LA-13564-MS

Radionuclide and Heavy Metal Concentrations in Fish from the Confluences of Major Canyons That Cross Los Alamos National Laboratory Lands with the Rio Grande

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

Edited by Hector Hinojosa, Group CIC-1

An Affirmative Action/Equal Opportunity Employer

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LA-13564-MS

Issued: February 1999

Radionuclide and Heavy Metal Concentrations in Fish from the Confluences of Major Canyons That Cross Los Alamos National Laboratory Lands with the Rio Grande

P. R. Fresquez
D. H. Kraig
M. A. Mullen
L. Naranjo, Jr.

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

RADIONUCLIDE AND HEAVY METAL CONCENTRATIONS IN FISH FROM THE CONFLUENCES OF MAJOR CANYONS THAT CROSS LOS ALAMOS NATIONAL LABORATORY LANDS WITH THE RIO GRANDE

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

ABSTRACT

Many canyons cross Los Alamos National Laboratory (LANL) lands, and during the early years of operations some of these canyons received various amounts of untreated radioactive waste effluents. Although most of the runoff and/or effluent flow in the canyons is lost to the underlying alluvium and to evapotranspiration before leaving LANL lands, some flow from excessive storm events may eventually reach the Rio Grande (RG). The purpose of this study was to determine the radionuclide and nonradionuclide (heavy metals) contents of bottom-feeding fish (catfish, carp, and suckers) collected from the confluences of some of the major canyons (Los Alamos, Mortandad, Pajarito, and Frijoles) that cross LANL lands with the RG and the potential radiological doses from the ingestion of these fish. Samples of muscle and bone (and viscera in some cases) were analyzed for ^{3}H, ^{90}Sr, ^{137}Cs, ^{tot}U, ^{238}Pu, ^{239,240}Pu, and ^{241}Am and Ag, As, Ba, Be, Cr, Cd, Cu, Hg, Ni, Pb, Sb, Se, and Tl. Most radionuclides, with the exception of ^{90}Sr, in the muscle plus bone portions of fish collected from the LANL canyons/RG study sites were not significantly (Wilcoxon Rank Sum test at $p = 0.05$) higher from fish collected upstream (San Ildefonso/background) of LANL. ^{90}Sr in fish muscle plus bone tissue significantly (Mann-Kendall test for trend at $p = 0.05$) increases in concentration starting from Los Alamos Canyon, the most upstream confluence (fish contained 3.4 pCi g^{-1} [126 Bq kg^{-1}]), to Frijoles Canyon, the most downstream confluence (fish contained 14 pCi g^{-1} [518 Bq kg^{-1}]). Based on the average concentrations (±2SD) of radionuclides in fish tissue from the four LANL confluences, the committed effective dose equivalent from the ingestion of 46 lb (21 kg) (maximum ingestion rate per person per year) of fish, after the subtraction of background, was 0.1 ± 0.1 mrem y^{-1} (1.0 ± 1.0 μSv y^{-1}), and was far below the International Commission on Radiological Protection (all pathway) permissible dose limit of 100 mrem y^{-1} (1000 μSv y^{-1}). Of the heavy metal elements that were found above the limits of detection (Ba, Cu, and Hg) in fish collected from the confluences of canyons that cross LANL and the RG, none were in significantly higher ($p < 0.05$) concentrations than background.

I. INTRODUCTION

Approximately 19 deep, mostly ephemeral, east to west drainage canyons cross Los Alamos National Laboratory (LANL) lands (Figure 1). During the early years of LANL operations (early 1940s), some of these canyon drainage systems, which are the major pathways to off-site receptors, received various amounts of untreated radioactive and nonradioactive (heavy metals) waste effluents (Purtymun, 1974; Hakonson et al., 1980; Hakonson et al., 1981; Fresquez et al., 1995; Bennett et al., 1996). As a result, some of these canyons contain measurable amounts of tritium (^{3}H), strontium (^{90}Sr), cesium (^{137}Cs), plutonium (^{238}Pu and $^{239,240}Pu$), and americium (^{241}Am) (ESP, 1998). Also, heavy metal elements, such as mercury (Hg) have been detected in some canyon bottom sediments (Hakonson et al., 1980). Although most of the runoff and/or effluent flow in the canyons is lost to the underlying alluvium and to evapotranspiration before leaving LANL lands (Stevens et al., 1993), some flow resulting from excessive storm events may eventually reach the Rio Grande (RG) (Abeele et al., 1981).

As part of the Environmental Surveillance Program at LANL, fish, which constitute a pathway by which radionuclides (Nelson and Whicker, 1969; Gustafson, 1969) and heavy metals (Bache et al., 1971; Driscoll et al., 1994) can be transferred to humans, are collected on an annual basis from Cochiti Reservoir (CR), a 10,690-acre flood and sediment control project located on the RG approximately five miles downstream of LANL. Various radionuclides and heavy metals are analyzed in fish from CR and compared to fish collected from Abiquiu Reservoir (AR), a reservoir upstream of LANL. This ongoing study has shown that, with the exception of uranium (U), all other elements in fish collected from CR were similar to radionuclide (Fresquez et al., 1994) and heavy metal (ESP, 1998) concentrations in fish collected from background locations.

