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Evaluation of Radioactive Liquid Effluent Releases From the Rancho Seco Nuclear Power Plant

Prepared by C. W. Miller, W. D. Cottrell, J. M. Loar, J. P. Witherspoon

Oak Ridge National Laboratory

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ABSTRACT

A project has been carried out by Oak Ridge National Laboratory (ORNL) to estimate the concentrations of radionuclides in the environment that have resulted from the release of radioactive materials in the liquid waste effluents from the Rancho Seco Nuclear Power Plant (RSNPP) and to estimate possible radiation doses to man resulting from current environmental concentrations. To carry out the objectives of this project, two visits were made to the RSNPP site by scientists from ORNL during November and December of 1984 to conduct an environmental sampling program around the site. Elevated levels of some radionuclides were found in the immediate environment of the plant. This radioactive contamination occurs primarily along streams receiving effluent from the plant and in fields irrigated with water from these streams. The primary contaminants are ^{137}Cs and ^{134}Cs with lesser amounts of ^{60}Co and ^{58}Co. Specific pathways of exposure and usage factors were not precisely known for the dose assessment of current and potential use of contaminated water and soil around the RSNPP. The ingestion of fish is the single most important pathway identified in this analysis.

EXECUTIVE SUMMARY

Small leaks in the steam-generation system at the Rancho Seco Nuclear Power Plant (RSNPP), located 56 km (35 miles) southeast of Sacramento, California, have led to the release of aqueous radioactive waste materials. Prior to the late summer of 1984, some amounts of radioactivity thus generated were periodically released to the environment. As a result of these releases, members of the general public could potentially be exposed to ionizing radiation. Because of this potential, the U.S. Nuclear Regulatory Commission (NRC) contracted with the Oak Ridge National Laboratory (ORNL) to conduct an evaluation of this radioactive contamination. The objectives of this project were to estimate the concentrations of radionuclides in the environment that have resulted from the RSNPP liquid releases and to estimate current possible radiation doses to man resulting from these releases.

To carry out the objectives of this project, two site visits were made to the RSNPP by ORNL scientists during November and December of 1984 to conduct an environmental sampling program in the vicinity of the site. Elevated levels of some radionuclides were found in the immediate environment of the plant. This radioactive contamination occurs primarily along streams receiving effluent from the plant and in fields irrigated with water from these streams. The highest levels of radionuclides occur immediately below the plant's release point, then decrease with distance from the plant downstream along Clay and Hadselville creeks, and approach background levels in Laguna Creek approximately 19 km from the plant. The primary contaminants are ^{137}Cs and ^{134}Cs with lesser amounts of ^{60}Co and ^{58}Co.

Higher-than-background levels of radioactivity were detected in fish inhabiting the stream that receives liquid effluent from the plant. Radionuclide concentrations in fish declined with increasing distance downstream of the RSNPP. Concentrations in green sunfish from Clay Creek at the plant boundary were 200 times background levels of the radionuclides sampled; concentraions decreased by 35% in Hadselville Creek, approximately 4 km downstream. Concentrations in fish decreased by almost an order of magnitude between the Hadselville Creek and upper Laguna Creek sites, which are an additional 4 km downstream of the release point. The highest cesium concentrations occurred in largemouth bass collected from a sump at the boundary of the RSNPP. At three of five sites, cesium concentrations were higher in piscivorous (e.g., largemouth bass) than in nonpiscivorous species.

Specific pathways of exposure and usage factors were not precisely known for the dose assessment of current and potential use of contaminated water and soil around the RSNPP. The ingestion of fish is the dominant exposure pathway identified in this analysis.

1. INTRODUCTION

The Rancho Seco Nuclear Power Plant (RSNPP) is located approximately 56 km (35 miles) southeast of Sacramento, California, in Sacramento County. Operated by the Sacramento Municipal Utility District (SMUD), this pressurized water reactor received its operating license from the U.S. Nuclear Regulatory Commission (NRC) in 1974.

