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CONCENTRATION OF RADIONUCLIDES IN FRESH WATER FISH DOWNSTREAM OF RANCHO SECO NUCLEAR GENERATING PLANT

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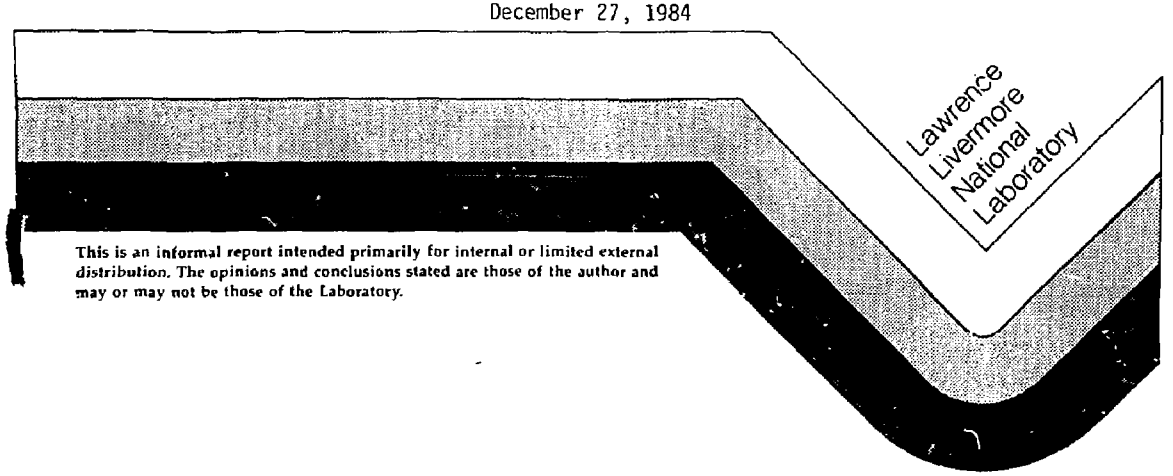

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ABSTRACT

Fish were collected for radionuclide analysis over a 5-month period in 1984 from creeks downstream of the Rancho Seco Nuclear Generating Plant, which has been discharging quantities of some fission and activation products to the waterway since 1981. Among the fish, the bluegill was selected for intensive study because it is very territorial and the radionuclide concentrations detected should be representative of the levels in the local environment at the downstream locations sampled. Among the gamma-emitting radionuclides routinely released, only ^{134}Cs and ^{137}Cs were detected in the edible flesh of fish. Concentrations in the flesh of fish decreased with distance from the plant. The relationship between concentration and distance was determined to be exponential. Exponential equations were generated to estimate concentrations in fish at downstream locations where no site-specific information was available. Mean concentrations of ^{137}Cs in bluegill collected during April, May, July and August from specific downstream stations were not significantly different in spite of the release of 131 mCi to the creeks between April and August. The concentrations in fish are not responding to changes in water concentrations brought about by plant discharges. Diet appears to be a more significant factor than size or weight or water concentration in regulating body burdens of ^{137}Cs in these fish.

INTRODUCTION

The Rancho Seco Nuclear Generating Station, operated by the Sacramento Municipal Utility District (SMUD), is located in Sacramento County near the town of Clay, California. Since 1981 small leaks in the steam-generation system have contributed to aqueous waste sources of radionuclides. These solutions and other operationally generated waste waters are collected and treated in regenerant holdup tanks. At intervals, the mixed treated solutions containing levels of some fission and activation products are released to one or two on-site retention basins. Periodically the contents, or fractions of the contents, in the basins are diluted and discharged to Clay Creek. The stream flows to the site-boundary fence, 0.6 km from the point of discharge, and continues until it intersects Hadselville Creek, 3.0 km downstream from the plant. Hadselville Creek intersects Laguna Creek 6.5 km downstream from the plant. Laguna Creek water drains into the Consumnes River at a point near Twin Cities Road between Interstate Highway 5 and State Highway 99.

Aquatic organisms that are indigenous to the natural creeks that receive the effluent water are exposed to concentrations of radionuclides. Because fish have been identified (1) as one connecting link between man and the aquatic food chain in this fresh water environment, a program was initiated in April 1984 to provide site-specific information and radionuclide-concentration data for the three most common edible species of fish: bluegill (Lepomis macrochirus), largemouth black bass (Micropetrus salmoides) and brown catfish (Ictalurus nebulous). Bluegill are both surface and bottom feeding omnivories, bass are carnivores and catfish are bottom feeding omnivores. Data gathered over a 5 month fishing season (April-August) in 1984 are discussed in this report with attention focused on the radiocesium isotopes, ^{134}Cs and ^{137}Cs because these two radionuclides are concentrated in the edible flesh of fresh water fishes from contaminated fresh water environments. According to release records provided by SMUD, the cumulative quantities of ^{134}Cs and ^{137}Cs discharged from the plant prior to November 1, 1984, were 195 and 503 mCi, respectively. The cumulative amounts are based on annual release data, decay corrected to October 30, 1984. The amounts of ^{134}Cs and ^{137}Cs released exceed the total quantity of other gamma-emitting radionuclides discharged from the plant since 1981.