Although there is a considerable amount of data on radionuclide and heavy metal concentrations in fish collected downstream of LANL at CR, there has been no attempt to characterize the fish at points along the RG that are closer to potential LANL contamination sources (e.g., canyons). The purpose of

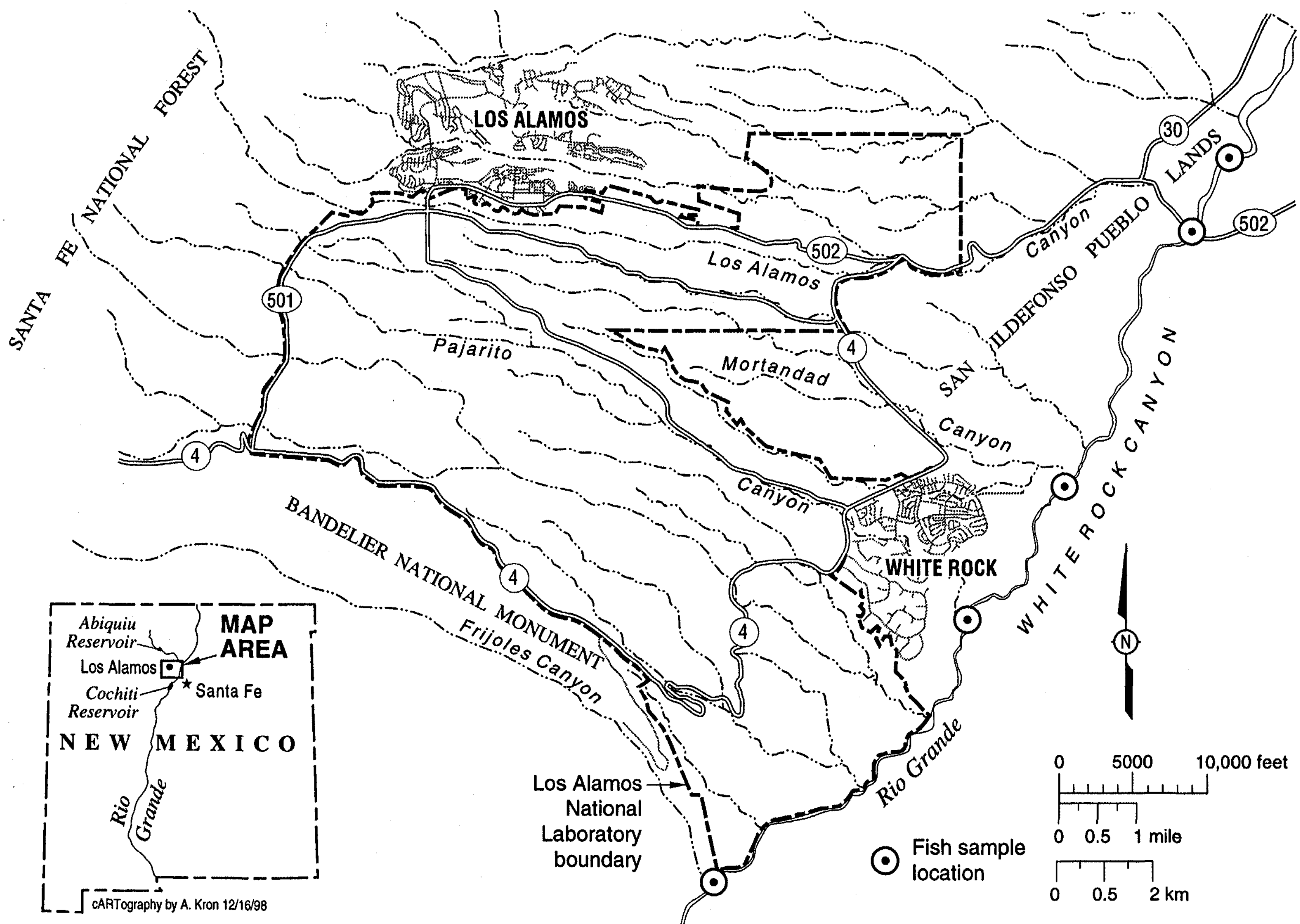

Figure 1. Locations of sites along the Rio Grande where fish were collected.

this study, therefore, was to determine radionuclide and heavy metal constituents in (bottom-feeding) fish collected at the confluences of some of the major canyons—Los Alamos, Mortandad, Pajarito, and Frijoles—that cross LANL lands with the RG. Bottom-feeding fish would be more likely than the surface feeders to ingest any contamination present in sediment materials.

II. METHODS

In September of 1997, samples of bottom-feeding fish—white sucker (*Catostomus commersoni*), channel catfish (*Ictalurus punctatus*), and carp (*Cyprinus carpio*)—were collected using a raft-mounted Smith-Root Electrofisher shocking device along the RG starting at San Ildefonso (SI) (upstream from any intermittent streams that cross LANL lands) and then from the confluences of Los Alamos Canyon (LAC), Mortandad Canyon (MC), Pajarito Canyon (PC), and Frioles Canyon (FC) (Figure 1). Also, bottom-feeding fish were collected from AR and CR with gill nets. These reservoirs are located upstream and downstream of the main study sites, respectively, and were added to this study for completeness and reference. Approximately 10 fish (each fish weighed between two to three lbs) from each study site were collected, placed into large plastic bags, marked for identification, and transferred to a processing laboratory in an ice chest cooled to 4°C. At the laboratory, the fish samples were processed by separating the muscle and associated skeleton from the viscera (entrails). The muscle plus bone samples were rinsed thoroughly with distilled water and towel dryed. About two to three fish were then added together to make four (composite) samples per site. Viscera were composited to make one sample per site.

