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ABSTRACT

This report summarizes the information compiled in 1984 while assessing the environmental impact of radionuclides in aquatic releases from the Rancho Seco Nuclear Power Generating Station. Gamma-emitting radionuclides discharged since 1981 are found in many of the dietary components derived from the creeks receiving the effluent wastewater. Some soils and crops are found to contain radionuclides that originate from the contaminated water that was transferred to land during the irrigation season. ^{134}Cs and ^{137}Cs are the primary gamma-emitting radionuclides detected in the edible flesh of fish from the creeks. Concentrations in the flesh of fish decreased exponentially with distance from the plant. No significant differences in the ^{137}Cs activity were found between male and female fish of equal size, but concentrations may vary in fish of different size, with the season and diet. 21% of the total ^{137}Cs and ^{134}Cs discharged between 1981 and 1984 is associated with the creek sediments to a distance of 27 km from the plant. Fractions of the missing inventory have been transferred to land during the irrigation season or to downstream regions more distant than 27 km from the plant. The radiocesium content of the sediments in 1984 decreased significantly in a downstream direction, much in the same manner as concentrations decreased in fish. Radioactivity originating from the plant was not above detection limits in any terrestrial food item sampled beyond 6.5 km from the plant. Based on the usage factors provided by individuals interviewed in a 1984 survey, the fish and aquatic-organism ingestion pathway contributed the largest radiological dose to humans utilizing products contaminated with the radionuclides in the liquid wastes discharged from the Rancho Seco Nuclear Power Generating Station in 1984.

INTRODUCTION

The Rancho Seco Nuclear Power Generating Station (Rancho Seco), operated by the Sacramento Municipal Utility District (SMUD), is located in Sacramento County near the town of Clay, California. Prior to 1980, no radionuclides were directly discharged from the plant to the aquatic environment. Since 1980, however, small leaks in the steam-generation system have contributed radioactivity to the liquid waste. The liquid-waste solutions are collected and treated in holdup tanks, and these treated solutions, containing fission and activation products, are periodically released to two on-site retention basins. The liquid contents in the retention basins are diluted and discharged into Clay Creek. This creek flows past the site-boundary fence, 0.6 km from the point of discharge, and continues under State Highway 104 until it intersects Hadselville Creek, 3.0 km downstream from the plant. Hadselville Creek intersects Laguna Creek 6.5 km from the plant, and Laguna Creek drains into the Cosumnes River at a point near Twin Cities Road between Interstate Highway 5 and State Highway 99.

Appendix I of Regulatory Guide 10 CFR 50, provides design guidelines for nuclear power plants. Under Sec. IIA (1), it requires "The calculated annual total quantity of all radioactive material above background to be released from each light-water-cooled nuclear power reactor to unrestricted areas will not result in an estimated annual dose, or dose commitment from liquid effluents for any individual in an unrestricted area from all pathways of exposure in excess of 3 millirems to the total body or 10 millirems to any organ." "Conformity to the above shall be demonstrated by calculational procedures based upon models and data such that actual exposure of an individual, through appropriate pathways, is unlikely to be substantially underestimated, all uncertainties being considered together." When site-specific data are not available, the parameters and models recommended in Regulatory Guide 1.109, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I," revised October 1977 (2), are accepted by the United States Nuclear Regulatory Commission (NRC) for calculating exposure via the liquid-effluent pathway.

In the 1983 effluent and waste-disposal annual report (3), prepared by SMUD, "maximum individual" doses were calculated using Regulatory Guide 1.109 (2) for a variety of liquid-effluent pathways, which included use of potable water, irrigated food crops, fish, and direct (recreational) exposure due to shoreline, swimming, and boating activities. The doses were estimated assuming the stream water is 100% plant effluent; no dilution during the rainy season; uniform activity release throughout the year; the fish pathway occurs for the entire year; the meat, milk, and garden-vegetable pathways are a result of irrigation and occur only during the second and third quarters of the year; and no usage of the stream as a domestic water supply. Inspection of exposure from all pathways during 1983 revealed that the fish-consumption pathway dominated and that ^{134}Cs and ^{137}Cs from this pathway contributed a dose of 106 mrem to the whole body of "maximum man." This value alone greatly exceeded the total exposure guideline of 3 mrem/yr to the whole body.

Recommendations and guidance provided by NRC have made use of the maximum-exposed-individual approach. Several of the parameters used in this approach may differ significantly at various sites because of different environmental conditions and because some parameters are based on conservative estimates. It is stated in Regulatory Guide 1.109 (2) that this approach "is subject to continuing review by the NRC staff and that the applicant is encouraged to use information and data applicable to a specific region or site when possible." Further, as discussed in Section III, A2 of Appendix I to 10 CFR Part 50 (1), "...take into account any real phenomena or actual exposure conditions. Such conditions could include actual values for residence times, measured environmental transport factors (such as bioaccumulation factors), or similar values actually determined for a specific site. Where site-specific information and data are used, however, its justification on the measurements or other methods used to derive the values should be described and documented."

In the spring of 1984, we proposed to remedy the deficiency of site-specific analytical information regarding the concentrations and distributions of the gamma-emitting radionuclides discharged from Rancho Seco, and we prepared a series of proposals to SMUD to provide information regarding the:

1. Concentrations of ^{134}Cs and ^{137}Cs in fish from an off-site pond.
2. Concentrations and distributions of radionuclides in sediment between the plant outfall and State Highway 104.

3. Concentrations of all gamma-emitting radionuclides in components of the aquatic environment downstream from Rancho Seco.

Some of these objectives have been met and the analytical results published and discussed (4,5).

In the fall of 1984, SMUD requested that we expand our original proposed studies to provide additional radiological information that could be used by SMUD in dose estimates for the surrounding population from other pathways, including terrestrial pathways, not covered in the original program. The reason for including terrestrial pathways stemmed, in part, from the analytical results obtained from analyses of the downstream sediments. Only 21% of the cesium isotopes released from Rancho Seco could be accounted for in stream sediments sampled to a distance of 27 km from the plant. Approximately 300 mCi of ^{137}Cs were discharged between the months of April and September during the last 4 years; this amount represents 60% of the total ^{137}Cs discharged to the creek since 1981. Most local ranchers use water from the creeks during the spring and summer to irrigate a variety of crops; therefore, a substantial amount of ^{137}Cs and ^{134}Cs released from the plant during this period of each year could have been transferred to the nearby ranchlands.

No reliable information existed on site-specific pathways by which radionuclides could reach humans, nor were there reliable usage factors for any product possibly contaminated by radionuclides released in the liquid effluents. A survey was undertaken to identify environmental pathways that could provide any potential radiological dose to individuals and to determine the annual quantities of any possible contaminated food products that were consumed. Verbal interviews were conducted with downstream landowners and residents in the fall of 1984, and a report of the pathways and usage factors identified from these interviews has been published (6). However, more recent interviews, conducted by personnel from NRC and SMUD with some of the same local fishermen and ranchers previously interviewed, have resulted in information that differs from that originally supplied. An attempt is currently being made by personnel from SMUD to resolve these discrepancies.

According to the SMUD liquid-effluent release data, the quantity of ^{137}Cs discharged to the creek during 1984 was more than the total amount released during all the three preceding years. Nevertheless, the present SMUD (7) calculation of the highest exposure to the total body from ingestion of fish in 1984, based on our reported site-specific results and usage factors (4,6), is significantly lower than the 106 mrem/yr computed when the

annual releases were lower, using the parameters recommended in Regulatory Guide 1.109. This finding demonstrates the importance of having reliable and updated site-specific information for use in dose estimates.

This report will discuss and summarize the previously published results (4,5,6), along with all other unpublished data determined from the analyses of environmental samples collected between April and November 1984 from the region downstream of Rancho Seco. Recommendations will also be made for future sampling and analysis efforts.

GAMMA-EMITTING RADIONUCLIDES DISCHARGED WITH LIQUID WASTES

Prior to 1980, no radionuclides were directly discharged from Rancho Seco to the aquatic environment. Steam-generator leaks, which occurred in May 1981, November 1982, September 1983, and July 1984, have contributed wastewater containing quantities of fission and activation products. The liquid-waste solutions are collected on-site and treated in holdup tanks. Periodically, these treated solutions are released from the tanks to two on-site retention basins, where the wastewaters are diluted and eventually discharged to Clay Creek. The quantities of radionuclides in the liquid waste contained in each holdup tank are determined by SMUD prior to releasing the material to the retention basins

The amount of each radionuclide in each of the 1312 batch releases that occurred between May 1981 and 1 Nov 1984 were obtained from data provided by SMUD. Activities in each batch release that occurred during 1981, 1982, 1983, and the first four months of 1984 are decay-corrected (using the appropriate half-life for the respective radionuclide) to 1 May 1984 and summed to produce annual and monthly totals.

A summary of the decay-corrected values of long-lived gamma-emitting radionuclides released from the tanks to the basins during the period of plant operation from May 1981 to November 1984 is presented in Table 1 (the date of 1 May 1984 is an arbitrary point of reference). These values represent the quantities that would be in the environment on 1 May 1984, assuming no loss by any process other than radioactive decay. We were recently informed (7) that 2.4 mCi of ^{137}Cs and 1.3 mCi of ^{134}Cs were released to the waste water in 1980. These quantities were not included in the summary tables. Quantities in the individual releases during any month after 1 May 1984 were decay-corrected

Table 1. All long-lived gamma-emitting radionuclides released in liquid effluents from Rancho Seco during the period May 1981 to November 1984.

	mCi released from holdup tanks to retention basins						
Radionuclide:	^{54}Mn	^{58}Co	^{60}Co	^{134}Cs	^{137}Cs	^{110m}Ag	activity ratio $^{134}Cs/^{137}Cs$
half life (d):	3.123×10^2	7.130×10^1	1.922×10^3	7.450×10^2	1.096×10^4	2.530×10^2	
Date of releases							
1981[a]	4.0	5.7	39.7	20.9	35.3	0.5	0.35
1982[a]	3.3	0.9	18.8	8.6	16.7	0.0	0.34
1983[a]	2.3	0.7	13.3	50.8	105	0.0	0.46
1/1984[a]	0.0	0.2	0.5	22.8	44.2	0.0	0.64
2/1984[a]	0.0	0.3	0.2	20.8	39.1	0.0	0.63
3/1984[a]	0.0	0.1	0.0	10.1	19.1	0.0	0.63
4/1984[a]	0.0	0.3	0.5	25.5	49.3	0.0	0.62
Total as of 1 May 1984[c]	9.6	8.2	73	158	359	0.5	0.44
5/1984[b]	2.2	2.8	14.0	26.1	54.4	1.2	0.48
6/1984[b]	0.1	0.1	2.8	13.9	30.3	0.0	0.46
7/1984[b]	0.0	1.6	0.3	3.3	9.1	0.0	0.36
8/1984[b]	0.0	2.2	0.5	22.9	50.8	0.2	0.45
9/1984[b]	0.0	1.3	0.3	1.2	3.3	0.0	0.36
10/1984[b]	0.0	0.6	0.2	0.2	0.7	0.0	0.29
11/1984[b]	0.0	0.0	0.0	0.0	0.0	0.0	
Total as of 1 Nov 1984[c]	3.1	5.3	55	194	502	1.3	0.39

[a] Decay-corrected to 1 May 1984.