RSNPP was designed to have no liquid radionuclide discharges; however, leaks in the steam-generator system have led to the creation of liquid radioactive waste materials. These wastes, as well as other waste waters generated by the RSNPP, are collected and treated in regenerate holdup tanks. Until late summer of 1984, the treated waters containing some amounts of radioactive fission and neutron activation products were periodically released to one or two on-site retention basins. The contents of these basins were diluted and subsequently released to Clay Creek. As can be seen in Fig. 1, Clay Creek leaves the RSNPP site-boundary fence approximately 0.5 km from the point of discharge and continues until it joins with Hadselville Creek, which in turn joins with other bodies of water farther downstream. The primary suspected radionuclides released via this pathway were ^{134}Cs and ^{137}Cs. However, small amounts of ^{3}H, ^{14}C, ^{60}Co, and other radionuclides would be expected to be released during normal operations. As a result, selected environmental samples were screened for these radionuclides as well as for ^{54}Mn, ^{238}U, ^{90}Sr, ^{238}Pu, ^{239}Pu, ^{244}Am, and others (see Appendix C).

Substantial liquid releases of radionuclides to the environment are no longer occurring at the RSNPP. However, it is evident from Fig. 1 that members of the general public could potentially be exposed to ionizing radiation as a result of the liquid effluent releases that have already taken place from the RSNPP. Game fish have been caught in unposted areas in the RSNPP environs. Water taken from Clay Creek, Hadselville Creek, and other streams is used to irrigate pasture lands upon which beef cattle have grazed. Because of these and other potential pathways of exposure, the NRC contracted with Oak Ridge National Laboratory (ORNL) to conduct an independent evaluation of the radioactive contamination from the RSNPP. The objectives of this