COLLECTION AND ANALYSIS

On the first and second field trips in April and May 1984, fish were collected from a pond and connecting sump located outside SMUD property, 0.6 km downstream from the retention basin outfall. On subsequent trips, fish were again collected near the site boundary and from 3 other downstream locations, stations R5, R8 and R11. Station R5 is at the intersection of Clay Station Road and Hadselville Creek, 4.6 km downstream of the outfall. Station R8, 12.6 km from the outfall, is near the intersection of Alta Mesa Road and Laguna Creek on the Kennifick ranch. Laguna Creek Station R11, 19.5 km from the outfall is on the DeAlberts ranch. Gill nets were used to catch some fish from the pond during April but all other collections were made by individuals using fishing gear with either worms or artificial lures. Between April 26 and August 14, 1984, the time of year most local residents fish at the creeks (1), a total of 234 fish were collected for analysis. Of this total, 156, 72 and 6 were, respectively, bluegill, bass and catfish. From the land and aquatic use survey (1) it was determined that these are the only fish caught for consumption by the local residents and that only the flesh of the fish is eaten. More bluegill than bass or catfish were collected because they are ubiquitous to the creeks and easy to catch. However, there were reasons, based on scientific considerations, to emphasize collections of bluegill. It had been shown that bluegill are the choice over bass and catfish as indicators of maximum uptake of radionuclides by edible fish from a study in the aquatic environment at the Savannah River Plant (2). Bluegill (as well as bass) are not migratory but very territorial and spend most of their lives in isolated areas in California streams (3). Therefore, the radionuclide concentrations measured in bluegill would be proportional to the concentrations in the local aquatic environment at the downstream locations sampled and would also reflect the maximum concentration that might be associated with any fish caught for consumption by man from any specific downstream location.

Samples were iced down and returned to Lawrence Livermore National Laboratory (LLNL) where the fish were kept frozen until processed. Standard length, sex and fresh whole body weight of each fish were recorded. The fish were dissected to provide samples of the edible flesh for analysis. The primary mode of accumulation of cesium by fresh water fishes is thought to be via absorption from food or ingested sediments rather than by direct uptake from water(4). Samples of the stomach content were then taken to determine

the nature of the food eaten and the radionuclides associated with the ingested material. On the basis of these analyses and other information a picture has been formed of the food intake during the months sampled. The flesh and contents from fish of the same species, collected from a sampling site, were sometimes pooled for analysis. The judgment to analyze single or pooled samples of fish was based on anticipated concentrations at the sampling sites. Each sample was dried in ovens at 90°C to constant dry weight, homogenized, transferred to aluminum or plastic containers which were sealed and analyzed by gamma spectrometry. Gamma spectrometry measurements were made on all separated samples at LLNL using a variety of Ge(Li)-diode detector systems. Counting times were usually 1000 minutes or longer for each sample. A general purpose computer program called GAMANAL was used for the data reduction of all generated spectra. The program searches a library of fission and activation products and naturally occurring radionuclides in order to identify radionuclides from any observed photopeak in the gamma spectra. All radionuclides routinely released to the waterway from the plant are included in the library. The program also generated an upper-limit amount of specific radionuclides based on those spectra regions where signals would be seen if the radionuclide were present in detectable quantities. Our mean minimal detectable concentrations (based on a counting time of 1000 minutes) for each of the principal longer-lived gamma emitting radionuclides discharged to Clay Creek are shown in Table 1.

Table 1. Mean detection limits for some gamma-emitting radionuclides released in liquid effluents from Rancho Seco (pCi/sample)[a].

Radionuclide	^{58}Co	^{60}Co	^{54}Mn	^{110m}Ag	^{137}Cs	^{134}Cs	^{125}Sb	^{131}I
Detection Limit (pCi/sample)	1.2	1.1	1.0	1.0	1.1	1.0	3.0	2.0

[a] Based on a counting time of 1000 minutes

RESULTS

Concentrations of the radionuclides measured in the muscle-tissue and stomach-content samples of the fish are given in the Appendix. All results have been decay corrected to the date of collection. The Appendix is arranged to show concentrations in samples of fish from each station in chronological order. The concentrations are listed relative to fresh wet weight but the dry/wet weight ratios provided may be applied to convert concentrations to a dry weight basis. Other than ^{134}Cs and ^{137}Cs, no gamma-emitting radionuclides from plant discharges were detected in the flesh of the fish. Quantities of ^{58}Co, ^{60}Co, ^{110m}Ag, ^{54}Mn in addition to ^{134}Cs and ^{137}Cs were sometimes found associated with the material ingested by the fish. After the cesium radionuclides, ^{60}Co is the next most abundant gamma-emitting radionuclide with half life greater than 30 days released to the creek. The absorption efficiency of cobalt from food is very low in fresh water fishes (4). This accounts for the absence (below detection limits) of ^{58}Co and ^{60}Co in the fish-flesh samples.

Whole body weight (g) and standard length (mm) of the bluegills collected between April and August from all creek stations ranged from 10 to over 190 g and from 70 to 160 mm. By the end of their first year, bluegill will have reached a length of 40-50 mm and then grow 20-50 mm in each subsequent year (3). A typical California bluegill would be 4-5 years old and weigh about 90 grams. Based on this information, it is estimated that the bluegills collected from the creeks range in age from 1 to 6 years. Kolehmainen (5) found variations in concentrations of ^{137}Cs among different sizes (ages or weight) of bluegill from White Oak Lake, Tennessee. He determined the concentration of ^{137}Cs increased with the size of fish linearly up to a fish weight of 70 g. No correlation existed between the concentration and weight of fish above 70 g, which was interpreted to mean that the concentration of ^{137}Cs in fish larger than 70 g was in a steady state. Similar correlations are seen from the data in the Appendix for individual fish collected 0.5-0.6 km from the plant on 5-18-84 and 8-14-84. For the 8-14-84 collections, the concentration of ^{137}Cs in the flesh of bluegills increased in individual fish weighing between 43 and 66 g. In the 5-18-84 collections, there is no correlation of ^{137}Cs concentrations with fish weights ranging between 88 and 190 g. The fish may therefore show some variations in concentration related

to weight. It was then necessary to account for any differences in concentration related to weight in order to generate an average concentration for a species from the mixed populations sampled at the different times. In order to do so, a weighted mean concentration of ^{134}Cs and ^{137}Cs in the flesh was computed from the sum of the product of the concentration (C_i), number of fish in a sample (n_i), and the whole body fresh weight (w_i). This sum is divided by the sum of the product of the whole body fresh weight and number of fish in the respective sample. Equation 1 was used with the concentration data in the Appendix to generate mean flesh concentrations for each sampling time and location sampled, and the mean concentration in fish over the entire period (April to August) at each station. Mean concentrations are shown in Table 2.

$$\bar{C}\ (pCi/g\ wet) = \Sigma\ C_i w_i n_i / \Sigma w_i n_i \qquad (1)$$

Average concentrations of ^{137}Cs, ^{134}Cs and ^{60}Co in the stomach contents of bluegill and bass collected 0.5-0.6 km from the plant are shown in Table 3. This table also provides data on the quantities of ^{134}Cs and ^{137}Cs and ^{60}Co discharged to the creek from the power plant during the non-sampling intervals.

