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Radionuclide Concentrations in Game and Nongame Fish Upstream and Downstream of Los Alamos National Laboratory: 1981 to 1993

Los Alamos
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environmental protection program at LANL, fish are collected on an annual basis upstream and downstream of the Laboratory to monitor Laboratory operations for potential radiological contamination to the food chain. Cochiti reservoir, a 10,690-acre flood and sediment control project, is located on the Rio Grande approximately five miles downstream from the Laboratory. Radionuclides in fish collected from Cochiti reservoir are compared to fish collected from Abiquiu, Heron, and El Vado reservoirs. Abiquiu, Heron, and El Vado are located on the Rio Chama river, upstream from the confluence of the Rio Grande and intermittent streams that cross Laboratory lands. These reservoirs are also sufficiently distant from the Laboratory as to be unaffected by airborne emissions.

This report summarizes radionuclide concentrations in game (surface-feeding) and nongame (bottom-feeding) fish collected by the LANL Environmental Protection Group (ESH-8) from 1981 to 1993.

II. METHODS

Samples of fish were collected from Cochiti, Abiquiu, Heron, and El Vado reservoirs located in northern New Mexico each year from 1981 to 1993 between the months of May and September using gill nets, trotlines, and rod and reel (Figure 1).

Fish were separated into two categories for analysis: game (surface-feeders) and nongame (bottom-feeders). Game or surface-feeding fish collected over the years consisted of Rainbow Trout (*Salmo gairdneri*), Brown Trout (*Salmo trutta*), Kokanee Salmon (*Oncorhynchus nerka*), Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieui*) White Crappie (*Pomoxis annularis*), and Walleye (*Stizostedion vitreum*). Nongame or bottom-feeding fish collected over the years included the White Sucker (*Catostomus commersoni*), Channel Catfish (*Ictalurus punctatus*), Carp (*Cyprinus carpio*), and Carp Sucker (*Carpiodes carpio*). The latter fish derive most of their food supply from the bottom portion of the reservoir(s), and would be most likely to ingest any contamination present in sediments than the surface-feeders.

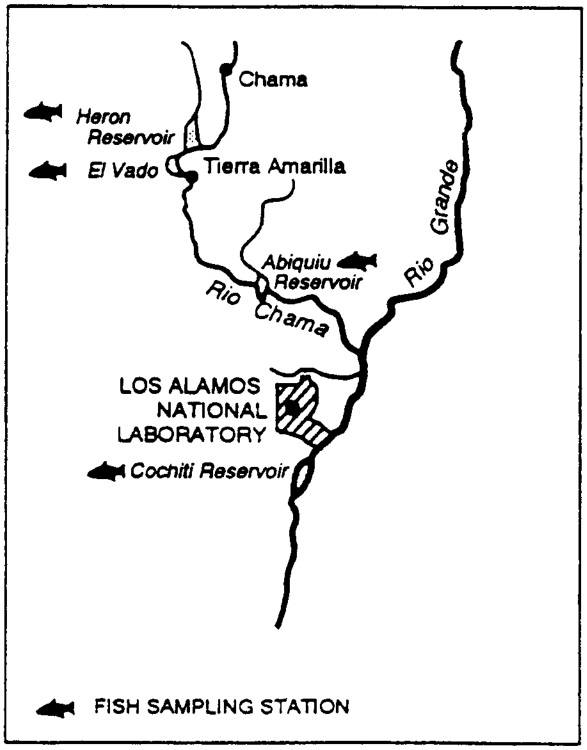

Fig. 1. Fish sampling locations.

All fish samples were gutted, heads and tails were removed, and samples were rinsed with distilled water. Approximately 1000 g of wet fish muscle (and associated skeleton) were placed into tared 1-L beakers and weighed. The beaker contents were oven dried at 80°C for 120 hrs, weighed, and ashed at 500°C for 120 hrs. The sample ash was weighed, pulverized, and homogenized before it was submitted to the Laboratory for the analysis of ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu, and total uranium (U). All methods of radiochemical analysis

RADIONUCLIDE CONCENTRATIONS IN GAME AND NONGAME FISH UPSTREAM AND DOWNSTREAM OF LOS ALAMOS NATIONAL LABORATORY: 1981 to 1993

by

P.R. Fresquez, D.R. Armstrong and J.G. Salazar

ABSTRACT

Radionuclide concentrations were determined in game (surface-feeding) and nongame (bottom-feeding) fish collected from reservoirs upstream (Abiquiu, Heron, and El Vado) and downstream (Cochiti) of Los Alamos National Laboratory from 1981 to 1993. The average levels of ^{90}Sr, ^{137}Cs, ^{238}Pu, and ^{239}Pu in game and nongame fish collected from Cochiti reservoir were not significantly different in fish collected from reservoirs upstream of the Laboratory. Total uranium was the only radionuclide that was found to be significantly higher in both game and nongame fish from Cochiti as compared to fish from Abiquiu, Heron, and El Vado. Uranium concentrations in fish collected from Cochiti, however, significantly decreased from 1981 to 1993, and no evidence of depleted uranium was found in fish samples collected from Cochiti in 1993. Based on the average concentration of radionuclides over the years the effective (radiation) dose equivalent from consuming 46 lb of game fish and nongame fish from Cochiti reservoir after natural background has been subtracted was 0.005 and 0.009 mrem/yr, respectively. The highest dose was <0.01% of the International Commission on Radiological Protection (ICRP) permissible dose limit for protecting members of the public.

I. INTRODUCTION

The source of most radioactive elements detected in the environment is from fallout produced by nuclear weapons testing (Klement 1965), the burn-up of satellite power sources in the atmosphere (Perkins and Thomas 1980), and common minerals in the earths crust (Wicker and Schultz 1982). Other sources include planned or unplanned releases of radioactive contaminated gases, solids and/or effluents from nuclear weapons research, and development and testing facilities (USDOE 1979). Treated radioactive liquid waste effluents, for example, are discharged by Los Alamos National Laboratory (LANL) into the dry canyon bottoms (Purtyman 1975). 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 river (Abeele et al. 1981).

Fish constitute one pathway by which radionuclides can be transferred to humans (Nelson and Wicker 1969, Gustafson 1969). As part of the salmon data collected from comparable (background) reservoirs and lakes in Colorado (Whicker et al. 1972, Nelson and Wicker 1969). Total U was the only radionuclide that was significantly higher in game fish collected from Cochiti as compared to background levels. The differences between the two mean values, however, were small (i.e., 2.0 ng/dry g).

Concentrations of ^{90}Sr, ^{137}Cs, ^{238}Pu, and ^{239}Pu in nongame fish collected downstream of the Laboratory were not significantly different from nongame fish collected from background locations (Table 2). Again, total U was significantly higher in nongame fish from Cochiti as compared to nongame fish collected upstream of the Laboratory. Although both game and nongame fish from Cochiti had higher uranium concentrations than fish collected upstream of the Laboratory, the isotopic ratio of ^{235}U (1.25 x 10^{13} atoms/g ash) to ^{238}U (1.74 x 10^{15} atoms/g ash) in Cochiti bottom-feeding fish collected during the 1993 season were consistent with naturally occurring uranium (e.g., 0.0072) (Efurd 1994). In other words, there was no evidence of depleted uranium in these fish samples. Depleted uranium, a by-product of uranium enrichment processes, has been used in dynamic weapons testing at Laboratory firing sites since the mid-1940s (Becker 1992). The uranium detected in fish samples from Cochiti (as well as from Abuiqui, Heron, and El Vado) was probably from common uranium-bearing minerals (Wicker and Schultz 1982). Natural uranium in soils from northern New Mexico and in Bandelier tuff around the Los Alamos area, for example, ranges in concentration from 1.3 to 3.9 µg/g (Purtymun et al. 1987) and from 4.0 to 11.4 µg/g (Crowe et al. 1978), respectively.