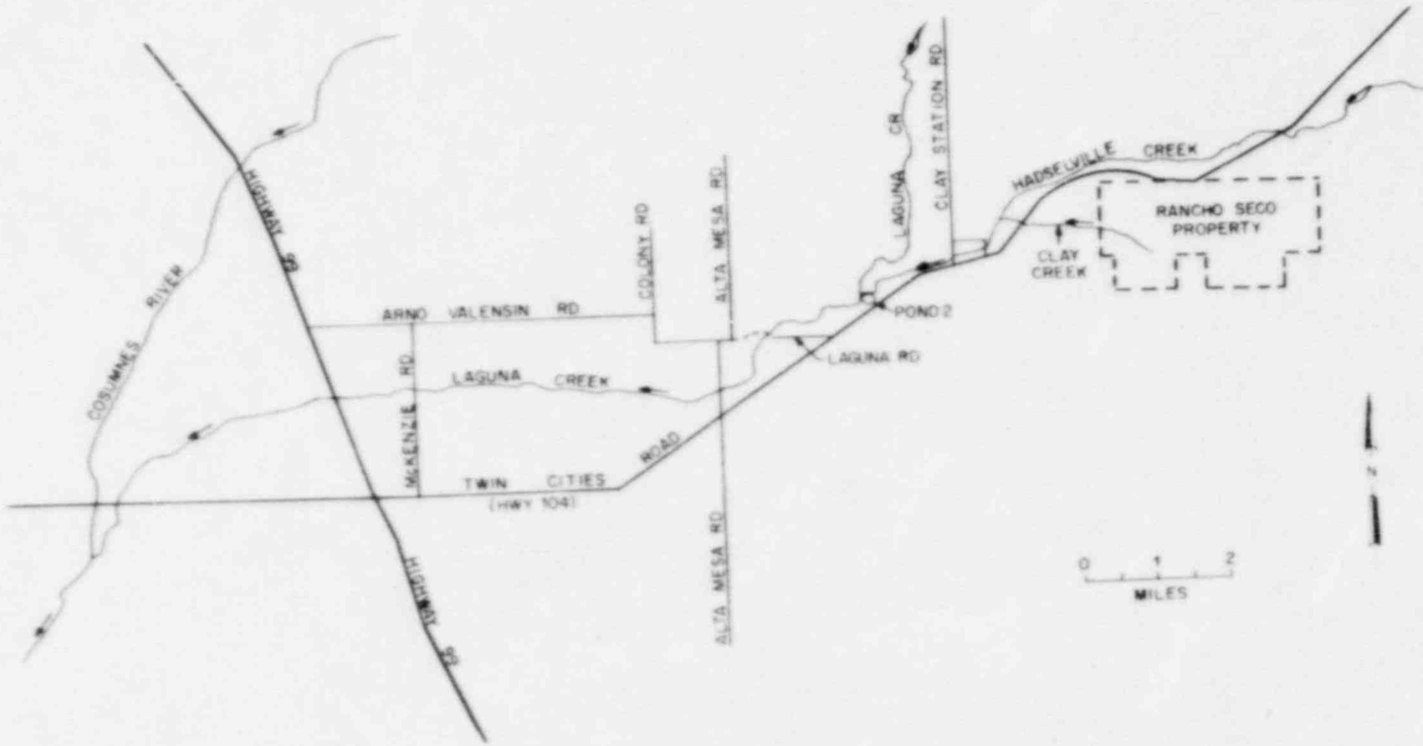

Fig. 1. The Ranchc Seco Nuclear Power Plant (RSNPP) and its environs.

project were to identify and estimate the concentrations of radionuclides in the environment resulting from the RSNPP liquid releases and to estimate possible current radiation doses to man resulting from these releases. The purpose of this report is to document the results of this evaluation for use by NRC.

To carry out the objectives of this report, two visits were made to the RSNPP site by scientists from ORNL. In November 1984, a small group spent approximately one week at the RSNPP obtaining preliminary environmental samples and constructing plans for the later, more detailed survey trip. A second, larger group of ORNL staff spent approximately two weeks in December 1984 at the RSNPP completing the environmental sampling program. This survey included measuring the following:

1. External gamma radiation levels along the stream banks and in fields adjacent to streams that received radioactive effluent from the plant.

2. Concentration of radionuclides in silt and water from streams and ponds that had received potentially contaminated liquid effluent.

3. Concentration of radionuclides in fish, frogs, and birds found in or near the potentially contaminated waterways.

4. Concentration of radionuclides in soil and vegetation from fields irrigated with water from affected streams.

5. Concentration of radionuclides in beef from a cow that had reportedly grazed on potentially contaminated pasture land.

6. Concentration of radionuclides in honey.

Section 2 of this report discusses the methods and procedures used to obtain these environmental samples, and Sect. 3 summarizes the environmental concentrations that were measured. Section 4 presents the dose assessments that were performed for various potential pathways of exposure based on the results of the environmental measurement activity. Estimates of the radionuclide inventory on irrigated fields are presented in Sect. 5, while Sect. 6 summarizes the results of the project. The appendixes provide more detailed results of the environmental sampling program.

It should be noted that current use of the land sampled in this study is for pasture only. No crops for human consumption are currently grown in these irrigated fields.

2. SURVEY METHODS AND PROCEDURES

2.1 MEASUREMENT OF EXTERNAL GAMMA RADIATION LEVELS

Gamma radiation levels were measured along the banks of Clay, Hadselville, and Laguna creeks and in fields identified as having been irrigated with water from either Clay or Hadselville creeks. Gamma scans were performed in the irrigated fields and along the banks of Clay Creek from the RSNPP waste outfall to the confluence of Clay and Hadselville creeks.

All gamma radiation measurements were made using portable scintillation (NaI) detectors. At selected locations, external gamma radiation levels were measured using both scintillation counters and pressurized ionization chambers. The relationship between these comparative measurements was used to convert scintillation counter measurements to dose (exposure) rates.

For convenience in scanning, the irrigated land was divided into fields (irrigation units, Fig. 2). Each field was scanned using a gamma scintillation detector held approximately 5 cm from the ground surface. Areas of elevated gamma radiation levels were noted, and the maximum level observed was recorded for each area.