Each sample was divided into three subsets to provide analysis material for ^{3}H, heavy metals, and radionuclides (another subset was taken for polychlorinated biphenyl analysis and will be reported elsewhere). For ^{3}H analysis, a small subsample (~100 wet g) was placed into a 1-L beaker and heated to collect distillate (water); for heavy metal analysis, a small subsample of muscle (fillet) was placed into a quart size Ziplock plastic bag; and, for radionuclide analysis, the rest of the sample was placed into a tared 2-L beaker and weighed. The beaker contents were oven dried at 75°C for 120 hr, weighed, and ashed incrementally to 500°C for 120 hr. The sample ash was weighed, pulverized, and homogenized before being submitted with the distillate water sample(s) and the wet muscle (fillet) sample to a LANL chemistry laboratory for the analysis of ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239,240}Pu, ^{241}Am, and total U; ^{3}H; and the heavy metal elements, Ag, As, Ba, Be, Cr, Cd, Cu, Hg, Ni, Pb, Sb, Se, and Tl, respectively. All methods of radiochemical and heavy metal analysis in fish have been described previously (Fresquez et al., 1994; Fresquez et al., 1996). Tritium results were expressed in pCi/mL of tissue moisture, heavy metals were reported in µg/g wet, and radionuclides were reported on an oven-dry-weight basis (dry g). All data are presented in Appendices A and B.

Variations in the mean radionuclide content in muscle plus bone between AR and CR and between SI/RG and LAC/RG, MC/RG, PC/RG, and FC/RG were assessed using a Wilcoxon Rank Sum Test at the 0.05 probability level (Gilbert, 1987). Trend analysis was completed using a Mann-Kendal test at the 0.05 probability level. Also, mean radionuclide concentrations in the muscle plus bone of the fish from the two reservoirs (n = 8) were compared with the radionuclide concentrations in fish collected from the LANL canyons/RG (n = 20). Summarized data may be found in Tables 1 and 2.

The committed effective dose equivalent (CEDE) was calculated following procedures recommended by the Department of Energy (USDOE, 1991) and the Nuclear Regulatory Commission (NRC, 1977). The general process for calculating radiological dose from ingestion of fish was as follows. First, after converting from dry to wet weight concentrations (dry/wet weight ratio = 0.288) (Fresquez and Ferenbaugh, 1998), the wet concentration of radionuclides in the meat was multiplied by a dose conversion factor that tells how much radiological dose occurs per unit of food ingested (USDOE 1988). Where different dose conversion factors are provided for a radionuclide, the most conservative (highest) factor was used. The final dose was calculated by multiplying the dose per unit ingested by the total number of units ingested. The dose calculated is the 50-year CEDE. Even though this dose would be received over a 50-year period, the entire dose was reported as though it occurred in the year the fish were ingested. Three calculations were performed: dose per lb of fish consumed, dose per average consumption rate (12.5 lb of fish), and dose per maximum consumption rate (46.2 lb of fish). The dose per lb of fish consumed was reported so that individuals may calculate their own doses based on their knowledge of their actual consumption rates. Finally, the CEDE was multiplied by 5×10^{-7} excess cancer fatalities per person-mrem (NCRP, 1993) to calculate the risk of excess cancer fatalities (RECF) from whole-body radiation from the consumption of fish. Bear in mind, however, that there is a sizable body of research that indicates that risk calculations typically overestimate the true hazard and that health effects from radiation, including cancer, have been observed in humans only at doses in excess of 10 rem (10,000 mrem) delivered at high dose rates (HPS, 1996). Therefore, RECF estimates are provided to the reader as a conservative and qualitative guide only.

III. RESULTS

a. Radionuclide Concentrations

1. Radionuclides in muscle plus bone of fish collected from CR were not significantly higher ($p < 0.05$) than radionuclides in muscle and bone from fish collected from AR (background) (Table 1). In fact, ^{238}Pu in muscle plus bone from fish collected from AR was significantly higher ($p < 0.05$) than ^{238}Pu concentrations in muscle plus bone from fish from CR. The radioactive elements detected in fish from AR and CR then are mostly a result of world wide fallout and natural sources.

2. Most radionuclides, with the exception of ^{90}Sr, in muscle plus bone of fish collected from the confluences of canyons that cross LANL with the RG were not significantly higher ($p < 0.05$) than radionuclides in muscle plus bone of fish collected at SI/RG (background).

3. Strontium-90 significantly increases (Mann-Kendall test for trend at $p = 0.05$) in concentration in muscle plus bone in fish collected from LAC/RG downtream to the FC/RG. There are numerous studies that show ^{90}Sr concentrations in above background concentrations in many canyon bottom sediments within LANL (Fresquez et al.,

1995; Bennett et al., 1996; Fresquez et al., 1998; ESP, 1998).

4. In most cases, radionuclide concentrations, particularly ^{tot}U, in viscera in fish from most sites were higher than radionuclides in the muscle plus bone portions of fish; this is probably a result of the viscera containing sediment (Gallegos et al., 1971) in which radionuclides readily bind (Whicker and Schultz, 1982).

5. Muscle plus bone in fish from the reservoirs (AR and CR) were significantly higher ($p < 0.05$) in ^{3}H concentrations than ^{3}H in the muscle plus bone in fish collected from sites along the RG (Table 2). In contrast, muscle plus bone in fish collected from LANL canyon sites along the RG were significantly higher ($p < 0.05$) in ^{90}Sr, $^{239,240}Pu$, and especially in ^{241}Am, than in fish collected from the reservoirs. Strontium-90 is the only isotope, however, that was attributed to LANL operations.

b. Committed Effective Dose Equivalent

1. All of the CEDEs from the consumption of various amounts of fish from various sources were very low and very similar to one another; the consumption of fish from the LANL canyons/RG, however, exhibited the highest CEDE—a reflection of the higher ^{90}Sr levels (Table 3).