DISCUSSION

Inspection of the results in Tables 2 and 3 and in the Appendix reveals several points of interest.

1). Mean concentrations of ^{137}Cs in the flesh of bluegill were everywhere equivalent to or greater than the concentrations in bass or catfish. This confirms the usefulness of this species as an indicator of maximum flesh concentrations among the edible fish collected from the creeks. Since some of the local fish eaters surveyed did not indicate a preference for a specific fish (1), it is recommended, in the absence of more specific data, that bluegill concentrations be used with appropriate usage factors in dose codes to calculate possible exposure to man from fish consumption.

2). The concentrations of ^{134}Cs and ^{137}Cs in the flesh of bluegill from stations 17-20 (0.5-0.6 km from the plant) did not differ significantly over the entire collection period between April

Table 2. Mean concentrations of ^{134}Cs and ^{137}Cs in flesh of bluegill and bass collected from downstream locations during 1984 (pCi/g wet wt).

Collection date	Distance from plant (km)	Bluegill: All fish whole body weight (g)	Bluegill: Number of fish	Bluegill: pCi/g wet wt ^{134}Cs	Bluegill: pCi/g wet wt ^{137}Cs	Bass: All fish mean whole body weight (g)	Bass: Number of fish	Bass: pCi/g wet wt. ^{134}Cs	Bass: pCi/g wet wt. ^{137}Cs
	Stations 17-20								
4-26-84	0.5-0.6	127	6	5.65	11.1	441	3	1.88	4.00
5-18-84	0.5-0.6	111	11	5.08	10.4	161	3	2.76	5.70
7-18-84	0.5-0.6	48	21	4.09	8.9	34	16	1.28	2.79
8-14-84	0.5-0.6	60	11	5.67	13.1	36	24	1.92	4.42
Mean for entire period		61		5.03	10.6	71		1.92	4.15
	Station R5								
7-18-84	4.6	42	6	2.75	5.80				
8-14-84	4.6	28	5	2.11	4.54	7	11	1.20	2.84
Mean for entire period		36		2.37	5.03	7		1.20	2.84
	Station R8								
7-18-84	12.6	51	15	0.28	0.57	148	4	0.25	0.57
8-14-84	12.6	37	29	0.26	0.54	214	5	0.26	0.57
Mean for entire period		42		0.27	0.55	185		0.26	0.57
	Station R11								
7-18-84	19.5	59	15	0.07	0.15	65	2	<0.02	0.06
8-14-84	19.5	52	14	0.05	0.10	173	4	0.07	0.14
Mean for entire period		55		0.06	0.13	137		0.06	0.13

Table 3. Mean concentrations of ^{134}Cs, ^{137}Cs and ^{60}Co in stomach contents of fish collected at the site boundary (0.5-0.6 km from the plant) and quantities discharged from the plant during non-sampling intervals.

	Concentrations in stomach content (pCi/g wet weight)					
	Bluegill			Bass		
Collection date	^{137}Cs	^{134}Cs	^{60}Co	^{137}Cs	^{134}Cs	^{60}Co
4-26-84	10.1	5.4	1.0	16.3	8.3	3.3
5-18-84	13.7	6.4	2.6	10.4	4.3	1.9
7-18-84	8.1	3.7	1.1	3.4	1.8	bd
8-14-84	27.9	11.7	1.8	7.3	3.1	bd

Plant releases to retention basins during non-sampling intervals

	mCi released[a]		
Interval	^{137}Cs	^{134}Cs	^{60}Co
4/26-5/18/84	23.9	10.5	13.6
5/18-7/18/84	70.1	35.3	3.3
7/18/-8/14-84	37.0	16.2	0.3
Total	131	62	17.2

[a] Release data provided by SMUD.

bd Below detection limits.

through August, or between July and August at the other downstream sampling stations in spite of the release of 131 and 62 mCi of ^{137}Cs and ^{134}Cs, respectively, from the plant to the creek between April and August. The concentrations in fish are clearly not responding to changes in the water concentrations brought about by the plant discharges. Some of the small differences in the mean concentration at each station noted over the period sampled may be related to the different weight groups represented, but these differences more likely result from a change in diet during the summer months. This latter statement will be clarified in a subsequent section. The similar values for the mean concentrations in the fish, especially over the period of April to August at the station 0.5-0.6 km from the plant, confirm the known characteristic that these stream dwelling fish are territorial and not migratory. It is, therefore, appropriate to use the mean concentration for ^{134}Cs and ^{137}Cs in flesh determined at each station over the entire fishing season in dose codes to estimate exposure from fish consumption.

3.) The mean concentrations of ^{134}Cs and ^{137}Cs in the flesh of fish decreased exponentially with distance downstream during 1984. From a regression analysis of the available data, expressions 2-7 were developed that relate the ^{137}Cs and ^{134}Cs flesh concentrations (C = pCi/g wet) in the different fish to downstream distance (D = km).