2.2 SOIL AND VEGETATION SAMPLING

Results of the radiation measurements made in the irrigated fields were used as a guide in selecting locations for soil and vegetation samplings. Generally, radiation levels were higher near irrigation pipe outlets and decreased with distance from the outlets in the direction of water flow across the fields. Each field that showed elevated levels of gamma radiation was divided into two or more areas based on the gamma levels observed. Representative samples of both soil and vegetation were collected from each area of each field. Samples were collected from an area 15 cm in diameter and 5 cm deep. At selected locations, to evaluate the depth of penetration of the contamination into the soil, samples were taken at 5-cm intervals from the surface to a depth of 30 cm. A total of 106 soil samples were collected from 80 sampling locations; however, because of resource limitations, only 57 samples were subjected to analyses.

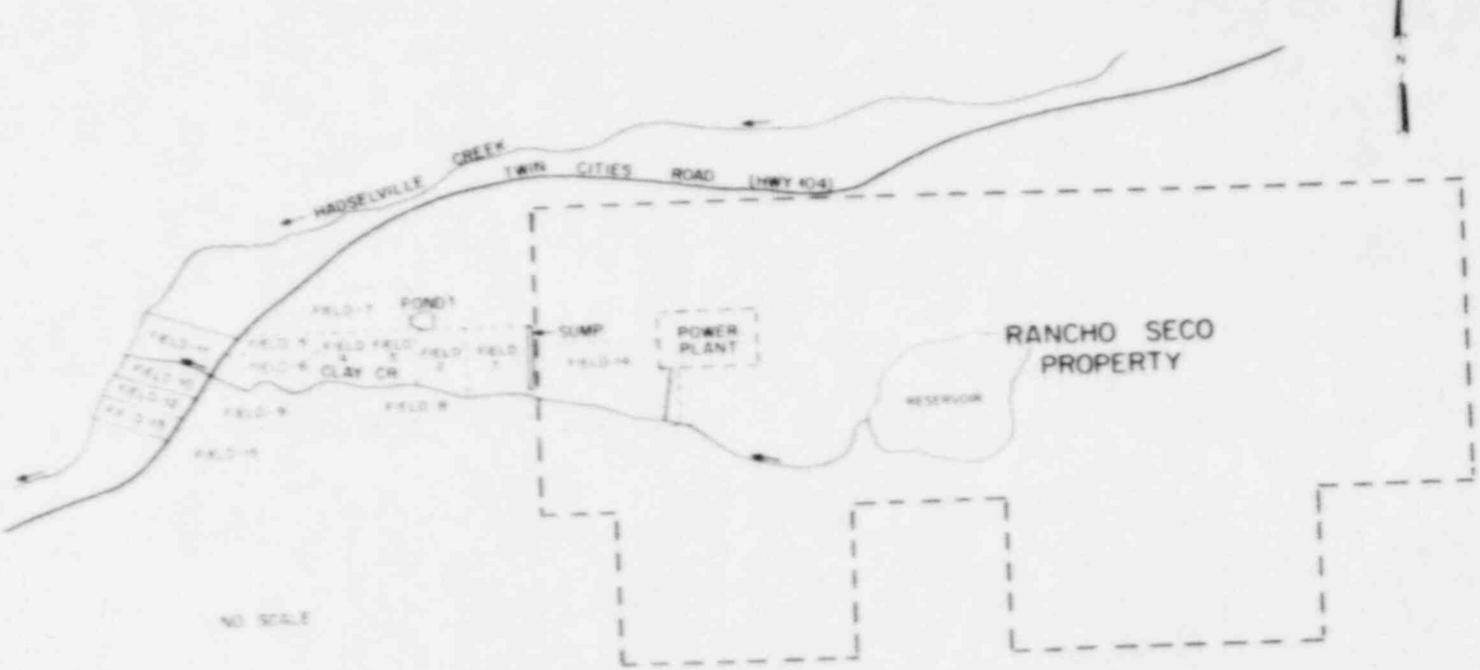

Fig. 2. Schematic of the Rancho Seco Nuclear Power Plant environs showing the division of irrigated land into units (fields) for sampling purposes

Exploratory radiochemical analyses were performed on a limited number of soil, silt, water, and vegetation samples. Based on the results of these analyses and on reported radionuclides discharged from the plant (Appendix C) together with their respective hazard indices, specific radionuclides were selected for investigation. These radionuclides are given in Appendix A, tables A-1 through A-5.