2. The CEDE from the consumption of 12.5 lb of fish (yearly average consumption per person per year) from CR after the subtraction of background (AR) was 0.0085 (± 0.0193) mrem/y.

3. The CEDE from the consumption of 46.2 lb of fish (yearly maximum consumption per person per year) from CR after the subtraction of background (AR) was 0.0314 (± 0.0711) mrem/y.

4. The CEDE from the consumption of 12.5 lb of fish from LANL canyons/RG after the subtraction of background (SI/RG) was 0.0283 (± 0.0129) mrem/y.

5. The CEDE from the consumption of 46.2 lb of fish from LANL canyons/RG after the subtraction of background (SI/RG) was 0.1040 (± 0.0476) mrem/y.

6. The upper (95%) level net CEDE (the CEDE plus two sigma minus background) for the consumption of 46.2 lb of fish from CR was 0.1737 mrem/y.

7. The upper (95%) level net CEDE for the consumption of 46.2 lb of fish from LANL canyons/RG was 0.1991 mrem/y.

8. The "worst case" net CEDE (0.1991 mrem/y) was less than 0.2% of the International Commisson on Radiological Protection public dose limit for all pathways of 100 mrem/y (ICRP, 1978).

9. Over 85% of the dose was a result of ^{90}Sr in the muscle plus bone portion of the fish. Strontium-90, an analog of Ca, deposits primarily in the bone (Whicker and Schultz, 1982); and, therefore, the dose to people that consume only the edible portions of the fish (muscle only), which most people do, would probably be significantly lower (i.e., about 85% lower).

c. Risk of Excess Cancer Fatalities

1. The highest net CEDE (0.1991 mrem/y) corresponded to a RECF of 1.1E-07 (0.1 in a million); this estimate was far below the Environmental Protection Agency upper bound guideline of 10^{-4} (100 in million) that is deemed acceptable for known or suspected carcinogens in air, drinking water, and at hazardous waste sites (USEPA, 1994). Again, the estimates of risk are usually conservative, and health effects from radiation have been observed in humans only at doses in excess of 10 rem delivered at high dose rates (HPS, 1996). Doses from the ingestion of fish collected at the confluences of canyons crossing LANL lands with the RG were a fraction of a mrem.

d. Heavy Metal Concentrations

1. Most heavy metal concentrations in muscle from fish collected from all study sites were below the limits of detection (LOD) (Table 4).

2. Of the heavy metal elements that were above the LOD in fish collected from the RG (Ba, Cu, and Hg), none of these metals in fish collected from the LANL canyons and the RG were in significantly higher ($p < 0.05$) concentrations than in fish collected at SI/RG (background).

3. Barium concentrations were significantly higher ($p < 0.05$) in muscle tissue from fish collected from AR and CR than in muscle in fish collected from the RG, and Hg in fish from AR was in signficantly higher ($p < 0.05$) concentrations than in fish from the RG.

All concentrations of Hg in muscle in fish from all study sites, however, were within 0.5 µg Hg/g wet which is typical of nonpolluted fresh water systems (Abernathy and Cumbie, 1977).

IV. CONCLUSIONS

Bottom-feeding fish—catfish, suckers, and carp—that were collected from the confluences of some of the major canyons that cross LANL lands with the RG exhibited similiar radionuclide (with the exception of ^{90}Sr), and nonradionuclide concentrations to fish collected upstream of any potential LANL contamination sources. Strontium-90 concentrations in fish from LANL canyons/RG may be associated with LANL operations; however, the concentrations of ^{90}Sr in fish decrease to background concentrations farther downstream of LANL at CR. And, based on the most conservative assumptions (a 95% source term and maximum consumption rate), LANL operations do not result in significant doses to the general public from consuming fish along the length of the RG as it passes through the eastern edge of LANL lands to CR. Moreover, since over 85% of the doses were a result of ^{90}Sr detected in the muscle plus bone portions of the fish and most of the ^{90}Sr is associated with the bone, the doses to people that consume only the edible portions of the fish (muscle only), would be significantly lower.

V. ACKNOWLEDGMENTS

We would like to thank the United States Fish and Wildlife Service, Department of Interior, for sampling and boating support—assistance by Joel Lusk, Sky Bristol, Zack Simpson, and Mark Wilson was very much appreciated. Also, we would like to thank Johnnye Lewis, representing San Ildefonso Pueblo; William DeRegan, Corp of Engineers at Cochiti Reservoir; Audrey Hayes, LANL Graduate Research Assistant; Joy Ferenbaugh, LANL Graduate Research Assistant; and Paul Torrez, LANL Undergraduate Student, for participating in sampling, laboratory processing, and/or general study site support.

Table 1. Mean radionuclide concentrations (± std dev) in muscle plus bone and viscera of fish collected upstream and downstream of LANL.