[b] Quantities released during the month. Decay-corrected to the end of the respective month.

[c] Decay-corrected sum released to the environment by the respective date.

NOTE: In addition to the above radionuclides, other gamma-emitting radionuclides occasionally released in 1984, according to SMUD records, include ^{131}I, ^{133}I, ^{135}I, ^{95}Nb, ^{136}Cs, and ^{24}Na. These radionuclides have not been detected in any environmental sample collected for analysis in 1984. ^{125}Sb was not reported in SMUD discharges, but small quantities of this radionuclide have been detected in the retention basins and in downstream sediment samples.

to the end of the respective month and summed to provide end-of-month decay-corrected totals. All releases were decay-corrected to 1 Nov 1984 and summed to provide a total for the quantity that would be in the environment as of 1 Nov 1984. The cumulative quantities of ^{134}Cs and ^{137}Cs discharged from the plant and decay-corrected to 1 Nov 1984 were 194 and 502 mCi, respectively. More ^{137}Cs was released during 1984 than the total amount released during the previous 3 years.

A change in processing procedures at the plant in late September 1984 has reduced the amounts of these gamma-emitting radionuclides in the liquid wastes since early October 1984, to undetectable quantities.

SAMPLE COLLECTION, PROCESSING, AND ANALYSES

General Comments

Table 2 shows the types and number of samples collected for analyses during 1984. Radiological data were generated for most of the dietary items identified during the survey (6). Unfortunately, sufficient results are lacking for concentrations in the edible portions of crayfish and in frog legs; both of these items were identified as dietary components by some individuals during the fall survey, a time of year when these organisms are very difficult to catch. Suitable collections of frogs and crayfish will be made during the spring and summer of 1985. Locations of the downstream sediment and fish-sampling stations are shown in Fig. 1, and detailed discussions of the fish and sediment collection methods, processing, and analyses can be found in previously published reports (4,5).

Fish Sampling and Processing

With a Scientific Collector's Permit issued by the State of California, a collector is allowed to catch freshwater fish in the state by hand, hook and line, seine, dip net, spear, scuba, traps, or other methods that require prior approval of patrol inspectors. All personnel involved with fish collecting in this study had valid Scientific Collector's Permits for 1984, and all collections were made using fishing gear with either bait or artificial lures. This method was adopted over other authorized fishing methods, or

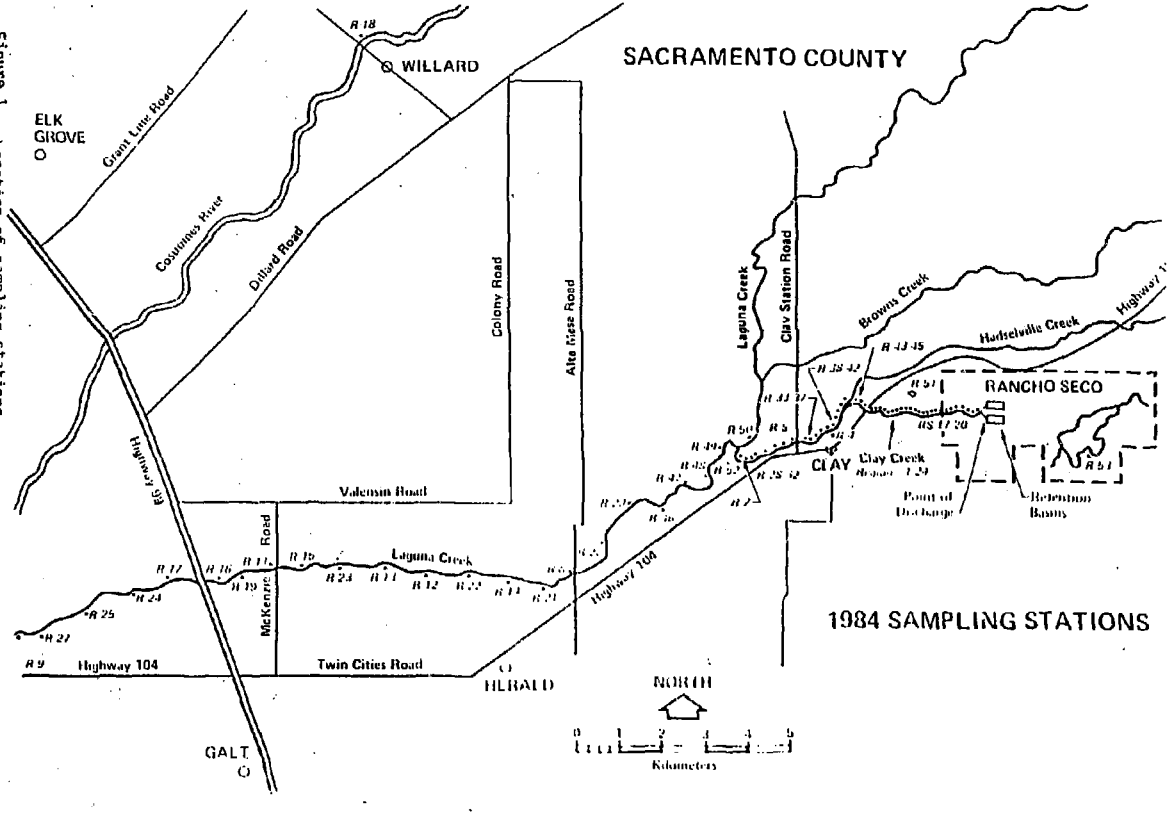

Figure 1. Location of sampling stations.

Table 2. Types of environmental samples collected and analyzed for gamma-emitting radionuclides in 1984.

Sample type	No. of samples collected	No. of subsamples analyzed
Fish		
Bluegill	190	76
Bass	114	52
Catfish	23	14
Carp	2	2
Crappie	6	2
Other aquatic organisms		
Crayfish	2	4
Duck	4	2
Terrestrial organisms		
Cow	1	3
Terrestrial products		
Milk	2	2
Corn	2	2
Berries	2	2
Grass	5	8
Alfalfa	1	1
Silage	1	1
Honey	1	1
Soil and sediments (all locations)	205	205
Sediment cores	29	117
Water samples	18	36
TOTAL	608	530

other methods such as chemical immobilization or electric shock, since it best mimicked the method used by local fishermen. Thus, the fish sampled would be more representative of the species normally caught from the creeks for consumption and would not be an indiscriminate collection of different species indigenous to California streams. Between April 26 and August 14, 1984, the time of year when most local residents fish at the creeks (6), a total of 234 fish were collected for analyses from different downstream locations. Of this total, 156, 72, and 6 were, respectively, bluegill, bass, and catfish. An additional 101 fish were caught later in the year. The land and aquatic use survey (6) indicated that bluegill, bass, and catfish were the species normally caught for consumption by the local residents. This fact justified the choice of our collection procedure.

More bluegill were collected than any other species because they were ubiquitous to the creeks and easy to catch. Also, there were reasons based on scientific considerations for the collections of bluegill. It had been shown from a study of the aquatic environment at the Savannah River Plant (8) that bluegill are the choice over bass and catfish as indicators of maximum uptake of radionuclides by edible fish. Bluegill (as well as bass) are not migratory, but are very territorial and spend most of their lives in localized areas in California streams (9). Therefore, the radionuclide concentrations measured in bluegill would be indicative of the concentrations in the local aquatic environment at the locations sampled and would also reflect the maximum concentration that might be associated with any fish caught for consumption by humans.

Samples were kept in ice and returned to Lawrence Livermore National Laboratory (LLNL), where the fish were frozen until processed. Standard length, sex, and fresh whole-body weight of each fish were recorded, and the fish were dissected to separate the edible flesh for analyses. The primary mode of accumulation of cesium by freshwater fishes has been shown to be via absorption from food or ingested sediments, rather than by direct uptake from water (10). Thus, samples from the gastrointestinal tract (GIT) were taken to determine the nature of the food eaten and the radionuclides associated with the ingested material. The flesh and GIT contents from fish of the same species, collected from the same 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, and transferred to aluminum or plastic containers for analysis by gamma spectrometry.

Water Sampling and Processing

Fifty-liter water samples were usually obtained at stations in conjunction with the fish collections. Water was pumped through 1-μm cartridge filters into 15-gal polyethylene containers and was returned to LLNL for processing. Cesium isotopes were first concentrated on ammonium molybdophosphate (AMP), the AMP was separated from the water by filtration, and the cesium was then separated from the AMP and prepared as solid samples for analyses on Ge(Li) detectors. The 1-μm filters containing the particulate material were ashed at 450°C, and concentrations of radionuclides in the particulate material were determined by gamma spectrometry.

Sediment Sampling and Processing

Two types of devices were used to collect samples of sediment. A stainless steel hand corer was used to sample a 6-cm-diam cylindrical core to a depth of 12 cm; the entire 12-cm section was analyzed as a single sample. A 5-cm-diam hand-held cylindrical-plastic core tube was used to obtain profile core samples to the maximum possible depth of penetration. The profile core was extruded backward from the plastic tube to minimize cross-contamination with the surface layer and was sectioned into 2- to 6-cm horizons. The outer 0.5-cm annulus was trimmed to remove any down-trained material, and the sectioned samples were analyzed to determine the vertical distribution of the radionuclides in the sediment column.

The locations of the downstream sample stations are shown in Fig. 1. The waterway was divided into six different regions for sampling purposes:

(1) The retention basins.
(2) Clay Creek between the plant discharge and Highway 104.
(3) Clay Creek from Highway 104 to the Hadselville Creek confluence.
(4) Hadselville Creek to the Laguna Creek confluence.

(5) Laguna Creek to a distance of 27 km from the plant.

(6) An irrigation pond near the intersection of Hadselville and Laguna Creeks.

Sampling dates and the number of sediment samples obtained from each region are provided elsewhere (5).