Samples of soil were dried at 110°C for 24 h and pulverized to a particle size <500 μm (-35 mesh). Aliquots of soil were counted on a Ge(Li) detector, and the spectra were analyzed by computer techniques. Concentrations of ^{238}U and ^{235}U in selected samples were determined by neutron-activation methods, and concentrations of alpha- and beta-emitting radionuclides were determined by radiochemical procedures (which are described in the ORNL master analytical chemistry manual).

Samples of vegetation were collected and placed in plastic bags and returned to ORNL for analyses. Vegetation samples were assayed as collected (wet) using techniques analogous to those used in assaying soil.

2.3 SILT AND WATER SAMPLING

Silt (sediment) and water samples were collected from Clay, Hadselville, and Laguna creeks and from sumps and holding ponds used in the process of transferring water from Clay and Hadselville creeks to irrigate the pasture fields. Silt samples were dried, pulverized, and analyzed using the same procedures and methods as were used for soil samples.

Water samples were collected in 1-gal (3.8 L) plastic containers and acidified with nitric acid (10 ml, 70% HNO_3/gal) to minimize adsorption of contaminants on container walls. Water sample analyses were performed using standard radiochemical separation and counting techniques (as described in the ORNL master analytical chemistry manual).

2.4 FISH, FROGS, AND GAME BIRDS

Because of their potential importance in the diet of several local residents, samples of fish, frogs, and game birds were collected to determine the concentrations of ^{137}Cs, ^{134}Cs, and ^{60}Co in the flesh.

These radionuclides were selected for analysis because they are routinely released from pressurized water reactors like that at the RSNPP and were found in a preliminary analysis of fish collected from the sump near Clay Creek in November. Because these radionuclides have relatively long half-lives (2 to 30 years), they can contribute a significant portion of the dose to man from fish consumption. No other gamma-ray emitters were found, either in the preliminary analysis of the November samples or in the analysis of selected samples collected in December (Appendix B). Water analyses indicated no levels of other radonuclides that would contribute significantly to dose to man from ingestion of fish (Appendix A).

2.4.1 Fish

Fish were collected in November and December 1984 at eight sites near the RSNPP (Table 1). Eight fish were collected by angling from the small sump adjacent to Clay Creek at the SMUD property line on the initial sampling trip in November. After obtaining a scientific collecting permit from the State of California, Department of Fish and Game, an additional 52 fish were collected by electroshocking during the week of December 9, 1984. A Smith-Root Type XV backpack electrofisher with a gasoline-powered generator capable of delivering up to 1200 V of pulsed direct current was used to sample approximately 50 to 150 m of stream, depending upon fish densities at the site. Although the sump adjacent to Clay Creek could be sampled by wading, a small boat was used to sample ponds 1 and 2.

Based on preliminary information indicating that bluegill, bass, and catfish constituted the catch of local anglers, we attempted to obtain samples of each group from the eight sites. At many sites, however, only two of three groups were present, and at some sites (e.g., Clay and Hadselville creeks), bluegill (Lepomis macrochirus) were not abundant. Consequently, the green sunfish (Lepomis cyanellus) was selected as a target species because (1) it was the dominant (most abundant) sunfish at most sites, and (2) it is large enough to be sought by anglers. Other target species included the largemouth bass (Micropterus salmoides), black bullhead (Ictalurus melas), and black crappie (Pomoxis nigromaculatus), which was found only in Laguna Creek

Table 1. Location and description of fish sampling sites in streams and ponds near the Rancho Seco Nuclear Power Plant