As expected, the bottom-feeders from both downstream and upstream reservoirs contained higher average uranium contents (12.5 ng/dry g) than the surface-feeders (3.9 ng/dry g). The higher concentration of uranium in bottom-feeders as compared to surface-feeders may be attributed to the ingestion of

Table 2. Average radionuclide contents in nongame (bottom- feeding) fish collected upstream and downstream of Los Alamos National Laboratory from 1981 to 1993.

	^{90}Sr 10^{-2}pCi/dry g		^{137}Cs 10^{-2}pCi/dry g		Uranium ng/dry g		^{238}Pu 10^{-5}pCi/dry g		^{239}Pu 10^{-5}pCi/dry g	
UPSTREAM										
N[1]	11.0		13.0		13.0		13.0		13.0	
Minimum	2.6	(2.0)[2]	-7.6	(100.0)	2.9	(4.6)	-0.2	(20.0)	3.0	(16.0)
Maximum	14.0	(10.0)	26.8	(67.0)	20.0	(30.0)	11.0	(62.0)	22.0	(152.0)
Mean	6.2	(7.0)a[3]	7.6	(19.3)a	7.6	(8.6)b	3.5	(6.3)a	6.3	(12.9)a
DOWNSTREAM										
N	11.0		13.0		13.0		13.0		13.0	
Minimum	1.5	(1.2)	-2.2	(20.8)	5.9	(7.2)	-5.0	(6.6)	-9.0	(42.0)
Maximum	8.0	(2.6)	17.8	(35.0)	66.0	(18.0)	7.6	(16.0)	11.0	(60.0)
Mean	4.3	(5.4)a	7.3	(12.4)a	17.3	(32.4)a	3.3	(7.2)a	2.4	(9.8)a

[1]N = Number of years measured.

[2](2 Sigma)

[3]Means within the same column followed by the same letter are not significantly different at the 0.05 level using a Student's t-test on normal or log-transfered data.

have been described previously (Salazar 1984). Results are reported on an oven-dry-weight basis (dry g). The ratio of ^{235}U to ^{238}U was determined by thermal ionization mass spectrometry (Efurd et al. 1993) on samples of fish ash collected and processed during the 1993 season.

Variations in the mean radionuclide content between upstream and downstream game and nongame fish samples were tested using a Student's t-test on normal or log-transferred data at the 0.05 probability level. All of the data collected were graphed and subjected to a nonparametric Mann-Kendall test for trends at the 0.05 probability level (Gilbert 1987). The effective (radiation) dose equivalent (EDE) was calculated from fish data collected from Cochiti reservoir using the methodology outlined in ICRP Publication 30 (ICRP 1978) and the public dose conversion factors in the Department of Energy report DOE/EH-0071 (USDOE 1984).

III. RESULTS AND DISCUSSION

All of the (radionuclide) data collected for game and nongame fish upstream and downstream of the Laboratory between 1981 to 1993 can be found in Appendix A and Appendix B, respectively. The range (minimum and maximum), mean radionuclide contents, and standard deviations (2 sigma) for these data are summarized in Tables 1 and 2.

Most radionuclides (^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu) were not significantly different in game fish collected from Cochiti reservoir as compared to game fish collected from the reservoirs located upstream of the Laboratory (Table 1). These data, particularly ^{90}Sr and ^{137}Cs, compare well with crappie, trout, and

Table 1. Average radionuclide contents in game (surface-feeding) fish collected upstream and downstream of Los Alamos National Laboratory from 1981 to 1993.

	^{90}Sr 10^{-2}pCi/dry g		^{137}Cs 10^{-2}pCi/dry g		Uranium ng/dry g		^{238}Pu 10^{-5}pCi/dry g		^{239}Pu 10^{-5}pCi/dry g	
UPSTREAM										
N[1]	11.0		13.0		13.0		13.0		13.0	
Minimum	1.0	(0.6)[2]	-8.0	(100.0)	1.2	(1.5)	-38.0	(24.0)	-0.4	(6.0)
Maximum	19.0	(30.0)	34.0	(30.0)	7.0	(32.0)	14.0	(86.0)	40.0	(194.0)
Mean	6.3	(10.7)a[3]	6.2	(21.5)a	2.9	(3.6)b	-1.4	(25.0)a	7.4	(20.9)a
DOWNSTREAM										
N	11.0		13.0		13.0		13.0		13.0	
Minimum	4.1	(1.8)	-7.9	(30.0)	1.6	(0.5)	-4.4	(24.0)	-4.0	(16.0)
Maximum	12.0	(8.9)	20.3	(42.0)	10.0	(11.0)	10.0	(6.0)	10.0	(32.0)
Mean	7.2	(4.8)a	3.6	(17.6)a	4.9	(4.9)a	3.0	(8.6)a	5.8	(7.2)a

[1]N = Number of years measured.
[2](2 Sigma)
[3]Means within the same column followed by the same letter are not significantly different at the 0.05 level using a Student's t-test on normal or log-transfered data.

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sediments on the bottom of the lake (Gallegos et al. 1971). Sediments represent the accumulation or sink compartment for most radionuclides (Wicker and Schultz 1982).

No upward trends in radionuclide contents in game or nongame fish were observed during the 1981-to-1993 measurement period in any of the radionuclide data from Cochiti reservoir (Figures 2 to 6). In fact, ^{90}Sr and total U in nongame fish significantly decrease over time. Total U in nongame fish collected from Cochiti reservoir significantly decreased from 66 ng/dry g in 1981 to 12.0 ng/dry g in 1993 (Figure 4).

Overall, the estimated radiation dose from consuming 21 kg (46.3 lb) of game and nongame fish from Cochiti reservoir after natural background has been subtracted was 0.005 ($\pm$0.001) and 0.009 ($\pm$0.085) mrem/yr. The highest value was <0.01% of the ICRP permissible dose limit of 100 mrem/yr from all pathways. Laboratory operations, therefore, do not result in significant doses, if any, to the general public from consuming fish from Cochiti reservoir.

ACKNOWLEDGMENT

Our special thanks to Belinda Harrigan, Consuelo Montoya and Dale Lyons for constructing the figures.

