 0.05 and 0.01 probability level, respectively, using a Wilcoxon Rank Sum (one-sided) Test.
[2]Edible was n = 3 and nonedible was n = 3.

Table 13. Comparison of mean (± 1 SD) heavy metal concentrations ($\mu g\ g^{-1}$) in edible and nonedible crop tissues grown in soils from Los Alamos Canyon (LAC).[1]

Location	As	Cd	Cr	Hg	Pb	Sb	Zn
Edible[2]	0.14 (0.08)	0.11 (0.01)	0.16 (0.11)	0.05 (0.00)	7.5 (6.0)	0.15 (0.00)	47 (15)
Nonedible[2]	0.50 (0.35)	1.06 (0.39)*	0.37 (0.06)*	0.05 (0.00)	1.3 (0.0)	0.15 (0.00)	74 (15)

[1]* denote significantly different from one another at the 0.05 probability level using a Wilcoxon Rank Sum (one-sided) Test.

[2]Edible was n = 3 and nonedible was n = 3.

Table 14. Total Committed Effective Dose Equivalent (CEDE) in mrem y^{-1} (± 2 sigma) from the Ingestion of Produce Collected from Los Alamos Canyon (LAC) and regional background (RBG).

Location	Pinto Beans	Sweet Corn	Zucchini Squash
LAC	25.4 (± 3.29)	4.63 (± 2.34)	29.9 (± 9.40)
RBG	0.328 (± 0.169)	0.0458 (± 0.0719)	0.0757 (± 0.111)

[1]The consumption rate per crop per person per year was 53 kg (117 lbs).

Table 15. Summary of the Maximum CEDE (CEDE + 2 sigma) by Radionuclide, the Total Maximum CEDE, the Total Maximum Net Positive CEDE and the RECF.

	Maximum CEDE (mrem y^{-1})								
Crop/Location	^{90}Sr	^{137}Cs	U_{tot}	^{238}Pu	^{239}Pu	^{3}H	^{241}Am	Total CEDE	RECF
Pinto Beans[1]									
LAC	25.20	3.40	0.0177	0.0039	0.0176	0.0026	0.0468	28.70	1.4×10^{-5}
RBG	0.3770	0.0503	0.0443	0.0005	0.0044	0.0008	0.0200	0.498	2.5×10^{-7}
(net positive)	24.90	3.35	0.0000	0.0034	0.0132	0.0019	0.0269	28.30	1.4×10^{-5}
Sweet Corn[1]									
LAC	4.06	2.85	0.0105	0.0049	0.0120	0.0027	0.0277	6.97	3.5×10^{-6}
RBG	0.0749	0.0123	0.0050	0.0050	0.0063	0.0019	0.0098	0.118	5.9×10^{-8}
(net positive)	3.99	2.83	0.0082	0.0000	0.0058	0.0008	0.0179	6.85	3.4×10^{-6}
Zucchini Squash[1]									
LAC	34.90	4.16	0.0008	0.0164	0.0512	0.0071	0.1140	39.30	2.0×10^{-5}
RBG	0.0562	0.0647	0.0274	0.0061	0.0092	0.0060	0.0171	0.187	9.3×10^{-8}
(net positive)	34.90	4.10	0.0000	0.0130	0.0420	0.0010	0.0969	39.10	2.0×10^{-5}
All Produce[2]									
LAC	64.20	10.40	0.0290	0.0252	0.0808	0.0124	0.1330	75.00	3.7×10^{-5}
RBG	0.5080	0.1270	0.0676	0.0116	0.0199	0.0087	0.0469	0.789	4.0×10^{-7}
(net positive)	63.80	10.30	0.0082	0.0164	0.0610	0.0037	0.1420	74.30	3.7×10^{-5}

[1]The consumption rate per produce is 53 kg (117 lbs).
[2]The consumption rate for all produce is 160 kg (352 lbs).

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Appendix A

Radionuclide Concentrations (dry weight) in Soils Collected from Los Alamos Canyon (LAC) and Regional Background (RBG).

	^{3}H pCi g^{-1}	^{137}Cs pCi g^{-1}	^{90}Sr pCi g^{-1}	^{tot}U μg g^{-1}	^{238}Pu pCi g^{-1}	^{239}Pu pCi g^{-1}	^{241}Am pCi g^{-1}	gross α pCi g^{-1}	gross β pCi g^{-1}	gross γ pCi g^{-1}
LAC										
GP-1	0.03	49.7	5.1	2.30	0.051	1.71	0.75	-5.85	33.85	67.51
GP-2	0.02	48.7	4.8	2.02	0.050	1.59	0.64	5.85	38.29	62.91
GP-3	0.02	43.3	4.8	1.76	0.047	1.56	0.66	5.85	33.31	67.42
GP-4	0.04	48.1	11.1	2.51	0.057	2.12	0.78	-5.85	18.92	50.56
RBG										
Chamita	0.05	0.41	0.6	2.43	0.003	0.016	0.007	4.8	5.5	2.4
Embudo	0.02	0.40	0.4	1.91	0.002	0.014	0.005	5.4	5.7	2.6
Santa Cruz	0.03	0.11	-0.1	2.18	0.001	0.008	0.004	5.3	5.8	2.8
Otowi	0.04	0.22	0.0	1.92	0.000	0.018	0.005	4.3	4.1	2.4
Jemez	0.01	0.26	0.1	3.18	0.002	0.012	0.006	5.0	4.3	3.8
Bernalillo	0.02	0.17	0.1	2.35	0.004	0.005	0.006	3.3	4.9	2.2
Cochiti	0.01	0.26	0.3	1.88	0.001	0.006	0.005	2.6	3.8	2.3

Appendix B

Heavy Metal Concentrations ($\mu g\ g^{-1}$ dry) in Soils Collected from Los Alamos Canyon (LAC) and Regional Background (RBG).