Sampling site	Location	Approximate distance downstream of RSNPP (km)	Sampling date(s), 1984
Clay Creek	At SMUD property line	0.5	December 10, 12
Hadselville Creek	Just above bridge on Clay Station Road	4.5	December 12
Laguna Creek	At Laguna Road	9.0	December 11
Laguna Creek	1.5 km above bridge on McKenzie Road	15.5	December 12
Dry Creek (control)	200 m below bridge on Rte. 104	[a]	December 12
Sump	Just north of Clay Creek at SMUD property line	0.5	November 14 December 10, 12
Pond 1	0.5 km SW of SMUD property line	1.0	December 10
Pond 2	Near Silva feedlots and adjacent to Hadselville Creek	6.0	December 11

[a]Sampling site located approximately 14 km east of the Rancho Seco Nuclear Power Plant.

at the Laguna Road site. Radionuclide analyses were limited to the three largest individuals of each species at each site. In some cases, one of these species was collected at a site but not analyzed because the individuals were judged to be too small to be kept by anglers (e.g., largemouth bass in Hadselville Creek and in Laguna Creek at Laguna Road). Finally, an adequate and a representative sample was not obtained from Laguna Creek near McKenzie Road. High stream flows and turbid water made electrofishing difficult, and only a few small fish were collected.

Fish collected from each sampling site were placed in plastic bags, stored on dry ice, shipped within 1 to 3 d to ORNL, and stored in a freezer. Prior to sample preparation, each fish was identified to species using the taxonomic keys of Eddy (1969) and Pflieger (1975); sexed, if possible; measured (total and standard lengths) to the nearest 0.1 cm; and, in most cases, weighed to the nearest 0.1 g. Weights were inadvertently omitted initially; thus, weights of these individuals were estimated from length-weight regressions for each species. To obtain an accurate estimation of weight based on length, the number of fish used in the regression analysis were maximized by including (1) those individuals collected but not analyzed and (2) individuals of the same species from different, but similar, sites (e.g., all stream sites, except Dry Creek, were combined).

A 6- to 15-g sample of axial muscle, excluding the skin, was removed from each fish. The sample was placed in a preweighed 25- by 150-mm glass tube, reweighed, and analyzed for ^{137}Cs, ^{134}Cs, and ^{60}Co with a Packard NaI(Tl) detector assembly connected to a Canberra Series 35 multichannel analyzer. Samples collected on November 14, 1984, were analyzed on December 10, and the samples that were collected December 9-13, 1984, were analyzed January 14-17, 1985. Counting timions obtained from the U.S. Environmental Protection Agency (EPA) Environmental Monitoring Systems Laboratory, Las Vegas, Nevada, and used to determine the counting efficiency for each isotope. The detection limit for all analyses was 0.45 pCi per sample (1 dpm divided by 2.22 dpm/pCi).

2.4.2 Frogs

Cool temperatures prevented the collection of an adequate sample of frogs. Very few individuals were observed during daytime surveys along the stream banks and shorelines of the small ponds. Gigging was attempted after sunset in Laguna Creek but was unsuccessful. The three individuals that were obtained were collected by electrofishing during the fish sampling program in December.

After obtaining the total body weight to the nearest 0.1 g, a 6- to 14-g sample of axial muscle (similar in weight to that taken from fish) was removed from the hind legs of each frog; placed in a preweighed 25- by 150-mm glass tube; reweighed; and analyzed for ^{137}Cs, ^{134}Cs, and ^{60}Co using the same procedures described for fish.

2.4.3 Game Birds

Several game bird species were collected in December from fields and small water bodies near Clay Creek downstream of the SMUD property line. Because the hunting season was closed for some species (e.g., ring-necked pheasant), a scientific collecting permit was obtained from the State of California, Department of Fish and Game. A shotgun was used for all collections. On both the November and December sampling trips, waterfowl were not found in abundance on the streams or small ponds near the RSNPP. Generally, only a few ducks, usually mallards, were observed at a given site. The low abundance and rather widespread distribution of waterfowl limited the collections to two coots. Although recognized as a game bird by the State of California, which regulates the hunting of this species, the coot is probably not as popular with hunters as is the mallard or teal (several species). Two ring-necked pheasants (a very popular game bird) and a single Wilson's snipe were also collected.

The total body weight of each bird was estimated to the nearest 1g, and a 6- to 9-g sample of axial muscle was taken from the breast. Analytical procedures were the same as those described for fish.