The sediment samples were dried in ovens at 90°C, homogenized, and sieved through 2-mm mesh screens to remove large rocks; the fine fraction was then transferred to containers for counting on Ge(Li) gamma spectrometers. Several separated rock samples were analyzed, and no man-made radionuclides above detection limits were found.

Terrestrial Sampling and Processing

Types of terrestrial samples collected in 1984 are identified in Table 2, and sample locations of the commercially grown products are provided in Appendix I. Soil samples were also collected with the alfalfa from the land of user "N" [a coded ID was assigned to each land user interviewed in the survey (6)]. Soil and pasture grass were sampled at stations numbered RSP 1 through 10 from the property of user "T." At each station, a 730-cm^2 section of soil was sampled to a depth of 15 cm with a power auger. Station RSP-1 is on land 50 m south of the irrigation pond on Clay Creek outside the Rancho Seco fence boundary line. Heading west, or downstream, RSP stations 2 through 10 were established every 50 m parallel to and 50 m from the south bank of the creek. This region of pastureland has not been cultivated for 3 years and is regularly irrigated with Clay Creek water. Each soil sample was dried, ball-milled, sieved, and transferred to standardized containers for analyses by gamma spectrometry.

Pasture grass was sampled at RSP 1, 5, and 10 and was subdivided into two sections. One section consisted of the portion of grass normally eaten by cattle, and the other section consisted of grass roots and adhering soil. At RSP-5, a column of soil was sampled to a depth of 46 cm, and the soil column was sectioned into 5-cm depth intervals between the surface and 30 cm. The bottom 15-cm increment was processed as a single sample.

Background soil and grass samples were obtained from a ranch northeast of Rancho Seco to determine the concentration of ^{137}Cs from global fallout in soil and grass from this region.

Gamma Analysis and Data Reduction

Gamma-spectrometry measurements were made on all samples at LLNL using a variety of Ge(Li)-diode detector systems. Counting times were usually 1000 min or longer for each sample. A general purpose computer program, called GAMANAL (11), was used for the data reduction of all gamma-ray spectra. GAMANAL compares the observed photopeak in the measured spectra with a library of gamma-ray fission and activation products and naturally occurring radionuclides to identify the radionuclides in the sample. The program then applies correction factors for sample size, density, counting time, counting geometry, and decay to convert the measured counting rate to pCi/g of sample on the reference date sampled. 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 min) for each of the principal longer-lived gamma-emitting radionuclides discharged to Clay Creek are shown in Table 3. These values are averages for the different sample configurations (geometries) used and are independent of sample weight. Samples prepared for analysis ranged in weight from a fraction of a gram, for dry stomach contents of fish, to over 300 g, for dry soil. Detection limits based on a per-gram basis are therefore different for samples of different weights.

Quality of data has always been an important aspect of our analytical measurements. As a standard practice, 5 to 10% of our time is devoted to quality-assurance work in all projects involving analytical measurements. This quality-assurance work includes:

- Analysis of background samples and blanks.
- Instrument calibration.
- Duplicate sampling and analysis.
- National and international interlaboratory standardization.
- Replicate measurements.
- Analysis and calibration traceable to National Bureau of Standards (NBS) samples.
- Appropriate statistical analysis of the results.

Table 3. Mean detection limits of selected 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	1	1	1	1	1	3	2

[a] Based on a counting time of 1000 min.

RESULTS

General Comments

Concentrations of gamma-emitting radionuclides in each sample of sediment collected between May and October 1984, and in samples of fish obtained between April and August 1984, have been tabulated in previously published reports (4,5). These documents should be consulted for details on radionuclide-concentration results and other relevant information regarding number, location, sample type, and dates sampled.

Aquatic Organisms

Appendices II through V give previously unreported concentrations of radionuclides determined in the muscle-tissue and GIT-content samples of fish collected from the creeks during October 1984, at stations located 0.5, 4.5, and 12.6 km downstream from the plant, and from an irrigation pond (also referred to as a pollution-control pond by the ranch owner) 5.4 km from the plant.

For all bluegill (Lepomis macrochirus) and largemouth black bass (Micropterus salmoides) caught between April and October 1984 from all creek stations, whole-body wet weight and standard length ranged from 4 to 190 g and 54 to 162 mm for the bluegill and from 4 to 902 g and 54 to 310 mm for the bass. Whole-body wet weight and standard length of the catfish (Ictalurus nebulosus) that were caught ranged from 32 to 617 g and from 117 to 260 mm. It was determined that the standard mean length (y) in mm was empirically related to the mean whole-body wet weight (x) in g of each species through a power function of the form $y = A\,x^B$. Regression analysis provided the best values for A and B for each species, and these values are shown in Table 4, along with the square of the correlation coefficient (r^2) and the number (N) of data points used. The values of A and B were recomputed for male and female bass; no significant differences were found in the values of A and B computed for each sex.

Table 4. A and B values relating length (y) to fish wet weight (x); number of data points used (N); and square of correlation coefficient (r^2).

	A	B	N	r^2
Bluegill	35.8	0.292	181	0.97
Bass - all	35.1	0.329	85	0.99
Bass - male	34.7	0.331	43	0.99
Bass - female	35.2	0.329	37	0.99
Catfish	42.1	0.302	22	0.92

Except for one sample, ^{134}Cs and ^{137}Cs were the only gamma-emitting radionuclides of plant origin that were detected in the flesh of fish collected from the creeks between April and October 1984. A single bluegill (sample J405, Appendix II) collected from station RS-17-20 during October 1984 contained levels of ^{60}Co above detection limits in the flesh. Data on the mean concentrations of ^{134}Cs and ^{137}Cs in the flesh of fish collected during this study are presented in Tables 5 and 6. The concentrations are averages weighted according to the total fresh weight of fish in each sample (4). Average concentrations of ^{137}Cs, ^{134}Cs, and ^{60}Co in the stomach contents of bluegill and bass collected from 0.5 to 0.6 km from the plant are shown in Table 7. This table also provides data on the quantities of ^{134}Cs, ^{137}Cs, and ^{60}Co discharged to the creek from the power plant during the nonsampling intervals.

Appendix VI contains the only results to date on the concentrations of radionuclides in eviscerated whole crayfish, including the exoskeleton. The concentrations of ^{134}Cs and ^{137}Cs (3.6 and 7.8 pCi/g wet, respectively) in the body and exoskeleton of the crayfish sampled 0.5 km from the plant on 18 July 1984 are similar to those in the flesh of bluegill (4.1 and 8.9 pCi/g wet, respectively) sampled on the same date from this same location. The fraction of the activity associated with the edible flesh of crayfish and the exoskeleton is not known at this time. For current dose estimates from crayfish consumption, it is recommended that the concentrations in the flesh of bluegill be substitued for crayfish until more reliable site-specific data are available.

Water Samples

Appendix VII contains all ^{134}Cs and ^{137}Cs concentrations determined in water samples collected from different stations during 1984. Concentrations are reported in the filtered particulate phase and in solution. One purpose for the water collections was to estimate the concentration factors for ^{137}Cs in bluegill and bass under the conditions that exist in the local environment. Concentration factors for a radionuclide in fish tissue may exhibit wide variations among bodies of water that are related to differences in stable-element or carrier-element analogue concentrations in the water. Therefore, the most useful value that can be

Table 5. 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	Station and distance from plant (km)	Bluegill: Mean fresh wt whole fish (g)	Bluegill: Number of fish	Bluegill: pCi/g wet ^{134}Cs	Bluegill: pCi/g wet ^{137}Cs	Bass: Mean fresh wt whole fish (g)	Bass: Number of fish	Bass: pCi/g wet ^{134}Cs	Bass: pCi/g wet ^{137}Cs
4-26-84	Station RS-17-20 (0.5-0.6 km)	127	6	5.7	11.1	188	1	3.3	7.0
5-18-84	Station RS-17-20 (0.5-0.6 km)	111	11	5.1	10.4	--	--	--	--
7-18-84	Station RS-17-20 (0.5-0.6 km)	48	21	4.1	8.9	34	16	1.3	2.8
8-14-84	Station RS-17-20 (0.5-0.6 km)	60	11	5.7	13.1	36	24	1.9	4.4
10-18-84	Station RS-17-20 (0.5-0.6 km)	81	5	6.4	15.2	173	6	5.0	11.8
Mean - entire period				5.2	11.0			3.1	7.2
4-26-84	Station RS-30 (0.6 km)[a]			--	--	567	2	1.6	3.5
5-18-84	Station RS-30 (0.6 km)	143	1	2.5	5.6	161	3	2.8	5.7
Mean - entire period				2.5	5.6			2.0	4.1
7-18-84	Station R-5 (4.6 km)	42	5	2.3	5.3	--	--	--	--
8-14-84	Station R-5 (4.6 km)	29	5	2.1	4.5	7	11	1.2	2.8
10-18-84	Station R-5 (4.6 km)	68	5	1.3	3.1	--	--	--	--
Mean - entire period				2.0	4.4			1.2	2.8
7-18-84	Station R-8 (12.6 km)	51	15	0.28	0.57	148	4	0.25	0.57
8-14-84	Station R-8 (12.6 km)	37	29	0.26	0.54	214	5	0.26	0.57
10-18-84	Station R-8 (12.6 km)	47	2	0.27	0.43	80	8	0.20	0.46
Mean - entire period				0.24	0.54			0.24	0.53
7-18-84	Station R-11 (19.5 km)	59	15	0.07	0.15	65	2	<0.02	0.06
8-14-84	Station R-11 (19.5 km)	52	14	0.05	0.10	173	4	0.07	0.14
Mean - entire period				0.06	0.13			0.06	0.13

[a] Station RS-30 is a sump pond connected to Clay Creek Station RS-17 by an underground pipe.

Table 6. Mean concentrations of ^{134}Cs and ^{137}Cs in flesh of other fish collected from downstream locations during 1984 (pCi/g wet wt).

Collection date	Station and distance from the plant (km)	mean fresh weight whole fish (g)	Number of fish	pCi/g wet ^{134}Cs	pCi/g wet ^{137}Cs
Catfish (*Ictalurus nebulosus*)					
4-26-84	Station RS-30 (0.6)[a]	617	1	0.93	2.05
10-17-84	Station R-52 (6 km)	206	5	2.22	5.10
7-18-84	Station R-11 (19.5 km)	50	5	0.03	0.08
Crappie (*Pomoxsis nigromaculatus*)					
10-16-84	Station R-8 (12.6 km)	86	6	0.16	0.33
Carp (*Cyprinis carpio*)					
8-14-84	Station R-11 (19.5 km)	281	1	bd	0.05

[a] Station RS-30 is a sump pond connected to Clay Creek Station RS-17 by an underground pipe.

bd below detection.