Location	^{3}H pCi mL^{-1}	^{90}Sr 10^{-2} pCi g^{-1} dry	^{137}Cs 10^{-2} pCi g^{-1} dry	^{tot}U ng 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
Abiquiu Reservoir (Background)							
Muscle + bone	0.13 (0.13)A[1]	2.48 (4.43)A	0.84 (0.25)A	10.5 (6.9)A	12.56 (12.2)A	5.5 (4.4)A	8.5 (5.4)A
San Ildefonso/Rio Grande (Background)							
Muscle + bone	-0.21 (0.05)a[2]	-0.75 (2.14)b	0.27 (1.59)a	10.9 (7.9)a	6.85 (14.9)a	33.0 (12.7)a	82.7 (55.3)a
Viscera	-0.10 (0.68)	0.88 (2.84)	0.19 (0.25)	76.2 (7.6)	45.36 (15.1)	85.1 (19.5)	31.2 (12.0)
Los Alamos Canyon/Rio Grande							
Muscle + bone	-0.07 (0.23)a	3.43 (5.95)a	1.27 (0.57)a	38.9 (34.4)a	28.58 (26.3)a	47.5 (45.1)a	119.6 (93.0)a
Viscera	-0.01 (0.68)	3.33 (5.67)	2.25 (3.42)	288.0 (28.8)	15.30 (9.9)	75.6 (18.0)	44.1 (14.4)
Mortandad Canyon/Rio Grande							
Muscle + bone	-0.16 (0.24)a	12.32 (3.57)a	0.24 (0.40)a	19.4 (19.1)a	6.03 (14.2)a	18.9 (16.1)a	79.8 (33.0)a
Viscera	-0.25 (0.66)	49.00 (18.00)	0.90 (0.20)	441.0 (44.0)	10.00 (14.0)	34.0 (20.0)	198.0 (36.0)
Pajarito Canyon/Rio Grande							
Muscle + bone	-0.07 (0.08)a	13.53 (3.34)a	0.40 (0.50)a	15.8 (8.5)a	3.23 (25.0)a	52.5 (31.9)a	97.1 (23.0)a
Viscera	-0.11 (0.67)	20.90 (9.00)	0.10 (0.20)	153.0 (15.0)	-1.00 (10.0)	135.0 (27.0)	57.0 (17.0)
Frijoles Canyon/Rio Grande							
Muscle + bone	-0.33 (0.14)a	13.66 (13.99)a	0.84 (0.92)a	13.3 (5.0)a	3.35 (12.7)a	15.7 (21.9)a	41.1 (34.0)a
Viscera	0.02 (0.68)	10.69 (8.99)	1.13 (0.24)	153.9 (15.4)	-6.48 (13.8)	27.5 (17.8)	54.3 (22.7)
Cochiti Reservoir							
Muscle + bone	0.12 (0.06)A	5.38 (7.67)A	1.20 (0.62)A	24.0 (14.3)A	0.46 (1.5)B	4.8 (1.5)A	-5.1 (27.2)A

[1]Means within the same column for Abiquiu and Cochiti (muscle + bone) followed by the same upper case letter were not signficantly different at the 0.05 probability levels using a nonparametric Wilcoxon Rank Sum test.

[2]Means within the same column for San Ildefonso, Los Alamos, Mortandad, Pajarito, and Frijoles (muscle + bone) followed by the same lower case letter were not signficantly different at the 0.05 probability levels using a nonparametric Wilcoxon Rank Sum test.

Table 2. Comparison of mean radionuclide concentrations (+/- std dev) in muscle plus bone of fish collected from area reservoirs and the Rio Grande.

Location	^{3}H pCi mL^{-1}	^{90}Sr 10^{-2} pCi g^{-1} dry	^{137}Cs 10^{-2} pCi g^{-1} dry	^{tot}U ng 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
Reservoirs	0.12 (0.10)a[1]	3.9 (6.1)b	1.02 (0.49)a	17.2 (12.8)a	6.5 (10.4)a	5.1 (3.1)b	1.7 (19.8)b
Rio Grande	-0.17 (0.18)b	10.7 (8.4)a[2]	0.60 (0.90)a	19.6 (19.4)a	9.6 (19.9)a	33.5 (29.2)a	84.1 (54.6)a

[1]Means within the same column followed by the same letter were not significantly different at the 0.05 probability levels using a nonparametric Wilcoxon Rank Sum test.
[2]Includes all sites along the RG, with the exception of SI.

Table 3. The committed effective dose equivalent for the ingestion of fish collected upstream and downstream of LANL.

Location	mrem/lb (±2SD)	Average[1] mrem/y (±2SD)	Maximum[2] mrem/y (±2SD)
Abiquiu Reservoir (background)	0.00086 (0.00153)	0.0108 (0.0192)	0.0398 (0.0707)
Cochiti Reservoir	0.00154 (0.00461)	0.0193 (0.0578)	0.0712 (0.2130)
San Ildefonso/Rio Grande (background)	0.00084 (0.00105)	0.0105 (0.0132)	0.0388 (0.0485)
LANL Canyons/Rio Grande	0.00314 (0.00311)	0.0388 (0.0390)	0.1428 (0.1436)

[1]Average consumption rate for muscle plus bone is 12.5 lb (5.7 kg) per person per year.
[2]Maximum consumption rate for muscle and bone is 46.2 lb (21.0 kg) per person per year.

Table 4. Mean total recoverable heavy metals (μg wet g^{-1} [± std dev]) in muscle of fish collected upstream and downstream of LANL.