3. ENVIRONMENTAL SURVEY RESULTS

3.1 TERRESTRIAL BACKGROUND MEASUREMENTS

Background external gamma radiation levels 1 m above the ground were measured at a number of locations in the Sacramento Valley. Four locations, at distances of 6.4 to 16 km from the RSNPP site and lying approximately north, south, east, and west of the site, were selected as having typical background levels for the general area. Gamma radiation exposure rates at these locations were very nearly uniform and averaged approximately 8 μR/h. Concentrations of radionuclides in soil at background locations averaged 0.41 pCi/g of ^{137}Cs, effectively zero pCi/g of ^{134}Cs, 0.73 pCi/g of ^{226}Ra, 0.77 pCi/g of ^{232}Th, and 8.3 pCi/g of ^{40}K. Background radionuclide concentrations in soil are given in Appendix A, Table A-1.

All direct meter readings reported in this document are gross readings; background radiation levels have not been subtracted because these readings were used for characterizing a location rather than quantifying the radionuclides present. Similarly, background levels have not been subtracted from radionuclide concentrations measured in environmental samples. However, doses from background locations were also calculated for comparison purposes.

3.2 EXTERNAL GAMMA RADIATION LEVELS

External gamma radiation levels were measured with gamma scintillation counters (NaI). As discussed previously, comparison measurements were made with a pressurized ionization chamber (PIC) at a number of locations in the fields and along the creeks. The relationship between these two sets of measurements was used to convert gamma scintillation counter measurements to approximate gamma dose rates in units of μR/h.

Gamma radiation dose rates in irrigated fields measured at 1 m from the ground surface ranged from background levels (8 μR/h) to about 14 μR/h. Gamma dose rates measured at the ground surface ranged from background levels to about 35 μR/h. Gamma dose rates measured over silt deposits along Clay Creek were as high as 38 μR/h at 1 m and ranged up to 85 μR/h at the surface. Dose rate measurements taken along the banks of Hadselville Creek, 15 m downstream from its confluence with Clay Creek, were 18 μR/h at 1 m and about 60 μR/h at the exposed silt surface. Surface radiation dose rates measured along Hadselville Creek approximately 3.2 km downstream from the entry of Clay Creek were as high as 37 μR/h.

3.3 SOIL SAMPLING

As discussed previously, soil sample locations were chosen to provide systematic unbiased sampling (i.e., sampling locations were systematically chosen within an area showing nearly uniform external gamma radiation levels). Locations of samples that were analyzed are shown in Figs. 3 through 8.

The primary radioactive contaminants found in soil samples were ^{137}Cs and ^{134}Cs with lesser amounts of ^{60}Co and ^{58}Co. Concentrations of ^{226}Ra, ^{238}U, ^{232}Th, and ^{40}K were generally at background levels. The maximum concentrations of ^{137}Cs and ^{134}Cs were 59 pCi/g and 23 pCi/g, respectively. Consistent with gamma radiation levels, the highest concentrations of radionuclides in soil occurred near the irrigation outlet pipes and decreased with distance from the pipes in the direction of water flow across the fields. The weighted average concentrations of ^{137}Cs and ^{134}Cs are listed by fields in Table 2. Complete analyses results are given in Appendix A, Table A-2.

3.4 VEGETATION SAMPLING

Vegetation samples (pasture grass) were collected at locations immediately adjacent to soil sampling locations and in general were designated by numbers corresponding to those of soil samples. Vegetation sample locations are given in Figs. 3 through 7. As in soil, the radionuclides of primary interest are ^{137}Cs and ^{134}Cs. Concentrations of ^{137}Cs and ^{134}Cs as high as 6500 pCi/kg and 2500 pCi/kg, respectively, were measured on a wet-weight basis in vegetation samples from irrigated fields. The concentrations of radionuclides in vegetation are distributed as in soil (i.e., higher near irrigation outlet pipes and decreasing with distance from the pipes in the direction of water flow across the fields). Average concentrations of ^{137}Cs and ^{134}Cs in vegetation samples are listed by