Table 7. Mean concentrations of ^{134}Cs, ^{137}Cs, and ^{60}Co in the GIT contents of fish collected at the site boundary (0.5 0.6 km from the plant, Station RS 17-20) and quantities discharged from the plant between sampling dates.

Collection date	Concentration in GIT contents (pCi/g wet weight)					
	Bluegill			Bass		
	^{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	--	--	--
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
10-18-84	6.9	2.8	bd	5.8	2.1	bd

Plant releases to retention basins during nonsampling intervals

Interval	mCi released[a]		
	^{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
8/14-10/18/84	18.6	7.9	1.0
Total	150	70	18.2

[a] Release data provided by SMUD.

bd below detection .

applied in an environment is a site-specific derived number. The concentration factor for fish (or tissue of fish) is defined as the steady-state ratio of the radionuclide concentration in the fish to that in water. Comparison of the ^{137}Cs concentrations in filtered creek water to bluegill and bass flesh is made in Table 8. Because of the random nature of the effluent releases, it is difficult to see good correlations between fish and water concentrations at stations nearest the plant, where highest water concentrations are encountered. The concentrations in the water at the more distant stations undergo less rapid changes with time, and the conditions are probably nearer to steady state. The mean concentration factors for ^{137}Cs in the flesh of bluegill and bass from stations R8 and R11 are 1.4×10^3 and 1.2×10^3, respectively. When compared with unfiltered water, the concentrations factors are 0.9×10^3 and 0.8×10^3, respectively. These values are recommended if a concentration-factor approach is required to meet certain radiological protection criteria. Shown for comparison in Table 9 are other published values for ^{137}Cs and stable cesium concentration factors in bluegill and bass. Our recommended values are in good agreement with published concentration factors, even though the latter were derived from a very different aquatic environment.

Sediments

The only unreported concentration data for sediment are from a 12-cm long core sample obtained on 26 Oct 1984 from a shallow pond, 440 m in circumference, located 400 m north of Clay Creek sediment station RS 12. The pond (station R-51 in Fig. 1) collects drainage water from elevated ground near the site boundary and is not connected to the creek where the liquid effluents are discharged. ^{137}Cs was above detection limits in the sediment, at a concentration of 0.20 ± 0.02 pCi/g dry. The computed inventory of ^{137}Cs in the upper 12 cm of sediment is 31 mCi/km^2. ^{134}Cs is approximately 40% of the ^{137}Cs concentration.

Terrestrial Foods

Concentrations of the radionuclides measured in various terrestrial food products collected in 1984 are shown in Appendix I. Radioactivity originating from the plant was not detected in any food item sampled beyond a distance of 6.5 km from the plant.

Table 8. ^{137}Cs concentrations in flesh of fish and creek water, and concentration factors (CF).

Date	Sampling station	Filtered water concentration (pCi/l)	Bluegill mean flesh concentration (pCi/g wet)	CF	Bass mean flesh concentration (pCi/g wet)	CF
4/26/84	RS-17-20	4.55	11.1	2.4×10^3	7.0	1.5×10^3
7/18/84	RS-17-20	0.26	8.9	34.0×10^3	2.8	11.0×10^3
8/15/84	RS-17-20	1.87	13.1	7.0×10^3	4.4	2.4×10^3
10/18/84	RS-17-20	2.13	15.2	7.1×10^3	11.8	5.5×10^3
7/18/84	R-5	1.61	5.8	3.6×10^3		
8/14/84	R-5	11.3	4.5	0.4×10^3	2.8	0.3×10^3
10/18/84	R-5	1.68	3.1	1.8×10^3		
7/18/84	R-8	0.45	0.57	1.3×10^3	0.57	1.3×10^3
8/14/84	R-8	0.60	0.54	0.9×10^3	0.57	1.0×10^3
10/18/84	R-8	0.23	0.43	1.9×10^3	0.46	2.0×10^3
7/18/84	R-11	0.11	0.13	1.4×10^3	0.06	0.5×10^3
		Range		$0.4-34 \times 10^3$		$0.3-11 \times 10^3$
	Recommended value for flesh			$1.4 \pm 0.4 \times 10^3$		$1.2 \pm 0.6 \times 10^3$

Table 9. Published concentration factors for ^{137}Cs in bluegill and bass.

Location	Tissue	Concentration factor ^{137}Cs	Concentration factor Stable Cs	Water	Ref.
Bluegill (*Lepomis macrochirus*)					
Clinch River, Tenn.	Flesh		1.7×10^3	Filtered	(12)
Par Pond, Tenn.	Flesh	0.9×10^3		Unfiltered	(8)
White Oak Lake, Tenn.	Whole	0.7×10^3		Filtered	(13)
Largemouth bass (*Micopterus salmoides*)					
White Oak Lake, Tenn.	Whole	0.9×10^3		Filtered	(13)
Par Pond, Tenn.	Flesh	1.2×10^3		Unfiltered	(8)
Wintergreen Lake, Mich.	Whole	1.5×10^3		Filtered	(14)

Soil and Pasture Grass

Results from the analyses of all soil and grass samples (including background samples) are shown in Appendices VIII through XII.

DISCUSSION

Because the concentration of ^{134}Cs in fish samples and other types of samples is about 42% of that of ^{137}Cs (a ratio similar to that in the liquid-waste discharges), there is no doubt that much of the cesium radioactivity detected in the samples resulted from wastes discharged from Rancho Seco, and not from global fallout.

There are marked differences in ^{137}Cs concentrations among various species of fish. Tables 5 and 6 show that the mean concentration of ^{137}Cs in the flesh of bluegill was always greater than (or at least equivalent to) the concentration in the flesh of other species collected from the same station on the same date. This finding supports the usefulness of bluegill as an indicator of maximum flesh concentrations among the edible fish collected from the creeks. If usage factors for specific species caught in the creeks are not known, it is recommended that mean bluegill concentrations be used with generic usage factors to estimate possible human exposure from fish consumption.

Station RS-17 (0.6 km from the plant discharge point) is the first location on the creek available to local fisherman outside the SMUD fence boundary. Bluegill caught at this station between April and October 1984 ranged in weight from 22 to 190 g and contained higher concentrations of ^{134}Cs and ^{137}Cs in the flesh than occurred in fish collected from any other downstream location. Concentrations of ^{134}Cs and ^{137}Cs in fish decrease with distance downstream from the plant.

Variations of ^{137}Cs concentrations were not large in fish of the same species from the same station of the creek over the period from April to October. During this period, concentrations in bluegill flesh from stations RS-17-20, R-5, R-8, and R-11 varied over the small ranges of 5 to 17, 3 to 7, 0.17 to 0.3 , and 0.1 to 0.2 pCi/g wet, for the respective stations. Similar small variations were found for ^{137}Cs concentrations in the flesh of bass from these stations.

Encountering such narrow ranges in concentrations among fish of different weight from each station was surprising. Kolehmainen (13) found approximately an order-of-magnitude variation in the concentration of ^{137}Cs in individual bluegill from White Oak Lake, Tenn., an environment considered to be under steady-state conditions. The creeks, unlike a lake, are far from a condition of steady state. Table 5 shows that, at station RS-17-20, there are differences noted in the computed monthly mean concentrations of ^{137}Cs in bluegill, with a minimum concentration in July and maximum concentrations in the spring and fall. Coincident with these differences in concentration are changes noted in the mean weight of the fish caught during tne months. One may argue that these small differences in concentration result from changes related to season, weight, or length. However, disregarding these factors, all ^{137}Cs concentration data for flesh from all bluegill collected between April and October fall on a normal distribution with an unweighted mean concentration of 11.7 ± 3.0 pCi/g. (The number of samples prepared from the fish collected at other stations was too small for a statistical treatment of the data.)

Based on the data from station RS-17-20, the assumption is made that it is appropriate to use mean concentrations of ^{134}Cs and ^{137}Cs in the flesh of bluegill to estimate exposure from fish consumption during the fishing season. The values for mean concentrations (weighted values shown in Table 5) would be as determined at each station over the entire season and would disregard possible differences due to weight or season.

The mean concentrations of ^{137}Cs determined in bluegill flesh between April and August at the different stations were used to develop a relationship between mean flesh concentration and distance downstream of the point of entry of the reactor effluent (4). This relationship, given by Eq. (1), is expressed by an exponential equation fitted to the data by a least-square analysis.

$$C \text{ (pCi/g wet)} = 12.9\, e^{-0.24\, D}, \qquad (1)$$

where D is the distance in km of the station (given in Table 5), downstream from the plant, where the fish were caught. With the use of this relationship, the predicted levels of ^{137}Cs in bluegill collected during October from stations RS-17-20, R-5, and R-8 differ from the measured

concentrations by an average of ±36%. In the absence of distance-specific concentration data, the expression for bluegill may be used with some degree of confidence to estimate the mean concentrations in fish from downstream fishing locations during the 1984 fishing season. The equation should not be used to estimate concentrations in fish from sumps or downstream ponds. An independent evaluation should be made of the dose derived by consuming any fish that were collected from the downstream sumps or ponds. Some of the ponds act as sediment traps and may have very different levels of radionuclides in the bottom deposits than occur in the sediments from the adjacent stream bed. The standing water in the ponds also provides an environment to fish different than moving water in the stream. The constants in Eq. (1), recomputed by a least-square analysis, do not significantly change in value when the October data are included to generate the mean fish concentration for the entire season shown in Table 5.

If differently contaminated populations of bluegill were moving into and out of the different fishing areas on the creek during the year, it would be highly unlikely to find a relationship between concentration and downstream distance. The fact that this correspondence exists is taken as evidence confirming the known territorial characteristics of these fish.

A similar relationship between radionuclide concentrations in bass and downstream distance was developed from the April-to-August data (4). However, because there were substantially fewer bass than bluegill analyzed, less confidence was placed on the relationship developed for bass. Including the October concentration data base for bass, the recalculation of mean concentrations and redetermination of the constants by a least-square analysis results in a change for the value of A, preceding the exponential, from 5.5 (4) to 7.7 and for the exponent, B, from -0.19 (4) to -0.21. Equation (2) is the current best relationship to estimate mean ^{137}Cs levels in bass from downstream locations during 1984.

$$C\ (pCi/g\ wet) = 7.7\ e^{-0.21\ D}. \qquad (2)$$

Sufficient data do not exist for catfish from the creek in 1984 to develop a relationship between concentration and distance; bluegill concentrations should be used for dose estimates if downstream site-specific catfish concentrations are not available.