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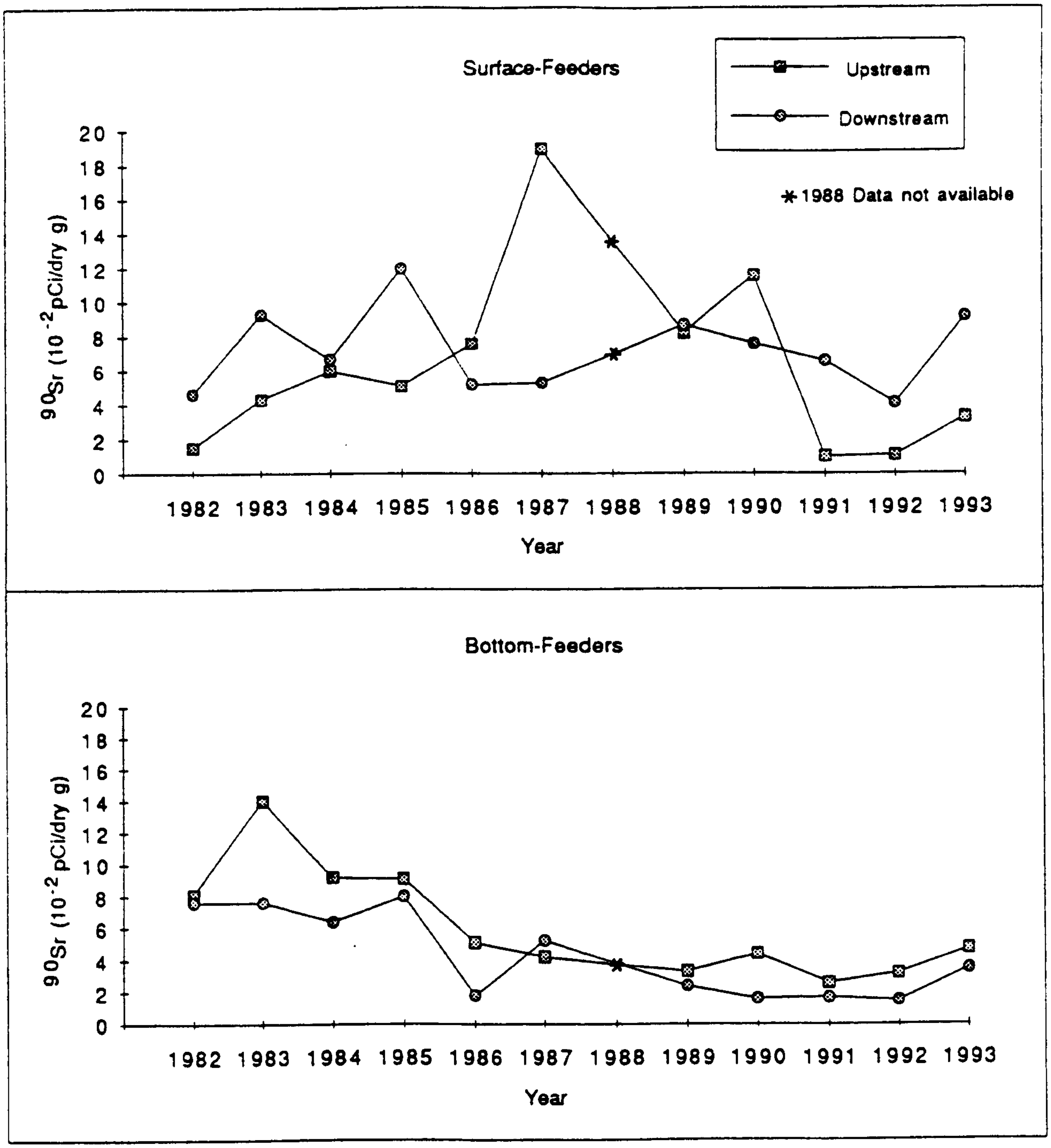

Figure 2. Strontium-90 Concentrations in Game (Surface-Feeding) and Non-game (Bottom-Feeding) Fish Collected Upstream and Downstream from LANL.

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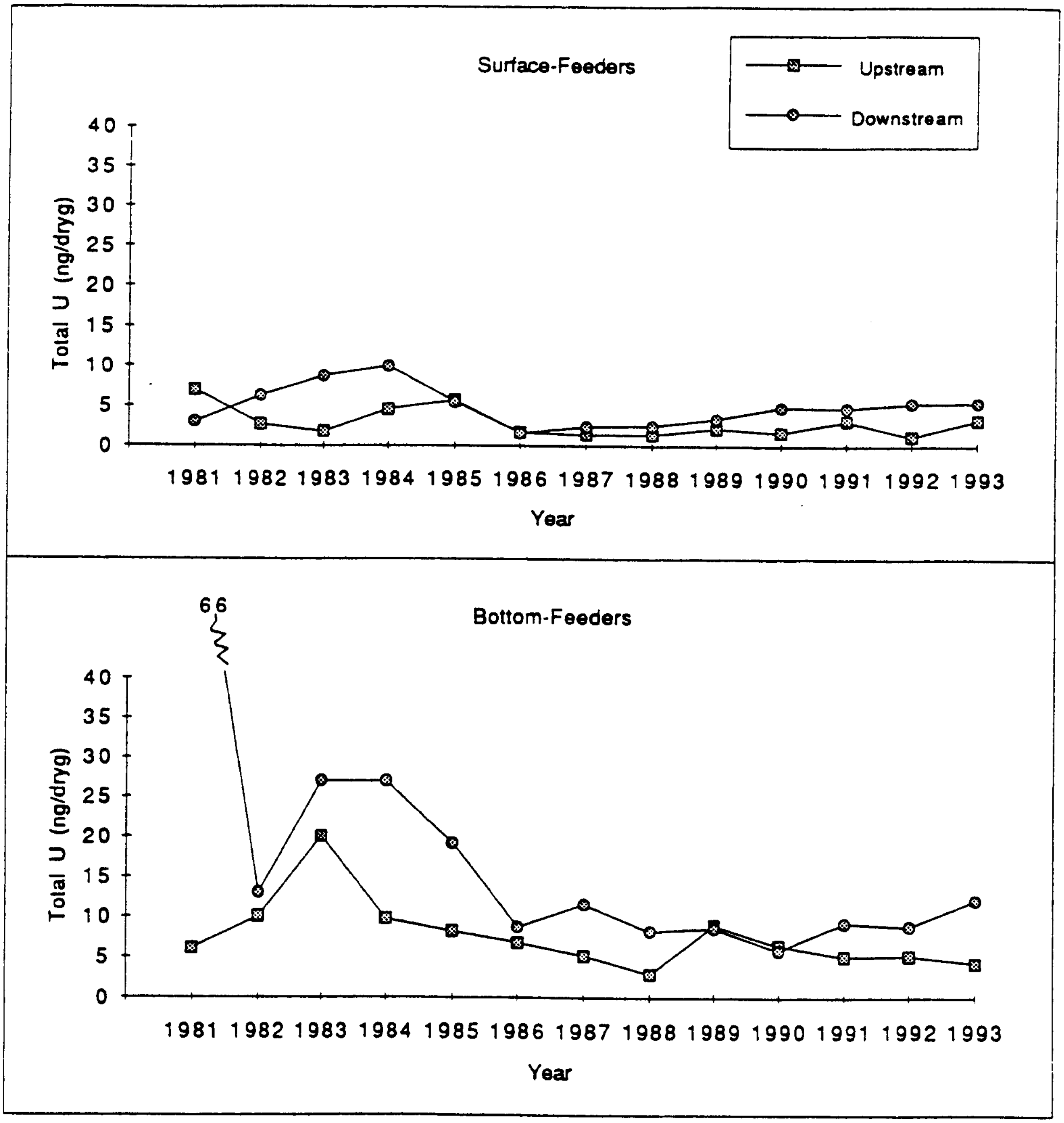

Figure 4. Total Uranium Concentrations in Game (Surface-Feeding) and Non-game (Bottom-Feeding) Fish Collected Upstream and Downstream from LANL.