Bluegill for ^{137}Cs:	$C=12.9e^{-0.239D}$	(2)
Bluegill for ^{134}Cs:	$C=6.17e^{-0.239D}$	(3)
Bass for ^{137}Cs:	$C=5.49e^{-0.187D}$	(4)
Bass for ^{134}Cs:	$C=2.45e^{-0.186D}$	(5)
Catfish for ^{137}Cs:	$C=2.75e^{-0.171D}$	(6)
Catfish for ^{134}Cs:	$C=1.03e^{-0.181D}$	(7)

The expressions for bluegill can be used with a degree of confidence to estimate concentrations in fish during 1984 from any downstream location when site-specific data are not available except at sumps or downstream water storage ponds. Because there were substantially fewer bass and catfish analyzed, less confidence is placed on the

relationships developed for these fish. Equations 2 and 3 (using bluegill as indicators for concentrations) are used to estimate downstream concentrations of ^{134}Cs and ^{137}Cs in flesh of fish collected from the fishing locations identified by the local residents (1). With the appropriate usage factors, the amount of ^{134}Cs and ^{137}Cs ingested with the fish consumed by different individuals during 1984 is computed and shown in Table 4. These values may be used with appropriate dose models and conversion factors to estimate exposure over the year to each identified local fisherman from the fish ingestion pathway.

4). Tables 2 and 3 show that in July, there was an abrupt decrease in the mean concentrations of ^{134}Cs and ^{137}Cs in the flesh and stomach contents of bluegill and bass from stations 17-20 when compared to the mean concentrations determined in the April and May collections and in the subsequent August collection. Between the May and July collections, 70 mCi of ^{137}Cs and 35 mCi of ^{134}Cs were discharged to the creek from the plant. These quantities were greater than the amounts released during the previous and subsequent non-sampling intervals. The decrease in the fish-flesh concentration clearly do not relate to the quantities in recent discharges, which suggests that the major source of the radionuclides found in fish is the food or sediment contaminated with activity previously released. In April and May, bluegill were easily caught using bass plugs and worms. The majority of material found in the contents of the stomach was unidentified benthic debris and sediment.

During July, the fish were observed emerging from the stream and ponds and feeding on insects. It was very difficult to catch fish during this period using plugs and worms. There was no trouble catching fish when artificial flies were used as bait. Adult and larval terrestrial and aquatic insects were the major components of the gut material from these fish along with some small snails and algae. There was no sediment or other unidentified benthic debris in the gut material. The complete absence of this material in the gut

Table 4. Activity (pCi/yr) of ^{134}Cs and ^{137}Cs ingested by identified users from the fish consumption pathway.

User ID[a]	Z_1	Z_2	Z_3	Z_4	T	H	N	R
Downstream fish collection points (km)[a]	0.5	6.5	6.5	12.5	6.5	12	13	18
Fish consumption (kg/yr)[a]	1	26	13	5	7	1	4	7
Fish flesh concentrations[b] (pCi/g wet weight)								
^{137}Cs	11.4	2.7	2.7	0.65	2.7	0.73	0.57	0.17
^{134}Cs	5.5	1.3	.3	0.31	1.3	0.35	0.28	0.08
pCi/yr ingested with fish (kg/yr x pCi/g x 10^3)								
^{137}Cs(all values x10^4)	1.1	7.0	3.5	0.33	1.9	0.07	0.23	0.12
^{134}Cs(all values x10^4)	0.55	3.4	1.7	0.16	0.91	0.04	0.11	0.06

[a] From ref. 1.

[b] Computed using equations 2 and 3 for bluegill and appropriate downstream distances listed in this table.

of the fish caught in July clearly shows there is a major change in feeding habits during the summer months. In August the gut contents still contained quantities of insects but the major component was again sediment, algae and unidentified benthic material. Differences in the ^{137}Cs levels between bluegills collected during May and July are believed to be caused by differences in the diet. The ^{137}Cs concentration is greater in bluegill consuming bottom material than in bluegill feeding primarily on terrestrial and aquatic insects.

A reasonably good correlation (regression coefficient, $r^2=0.86$) was developed between the concentration of ^{137}Cs determined in the flesh and stomach contents of bluegill from all downstream locations. The relationship, determined from a power regression analysis of the individual fish-flesh and stomach-content concentration data, is given by equation 8.

$$^{137}Cs \text{ in flesh (pCi/g wet)} = 0.735S^{0.95} \quad (8)$$

S=bluegill stomach content concentration in pCi/g wet

It is possible to estimate (to within a factor of 2) the concentration of ^{137}Cs in individual bluegill flesh from the concentration determined in the dietary components. This relationship is independent of fish size and downstream location. It would appear that the primary mode of accumulation of radiocesium by fresh water fish is by absorption from food or ingested sediments. The differences in concentration among different sized bluegill may be related to diet rather than weight or size.

5). Filtered water samples were usually collected in conjunction with the fish collections. A comparison of the ^{137}Cs concentrations in filtered water and bluegill and bass flesh is shown in Table 5. Concentration factors for ^{137}Cs in flesh of bluegill and bass range over two orders of magnitude. Because of the nature of the pulsed releases of ^{134}Cs and ^{137}Cs from the plant, it is impossible to see any

good correlation (concentration factors) between water and fish concentrations. If a concentration factor approach is required to meet certain radiological protection criteria, it is recommended that the concentration factors determined for ^{137}Cs at the furthest downstream locations be adopted. The concentrations in the water and fish at these stations probably undergo smaller changes with time (and are nearer to steady state conditions) than the concentrations in water from stations nearer the plant outfall.