	Ag	As	Ba[2]	Be	Cr	Cd	Cu[2]	Hg[2]	Ni	Pb	Sb	Se	Tl
Abiquiu Reservoir (Background)													
	0.13*[1]	0.25*	0.06*	0.053*	0.06*	0.11*	0.82*	0.34	1.13*	1.25*	1.25*	0.28*	1.25*
	(0.00)	(0.00)	(0.00)	(0.023)	(0.00)	(0.05)	(0.00)	(0.10)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
San Ildefonso/Rio Grande (Background)													
	0.20*	0.13	0.49	0.075*	0.13*	0.15*	0.90	0.21	0.70*	0.15*	0.15*	0.29	0.15*
	(0.00)	(0.05)	(0.41)	(0.000)	(0.07)	(0.00)	(0.42)	(0.03)	(0.31)	(0.00)	(0.00)	(0.10)	(0.00)
Los Alamos Canyon/Rio Grande													
	0.20*	0.10*	1.05	0.075*	0.10*	0.15*	0.54	0.17	0.45*	0.15*	0.15*	0.53*	0.15*
	(0.00)	(0.00)	(1.50)	(0.000)	(0.00)	(0.00)	(0.34)	(0.03)	(0.00)	(0.00)	(0.00)	(0.46)	(0.00)
Mortandad Canyon/Rio Grande													
	0.20*	0.10*	0.35	0.075*	0.21*	0.15*	0.68	0.16	0.88*	0.15*	0.15*	0.29	0.15*
	(0.00)	(0.00)	(0.15)	(0.000)	(0.14)	(0.00)	(0.12)	(0.06)	(0.55)	(0.00)	(0.00)	(0.10)	(0.00)
Pajarito Canyon/Rio Grande													
	0.20*	0.10*	1.36	0.075*	0.10*	0.15*	0.68	0.16	0.63*	0.19*	0.15*	0.28*	0.15*
	(0.00)	(0.00)	(1.42)	(0.000)	(0.00)	(0.00)	(0.56)	(0.04)	(0.35)	(0.08)	(0.00)	(0.17)	(0.00)
Frijoles Canyon/Rio Grande													
	0.20*	0.10*	0.54	0.075*	0.10*	0.15*	0.75	0.21	0.70*	0.21*	0.15*	0.34	0.15*
	(0.00)	(0.00)	(0.46)	(0.000)	(0.00)	(0.00)	(0.18)	(0.05)	(0.31)	(0.13)	(0.00)	(0.13)	(0.00)
Cochiti Reservoir													
	0.07*	0.25*	0.03*	0.030*	0.32*	0.06*	0.42*	0.21	0.58*	1.25*	1.25*	0.28*	1.25*
	(0.00)	(0.00)	(0.03)	(0.030)	(0.28)	(0.04)	(0.37)	(0.10)	(0.50)	(0.00)	(0.00)	(0.00)	(0.00)

[1]Values identified with an * were below the limits of detection (< values) and were reduced by one-half their concentration.
[2]There were no signficantly different means of Ba, Cu, and Hg for Abiquiu versus Cochiti or for San Ildefonso versus Los Alamos, Mortandad, Pajarito, and Frijoles at the 0.05 probability level using a nonparametric Wilcoxon Rank Sum test.

VI. REFERENCES

Abeele, W.V., M.L. Wheeler, and B.W. Burton, "Geohydrology of Bandelier Tuff," Los Alamos Scientific Laboratory report LA-8962-MS (1981).

Abernathy, A.R., and P.M. Cumbie "Mercury Accumulation by Largemouth Bass in Recently Impounded Reservoirs," Bulletin of Environ Contamination and Toxicology, 17:595-602 (1977).

Bache, C.A., W.H. Gutenmann, and D.J. Lusk, "Residues of Total Mercury and Methylemercuric Salts in Lake Trout as a Function of Age," Science 172:951-952 (1971).

Bennett, K., J. Biggs, and P.R. Fresquez, "Radionuclide Contaminant Analysis of Small Mammals, Plants and Sediments within Mortandad Canyon, 1994," Los Alamos National Laboratory report LA-13104-MS (1996).

Driscoll, C.T., C. Yan, C.L. Schofield, R.K. Munson, and J.G. Holsapple, "The Mercury Cycle and Fish in the Adirondack Lakes," Environmental Science and Technology, 28:136-143 (1994).

ESP (Environmental Surveillance Program), "Environmental Surveillance at Los Alamos during 1997," Los Alamos National Laboratory report LA-13487-ENV (1998).

Fresquez, P.R., and J.K. Ferenbaugh, "Moisture Conversion Ratios for the Foodstuffs and Biota Environmental Surveillance Programs at Los Alamos National Laboratory," Los Alamos National Laboratory report LA-UR-98-1054 (1998).

Fresquez, P.R., D.R. Armstrong and J.G. Salazar, "Radionuclide Concentrations in Game and Nongame Fish Upstream and Downstream of Los Alamos National Laboratory: 1981 to 1993," Los Alamos National Laboratory report LA-12818-MS (1994).

Fresquez, P.R., T.E. Foxx, and L. Naranjo, Jr., "Strontium Concentrations in Chamisa (*Chrysothamnus nauseosus*) Shrub Plants Growing in a Former Liquid Waste Disposal Area in Bayo Canyon," Los Alamos National Laboratory report LA-13050-MS (1995).

Fresquez, P.R., D.R. Armstrong, and L. Naranjo, Jr., "Radionuclide and Heavy Metal Concentrations in Soil, Vegetation, and Fish Collected Around and Within Tsicoma Lake in Santa Clara Canyon," Los Alamos National Laboratory report LA-13144-MS (1996).

Gallegos, A.F., F.W. Whicker, and T.E. Hakonson, "Accumulation of Radiocesium in Rainbow Trout via a Non-Food Chain Pathway," Proc. 5th Ann. Health Physics Society Midyear Topical Symposium, Health Physics Aspects of Nuclear Facility Siting, P.G. Voillique and B.R Baldwin, Eds. Comps, IL (1971).

Gilbert, R.O., *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York, N.Y. (1987).

Gustafson, P.F., "Cesium-137 in Freshwater Fish During 1954-1965," in Symposium on Radioecology, U.S. Atomic Energy Commission report CONF-670503, D.J. Nelson and F.C. Evans, Eds, U.S. Atomic Energy Commission, Washington, D.C. (1969).

Hakonson, T.E., R.L. Watters, and W.C. Hanson, "The Transport of Plutonium in Terrestrial Ecosystems," Health Physics **40,** 63–69 (1981).