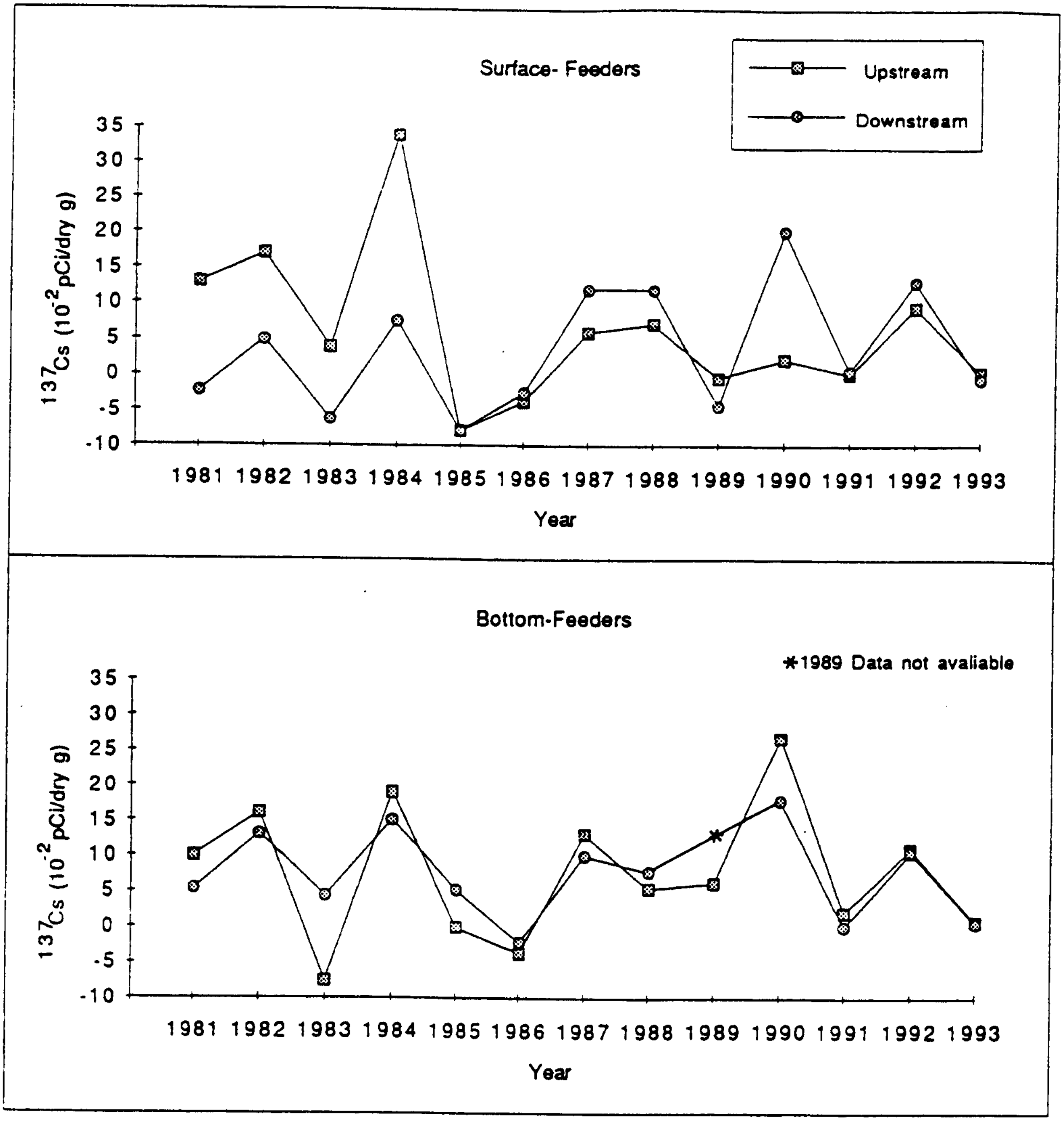

Figure 3. Cesium-137 Concentrations in Game (Surface-Feeding) and Non-game (Bottom-Feeding) Fish Collected Upstream and Downstream from LANL.

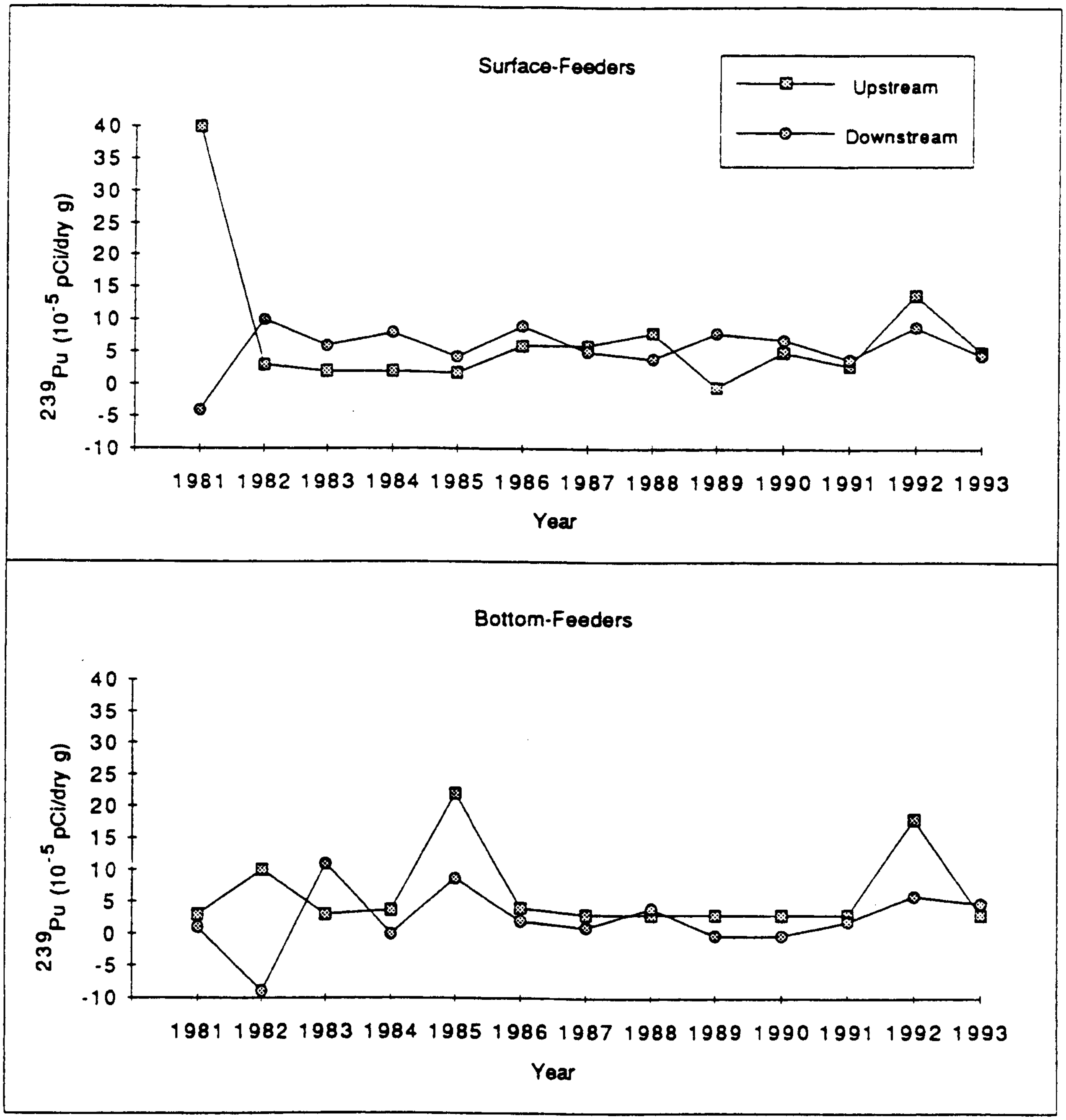

Figure 6. Pu-239 Concentrations in Game (Surface-Feeding) and Non-game (Bottom-Feeding) Fish Collected Upstream and Downstream from LANL.