There are several conflicting results for which reasonable interpretations cannot yet be made. It would appear that the releases of

^{137}Cs and ^{134}Cs that occurred between April and November, shown in Table 7, do not greatly influence the body burdens of the fish collected from station RS-17-20. Between the May and July fish collections, for example, 70 mCi of ^{137}Cs were discharged to the creek. These quantities were greater than the amounts released during the previous and subsequent sampling intervals, yet the mean concentrations of ^{137}Cs in bluegill and bass (Table 5) collected in July were the lowest found. During the release intervals considered in Table 7, less ^{137}Cs was discharged to the creek between 14 August and 18 October than during the other intervals; however, concentrations of ^{137}Cs increased in the flesh of bluegill and bass during this period. Between July and October, there was successively less ^{137}Cs discharged during the nonsampling intervals, but the concentrations in bluegill and bass increased over this period. On the other hand, concentrations of ^{137}Cs in bluegill from station R-5 especially, and from R-8, decreased between July and October, reflecting the changing concentrations in the releases during this period. The concentrations of ^{137}Cs in bluegill from all downstream locations are not changing or responding to the different quantities released from the plant.

In other studies with bluegill and bass from White Oak Lake, Tenn., between June 1967 and January 1969 (13), and with bass from Wintergreen Lake, Mich., during the period May to October 1969 (14), concentrations of ^{137}Cs in both species showed seasonal variations, with minimum concentrations during August and higher concentrations in the spring and fall. It was speculated that the variations during the year could result from changes in the diet. A similar trend is seen in the mean concentration data shown in Table 5 for bluegill and bass from station RS-17-20. During the months of this study, minimum concentrations were found in the flesh of these fish during July (rather than August), and the concentrations increased to maximum levels in the late fall. This trend, if seasonal, was not found at stations R-5 or R-8, where concentrations in bluegill decreased between July and October. Dominant dietary items in the GIT were examined and found to change from benthic material in spring, to insects in summer, and back to benthic material in fall. The same change, however, was noted in the composition of the GIT-content samples from fish sampled at all stations. Unless there are different proportions of ^{137}Cs associated with the ingested material that are more or less readily absorbed across the gut at the different downstream

distances, the same seasonal trends are not evident everywhere. The previously cited studies (13,14) also have shown some relationships between body burdens of ^{137}Cs in fish and whole-body weight that may explain some variations noted in the fish concentrations. Kolehmainen (13) found that the concentrations of ^{137}Cs in bluegill from White Oak Lake increased with size of fish linearly up to 70 g; no correlation was found between the concentration and the weight of fish above 70 g. Spigarelli (14) noted that, in bass from Wintergreen Lake, the relationship between weight and ^{137}Cs activity was curvilinear, with a positive slope up to approximately 1000 g and a negative slope above 1000 g. More bass were caught at station RS-17-20 than at the other stations, but all of the fish caught were less than 1000 g in total wet weight. However, the mean concentration of ^{137}Cs in bass did increase in the three sample-weight groups of 0 to 100, 100 to 200, and greater than 200 g. The computed mean concentration of ^{137}Cs in the flesh of these three groups is 4.0 ± 2.5, 6.9 ± 1.0, and 11.8 ± 4.0 pCi/g, respectively. This change follows the increasing slope in concentration with weight found by Spigarelli (14) and warns that there may be higher concentrations of ^{137}Cs associated with the flesh of larger bass that we did not sample on this program. However, it is possible that some local fishermen may have caught and eaten fish of larger sizes in 1984. If the concentration in bass from station RS-17-20 increases with weight, with the same slope found for bass from Wintergreen Lake, then (by extrapolation) the flesh from a 1000-g bass could have contained 17 to 25 pCi/g of ^{137}Cs. A collection and analysis of larger-size bass in the 1985 program would confirm this possibility.

A comparison between concentration and weight of bluegill from station RS-17-20 indicates the possibility of a curvilinear relationship, as Spigarelli (14) found for bass. However, if there are variations in ^{137}Cs concentrations related to both season and weight, then all monthly data should be compared independently. The relationship between flesh concentration (C = pCi/g wet weight) and whole-body wet weight (W = grams) during the months of May, July, August, and October was simulated by a curvilinear equation fitted to the data by a least-square analysis:

$$C = A \times W \times e^{BW}, \qquad (3)$$

where A and B are constants to be determined. The values of A and B, the regression coefficients, and the weight of fish with the maximum concentration

[determined by differentiating Eq. (3) and setting dC/dW to zero] are given in Table 10. Also shown are the values for A and B computed for all bluegill (assuming no seasonal effect) and for all male and female bluegill caught between April and October. In Table 11, the concentrations of ^{137}Cs are computed for flesh of different-weight fish during different periods using the appropriate values for A and B from Table 10. There are some subtle differences in the concentrations computed for the different sizes of fish during the months sampled that suggest concentrations may change with season.

None of the computed monthly concentrations are significantly different from the concentration estimated using all results between April and October. No significant difference in the ^{137}Cs activity was evident between male and female bluegill of equal weight. Sufficient concentration data do not exist for single fish (collected at other downstream locations) to develop similar relationships. In 1984, the fish concentration data base was not generated for the purpose of permitting rigorous interpretations of seasonal and weight dependence of fish concentrations. However, these preliminary results do suggest some interesting correlations, which we hope to develop better during the 1985 program.

Concentrations of radionuclides in the downstream sediments in contact with the effluent water discharged from Rancho Seco have been summarized and discussed by Wong et al. (5). Only 21% of the ^{134}Cs and ^{137}Cs discharged between 1981 and 1984 is associated with the top 12 cm of bottom sediments of Clay, Hadselville, and Laguna Creeks to a distance of 27 km from the plant. Radiocesium content of the sediments decreased significantly in a downstream direction from the point of introduction of the effluent water. A reasonable exponential correlation ($r^2 = 0.88$) was found between the sediment areal concentration (mCi/km^2) and distance, D (km), from Rancho Seco, as given by Eq. (4).

$$^{137}Cs\ (mCi/km^2) = a\ e^{-b\ D\ (km)} \qquad (4)$$

The values computed for a and b from the 1984 results were 1660 mCi/km^2 and 0.26 km^{-1}, respectively. This equation may be used to estimate concentrations of ^{137}Cs in surface sediments at any downstream location

Table 10. Values of A and B determined from Eq. (3), relating monthly ^{137}Cs concentrations in bluegill and whole-body weight.

Month	No. of fish	A	B	r^2	W^a_{max}	C^b_{max}
May	9	0.33	-0.010	0.90	100	12.1
July	5	0.31	-0.010	0.85	100	11.4
August	11	0.55	-0.015	0.60	67	13.5
October	5	0.44	-0.010	0.86	100	16.2
May-Oct	30	0.40	-0.011	0.77	91	13.4
May-Oct (male only)	19	0.48	-0.013	0.88	77	13.6
May-Oct (female only)	11	0.40	-0.011	0.97	91	13.4

[a] Weight of fish with computed maximum concentration.

[b] Computed from W_{max} and Eq. (3).

Table 11. Concentrations of ^{137}Cs in flesh for different-weight bluegill using the coefficients from Table 10.

Wt of bluegill (g)	^{137}Cs (pCi/g wet)						
	May	July	Aug	Oct	May-Oct	Male	Female
25	6.3	6.0	9.4	8.5	7.6	8.7	7.6
50	9.9	9.4	12.9	13.3	11.5	12.5	11.5
75	11.5	10.9	13.3	15.6	13.1	13.6	13.1
100	12.0	11.4	12.2	16.1	13.3	13.1	13.3
125	11.7	11.1	10.5	15.7	12.6	11.8	12.6
150	10.9	10.3	8.6	14.7	11.5	10.2	11.5
200	8.9	8.4	5.5	11.9	8.9	7.1	8.9

(excluding ponds) during 1984. ^{134}Cs is approximately 40% of the ^{137}Cs activity. Note that the exponent of 0.26 in Eq. (4) is close in value to 0.24, the exponent in Eq. (1) that relates ^{137}Cs concentrations in bluegill with downstream distance. Thus, there appears to be a close correlation between the fish body burdens and quantities of ^{137}Cs activity released that were retained in the downstream sediments.

Equation (4) only describes the downstream distribution for ^{137}Cs inventories determined in 1984. With time, the downstream patterns of ^{137}Cs and ^{134}Cs concentrations in the creek sediments will change. ^{134}Cs levels will decrease over the next few years by physical decay; some contaminated sediments will suspend and move downstream during periods of high flow rates brought about by rain and runoff; and some ^{137}Cs will remobilize from the stream sediments and migrate downstream in solution. A fraction of this ^{137}Cs may readsorb on new sediment surfaces, remain in solution, or be transferred to land during the irrigation season. All these and other processes may possibly extend the region of contamination and alter the downstream inventories of ^{137}Cs with time, making it now difficult to predict what the distributions of ^{137}Cs in sediments may look like in the future. It is likewise not possible to predict the pattern of the downstream distributions of radionuclides in the sediments during 1981, 1982, or 1983 because of the many processes that may have affected the distributions to different degrees during each year.

For the same reasons, it is not possible to reconstruct past fish concentrations or to now predict what future concentrations may be at locations along the creek. However, if the assumption is made that the same fraction of the total amount of ^{137}Cs in each past annual release was distributed proportionally among all environmental components, then it is instructive to relate the concentrations of ^{137}Cs in fish to what was known of its concentration in the discharges. Such calculations are useful because they make it possible to predict mean concentrations that the fish may have obtained in past years. Methods similar to this approach have been used with considerable effect in the radiological control of fission-product discharges from the Sellafield fuel-reprocessing facility in England (15). Shown in Table 12 are the cumulative quantities of ^{137}Cs discharged from Rancho Seco as of the fish collection dates in 1984. The mean monthly concentration of ^{137}Cs (Table 5) in monthly collections of bluegill from each station is

divided by the respective cumulative quantity discharged. The monthly values are averaged in Table 12 to provide an estimate of the mean pCi/g of ^{137}Cs in bluegill relative to the cumulative quantity released. From the release data in Table 1, the cumulative quantity of ^{137}Cs discharged by the end of 1981, 1982, 1983, and 1984 can be easily computed. These values are multiplied by the mean value for pCi/g per Ci released at each station to provide an estimate of what the concentration of ^{137}Cs may have been in fish during each of the past 4 years at the downstream locations. These estimated values are shown in Table 12. It is also possible to develop exponential equations, similar to Eq. (1), by a least-square analysis of these data to relate pCi/g/Ci released in any year with downstream distance and to reconstruct, with these heuristic models, concentrations in bluegill from any downstream location for retrospective dose estimates from the fish-consumption pathway.