Table 5. ^{137}Cs levels in flesh of fish and creek water and concentration factors

Date	Sampling station	Filtered water concentration (pCi/l)	Bluegill mean flesh conc. (pCi/kg)	CF[a]	Bass mean flesh conc. (pCi/kg)	CF[a]
4/26/84	17-20	4.55	11100	2.4	4000	0.88
7/18/84	R5	1.61	5800	3.6		
7/18/84	R11	0.11	150	1.4	60	0.54
7/18/84	R8	0.45	570	1.3	570	1.3
7/18/84	17-20	0.26	8900	34.0	2790	11.0
8/14/84	R5	11.3	4540	0.4	2840	0.25
8/14/84	17-20	1.87	13100	7.0	4420	2.4
Range				0.4-34		0.25-11

[a] CF = concentration factor = pCi/kg flesh (wet weight) divided by the water concentration in pCi/l. All values x 10^3.

PRINCIPAL CONCLUSIONS

1. Of the gamma-emitting radionuclides routinely discharged in liquid effluents from the Rancho Seco Nuclear Generating Station, only ^{137}Cs and ^{134}Cs are above detection limits in the edible flesh of fish collected downstream of the discharge.

2. Concentrations of ^{134}Cs and ^{137}Cs in the flesh of bluegill were either equivalent to or greater than the concentrations in the flesh of bass and catfish from all locations sampled. Bluegill are the best environmental indicator species for future monitoring programs at the creek to assess dose from the fish-consumption pathway.

3. Mean concentrations of ^{134}Cs and ^{137}Cs in the flesh and stomach contents of fish decreased with distance from the plant. The relationship between concentrations in bluegill and distance was determined to be exponential. Exponential equations were generated to estimate concentrations in bluegill at downstream locations where no site-specific data were available.

4. In 1984, identified consumers of bluegill flesh ingested from 0.07×10^4 to 7×10^4 pCi of ^{134}Cs and from 0.04×10^4 to 3.4×10^4 pCi of ^{134}Cs.

5. Concentrations of ^{134}Cs and ^{137}Cs in fish muscle did not respond to changes in water concentrations brought about by the plant releases. Diet appears to be a more significant factor than size in determining ^{137}Cs body burdens. The ^{137}Cs concentrations are higher in bluegill consuming bottom fauna than in bluegill feeding primarily on terrestrial and aquatic insects.

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APPENDIX

Concentrations of radionuclides in flesh of fish caught on 4-26-84, 0.6 km from the plant outfall.

Sample ID	Common name	Number of fish in pooled sample	Dry/wet wt	Mean fresh wt whole fish (g)	pCi/g wet wt[c] ^{134}Cs	^{137}Cs
836	Bluegill[a]	6	0.207	127	5.65(1)	11.1(1)
838	Largemouth Bass[a]	1	0.161	188	3.25(2)	7.02(2)
840	Largemouth Bass[b]	1	0.193	233	1.06(4)	2.34(3)
842	Largemouth Bass[b]	1	0.182	902	1.75(1)	3.78(1)
844	Catfish[b]	1	0.150	617	0.93(2)	2.05(2)

[a] - Collected from irrigation pond (sediment station 17)

[b] - Collected from connecting sump (sediment station 30)

[c] - Number in parenthesis is the 1 σ counting error expressed as % of value listed.

Concentrations of radionuclides in stomach content of fish caught on 4-26-84, 0.6 km from the plant outfall.

Sample ID[a]	Common Name	Dry/wet wt	pCi/g wet wt[b] ^{134}Cs	^{137}Cs	^{60}Co	^{58}Co	^{54}Mn
837(836)	Bluegill	0.190	5.37(3)	10.1(3)	1.0(13)	0.86(25)	0.43(22)
839(838)	Largemouth Bass	0.139	8.33(3)	16.3(3)	3.26(7)	1.7(14)	0.82(32)
843(842)	Largemouth Bass	0.163	0.67(21)	1.5(15)	<0.2	<0.2	<0.2
845(844)	Catfish	0.125	7.05(1)	14.2(1)	1.75(4)	0.39(17)	0.52(12)

[a] See previous table for concentrations in flesh and related information. Number in parenthesis is the sample ID for the respective flesh sample.

[b] Number in parenthesis is the 1 σ counting error expressed as % of value listed.

Concentrations of radionuclides in flesh of fish caught on 5-18-84, 0.6 km from the plant outfall.

Sample ID	Common name	Number of fish in pooled sample	Dry/wet wt	Mean fresh wt whole fish (g)	pCi/g wet wt[c] ^{134}Cs	^{137}Cs
860	Bluegill[a]	1	0.190	190	4.29(1)	8.58(1)
862	Bluegill[a]	1	0.189	123	6.12(2)	12.6(1)
864	Bluegill[a]	1	0.188	120	6.00(2)	12.1(2)
866	Bluegill[a]	1	0.218	123	5.11(2)	11.2(1)
868	Bluegill[a]	1	0.190	138	6.10(1)	12.2(1)
870	Bluegill[a]	1	0.194	117	6.41(2)	13.0(1)
872	Bluegill[a]	1	0.190	121	5.62(2)	11.4(2)
874	Bluegill[a]	1	0.191	126	2.29(3)	5.01(2)
876	Bluegill[a]	1	0.195	88	4.34(2)	8.84(2)
878	Bluegill[a]	2	0.196	40	4.61(2)	9.43(2)
880	Largemouth Bass[b]	3	0.201	161	2.76(2)	5.70(2)
882	Bluegill[b]	1	0.194	143	2.45(2)	5.63(2)

[a] - Collected from irrigation pond (sediment station 17)

[b] - Collected from connecting pump (sediment station 30)

[c] - Number in parenthesis is the 1 σ counting error expressed as % of value listed.

Concentrations of radionuclides in stomach content of fish caught on 5-18-84, 0.6 km from the plant outfall.