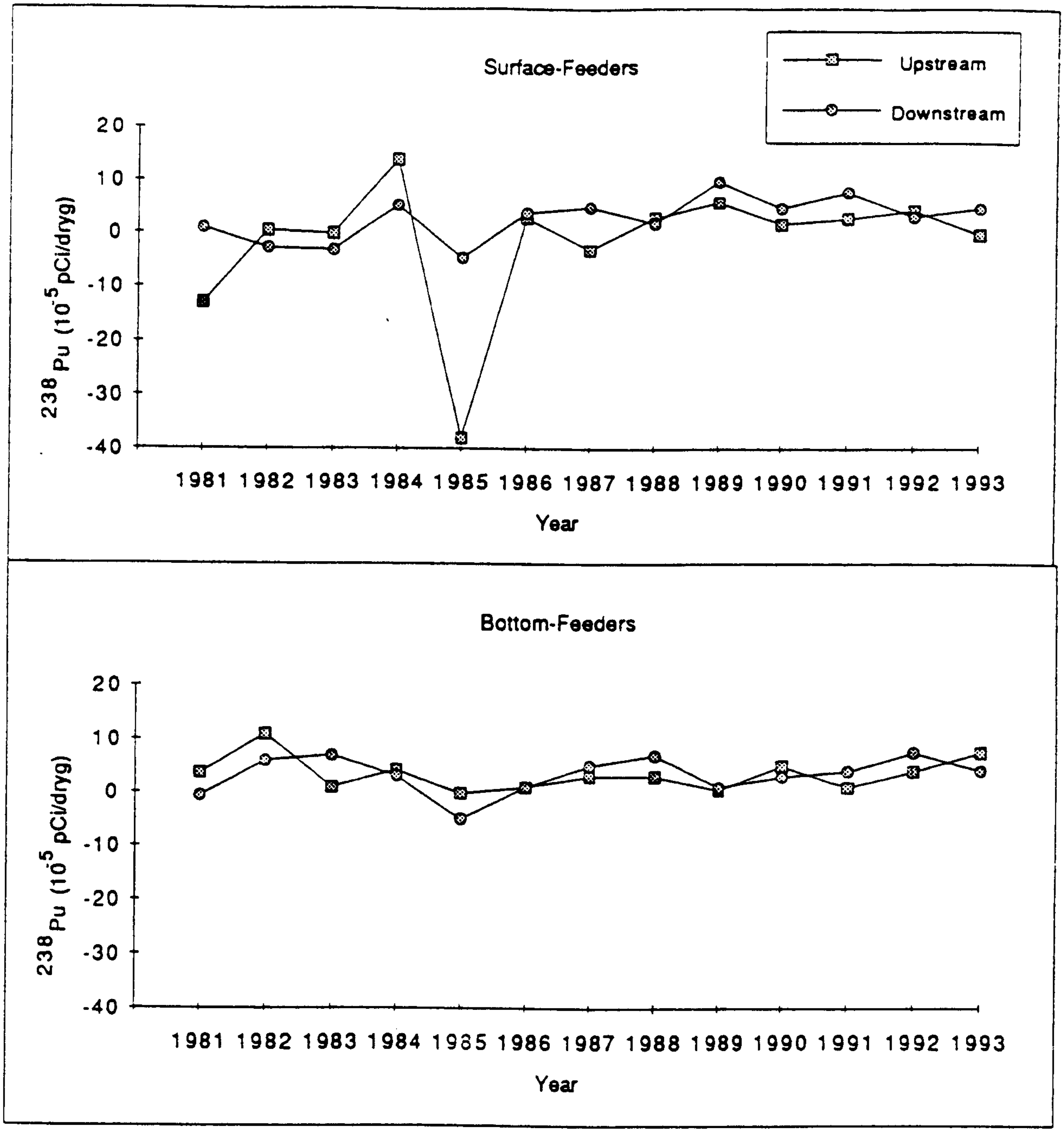

Figure 5. Pu-238 Concentrations in Game (Surface-Feeding) and Non-game (Bottom-Feeding) Fish Collected Upstream and Downstream from LANL.

APPENDIX A (cont)

	^{90}Sr 10^{-2} pCi/dry g		^{137}Cs 10^{-2} pCi/dry g		Total U ng/dry g		^{238}Pu 10^{-5} pCi/dry g		^{239}Pu 10^{-5} pCi/dry g	
					1984					
UPSTREAM										
N	15		14		15		15		15	
MIN	0.6	(0.3)	2.3	(68.0)	0.6	(0.4)	-230.0	(52.0)	-15.0	(60.0)
MAX	18.0	(1.9)	110.0	(120.0)	7.3	(52.0)	140.0	(84.0)	27.0	(52.0)
MEAN	6.0	(11.0)	34.0	(30.0)	4.6	(2.0)	14.0	(86.0)	2.0	(22.0)
DOWNSTREAM										
N	10		10		10		9		9	
MIN	-0.1	(1.4)	-29.0	(168.0)	2.8	(24.0)	-4.5	(44.0)	0.0	(0.0)
MAX	14.0	(2.4)	39.0	(72.0)	40.0	(16.4)	14.0	(128.0)	14.0	(148.0)
MEAN	6.7	(9.6)	7.6	(21.0)	10.0	(11.0)	5.3	(6.1)	8.0	(94.0)
					1985					
UPSTREAM										
N	5		5		5		5		5	
MIN	3.9	(-.-)	-91.0	(-.-)	1.5	(-.-)	-180.0	(-.-)	0.0	(-.-)
MAX	11.0	(-.-)	41.0	(-.-)	17.9	(-.-)	1.3	(-.-)	0.3	(-.-)
MEAN	5.1	(10.2)	-8.0	(100.0)	5.7	(14.0)	-38.0	(160.0)	1.8	(4.2)
DOWNSTREAM										
N	10		10		9		10		10	
MIN	2.7	(-.-)	-25.0	(-.-)	1.6	(-.-)	-4.9	(-.-)	0.0	(-.-)
MAX	35.0	(-.-)	15.0	(-.-)	8.9	(-.-)	8.1	(-.-)	18.0	(-.-)
MEAN	12.0	(18.0)	-7.9	(30.0)	5.5	(4.4)	-4.4	(24.0)	4.2	(10.4)
					1986					
UPSTREAM										
N	16		16		16		5		5	
MIN	4.7	(0.6)	-14.0	(11.0)	0.7	(0.2)	-12.0	(30.0)	-3.0	(12.0)
MAX	9.6	(0.6)	4.6	(-.-)	2.7	(0.6)	12.0	(18.0)	10.0	(18.0)
MEAN	7.6	(2.8)	-3.8	(11.4)	1.7	(1.1)	3.0	(20.0)	6.0	(10.0)
DOWNSTREAM										
N	10		10		10		5		5	
MIN	3.6	(0.6)	-7.9	(9.5)	1.2	(0.2)	-3.0	(18.0)	2.0	(8.0)
MAX	6.5	(0.6)	4.7	(2.0)	2.0	(0.4)	15.0	(16.0)	21.0	(20.0)
MEAN	5.2	(1.6)	-2.6	(7.4)	1.6	(0.5)	4.0	(14.0)	9.0	(14.0)

APPENDIX A
Radionuclide Concentrations in Game (Surface-Feeding) Fish Upstream and Downstream of Los Alamos National Laboratory From 1981 to 1993.