Hakonson, T.E., G.C. White, E.S. Gladney, and M. Dreicer, "The Distribution of Mercury, Cesium-137, and Plutonium in an Intermittent Stream at Los Alamos," Journal of Environmental Quality 9: 289-292 (1980).

HPS, Health Physics Society, "Radiation Risk in Perspective," Health Physics Society Position Statement, HPS Newsletter (1996).

ICRP (International Commission on Radiological Protection), "Limits of Intakes of Radionuclides by Workers," International Commission on Radiological Protection Publication 30, Pergamon Press, New York, NY (1978).

Nelson, W.C., and F.W. Whicker, "Cesium-137 in Some Colorado Game Fish, 1965-66," in Symposium on Radioecology, U.S. Atomic Energy Commission report CONF-670503, Nelson, D.J. and F.C. Evans, Eds, U.S. Atomic Energy Commission, Washington, D.C. (1969).

NCRP (National Council on Radiation Protection and Measurements), "Limitation of Exposure to Ionizing Radiation," NCRP report No. 116 Washington D.C. (1993).

NRC (Nuclear Regulatory Commission), "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR 50," Appendix I, NRC Report, Regulatory Guide 1.109 (1977).

Perkins, R.W., and C.W. Thomas, "Worldwide Fallout," in Transuranic Elements in the Environment, Technical Information Center, U.S. Department of Energy, Washington, D.C. (1980).

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

Stevens, D.B., P.M. Kearl, and R.W. Lee, "Hydrogeologic Review for the Environmental Restoration Program at Los Alamos National Laboratory," LANL Hydrogeology Panel Final Report, Daniel B. Stephens and Associates, Inc., Albuquerque, N.M., (1993).

USDOE (U.S. Department of Energy), "Internal Dose Conversion Factors for Calculation of Dose to the Public," USDOE report DOE/EP-0071 (1988).

USDOE (U.S. Department of Energy), "Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance," USDOE report DOE/EH-0173T (1991).

USEPA (United States Environmental Protection Agency), "Natural Oil and Hazardous Substance Pollution Contingency Plan: Subpart E: Hazardous Substance Reponse; Section 430," (Remedial Investigation/Feasibility Study and Selection of Remedy) (e)(2)(A)(2), S9FR47416, Washington, D.C. (1994).

Whicker, W.F., and V. Schultz, *Radioecology: Nuclear Energy and the Environment*, CRC Press, Inc., Boca Raton, FL (1982).

APPENDIX A

RADIONUCLIDE CONCENTRATIONS (± COUNTING UNCERTAINTY) IN BOTTOM-FEEDING (NONGAME) FISH COLLECTED FROM THE CONFLUENCES OF MAJOR CANYONS FROM LOS ALAMOS NATIONAL LABORATORY WITH THE RIO GRANDE IN 1997.

Location	^{3}H pCi mL^{-1}	^{90}Sr 10^{-2} pCi g^{-1} dry	^{137}Cs 10^{-2} pCi g^{-1} dry	^{tot}U ng 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
Abiquiu Reservoir							
AR 1	0.00 (0.65)	0.82 (9.0)	1.07 (0.33)	9.8 (0.82)	6.6 (2.5)	5.7 (3.3)	2.5 (4.1)
AR 2	0.24 (0.67)	-0.58 (9.3)	0.93 (0.35)	22.0 (2.32)	3.5 (3.5)	11.6 (5.8)	11.6 (8.1)
AR 3	0.26 (0.67)	10.09 (14.0)	0.74 (1.15)	9.8 (0.82)	6.6 (4.9)	-0.8 (3.3)	9.8 (5.7)
AR 4	0.15 (0.66)	-0.46 (7.5)	0.46 (0.58)	7.0 (1.16)	33.6 (9.3)	5.5 (6.2)	3.5 (4.6)
AR 5	-0.02 (0.65)	2.52 (14.4)	1.01 (0.38)	3.8 (1.26)	12.6 (14.1)	5.5 (6.2)	15.1 (8.8)
San Ildefonso/Rio Grande							
SI 1	-0.24 (0.67)	0.00 (3.5)	1.33 (0.30)	5.2 (0.74)	17.8 (20.0)	38.5 (25.9)	55.5 (14.1)
SI 2	-0.22 (0.67)	1.94 (4.6)	1.73 (0.41)	22.4 (2.04)	-15.3 (8.2)	45.9 (17.3)	165.2 (29.6)
SI 3	-0.14 (0.67)	-2.27 (4.9)	-0.22 (19.40)	9.7 (1.08)	13.0 (15.1)	16.2 (17.3)	62.6 (34.6)
SI 4	-0.25 (0.66)	-2.66 (3.3)	-1.75 (12.60)	6.3 (0.70)	11.9 (10.5)	31.5 (14.0)	47.6 (18.9)
Los Alamos Canyon/Rio Grande							
LA 1	-0.19 (0.67)	-0.43 (2.9)	0.74 (1.05)	3.1 (0.62)	49.0 (15.5)	18.6 (14.3)	41.5 (13.6)
LA 2	-0.33 (0.66)	0.98 (6.0)	1.83 (0.37)	15.9 (1.22)	26.8 (17.1)	108.6 (28.1)	248.9 (42.7)
LA 3	0.17 (0.69)	0.85 (6.2)	1.69 (2.68)	70.5 (7.05)	46.5 (33.8)	53.6 (38.1)	124.1 (36.7)
LA 4	0.06 (0.69)	12.3 (23.5)	0.80 (1.20)	66.0 (7.00)	-8.0 (5.0)	9.0 (9.0)	64.0 (24.0)

APPENDIX A (Cont.).