Table 13 is a summary showing the percent of the activities, previously discharged from the plant, that are now present in the sediments from the different locations sampled in 1984. Only 19 to 47% of the radionuclides released to the creek since 1981 could be accounted for in the creek sediments. The largest fraction of the more particle-reactive radionuclides, such as ^{110m}Ag, ^{54}Mn, ^{60}Co, and ^{58}Co, was found in the retention-basin sediments. These radionuclides were not detected in any sample collected from the creek farther than 6.5 km from the plant.

Only 21% of the released cesium isotopes are accounted for in the stream-bed sediments. There are other possible sinks for the remaining inventories of ^{137}Cs and ^{134}Cs. Approximately 300 mCi of ^{137}Cs were discharged between the months of April and September during the last 4 years; this amount represents 60% of the total ^{137}Cs discharged to the creek since 1981. Most local ranchers use water from the creek during the spring and summer to irrigate a variety of crops (6), and it was determined that 67% or more of the water discharged from the plant between March and September was used for irrigation in 1984 (6). Therefore, a substantial amount of ^{137}Cs released from the plant during this period of each year could have been transferred to the nearby farmlands. ^{134}Cs and ^{137}Cs are detectable in soil samples and grass collected from a single irrigated pasture (Appendices VIII through X); however, these data alone, from a few soil samples, are not sufficient to estimate the quantities of radionuclides

Table 12. Relative concentrations of ^{137}Cs in bluegill and cumulative quantities discharged. Estimated concentrations in bluegill at downstream locations in 1981, 1982, and 1983.

Month/1984	Cumulative ^{137}Cs (Ci) discharged (1981 to month in 1984)	^{137}Cs pCi/g wet bluegill flesh/cumulative release (Ci) at downstream station during month sampled[a]			
		Station-downstream distance (km)			
		0.55	4.6	12.6	19.5
April	0.36	31			
May	0.38	27			
July	0.45	20	13	1.3	0.33
August	0.49	27	9	1.1	0.29
October	0.50	30	6	0.9	
Mean		27 ± 4	9 ± 4	1.1 ± 0.2	0.31 ± 0.03
		Estimated pCi/g in bluegill flesh at downstream stations listed above			
End of 1981		2.3	0.8	0.1	0.03
End of 1982		2.8	0.9	0.1	0.03
End of 1983		5.6	1.9	0.2	0.06
End of 1984		13.6	4.5	0.6	0.16

[a] Flesh concentrations (pCi/g wet) are given in Table 5.

Table 13. Estimated percent of the total inventory of radionuclides released from the plant associated with the creek sediments in 1984.

Area	Percent of discharged activities in sediment					
	^{54}Mn	^{58}Co	^{60}Co	^{110m}Ag	^{134}Cs	^{137}Cs
1. Retention basins	23	13	21	38	2	2
2. Clay Creek (Plant to Hwy 104)	6	4	6	9	7	7
3. Clay Creek (Hwy 104 to Hadselville confluence)	0.2	0.2	0.1	0.1	0.3	0.3
4. Hadselville Creek (from Clay Creek confluence to Laguna Creek)	1.8	1.4	0.7	bd	5.8	5.2
5. Irrigation Pond (off Hadselville Creek, R-51)	1.8	bd	2.1	bd	4.9	5
6. Laguna Creek (between 7 and 27 km from the Rancho Seco Plant)	bd	bd	bd	bd	1.3	1.3
Percent inventory - all areas:	33	19	30	47	21	21

bd below detection.

transferred to land by irrigation. In the fall of 1984, the EG&G Co. conducted an aerial radiological survey of the land around Rancho Seco to identify any of the downstream regions contaminated with levels of radioactivity. This survey information, when published, will be used to develop any future terrestrial soil-sampling program that appears warranted.

The activity ratios of ^{134}Cs to ^{137}Cs in the soil indicate that not all the ^{137}Cs in the irrigated land originated from plant discharges. The activity ratios of $^{134}Cs/^{137}Cs$ in discharges during 1981, 1982, 1983, and 1984, decay corrected to November 1984, were 0.21, 0.29, 0.41, and 0.43, respectively. The activity ratios in the soil samples for stations RSP-3 to -10 (Appendix VIII) were all less than 0.20. The reasonable assumption is made that there are no differences in the chemical, physical, or biological behavior of the two cesium isotopes. To find a ratio less than 0.20 in the environment means that the plant discharges had to be mixed in the soil with quantities of global fallout ^{137}Cs.

The soil from station RSP-10 (Appendix VIII) has a $^{134}Cs/^{137}Cs$ activity ratio of 0.05. The decay-corrected total quantity of ^{134}Cs and ^{137}Cs released from the plant since 1981 results in an activity ratio of 0.39 by November 1984 (Table 1). This value should be the soil ratio if there were equal applications of contaminated water to the irrigated plot between 1981 and 1984. The concentration of ^{137}Cs in the soil at RSP-10 is 0.66 pCi/g. Using expressions (5), (6), and (7) to develop the general Eq. (8), it can be shown that, of the 0.66 pCi/g of ^{137}Cs detected, 0.58 pCi/g originated from global fallout.

$$^{134}Cs \text{ (from plant)} = 0.39\ ^{137}Cs \text{ (from plant)}, \tag{5}$$

$$\frac{^{134}Cs \text{ (from plant)}}{^{137}Cs \text{ (plant)} + ^{137}Cs \text{ (fallout)}} = R, \tag{6}$$

$$^{137}Cs \text{ (plant)} + ^{137}Cs \text{ (fallout)} = y \text{ (total pCi/g in soil)}, \tag{7}$$

$$^{137}Cs \text{ (fallout)} = (0.39 - R)\ (y/0.39)\ \text{(pCi/g)}, \tag{8}$$

where R is the $^{134}Cs/^{137}Cs$ activity ratio in the soil and y is the total ^{137}Cs activity in pCi/g. The mean fallout ^{137}Cs computed in the 10 RSP soil samples from Eq. (8) is 0.64 $\pm$ 0.17 pCi/g. The mean fallout ^{137}Cs inventory in this pasture soil, to 15.2 cm depth, is 31 mCi/km^2.

The concentration profile in the soil column from station RSP-5 (Appendix IX) shows that the largest ratio of ^{134}Cs to ^{137}Cs activity is found in the upper 5 cm of soil. Had the soil been sectioned into smaller increments, a ratio of 0.39 or more would probably have been found in the surface section.

The activity ratios of ^{134}Cs to ^{137}Cs in the pasture-grass samples (Appendix X) from stations RSP-1, 5, and 10 differ from those determined in the soil sampled to 15 cm at the respective stations. Roots were found throughout the soil column to at least 25 cm. To account for the higher-than-soil activity ratios in the grass, it would appear either that the grass must derive its burden of ^{134}Cs and ^{137}Cs from the upper few centimeters of irrigated soil only, and not from the entire root zone, or that fallout ^{137}Cs, being in the soil for a longer period of time, is more immobilized than recently applied cesium isotopes from the plant releases. Flesh from a 7-year-old cow grazing on this land contained low concentrations of ^{134}Cs and ^{137}Cs (Appendix I), with an activity ratio consistent with the value found in the sampled pasture grass.

An unusual, and presently unexplained, feature is the difference consistently found between the $^{134}Cs/^{137}Cs$ activity ratios in filtered water and in the particulate material sampled from the creeks during 1984 (Appendix VII). The activity ratio of the cesium isotopes in solution was consistently less than the ratio of the isotopes associated with the material filtered from water at all stations downstream of the plant. It would appear that the radiocesium is very firmly held to the resuspended bottom particles and is not easily displaced or exchanged.

Water samples taken 20 km from the plant during October, after the Rancho Seco discharges stopped, contain small but measurable quantities of ^{134}Cs and ^{137}Cs above background concentrations (Appendix VII). Quantities of ^{134}Cs and ^{137}Cs are mobilized from the sedimentary deposits and transported in solution downstream to regions farther than 20 km from the plant.

CONCLUSIONS

Gamma-emitting radionuclides released from the Rancho Seco Nuclear Power Generating Station since 1980 are found in many of the dietary components derived from the creeks receiving the effluent discharges. Some soils and food crops are found to contain radionuclides that originate from contaminated discharge water that was transferred to the land during the irrigation seasons.

Of the radionuclides released, ^{134}Cs and ^{137}Cs are the primary gamma-emitting radionuclides detected in the edible flesh of fish from the creeks. There are differences in the concentrations of ^{134}Cs and ^{137}Cs among species, and concentrations in the flesh of bluegill (during 1984) were either equivalent to or greater than concentrations in the flesh of other fish caught from all locations sampled. Highest concentrations were detected in the flesh of fish sampled nearest to the plant. Concentrations in fish tissue decreased with distance downstream from the point of effluent waste discharge. Exponential equations were generated, from a least-squares analysis, to relate the concentration of ^{137}Cs in fish flesh during 1984 to downstream distance. These equations may be useful for estimating concentrations in bluegill and bass from the stream where no site-specific data are available.

A heuristic model was proposed to estimate concentrations in fish from downstream locations during 1981, 1982, and 1983. No significant differences in the ^{137}Cs activity were found between male and female fish of equal size, but concentrations may vary, in fish of different size (or length) with the season and diet. Based on water and flesh concentrations, recommended ^{137}Cs concentration factors for bluegill and bass are 1.4×10^3 and 1.2×10^3, respectively.

Because many previous studies (summarized in Ref. 10) showed high adsorption of ^{137}Cs to freshwater sediments, it was anticipated that a major fraction of the cesium radionuclides would be associated with the creek sediments. It was found, however, that only 21% of the total ^{137}Cs and ^{134}Cs discharged between 1981 and 1984 is associated with the top 12 cm of the bottom sediments of Clay, Hadselville, and Laguna Creeks to a distance of 27 km from the plant. Other gamma-emitting radionuclides routinely released from the plant, e.g., ^{110m}Ag, ^{54}Mn, ^{60}Co, and ^{58}Co, were not above detection limits in any sediments collected further than 6.5 km from the plant. Fractions of the missing ^{137}Cs and ^{134}Cs inventory have been transferred to land or to downstream regions more distant than 27 km from the plant.

The radiocesium content of the sediments in 1984 decreased significantly in a downstream direction, much in the same manner as concentrations decreased in fish. A reasonable exponential correlation was found between sediment areal concentration (mCi/km^2) and downstream distance. There appears to be

a close correlation between downstream fish body burdens of ^{134}Cs and ^{137}Cs and quantities discharged that are retained by the downstream sediments.