	^{90}Sr 10^{-2} pCi/dry g		^{137}Cs 10^{-2} pCi/dry g		Total U ng/dry g		^{238}Pu 10^{-5} pCi/dry g		^{239}Pu 10^{-5} pCi/dry g	
1981										
UPSTREAM										
N[1]	0		7		7		7		7	
MIN	-.-[2]	(-.-)[3]	-4.0	(-.-)	0.0	(-.-)	-120.0	(-.-)	-4.0	(-.-)
MAX	-.-	(-.-)	41.0	(-.-)	42.0	(-.-)	14.0	(-.-)	260.0	(-.-)
MEAN	-.-	(-.-)[4]	13.0	(34.0)	7.0	(32.0)	-13.0	(94.0)	40.0	(194.0)
DOWNSTREAM										
N	0		1		1		1		1	
MIN	-.-	(-.-)	-2.4	(9.6)	3.0	(2.0)	1.0	(4.0)	-4.0	(16.0)
MAX	-.-	(-.-)	-2.4	(9.6)	3.0	(2.0)	1.0	(4.0)	-4.0	(16.0)
MEAN	-.-	(-.-)	-2.4	(0.0)	3.0	(0.0)	1.0	(0.0)	-4.0	(0.0)
1982										
UPSTREAM										
N	4		5		5		5		5	
MIN	0.0	(0.0)	4.4	(3.4)	0.0	(0.6)	-5.0	(4.0)	-6.0	(16.0)
MAX	2.9	(0.0)	35.0	(26.0)	4.4	(1.2)	6.0	(20.0)	17.0	(26.0)
MEAN	1.5	(2.4)	17.0	(24.0)	2.7	(3.2)	0.5	(8.8)	3.0	(17.4)
DOWNSTREAM										
N	4		4		4		4		4	
MIN	1.4	(0.0)	-13.0	(28.0)	0.0	(7.2)	-12.0	(16.0)	-7.0	(36.0)
MAX	11.5	(1.0)	16.0	(10.0)	13.9	(11.2)	110.0	(60.0)	30.0	(40.0)
MEAN	4.6	(9.2)	5.0	(26.0)	6.3	(12.0)	-2.7	(124.0)	10.0	(32.0)
1983										
UPSTREAM										
N	5		8		8		8		8	
MIN	1.0	(0.0)	-6.1	(10.0)	0.0	(3.8)	-6.0	(10.0)	-12.0	(10.0)
MAX	11.0	(2.0)	10.0	(12.0)	6.1	(2.0)	6.0	(6.0)	6.0	(10.0)
MEAN	4.3	(8.0)	3.8	(11.0)	1.8	(4.8)	0.0	(10.0)	2.0	(12.0)
DOWNSTREAM										
N	6		8		8		8		8	
MIN	4.9	(0.4)	-58.0	(108.0)	5.3	(3.6)	-14.0	(14.0)	-11.0	(18.0)
MAX	18.0	(1.4)	15.0	(14.0)	21.0	(10.0)	6.0	(0.0)	21.0	(0.0)
MEAN	9.3	(9.2)	-6.3	(50.0)	8.8	(10.2)	-3.0	(16.0)	6.0	(18.0)

APPENDIX A (cont)

	^{90}Sr 10^{-2} pCi/dry g		^{137}Cs 10^{-2} pCi/dry g		Total U ng/dry g		^{238}Pu 10^{-5} pCi/dry g		^{239}Pu 10^{-5} pCi/dry g	
1990										
UPSTREAM										
N	36		46		46		25		25	
MIN	2.6	(0.4)	-21.0	(24.0)	0.5	(0.2)	-14.0	(22.0)	-5.0	(12.0)
MAX	50.0	(5.2)	24.0	(34.0)	3.2	(0.6)	14.0	(20.0)	14.0	(28.0)
MEAN	11.6	(12.8)	2.2	(10.4)	1.7	(0.8)	2.0	(8.0)	5.0	(8.0)
DOWNSTREAM										
N	12		12		12		12		12	
MIN	4.8	(1.2)	-3.2	(12.0)	3.6	(0.2)	-11.0	(6.0)	-5.0	(6.0)
MAX	12.2	(3.6)	49.6	(92.0)	7.6	(1.4)	21.0	(70.0)	35.0	(52.0)
MEAN	7.6	(3.8)	20.3	(41.8)	4.9	(2.0)	5.0	(20.0)	7.0	(22.0)
1991										
UPSTREAM										
N	12		12		12		12		12	
MIN	0.6	(2.4)	-3.7	(1.8)	1.7	(0.4)	0.0	(4.0)	-3.0	(4.0)
MAX	1.6	(5.2)	2.4	(5.2)	5.2	(1.0)	8.0	(22.0)	10.0	(20.0)
MEAN	1.0	(0.6)	0.1	(3.2)	3.2	(2.0)	3.0	(8.0)	3.0	(8.0)
DOWNSTREAM										
N	12		12		12		12		12	
MIN	3.9	(5.2)	-2.4	(0.4)	3.6	(0.6)	0.0	(12.0)	-6.0	(6.0)
MAX	9.0	(6.4)	5.5	(6.4)	6.4	(1.4)	16.0	(32.0)	16.0	(32.0)
MEAN	6.6	(2.8)	0.6	(4.2)	4.8	(2.0)	8.0	(14.0)	4.0	(16.0)
1992										
UPSTREAM										
N	18		18		18		18		18	
MIN	0.2	(0.4)	-6.8	(21.6)	0.2	(0.0)	0.0	(18.0)	0.0	(16.0)
MAX	4.5	(3.0)	29.0	(23.0)	3.6	(0.2)	22.0	(66.0)	112.0	(50.0)
MEAN	1.1	(2.0)	9.6	(16.8)	1.2	(1.5)	4.5	(14.0)	14.0	(50.0)
DOWNSTREAM										
N	12		12		12		12		12	
MIN	2.6	(2.6)	4.6	(12.6)	2.2	(0.2)	0.0	(72.0)	0.0	(51.0)
MAX	5.6	(2.8)	27.9	(14.2)	35.0	(0.4)	14.0	(84.0)	60.0	(50.0)
MEAN	4.1	(1.8)	13.2	(12.6)	5.4	(18.6)	3.3	(12.0)	9.0	(34.0)

APPENDIX A (cont)

	^{90}Sr 10^{-2} pCi/dry g		^{137}Cs 10^{-2} pCi/dry g		Total U ng/dry g		^{238}Pu 10^{-5} pCi/dry g		^{239}Pu 10^{-5} pCi/dry g	
					1987					
UPSTREAM										
N	10		10		10		5		5	
MIN	2.6	(0.4)	-21.0	(24.0)	0.4	(0.2)	-14.0	(22.0)	5.0	(16.0)
MAX	50.0	(5.0)	24.0	(34.0)	1.9	(0.4)	5.0	(12.0)	8.0	(16.0)
MEAN	19.0	(30.0)	6.0	(26.0)	1.4	(0.8)	-3.0	(16.0)	6.0	(2.0)
DOWNSTREAM										
N	10		10		10		5		5	
MIN	1.5	(0.2)	-7.0	(42.0)	1.2	(0.2)	-8.0	(14.0)	-3.0	(6.0)
MAX	12.0	(2.6)	24.5	(26.0)	2.6	(0.6)	17.0	(20.0)	12.0	(10.0)
MEAN	5.3	(8.4)	12.0	(18.6)	2.4	(1.2)	5.0	(20.0)	5.0	(12.0)
					1988					
UPSTREAM										
N	0		10		10		10		10	
MIN	-.-	(-.-)	-18.0	(20.0)	0.7	(0.1)	-9.0	(20.0)	0.0	(20.0)
MAX	-.-	(-.-)	15.0	(24.0)	2.0	(0.4)	14.0	(32.0)	14.0	(28.0)
MEAN	-.-	(-.-)	7.1	(20.2)	1.4	(0.8)	3.0	(14.0)	8.0	(10.0)
DOWNSTREAM										
N	0		10		10		10		10	
MIN	-.-	(-.-)	5.7	(18.4)	0.8	(0.2)	-7.0	(16.0)	0.0	(20.0)
MAX	-.-	(-.-)	20.0	(17.2)	4.0	(0.8)	18.0	(20.0)	13.0	(14.0)
MEAN	-.-	(-.-)	12.0	(10.0)	2.5	(2.0)	2.0	(14.0)	4.0	(8.0)
					1989					
UPSTREAM										
N	10		10		10		5		5	
MIN	3.6	(15.6)	-15.0	(24.0)	1.5	(0.4)	3.0	(20.0)	-5.0	(12.0)
MAX	12.0	(15.0)	10.0	(20.0)	3.2	(0.6)	14.0	(20.0)	3.0	(12.0)
MEAN	8.2	(5.6)	-0.4	(14.8)	2.2	(1.2)	6.0	(10.0)	-0.4	(6.0)
DOWNSTREAM										
N	10		10		10		5		5	
MIN	4.3	(13.0)	-4.5	(40.0)	2.5	(0.4)	9.0	(18.0)	-3.0	(18.0)
MAX	1.0	(32.0)	18.0	(36.0)	4.4	(0.8)	17.0	(16.0)	16.0	(20.0)
MEAN	8.7	(3.6)	-4.4	(32.0)	3.4	(1.2)	10.0	(6.0)	8.0	(14.0)