Location	^{3}H pCi mL^{-1}	^{90}Sr 10^{-2} pCi g^{-1} dry	^{137}Cs 10^{-2} pCi g^{-1} dry	^{tot}U ng 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
Mortandad Canyon/Rio Grande							
M 1	-0.24 (0.67)	17.4 (14.9)	-0.12 (21.40)	13.1 (1.19)	-1.2 (15.5)	22.6 (22.6)	66.6 (26.2)
M 2	-0.18 (0.67)	12.2 (9.3)	0.32 (0.40)	9.6 (0.80)	-10.4 (5.6)	4.0 (8.8)	106.4 (26.4)
M 3	0.17 (0.69)	9.7 (15.4)	-0.00 (23.20)	47.7 (5.16)	16.8 (19.4)	40.0 (24.5)	107.1 (29.7)
M 4	-0.40 (0.65)	10.0 (8.8)	0.77 (1.12)	7.0 (0.70)	18.9 (9.8)	9.1 (9.1)	39.2 (16.8)
Pajarito Canyon/Rio Grande							
P 1	-0.16 (0.67)	11.7 (10.0)	-0.32 (14.60)	28.4 (3.24)	-11.3 (8.1)	61.6 (20.3)	64.0 (17.8)
P 2	-0.07 (0.68)	14.9 (13.6)	0.85 (0.36)	10.9 (1.21)	0.0 (13.3)	49.6 (21.8)	102.9 (26.6)
P 3	0.04 (0.68)	10.0 (15.1)	0.51 (0.25)	12.7 (1.27)	39.4 (24.1)	87.6 (33.0)	104.1 (27.9)
P 4	-0.08 (0.68)	17.5 (15.2)	0.55 (0.83)	11.0 (1.38)	-15.2 (23.5)	11.0 (34.5)	117.3 (33.1)
Frijoles Canyon/Rio Grande							
B 1	-0.53 (0.65)	8.3 (16.8)	1.94 (0.39)	19.4 (2.58)	1.3 (15.5)	-9.0 (19.4)	28.4 (32.3)
B 2	-0.21 (0.67)	34.1 (29.5)	-0.10 (18.00)	15.0 (2.00)	-9.0 (7.0)	37.0 (13.0)	43.0 (37.0)
B 3	-0.34 (0.66)	9.8 (18.3)	1.22 (1.86)	10.5 (0.81)	21.1 (13.8)	4.1 (12.2)	86.7 (31.6)
B 4	-0.25 (0.66)	2.5 (21.2)	0.31 (0.52)	8.2 (1.03)	0.0 (13.4)	30.9 (18.5)	6.2 (29.9)
Cochiti Reservoir							
CR 1	0.06 (0.66)	2.7 (1.8)	2.02 (0.50)	6.3 (1.26)	0.0 (1.3)	6.3 (2.5)	11.3 (3.8)
CR 2	0.20 (0.67)	0.0 (0.9)	1.64 (0.41)	11.5 (0.82)	-1.6 (0.8)	5.7 (1.6)	2.5 (3.3)
CR 3	0.14 (0.66)	0.8 (1.4)	0.46 (0.12)	30.2 (3.48)	1.2 (1.2)	4.6 (2.3)	-53.4 (10.4)
CR 4	0.07 (0.66)	4.8 (6.6)	0.93 (0.23)	32.5 (3.48)	2.3 (1.2)	2.3 (2.3)	8.1 (2.3)
CR 5	0.13 (0.66)	18.7 (13.5)	0.93 (0.23)	39.4 (3.48)	0.5 (1.7)	4.8 (1.8)	5.8 (7.0)

APPENDIX B

HEAVY METALS CONCENTRATIONS (µg/g wet [ppm]) IN BOTTOM-FEEDING (NONGAME) FISH COLLECTED FROM THE CONFLUENCE OF MAJOR CANYONS FROM LOS ALAMOS NATIONAL LABORATORY WITH THE RIO GRANDE IN 1997.

Location	Ba	Cu	Hg
Abiquiu Reservoir			
AR 1	0.063	0.82	0.29
AR 2	0.063	0.82	0.27
AR 3	0.063	0.82	0.26
AR 4	0.063	0.82	0.48
AR 5	0.063	0.82	0.41
San Ildefonso/Rio Grande			
SI 1	0.31	0.74	0.21
SI 2	1.10	1.50	0.24
SI 3	0.27	0.83	0.20
SI 4	0.26	0.54	0.18
Los Alamos Canyon/Rio Grande			
LA 1	0.30	0.20	0.17
LA 2	3.30	0.40	0.14
LA 3	0.26	0.54	0.16
LA 4	0.33	1.00	0.20
Mortandad Canyon/Rio Grande			
M 1	0.30	0.60	0.15
M 2	0.16	0.58	0.13
M 3	0.50	0.71	0.24
M 4	0.44	0.83	0.10
Pajarito Canyon/Rio Grande			
P 1	0.13	0.21	0.17
P 2	3.40	0.85	0.13
P 3	0.80	0.27	0.21
P 4	1.10	1.40	0.13

APPENDIX B (Cont.).

Location	Ba	Cu	Hg
Frijoles Canyon/Rio Grande			
B 1	0.47	0.97	0.22
B 2	1.20	0.70	0.15
B 3	0.14	0.53	0.27
B 4	0.35	0.78	0.19
Cochiti Reservoir			
CR 1	0.012	0.15	0.37
CR 2	0.013	0.15	0.19
CR 3	0.013	0.15	0.18
CR 4	0.063	0.82	0.09
CR 5	0.063	0.82	0.21

Los Alamos
NATIONAL LABORATORY

Los Alamos, New Mexico 87545