Sample ID[a]	Common Name	Dry/wet wt	pCi/g wet wt[b] ^{134}Cs	^{137}Cs	^{60}Co	^{58}Co	^{110m}Ag	^{54}Mn
861(860)[a]	Bluegill	0.167	6.19(5)	12.8(4)	2.33(11)	bd	bd	bd
863(862)	Bluegill	0.165	5.9(10)	13.1(5)	bd	bd	bd	bd
865(864)	Bluegill	0.243	5.31(7)	11.8(5)	3.3(10)	1.5(35)	1.5(16)	0.88(40)
867(866)	Bluegill	0.213	3.79(7)	7.64(6)	bd	bd	bd	bd
869(868)	Bluegill	0.176	9.83(6)	17.2(6)	2.3(30)	bd	bd	bd
871(870)	Bluegill	0.172	6.8(11)	16.9(8)	bd	bd	bd	bd
873(872)	Bluegill	0.213	5.4(10)	12.5(13)	2.5(26)	1.5(70)	bd	bd
875(874)	Bluegill	0.209	6.72(8)	14.4(6)	4.0(18)	3.1(26)	3.3(13)	2.0(37)
877(876)	Bluegill	0.211	8.10(9)	15.8(7)	2.0(34)	bd	bd	bd
879(878)	Bluegill	0.136	5.8(16)	14.7(9)	2.1(44)	bd	bd	bd
881(880)	Largemouth Bass	0.187	4.31(7)	10.4(4)	1.9(12)	bd	bd	bd
883(882)	Bluegill	0.212	bd	7.7(23)	bd	bd	bd	bd

[a] See previous table for concentrations in flesh and related information. Number in parenthesis is the sample ID for the respective flesh sample.

[b] Number in parenthesis is the 1 σ counting error expressed as % of value listed.

bd - Below detection limits.

Concentrations of radionuclides in flesh of fish collected on 7-18-84 at sediment stations 18-20 on Clay Creek, 0.5 km from the plant outfall.

Sample ID	Common name	Number of fish in pooled sample	Dry/wet wt	Mean fresh wt whole fish (g)	pCi/g wet wt[a] ^{134}Cs	^{137}Cs
J128	Largemouth Bass	3	0.189	80	1.61(2)	3.47(2)
J130	Largemouth Bass	3	0.199	56	1.00(4)	2.38(4)
J132	Largemouth Bass	10	0.191	15	1.07(11)	2.17(6)
J136	Bluegill	2	0.183	114	5.67(1)	12.2(1)
J138	Bluegill	3	0.191	67	4.20(2)	8.84(2)
J140	Bluegill	6	0.196	48	3.51(1)	7.60(1)
J142	Bluegill	6	0.188	34	3.56(2)	7.58(2)
J144	Bluegill	4	0.193	22	2.92(3)	6.49(2)

[a] Number in parenthesis is the 1 σ counting error expressed as % of value listed.

Concentrations of radionuclides in stomach content of fish caught on 7-18-84 at sediment stations 18-20 on Clay Creek, 0.5 km from the plant outfall.

Sample ID[a]	Common Name	Dry/wet wt.	pCi/g wet wt[b] ^{134}Cs	^{137}Cs	^{110m}Ag	^{60}Co	^{54}Mn
J129(J128)	Largemouth Bass	0.150	1.3(30)	2.5(23)	bd	bd	bd
J131(J130)	Largemouth Bass	0.140	1.4(22)	3.0(17)	bd	bd	bd
J133(J132)	Largemouth Bass	0.180	2.9(22)	4.8(24)	bd	bd	bd
J137(J136)	Bluegill	0.200	4.25(6)	9.67(4)	0.71(28)	1.0(27)	1.9(17)
J139(J138)	Bluegill	0.190	2.61(9)	6.54(6)	bd	1.3 (23)	bd
J141(J140)	Bluegill	0.220	3.01(4)	7.07(4)	0.86(18)	0.87(14)	0.48(34)
J143(J142)	Bluegill	0.255	4.88(8)	9.92(6)	1.6(31)	bd	bd
J145(J144)	Bluegill	0.189	3.9(17)	7.6(14)	bd	bd	bd

[a] See previous table for concentrations in flesh and related information. Number in parenthesis is the sample ID for the respective flesh sample.

[b] Number in parenthesis is the 1 σ counting error expressed as % of value listed.

bd = Below detection limits.

Concentrations of radionuclides in flesh of fish collected on 8-14-84 at sediment stations 18-20 on Clay Creek, 0.5 km from the plant outfall.

Sample ID	Common name	Number of fish in pooled sample	Dry/wet wt	Mean fresh wt whole fish (g)	pCi/g wet wt[c] ^{134}Cs	^{137}Cs
J206	Bluegill	1	0.209	80	4.77(1)	10.4(1)
J208	Bluegill	1	0.208	71	4.80(2)	10.9(1)
J210	Bluegill	1	0.206	77	5.51(1)	13.6(1)
J212	Bluegill	1	0.202	65	7.17(2)	16.3(1)
J214	Bluegill	1	0.206	66	6.75(2)	16.2(1)
J216	Bluegill	1	0.194	57	5.60(2)	13.0(1)
J218	Bluegill	1	0.199	55	7.05(1)	15.7(1)
J220	Bluegill	1	0.197	49	5.90(2)	13.3(1)
J222	Bluegill	1	0.199	49	5.29(1)	12.2(1)
J224	Bluegill	1	0.202	46	4.54(2)	10.3(2)
J226	Bluegill	1	0.207	43	4.84(2)	11.1(2)
J228	Largemouth Bass	1	0.205	134	2.28(2)	5.51(1)
J230	Largemouth Bass	1	0.200	112	3.34(2)	7.58(1)
J232	Largemouth Bass	1	0.198	87	1.55(2)	3.43(2)
J234	Largemouth Bass	1	0.203	70	1.15(3)	2.59(3)
J236	Largemouth Bass	1	0.206	78	1.07(3)	2.45(2)
J238	Largemouth Bass	1	0.203	59	1.05(8)	2.36(3)
J240	Largemouth Bass	1	0.201	60	1.07(4)	2.27(3)
J242	Largemouth Bass	3	0.192	29	2.37(3)	5.90(1)
J244	Largemouth Bass	4	0.196	18	2.18(2)	4.88(2)
J246	Largemouth Bass	5	0.196	13	1.57(3)	3.43(3)
J248	Largemouth Bass	5	0.196	11	2.18(2)	4.82(2)

[a] Number in parenthesis is the 1 σ counting error expressed as % of value listed.