APPENDIX B
Radionuclide Concentrations in Nongame (Bottom-Feeding) Fish Upstream and Downstream of Los Alamos National Laboratory From 1981 to 1993

	^{90}Sr 10^{-2} pCi/dry g		^{137}Cs 10^{-2} pCi/dry g		Total U ng/dry g		^{238}Pu 10^{-5} pCi/dry g		^{239}Pu 10^{-5} pCi/dry g	
1981										
UPSTREAM										
N[1]	0		6		6		6		6	
MIN	-.-[2]	(-.-)[3]	1.0	(-.-)	2.0	(-.-)	-2.0	(-.-)	-2.0	(-.-)
MAX	-.-	(-.-)	26.0	(-.-)	16.0	(-.-)	9.0	(-.-)	6.0	(-.-)
MEAN	-.-	(-.-)[4]	10.0	(20.0)	6.1	(10.4)	3.7	(9.0)	3.0	(6.4)
DOWNSTREAM										
N	0		8		8		8		8	
MIN	-.-	(-.-)	-10.0	(-.-)	18.0	(-.-)	-7.0	(-.-)	-13.0	(-.-)
MAX	-.-	(-.-)	17.0	(-.-)	29.0	(-.-)	3.0	(-.-)	19.0	(-.-)
MEAN	-.-	(-.-)	5.3	(18.0)	66.0	(18.0)	-0.6	(6.6)	1.0	(20.0)
1982										
UPSTREAM										
N	15		16		16		16		16	
MIN	0.32	3.0	-20.0	(34.0)	0.0	(3.2)	-16.0	(18.0)	-9.0	(16.0)
MAX	13.1	(1.8)	43.0	(34.0)	22.4	(4.4)	120.0	(140.0)	63.0	(32.0)
MEAN	8.1	(8.6)	16.0	(36.0)	10.0	(12.8)	11.0	(62.0)	10.0	(34.0)
DOWNSTREAM										
N	7		8		8		8		8	
MIN	4.0	(6.0)	-12.0	(4.0)	4.2	(1.6)	-10.0	(40.0)	-40.0	(60.0)
MAX	124.0	(1.2)	32.0	(114.0)	21.9	(6.8)	20.0	(40.0)	15.0	(20.0)
MEAN	7.6	(5.6)	13.0	(28.0)	13.0	(13.2)	6.0	(20.0)	-9.0	(42.0)
1983										
UPSTREAM										
N	10		10		10		10		10	
MIN	6.9	(0.8)	-140.0	(240.0)	7.9	(2.0)	-2.0	(8.0)	-9.0	(20.0)
MAX	23.0	(1.8)	39.0	(56.0)	50.7	(10.2)	4.0	(22.0)	11.0	(12.0)
MEAN	14.0	(10.0)	-7.6	(98.0)	20.0	(28.0)	1.0	(4.0)	3.0	(12.0)
DOWNSTREAM										
N	12		13		13		13		13	
MIN	3.5	(0.6)	-19.0	(15.2)	7.9	(0.2)	-5.0	(2.0)	-18.0	(4.0)
MAX	11.0	(1.0)	17.0	(20.0)	56.0	(114.0)	56.0	(44.0)	78.0	(44.0)
MEAN	7.6	(5.0)	4.3	(22.0)	27.0	(28.0)	7.0	(30.0)	11.0	(58.0)

	^{90}Sr 10^{-2} pCi/dry g		^{137}Cs 10^{-2} pCi/dry g		Total U ng/dry g		^{238}Pu 10^{-5} pCi/dry g		^{239}Pu 10^{-5} pCi/dry g	
					1993					
UPSTREAM										
N	9		8		9		9		9	
MIN	0.7	(1.4)	-1.8	(2.1)	0.3	(0.2)	0.0	(42.0)	0.0	(40.0)
MAX	9.1	(2.6)	2.0	(2.8)	9.8	(2.8)	0.0	(90.0)	22.0	(44.0)
MEAN	3.2	(5.5)	0.4	(2.4)	3.3	(5.8)	0.0	(0.0)	5.1	(16.6)
DOWNSTREAM										
N	8		8		8		8		8	
MIN	3.4	(3.4)	-5.2	(3.3)	0.3	(3.8)	0.0	(96.0)	0.0	(64.0)
MAX	17.1	(4.8)	1.7	(4.3)	20.7	(5.6)	40.0	(120.0)	20.0	(80.0)
MEAN	9.2	(9.2)	-0.6	(4.8)	5.5	(13.0)	5.0	(28.2)	4.6	(17.2)

[1]N=number of composite samples.
[2]-.-=analysis not performed, lost in analysis, or not completed.
[3](±2counting uncertainty).
[4](±2standard deviation).

APPENDIX B (cont)

	^{90}Sr 10^{-2} pCi/dry g		^{137}Cs 10^{-2} pCi/dry g		Total U ng/dry g		^{238}Pu 10^{-5} pCi/dry g		^{239}Pu 10^{-5} pCi/dry g	
1987										
UPSTREAM										
N	10		10		10		5		5	
MIN	1.4	(0.4)	-3.5	(15.6)	1.4	(0.2)	0.0	(8.0)	0.0	(12.0)
MAX	14.0	(1.6)	29.0	(19.8)	9.3	(1.8)	10.0	(20.0)	7.0	(8.0)
MEAN	4.2	(7.2)	13.0	(18.0)	5.2	(4.0)	3.0	(8.0)	3.0	(6.0)
DOWNSTREAM										
N	10		10		10		5		5	
MIN	1.2	(0.4)	-14.0	(20.0)	6.2	(1.2)	-5.0	(10.0)	-5.0	(8.0)
MAX	24.0	(5.2)	27.0	(20.0)	19.0	(3.8)	14.0	(2.0)	8.0	(12.0)
MEAN	5.2	(14.4)	10.0	(24.0)	11.5	(10.0)	5.0	(16.0)	1.0	(12.0)
1988										
UPSTREAM										
N	0		10		10		10		10	
MIN	-.-	(-.-)	-6.7	(19.0)	0.3	(0.06)	0.0	(16.0)	-6.0	(12.0)
MAX	-.-	(-.-)	45.0	(28.0)	6.4	(1.2)	12.0	(16.0)	10.0	(14.0)
MEAN	-.-	(-.-)	5.4	(30.0)	2.9	(4.6)	3.0	(8.0)	3.0	(8.0)
DOWNSTREAM										
N	0		10		10		10		10	
MIN	-.-	(-.-)	2.2	(16.4)	3.5	(0.8)	0.0	(12.0)	-4.0	(20.0)
MAX	-.-	(-.-)	17.0	(24.0)	12.0	(2.4)	23.0	(22.0)	23.0	(20.0)
MEAN	-.-	(-.-)	7.7	(10.2)	8.2	(5.8)	7.0	(18.0)	4.0	(14.0)
1989										
UPSTREAM										
N	7		7		7		5		5	
MIN	1.6	(11.0)	0.0	(19.8)	6.4	(1.2)	-4.0	(6.0)	0.0	(12.0)
MAX	5.5	(10.4)	16.0	(28.0)	12.0	(2.4)	7.0	(12.0)	5.0	(8.0)
MEAN	3.3	(2.8)	6.2	(14.2)	9.0	(3.2)	0.5	(10.0)	3.0	(4.0)
DOWNSTREAM										
N	9		9		9		5		5	
MIN	1.1	(9.6)	-560.0	(1040.0)	3.7	(0.8)	-4.0	(12.0)	-4.0	(8.0)
MAX	3.5	(14.4)	-19.0	(94.0)	15.0	(3.0)	7.0	(12.0)	3.0	(6.0)
MEAN	2.4	(1.8)	-140.0	(360.0)	8.6	(8.2)	1.0	(8.0)	-0.2	(6.0)