Radioactivity originating from the plant was not above detection limits in any terrestrial food item sampled beyond 6.5 km from the plant, and only ^{134}Cs and ^{137}Cs were detected in animal and milk samples collected near the plant boundary. Irrigated soil contains a mixture of ^{137}Cs from global fallout and ^{137}Cs (along with ^{134}Cs) of plant origin. The total inventory of ^{137}Cs transferred to downstream irrigated land is not known at this time. It is not yet possible to provide any estimate of the amounts of radioactivity exported from the area with agricultural products.

Based on the usage factors provided by individuals interviewed in a survey conducted in 1984, and on the concentrations in dietary components, the fish and aquatic organism ingestion pathway contributed the largest radiological dose to humans who utilized products contaminated with the radionuclides in the liquid wastes discharged from the Rancho Seco Nuclear Power Generating Station in 1984 (7).

RECOMMENDATIONS FOR FUTURE STUDIES

This was the first major study conducted of the aquatic and terrestrial environment contaminated with radionuclides discharged from the Rancho Seco Nuclear Power Generating Station since initiation of the first releases to the area in 1981. During the short tenure of this program, we feel there have been some notable scientific contributions to understand better the distribution, fate, and accumulation, by aquatic and terrestrial organisms, of the different gamma-emitting radionuclides previously discharged with the wastewater from Rancho Seco. Our findings from this study are published in this and in three previous reports completed over the last 6 months. There still remain, however, substantial gaps in our knowledge concerning the fate of the environmental levels of radioactivity released from plant.

Releases of ^{134}Cs and ^{137}Cs (the two radionuclides contributing the major fraction of estimated dose to humans) and other gamma-emitting radionuclides from Rancho Seco stopped in mid-October 1984. NRC regulations will be satisfied during 1985 and in future years if there are no additional aquatic releases of these radionuclides to the environment. However,

continued studies in the local environment will be required to provide reasonable assurance to the local population, to government agencies, and to other interested parties that no individual will receive an annual dose to the whole body from radioactivity previously discharged that exceeds the EPA guideline of 25 mrem or 75 mrem to the thyroid.

The creek has recently been posted to a distance of 7 Km from the plant, with no-fishing signs, and the dose during 1985 from the fish-consumption pathway will be zero to individuals abiding with this restriction. However, this restriction cannot continue indefinitely. There have been no studies conducted in this or other countries where components in streambed sediments are the source of radionuclides to aquatic organisms, which is the situation in the aquatic environment downstream of Rancho Seco if there are no further releases. Furthermore, there are no reliable models for estimating the time required to reduce levels of activities, by natural processes, to the lowest practical dose rates from different ingestion pathways. A high-priority objective will be to determine the rate at which the ^{137}Cs and ^{134}Cs concentrations change in fish and other organisms from the creek so that reasonable decisions can be made whether to continue fishing restrictions or to consider other remedial actions.

Based on our work, and on more recent surveys conducted by personnel from SMUD, we have now reasonably well identified the critical pathways by which gamma-emitting radionuclides are reaching humans. Thus, we can now undertake a more sensible deployment of resources and manpower.

To provide the best means of estimating the most realistic future dose to humans from consumption or use of products contaminated with radioactivity from the previously discharged wastes, the program in 1985 should focus on the following elements:

- Concentrations should be determined in all those aquatic food products identified during the land and aquatic use survey for which little or no radiological information is available. These products include edible frog legs, crayfish, larger individual bass samples (>200 g), catfish, and other edible species of fish from different locations downstream of Rancho Seco. An attempt should be made to assess the differences in concentration found in these species as a function of distance from the plant, season of the year, and size of the organism.

- Collections of bass and bluegill should continue from the stations sampled in 1984 to determine what change, if any, has occurred in body burdens during 1985. These samples will be critical to estimate the current rate of change in fish concentrations. Additional downstream sampling locations should be added to the program to define better the relationship between concentration and downstream distance.
- At stations nearest the plant, where concentrations in the flesh of fish are high, individual fish of different size should be collected for analysis during different months of the year to establish the relationship between concentration, size, and season.
- Water sampling and analysis should continue throughout the year to estimate the quantities of radionuclides remobilized to solution from the bottom sediments and the fate of these radionuclides in the environment (i.e., quantities transported downstream, applied to land with irrigation water, or readsorbed).
- Soil sampling should be conducted in the vicinity of each downstream irrigation pump, with the data from the sample analyses used to estimate whether individuals using or servicing the pumps during the year receive any external exposure from past discharged activities in the soil.
- Sediment and fish concentrations were found to decrease in a similar manner with downstream distance from the plant. Any major change in the concentration of ^{137}Cs in fish should indicate that a change has occurred in sediment concentrations from the local region. Sediment sampling should be conducted to confirm any suspected change.
- Irrigated terrestrial food products, identified in the survey and used as food, should be sampled at intervals (to be defined) by personnel from Rancho Seco and analyzed as part of their routine monitoring program. Based on our 1984 results, terrestrial foods from irrigated land more distant than 6.5 km from the plant require sampling no more frequently than once a year. Foods from irrigated land closer to the plant should be sampled during each harvest, if this occurs more than once a year. Wild-growing food products, such as berries from the creek banks, honey from hives, and ducks or other wild birds known to visit the creeks or consume food from irrigated

land, should be sampled for analyses on an annual basis. Samples of beef (especially from user "T") should be obtained for analysis whenever a local rancher slaughters cattle known to feed on contaminated grass. There is no longer a need to continue sampling "indicator species," and monitoring efforts should focus on identified critical samples in pathways that provide some dose to humans.

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APPENDIX I

CONCENTRATIONS OF RADIONUCLIDES IN DIFFERENT TERRESTRIAL SAMPLES

Sample Description - Collection Date	(pCi/g wet wt)[a] ^{137}Cs	^{134}Cs
Berries 10-30-84		
Collected from bushes on the bank of Clay Creek at Highway 104-2.4 km from the plant	bd	bd
Alfalfa 11-7-84		
Collected from the land of user "N" -13 km from the plant	bd	bd
Silage 10-31-84		
Collected from user "P"-19 km from the plant	0.006 (23)	bd
Honey 12-1-84		
Collected from a hive of user "T"-6.5 km from the plant	bd	bd
Corn 10-30-84		
Collected from land of user "O"-10 km from the plant	bd	bd
Milk 11-1-84		
Collected from a range cow grazing on land of user "T"-0.6-2.3 km from the plant	0.005 (11)	0.002 (16)
Beef 11-1-84		
From a 7-year-old cow grazing on land of user "T"-0.6-2.3 km from the plant		
Hamburger	0.057 (17)	0.032 (21)
Sirloin Steak	0.076 (1)	0.026 (2)
Sirloin Bone	0.019 (18)	bd
Muscovy Duck 11-1-84		
Collected from Laguna Creek on land of user "T"-6.5 km from the plant		
Duck #1 breast muscle	0.12 (7)	0.049 (11)
Duck #2 breast muscle	0.07 (49)	0.027 (12)

a Value in parenthesis is the 1σ counting error expressed as % of the listed value. All other gamma-emitting radionuclides were below detection limits.

bd below detection.

APPENDIX II

CONCENTRATIONS OF RADIONUCLIDES IN FLESH OF FISH CAUGHT ON 10-18-84, 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
J389	Largemouth bass	1	0.219	556	6.2(2)	14.7 (1)
J391	Largemouth bass	1	0.210	203	3.9(2)	9.0 (1)
J393	Largemouth bass	1	0.172	141	3.5 (2)	8.2 (2)
J395	Largemouth bass	1	0.207	100	2.7 (3)	6.3 (2)
J397	Largemouth bass	2	0.205	21	5.2 (4)	11.6 (3)
J399	Bluegill	1	0.188	121	6.2 (2)	14.3 (2)
J401	Bluegill	1	0.188	107	7.0 (2	17.1 (2)
J403	Bluegill	1	0.196	74	6.4 (2)	15.1 (2)
J405[b]	Bluegill	1	0.196	59	7.2 (2)	17.0 (1)
J407	Bluegill	1	0.188	46	4.1 (2)	10.9 (2)

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

b This sample contained 0.14 (30) pCi/g of ^{60}Co.

APPENDIX II (cont'd)

CONCENTRATIONS OF RADIONUCLIDES IN THE GIT CONTENTS OF FISH COLLECTED ON 10-13-84, 3.5 km FROM THE PLANT OUTFALL

Sample ID[a]	Common Name	Dry/wet wt	^{134}Cs	pCi/g wet ^{137}Cs	^{60}Co	^{58}Co	^{110m}Ag	^{54}Mn
J390 (389)[a]	Largemouth bass	0.145	2.3 (8)	5.3 (6)	bd	bd	bd	bd
J392 (391)	Largemouth bass	0.143	1.2(7)	2.3 (11)	bd	bd	bd	bd
J394 (393)	Largemouth bass	0.182	3.0 (27)	10.2 (17)	bd	bd	bd	bd
J398 (397)	Largemouth bass	0.200	bd	bd	bd	bd	bd	bd
J400 (J399)	Bluegill	0.173	1.7 (22)	5.3 (7)	bd	bd	1.7(21)	bd
J402 (J401)	Bluegill	0.162	3.7 (11)	8.8 (6)	bd	bd	bd	bd
J404 (J403)	Bluegill	0.146	3.0 (27)	6.2 (21)	bd	bd	bd	bd

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

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

bd Below detection.

APPENDIX III

CONCENTRATIONS OF RADIONUCLIDES IN FLESH OF FISH COLLECTED ON 10-17-84 AT STATION 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	^{137}Cs
J387	Bluegill	5	0.205	68	1.3 (2)	3.1 (2)

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

APPENDIX III (cont'd)

CONCENTRATIONS OF RADIONUCLIDES IN THE GIT CONTENTS OF FISH COLLECTED ON 10-17-84 AT STATION R-5, 4.6 km FROM THE PLANT OUTFALL

Sample ID[a]	Common name	Dry/wet wt	pCi/g wet wt[b] ^{134}Cs	^{137}Cs
J38E (387)	Bluegill	0.133	0.85 (14)	2.3 (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 1σ counting error expressed as % of value listed.

APPENDIX IV

CONCENTRATIONS OF RADIONUCLIDES IN FLESH OF FISH COLLECTED ON 10-16-84 AT STATION 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
J379	Largemouth bass	8	0.201	98	0.20 (5)	0.46 (3)
J381	Crappie	6	0.196	86	0.16 (7)	0.33 (7)
J383	Bluegill	2	0.197	47	0.24 (22)	0.43 (16)

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

APPENDIX IV (cont'd)

CONCENTRATIONS OF RADIONUCLIDES IN THE GIT CONTENTS OF FISH CAUGHT ON 10-16-84 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
J380 (J379)	Largemouth bass	0.197	bd	0.7 (26)
J382 (J381)	Crappie	0.149	bd	bd
J384 (J383)	Bluegill	0.176	bd	0.4 (39)

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 1σ counting error expressed as % of value listed.

bd below detection.