Concentrations of radionuclides in stomach content of fish collected on 8-14-84 at sediment stations 18-20 on Clay Creek, 0.5 km from the plant outfall.

Sample ID[a]	Common Name	Dry/wet wt	pCi/g wet wt[b] ^{134}Cs	^{137}Cs	^{60}Co	^{58}Co	^{110m}Ag	^{54}Mn
J207(J206)	Bluegill	0.159	9.63(7)	25.0(7)	bd	5.3(28)	bd	bd
J209(J208)	Bluegill	0.220	12.3(7)	33(9)	bd	bd	bd	bd
J211(J210)	Bluegill	0.206	11.6(6)	25.9(4)	1.4(70)	6.7(34)	6.9(11)	bd
J213(J212)	Bluegill	0.204	10.7(5)	24.6(3)	1.4(30)	7.4(18)	6.1(10)	bd
J215(J214)	Bluegill	0.262	16.6(5)	36.5(3)	2.2(28)	8.2(22)	4.7(15)	bd
J217(J216)	Bluegill	0.181	8.25(6)	16.9(5)	2.2(19)	14(12)	4.4(13)	1.6(38)
J219(J218)	Bluegill	0.270	14.3(7)	31.7(5)	bd	15(23)	11(11)	bd
J221(J220)	Bluegill	0.223	14.0(7)	37.8(7)	bd	7.3(40)	bd	bd
J223(J222)	Bluegill	0.186	12.7(6)	31(10)	bd	10(50)	bd	bd
J225(J224)	Bluegill	0.203	6.8(12)	19(9)	bd	bd	bd	bd
J227(J226)	Bluegill	0.200	12(13)	27(9)	bd	bd	7.6(24)	bd
J229(J228)	Largemouth Bass	0.160	4.1(25)	7.9(19)	bd	bd	bd	bd
J231(J230)	Largemouth Bass	0.161	bd	8.5(35)	bd	bd	bd	bd
J233(J232)	Largemouth Bass	0.130	bd	2.4(28)	bd	bd	bd	bd
J235(J234)	Largemouth Bass	0.170						
J237(J236)	Largemouth Bass	0.118						
J239(J238)	Largemouth Bass	0.125	bd	1.8(33)	bd	bd	bd	bd
J241(J240)	Largemouth Bass	0.120	bd	1.5(29)	bd	bd	bd	bd
J243(J242)	Largemouth Bass	0.149	10(7)	22.1(4)	bd	bd	bd	bd
J245(J244)	Largemouth Bass	0.155	bd	6.3(24)	bd	bd	bd	bd
J247(J246)	Largemouth Bass	0.159	bd	6.4(27)	bd	bd	bd	bd
J249(J248)	Largemouth Bass	0.212	4.6(30)	9.5(29)	bd	bd	bd	bd

[a] See previous table for concentrations in flesh and related information. Number in parenthesis is the sample ID for the respective flesh sample.

[b] Number in parenthesis is the 1 σ counting error expressed as % of value listed.

bd - Below detection limits.

Concentrations of radionuclides in flesh of fish collected on 7-18-84 at stations R5, 4.6 km from the plant outfall.

Sample ID	Common name	Number of fish in pooled sample	Dry/wet wt	Mean fresh wt whole fish (g)	pCi/g wet wt[a] ^{134}Cs	^{137}Cs
J124	Bluegill	6	0.186	42	3.09(1)	6.62(2)
J126	Bluegill	5	0.184	28	2.15(3)	4.34(3)

[a] Number in parenthesis in the 1 σ counting error exposed as % of value listed.

Concentrations of radionuclides in stomach content of fish caught on 7-18-84 at station R-5, 4.6 km downstream from the plant outfall.

Sample ID[a]	Common name	Dry/wet wt	pCi/g wet wt[b] ^{134}Cs	^{137}Cs
J125 (J124)	Bluegill	0.183	2.75(7)	6.71(6)
J127 (J126)	Bluegill	0.186	3.3(11)	6.0(9)

[a] See previous table for concentrations in flesh and related information. Number in parenthesis is the sample ID for the respective flesh sample.

[b] Number in parenthesis is the 1 σ counting error expressed as % of value listed. All other radionuclides are below detection limits.

Concentrations of radionuclides in flesh of fish collected on 8-14-84 at stations R-5, 4.6 km from the plant outfall.

Sample ID	Common name	Number of fish in pooled sample	Dry/wet wt	Mean fresh wt whole fish (g)	pCi/g wet wt[a] ^{134}Cs	pCi/g wet wt[a] ^{137}Cs
J196	Bluegill	2	0.177	55	2.58(2)	5.54(2)
J198	Bluegill	7	0.205	30	2.11(1)	4.57(1)
J200	Bluegill	6	0.187	24	2.06(2)	4.45(2)
J202	Bluegill	8	0.190	16	1.77(2)	3.72(2)
J204	Largemouth Bass	11	0.196	7	1.20(3)	2.84(3)

[a] Number in parenthesis in the 1 σ counting error exposed as % of value listed.

Concentrations of radionuclides in stomach content of fish collected on 8-14-84 at station R-5, 4.6 km downstream from the plant outfall.