APPENDIX B (cont)

	^{90}Sr 10^{-2} pCi/dry g		^{137}Cs 10^{-2} pCi/dry g		Total U ng/dry g		^{238}Pu 10^{-5} pCi/dry g		^{239}Pu 10^{-5} pCi/dry g	
1984										
UPSTREAM										
N	21		19		21		21		21	
MIN	4.1	(0.9)	-15.0	(76.0)	3.1	(1.2)	-15.0	(32.0)	-13.0	(32.0)
MAX	17.0	(1.6)	56.0	(128.0)	18.0	(7.2)	75.0	(88.0)	78.0	(380.0)
MEAN	9.2	(5.8)	19.0	(18.0)	9.7	(4.4)	4.2	(36.0)	3.7	(36.0)
DOWNSTREAM										
N	21		21		21		21		21	
MIN	5.9	(0.68)	-23.0	(76.0)	5.9	(3.2)	-42.0	(360.0)	-130.0	(280.0)
MAX	9.5	(1.52)	77.0	(120.0)	75.0	(280.0)	58.0	(240.0)	39.0	(240.0)
MEAN	6.4	(4.8)	15.0	(21.0)	27.0	(20.0)	3.1	(34.0)	0.0	(62.0)
1985										
UPSTREAM										
N	18		18		18		18		18	
MIN	2.1	(-.-)	-17.0	(-.-)	3.7	(-.-)	-14.0	(-.-)	-4.3	(-.-)
MAX	23.0	(-.-)	19.0	(-.-)	23.9	(-.-)	35.0	(-.-)	320.0	(-.-)
MEAN	9.2	(-.-)	-0.0	(18.4)	8.20	(9.6)	-0.19	(20.0)	22.0	(152.0)
DOWNSTREAM										
N	6		6		6		6		6	
MIN	3.5	(-.-)	-5.5	(-.-)	9.6	(-.-)	81.0	(-.-)	2.7	(-.-)
MAX	11.0	(-.-)	14.0	(-.-)	51.2	(-.-)	0.0	(-.-)	21.0	(-.-)
MEAN	8.0	(3.2)	5.2	(16.2)	19.2	(31.6)	-5.0	(6.6)	8.7	(13.0)
1986										
UPSTREAM										
N	7		7		7		5		5	
MIN	3.2	(0.4)	-8.1	(6.6)	2.3	(0.4)	-2.0	(14.0)	0.0	(12.0)
MAX	9.5	(0.4)	4.9	(7.4)	11.0	(2.0)	4.0	(14.0)	9.0	(12.0)
MEAN	5.1	(4.6)	-3.7	(7.4)	6.8	(7.4)	1.0	(6.0)	4.0	(8.0)
DOWNSTREAM										
N	8		8		8		5		5	
MIN	1.1	(0.2)	-7.5	(12.2)	3.2	(0.6)	-1.0	(4.0)	0.0	(10.0)
MAX	2.6	(0.4)	0.2	(3.4)	15.0	(4.0)	3.0	(10.0)	10.0	(14.0)
MEAN	1.8	(1.0)	-2.2	(5.6)	8.7	(7.4)	1.0	(4.0)	2.0	(8.0)

APPENDIX B (cont)

	^{90}Sr 10^{-2} pCi/dry g		^{137}Cs 10^{-2} pCi/dry g		Total U ng/dry g		^{238}Pu 10^{-5} pCi/dry g		^{239}Pu 10^{-5} pCi/dry g	
					1993					
UPSTREAM										
N	12		11		12		12		12	
MIN	2.1	(1.4)	-0.2	(2.0)	1.6	(0.3)	0.0	(42.0)	0.0	(28.0)
MAX	9.8	(2.8)	1.8	(2.5)	9.5	(2.4)	27.0	(54.0)	9.0	(36.0)
MEAN	4.7	(5.3)	0.8	(1.3)	4.3	(4.4)	7.6	(18.2)	2.9	(8.5)
DOWNSTREAM										
N	10		9		10		10		10	
MIN	2.1	(1.4)	-1.3	(2.7)	4.3	(0.8)	-9.0	(54.0)	0.0	(28.0)
MAX	8.0	(1.6)	2.3	(2.7)	24.3	(13.2)	28.0	(84.0)	12.0	(48.0)
MEAN	3.5	(3.6)	0.5	(2.5)	12.0	(10.4)	4.2	(21.0)	5.3	(9.6)

[1]N=number of composite samples.
[2]-.-=analysis not performed, lost in analysis, or not completed.
[3](±2counting uncertainty).
[4](±2standard deviation).

	^{90}Sr 10^{-2} pCi/dry g		^{137}Cs 10^{-2} pCi/dry g		Total U ng/dry g		^{238}Pu 10^{-5} pCi/dry g		^{239}Pu 10^{-5} pCi/dry g	
1990										
UPSTREAM										
N	11		11		11		11		11	
MIN	0.2	(0.4)	-9.0	(11.6)	0.7	(0.2)	-7.0	(4.0)	0.0	(4.0)
MAX	9.8	(2.0)	92.7	(150.0)	12.3	(2.6)	27.0	(64.0)	16.0	(64.0)
MEAN	4.4	(6.2)	26.8	(66.8)	6.5	(1.2)	5.0	(20.0)	3.0	(16.0)
DOWNSTREAM										
N	12		12		12		12		12	
MIN	0.5	(0.4)	4.8	(8.8)	1.4	(0.4)	-8.0	(0.0)	-6.0	(2.0)
MAX	3.0	(0.8)	64.2	(76.8)	10.4	(2.0)	13.0	(18.0)	5.0	(14.0)
MEAN	1.6	(1.8)	17.8	(35.4)	5.9	(7.2)	3.0	(14.0)	-0.2	(6.0)
1991										
UPSTREAM										
N	12		12		12		12		12	
MIN	0.4	(1.6)	-1.7	(1.2)	0.7	(0.2)	-18.0	(4.0)	-5.0	(6.0)
MAX	3.6	(7.2)	24.5	(7.2)	12.5	(2.4)	16.0	(36.0)	8.0	(36.0)
MEAN	2.6	(2.0)	2.1	(14.2)	5.1	(6.0)	1.0	(20.0)	3.0	(6.0)
DOWNSTREAM										
N	11		11		11		11		11	
MIN	0.6	(2.4)	-1.2	(1.8)	4.0	(0.8)	-8.0	(0.0)	-4.0	(6.0)
MAX	2.7	(3.6)	1.3	(3.6)	16.5	(3.2)	14.0	(28.0)	7.0	(18.0)
MEAN	1.7	(1.4)	0.1	(1.8)	9.2	(8.4)	4.0	(12.0)	2.0	(8.0)
1992										
UPSTREAM										
N	20		20		20		20		20	
MIN	0.5	(0.4)	0.0	(0.0)	0.8	(0.0)	0.0	(30.0)	0.0	(40.0)
MAX	5.6	(2.8)	29.4	(25.4)	17.0	(1.0)	24.0	(72.0)	99.0	(44.0)
MEAN	3.2	(39.6)	11.0	(14.4)	5.2	(8.0)	4.0	(14.0)	18.0	(56.0)
DOWNSTREAM										
N	12		12		12		12		12	
MIN	0.5	(1.0)	1.6	(23.4)	5.1	(0.2)	0.0	(36.0)	0.0	(16.0)
MAX	2.4	(1.6)	24.2	(14.4)	16.0	(0.8)	27.0	(54.0)	24.0	(31.0)
MEAN	1.5	(1.2)	10.5	(12.6)	8.8	(6.4)	7.6	(16.0)	6.0	(14.0)