	As	Hg	Se	Cd	Cr	Pb	Zn
LAC							
GP-1	1.84	0.05	0.2	0.04	2.38	6.34	17.9
GP-2	0.39	0.05	0.2	0.18	2.25	7.36	19.0
GP-3	0.93	0.05	0.2	0.12	4.99	16.2	31.0
GP-4	1.22	0.05	0.2	0.22	7.01	16.7	40.0
RBG							
Chamita	2.3	0.04	0.4	0.13	7.43	11.60	33.6
Embudo	1.7	0.05	0.3	0.13	8.59	7.21	28.0
Santa Cruz	4.6	0.04	0.5	0.13	12.00	13.90	40.2
Otowi	1.8	0.04	0.3	0.13	8.37	7.20	26.5
Jemez	5.7	0.05	0.5	0.13	6.93	6.96	26.5
Bernalillo	4.1	0.05	0.4	0.13	7.78	10.90	38.8
Cochiti	3.0	0.05	0.4	0.13	6.55	8.32	26.7

Appendix C

Radionuclide Concentrations (dry weight) in Edible Crop Tissue Collected from Los Alamos Canyon (LAC) and Regional Background (RBG)

Squash[1]	^{3}H pCi mL^{-1}	^{137}Cs 10^{-3} pCi g^{-1}	^{90}Sr 10^{-2} pCi g^{-1}	^{tot}U ng g^{-1}	^{238}Pu 10^{-5} pCi g^{-1}	^{239}Pu 10^{-5} pCi g^{-1}	^{241}Am 10^{-5} pCi g^{-1}
LAC							
GP-1	0.3	6336.0	2559.6	1.8	-6.0	103.5	179.9
GP-2	0.3	8580.0	3174.0	3.0	37.0	64.0	272.0
GP-3	1.1	3260.0	2427.0	4.0	-4.8	43.2	111.0
GP-4	0.7	3784.0	2447.5	2.2	21.6	115.2	167.2
RBG							
Farmington	-0.3	43.5	1.50	6.0	-7.2	2.7	28.5
Espanola	-0.2	107.0	4.00	7.0	2.0	19.0	21.0
Jemez	-0.5	-31.2	3.60	6.0	5.0	10.0	18.0
Rio Chama	0.5	64.8	3.60	7.2	13.2	16.5	40.8

[1]The average dry/wet and ash/dry weight ratios for squash was 0.05 and 0.10.

Appendix C (Cont.)

Corn[1]	^{3}H pCi mL^{-1}	^{137}Cs 10^{-3} pCi g^{-1}	^{90}Sr 10^{-2} pCi g^{-1}	^{tot}U ng g^{-1}	^{238}Pu 10^{-5} pCi g^{-1}	^{239}Pu 10^{-5} pCi g^{-1}	^{241}Am 10^{-5} pCi g^{-1}
LAC							
GP-1	0.4	2847.0	140.10	5.1	6.3	8.4	38.4
GP-2	0.5	2370.0	178.20	1.8	4.8	11.0	27.9
GP-3	0.7	1926.0	191.40	0.9	6.3	14.4	21.6
GP-4	0.9	477.0	179.70	0.6	2.1	2.1	23.4
RBG							
Farmington	-0.2	8.7	1.50	1.2	-0.3	1.2	9.0
Espanola	-0.2	13.8	1.40	0.8	0.3	5.7	3.2
Jemez	0.3	5.1	0.30	0.9	6.0	6.3	7.5
Rio Chama	0.5	11.1	3.30	0.9	5.1	-0.9	-3.3

[1]The average dry/wet and ash/dry weight ratios for corn was 0.27 and 0.03.

Appendix D

Heavy Metal Concentrations (µg g^{-1} dry) in Edible Crop Tissue Collected from Los Alamos Canyon (LAC) and Regional Background (RBG)

	As	Hg	Sb	Cd	Cr	Pb	Zn
Squash							
LAC							
GP-1	0.6	0.05*	0.15*	0.31	0.23	1.2*	46.0
GP-2	0.1*	0.05*	0.15*	0.12*	0.08*	1.2*	49.0
GP-3	0.1*	0.05*	0.15*	0.27	0.08*	1.2*	43.0
GP-4	0.1*	0.05*	0.15*	0.12*	0.08*	1.2*	41.0
RBG							
Farmington	0.1*	0.05*	0.15*	0.12*	0.08*	1.2*	60.0
Espanola	0.1*	0.05*	0.15*	0.12*	0.08*	1.2*	14.0
Jemez	0.1*	0.05*	0.15*	0.12*	0.08*	1.2*	51.0
Rio Chama	0.1*	0.05*	0.15*	0.12*	0.08*	1.2*	20.0

*Less than values were reduced by one-half concentration.

Appendix D (Cont.)

Corn	As	Hg	Sb	Cd	Cr	Pb	Zn
LAC							
GP-1	0.1*	0.05*	0.15*	0.12*	0.08*	5.6	61.0
GP-2	0.1*	0.05*	0.15*	0.12*	0.08*	12.0	110.0
GP-3	0.1*	0.05*	0.15*	0.12*	0.08*	9.2	42.0
GP-4	0.1*	0.05*	0.15*	0.12*	0.93*	6.8	41.0
RGB							
Farmington	0.1*	0.05*	0.15*	0.12*	0.08*	12.0	28.0
Espanola	0.1*	0.05*	0.15*	0.12*	0.08*	4.0	24.0
Jemez	0.1*	0.05*	0.15*	0.12*	0.08*	11.0	27.0
Rio Chama	0.1*	0.05*	0.15*	0.12*	0.08*	3.5	39.0

*Less than values were reduced by one-half concentration.