Sample ID[a]	Common name	Dry/wet wt	pCi/g wet wt[b] ^{134}Cs	^{137}Cs	^{54}Mn
J197(J196)	Bluegill	0.124	2.4(27)	7.1(14)	bd
J199(J198)	Bluegill	0.152	2.25(7)	4.89(7)	bd
J201(J200)	Bluegill	0.173	5.68(6)	12.3(5)	1.1(30)
J203(J202	Bluegill	0.181	2.4(24)	5.1(18)	bd
J205(J204)	Largemouth bass	0.149	bd	bd	bd

[a] See previous table for concentrations in flesh and related information. Number in parenthesis is the sample ID for the respective flesh sample.

[b] Number in parenthesis is the 1 σ counting error expressed as % of value listed.

bd - Below detection limits. All other radionuclides were below detection limits.

Concentrations of radionuclides in flesh of fish collected on 7-18-84 at stations R-8, 12.6 km from the plant outfall.

Sample ID	Common name	Number of fish in pooled sample	Dry/wet wt	Mean fresh wt whole fish (g)	pCi/g wet wt[a] ^{134}Cs	^{137}Cs
J118	Bluegill	4	0.188	94	0.16(7)	0.34(7)
J120	Bluegill	11	0.190	36	0.39(5)	0.79(4)
J122	Largemouth bass	4	0.202	148	0.25(4)	0.57(3)

[a] Number in parenthesis in the 1 σ counting error exposed as % of value listed.

Concentrations of radionuclides in stomach contents of fish caught on 7-18-84 at station R-8, 12.6 km from the plant outfall.

Sample ID[a]	Common name	Dry/wet wt	pCi/g wet wt[b] ^{134}Cs	^{137}Cs	^{60}Co
J119(J118)	Bluegill	0.171	0.17(33)	0.49(17)	0.51(75)
J121(J120)	Bluegill	0.195	0.40(28)	0.89(19)	bd
J123(J122)	Largemouth bass	0.159	bd	0.48(24)	bd

[a] See previous table for concentrations in flesh and related information. Number in parenthesis is the sample ID for the respective flesh sample.

[b] Number in parenthesis is the 1 σ counting error expressed as of % of value listed.

bd - Below detection limits. All other radionuclides were below detection limits.

Concentrations of radionuclides in flesh of fish collected on 8-14-84 at stations R-8, 12.6 km from the plant outfall.

Sample ID	Common name	Number of fish in pooled sample	Dry/wet wt	Mean fresh wt whole fish (g)	pCi/g wet wt[a] ^{134}Cs	^{137}Cs
J178	Largemouth Bass	1	0.215	653	0.28(8)	0.63(7)
J180	Largemouth Bass	4	0.202	104	0.23(3)	0.49(3)
J182	Bluegill	7	0.184	57	0.26(3)	0.56(3)
J184	Bluegill	9	0.186	39	0.30(5)	0.62(3)
J186	Bluegill	13	0.186	26	0.22(4)	0.44(4)

[a] Number in parenthesis in the 1 σ counting error exposed as % of value listed.

Concentrations of radionuclides in stomach contents of fish collected on 8-14-84 at station R-8, 12.6 km from the of plant outfall.

Sample ID[a]	Common name	Dry/wet wt	pCi/g wet wt [b] ^{134}Cs	^{137}Cs
J179(J178)	Largemouth bass	0.175		
J181(J180)	Largemouth bass	0.160	bd	0.75(20)
J183(J182)	Bluegill	0.175	0.45(22)	0.91(16)
J185(J184)	Bluegill	0.189	1.19(9)	2.74(6)
J187(J186)	Bluegill	0.203	0.81(17)	2.1(11)

[a] See previous table for concentrations in flesh and related information. Number in parenthesis is the sample ID for the respective flesh sample.

[b] Number in parenthesis is the 1 σ counting error expressed as of % of value listed.

bd - Below detection limits. All other radionuclides were below detection limits.

Concentrations of radionuclides in flesh of fish collected on 7-18-84 at stations R-11, 19.5 km from the plant outfall.

Sample ID	Common name	Number of fish in pooled sample	Dry/wet wt	Mean fresh wt whole fish (g)	pCi/g wet wt[a] ^{134}Cs	^{137}Cs
J110	Bluegill	8	0.185	81	0.080(11)	0.17(12)
J112	Bluegill	7	0.193	33	<0.04	0.095(30)
J114	Largemouth bass	2	0.201	65	<0.02	0.059(39)
J116	Catfish	5	0.185	50	0.034(28)	0.075(24)

[a] Number in parenthesis in the 1 σ counting error exposed as % of value listed.

Concentrations of Radionuclides in stomach content of fish caught on 7-18-84 at station R11, 19.5 km from the of plant outfall.

Sample ID[a]	Common name	Dry/wet wt	pCi/g wet wt[b] ^{134}Cs	^{137}Cs
J111 (J110)	Bluegill	0.172	bd	0.16(26)
J113(J112)	Bluegill	0.217	bd	bd
J115(J114)	Largemouth bass	0.155	bd	bd
J117(J116)	Catfish	0.243	bd	bd

[a] See previous table for concentrations in flesh and related information. Number in parenthesis is the sample ID for the respective flesh sample.

[b] Number in parenthesis is the 1 σ counting error expressed as of % of value listed.

bd - Below detection limits. All other radionuclides were below detection limits.

Concentrations of radionuclides in flesh of fish collected on 8-14-84 at stations R-11, 19.5 km from the plant outfall.

Sample ID	Common name	Number of fish in pooled sample	Dry/wet wt	Mean fresh wt whole fish (g)	pCi/g wet wt[a] ^{134}Cs	^{137}Cs
J188	Carp	1	0.189	281	bd	0.051(30)
J190	Largemouth Bass	4	0.202	173	0.073(8)	0.14(6)
J194	Bluegill	14	0.194	52	0.046(10)	0.10(10)

[a] Number in parenthesis in the 1 σ counting error exposed as % of value listed. All radionuclides were below detection limits in stomach contents.