APPENDIX V

CONCENTRATIONS OF RADIONUCLIDES IN FLESH OF CATFISH COLLECTED ON 10-17-84 FROM A POND, 6.0 km FROM THE PLANT OUTFALL

Sample ID	Number of fish in pooled sample	Dry/wet wt	Mean fresh whole wt fish (g)	pCi/g wet wt[a] ^{134}Cs	^{137}Cs
J367	1	0.205	211	1.9 (2)	4.2 (2)
J369	1	0.218	233	2.7 (2)	6.6 (1)
J371	1	0.185	203	2.6 (2)	5.8 (2)
J373	1	0.223	166	2.2 (3)	5.0 (2)
J375	1	0.189	219	1.7 (2)	3.8 (2)

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

APPENDIX V (cont'd)

CONCENTRATIONS OF RADIONUCLIDES IN THE GIT CONTENTS OF CATFISH COLLECTED ON 10-17-84 FROM A POND, 5.4 km FROM THE PLANT OUTFALL

Sample ID[a]	Dry/wet wt	pCi/g wet wt[b] ^{134}Cs	^{137}Cs
J368 (J367)	0.138	1.5 (11)	3.3 (9)
J370 (J369)	0.128	2.7 (33)	5.9 (4)
J372 (J371)	0.117	1.6 (21)	3.2 (15)
J376 (J375)	0.140	1.2 (35)	2.9 (21)

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

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

APPENDIX VI

CONCENTRATION OF RADIONUCLIDES IN CRAYFISH (Cambarus sp.)

Sample ID	Location & date sampled, (distance from plant km)	Tissue	Dry/wet wt	pCi/g wet[a] ^{134}Cs	^{137}Cs	^{110m}Ag
J192	R-11,14 Aug 84	Eviscerated				
	(20 km)	wholebody	0.249	bd	bd	bd
J193		viscera	0.116	bd	bd	bd
J134	RS-19,18 July 84	Eviscerated				
	(0.5 km)	wholebody	0.290	3.6 (2)	7.8 (2)	bd
J135		viscera	0.188	3.6 (16)	7.3 (13)	3.4(40)

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

bd below detection.

APPENDIX VII

RADIONUCLIDE CONCENTRATIONS IN CREEK-WATER SAMPLES[a]

Station ID	Distance[b] (km)	Date sampled	pCi/l[e] ^{134}Cs Prefilter	^{134}Cs Water	^{137}Cs Prefilter	^{137}Cs Water	Activity Ratio $^{134}Cs/^{137}Cs$ Prefilter	Activity Ratio $^{134}Cs/^{137}Cs$ Water
RS-20	0.6	4-26-84	0.46 (3)	2.48 (2)	1.04 (1)	6.04 (1)	0.44	0.41
RS-20	0.6	4-26-84	0.46 (2)	1.65 (3)	0.89 (2)	3.70 (2)	0.52	0.45
RS-20	0.6	7-19-84	0.06 (47)	0.38 (23)	0.17 (15)	0.26 (8)	0.35	0.31
RS-20	0.6	8-15-84	0.35 (6)	0.56 (8)	0.74 (6)	1.87 (3)	0.47	0.30
RS-20	0.6	10-13-84	0.46 (4)	0.74 (4)	0.94 (4)	2.13 (2)	0.49	0.35
R-5	6	7-18-84	0.83 (4)	0.55 (5)	1.81 (3)	1.61 (2)	0.46	0.34
R-5	6	8-15-84	1.80 (2)	3.34 (5)	3.82 (2)	11.3 (3)	0.47	0.30
R-5	6	10-17-84	0.22(7)	0.52 (5)	0.67 (5)	1.68 (2)	0.42	0.31
R-52[c]	6	10-17-84	0.24(10)	0.15 (5)	0.56 (6)	0.51 (3)	0.43	0.29
R-8	13	7-18-84	0.09(22)	0.15 (13)	0.19 (14)	0.45 (6)	0.47	0.33
R-8	13	8-14-84	0.10(20)	bd	0.20 (13)	0.6 (30)	0.50	--
R-8	13	10-16-84	0.08(20)	0.06 (11)	0.09 (18)	0.23 (3)	0.55	0.26
R-11	20	7-18-84	0.03(23)	0.06 (21)	0.16 (18)	0.11 (15)	0.50	0.54
R-11	20	8-15-84	bd	bd	bd	bd	--	--
R-11	20	10-15-84	bd	0.315 (23)	bd	0.073 (10)	--	0.21
R-53[d]		10-13-84	bd	bd	bd	0.012 (17)	--	--
Cosumnes River		8-13-84	bd	bd	bd	bd		

[a] All samples were prefiltered through 1-μm filters.

[b] Distance in km from Rancho Seco to station.

[c] Irrigation pond on land of rancher "T."

[d] Background sample from Rancho Seco Lake; 2.2 km east of plant.

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

bd: below detection.

APPENDIX VIII

CONCENTRATIONS OF RADIONUCLIDES IN RSP SOIL SAMPLES

Sample ID	pCi/g dry[a]				Total sample	Activity Ratio
	^{54}Mn	^{60}Co	^{134}Cs	^{137}Cs	dry weight (g)	$^{134}Cs/^{137}Cs$
(318)RSP-1	0.08 (24)	0.46 (3)	0.45 (4)	1.87 (3)	3602	0.24
(337)RSP-2	bd	0.32 (5)	1.22 (3)	3.89 (1)	2760	0.31
(338)RSP-3	bd	0.08 (15)	0.25 (7)	1.46 (2)	3240	0.17
(339)RSP-4	0.04 (46)	0.05 (23)	0.09 (14)	1.14 (3)	3960	0.08
(340)RSP-5	bd	0.04 (26)	0.08 (20)	0.63 (3)	3270	0.12
(341)RSP-6	bd	0.04 (26)	0.04 (32)	0.49 (4)	3320	0.08
(342)RSP-7	bd	bd	0.06 (29)	0.63 (3)	3900	0.10
(343)RSP-8	bd	bd	0.16 (11)	1.00 (6)	4135	0.16
(344)RSP-9	bd	bd	0.11 (17)	0.96 (3)	3980	0.11
(345)RSP-10	bd	bd	0.03 (37)	0.56 (3)	3720	0.05

[a] Value in parentnesis is the 1σ counting error expressed as % of the listed value. All other radionuclides are below detection limits. Soil was sampled to a depth of 15.2 cm; the surface area sampled was 730 cm^2.

bd below detection.

APPENDIX IX

CONCENTRATIONS OF RADIONUCLIDES IN A SOIL PROFILE AT RSP-5

Sample ID	Depth interval (cm)	pCi/g dry[a]			Total sample dry weight (g)	Activity Ratio
		^{60}Co	^{134}Cs	^{137}Cs		$^{134}Cs/^{137}Cs$
349	0- 5.1	0.07 (22)	0.27 (7)	1.13 (3)	220	0.24
350	5.1-10.2	0.04 (32)	0.05 (37)	0.51 (5)	229	0.10
351	10.2-15.3	0.06 (19)	0.06 (19)	0.60 (3)	347	0.10
352	15.3-20.4	0.04 (24)	0.09 (17)	0.92 (4)	351	0.10
353	20.4-25.5	0.05 (29)	0.05 (30)	0.73 (4)	428	0.07
354	25.5-30.6	bd	bd	0.22 (7)	374	
355	30.6-45.7	bd	bd	bd	236	

[a] Value in parentnesis is the 1σ counting error expressed as % of the listed value. The surface area sampled was 103.2 cm^2.

bd below detection.

APPENDIX X

CONCENTRATIONS OF RADIONUCLIDES IN PASTURE GRASS FROM RSP STATIONS

Sample ID	RSP station	Fraction[c]	pCi/g fresh wt[a]						Activity Ratio
			^{58}Co	^{54}Mn	^{60}Co	^{134}Cs	^{137}Cs	^{110m}Ag	$^{134}Cs/^{137}Cs$
324	1	upper	1.30 (2)	0.16 (9)	0.89 (2)	3.35 (2)	7.91 (1)	0.21 (5)	0.42
325	1	lower	1.47 (3)	0.27 (5)	1.92 (5)	7.69 (1)	19.7 (1)	0.26 (11)	0.39
326	5	upper	bd	bd	bd	0.03 (21)	0.08 (13)	bd	0.36
327	5	lower	bd	bd	bd	0.05 (33)	0.17 (12)	bd	0.29
328	10	upper	bd	bd	bd	0.02 (17)	0.059 (4)	bd	0.34
329	10	lower	bd	bd	bd	0.10 (6)	0.30 (4)	bd	0.33
330	Background[b]	lower	bd	bd	bd	bd	bd	bd	
331	Station	lower	bd	bd	bd	bd	bd	bd	

[a] Value in parenthesis is the 1σ counting error expressed as % of the value listed. Upper section consists of grass blades only. Lower section includes roots and any adhering soil.

[b] Background grass samples from Marciel Ranch located east of Rancho Seco.

[c] See text.

bd below detection.

APPENDIX XI

BACKGROUND CONCENTRATION OF FALLOUT ^{137}Cs IN SOIL SAMPLES[a]

Sample ID	Soil No.	Depth increment (cm)	Total dry wt (g)	pCi/g dry[b] ^{137}Cs		mCi/km^2 ^{137}Cs
360	1	0-5	1575	0.39 (7)		7
361	1	5-10	1847	0.26 (4)		5
					Total	12
362	2	0-5	1572	0.52 (5)		9
363	2	5-10	1600	0.45 (2)		8
					Total	17
364	3	0-5	1957	0.91 (2)		19
365	3	5-10	1238	0.27 (4)		4
					Total	23

[a] Soil samples were taken from Marciel Ranch located east of Rancho Seco.

[b] Value in parenthesis is the 1σ counting error expressed as % of the listed value. Surface area sampled was 929cm^2.

APPENDIX XII

CONCENTRATION OF RADIONUCLIDES IN USER "N" RANCH SOIL[a]

Sample ID	Total dry wt (gm)	pCi/g dry[b]		mCi/km^2
		^{134}Cs	^{137}Cs	^{137}Cs
346	1530	bd	0.04 (28)	3
347	1250	bd	bd	<1
348	1350	bd	0.03 (29)	2

a Soil was sampled to a depth of 10.2 cm. Surface area sampled was 233 cm^2.

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

bd below detection.