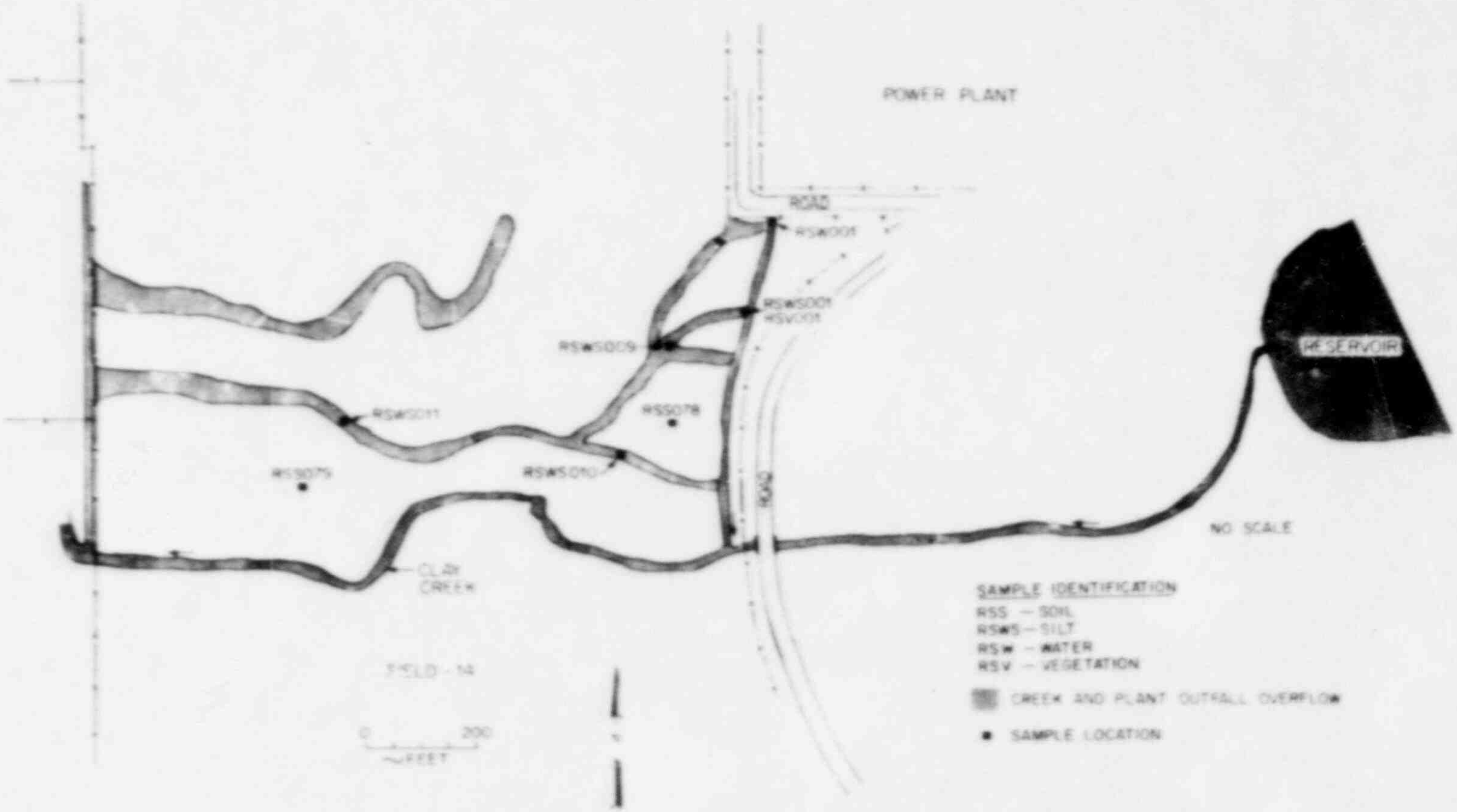

Fig. 3. Sampling locations in Field 14 (Sacramento Municipal Utility District property), showing overflow of Clay Creek into field.

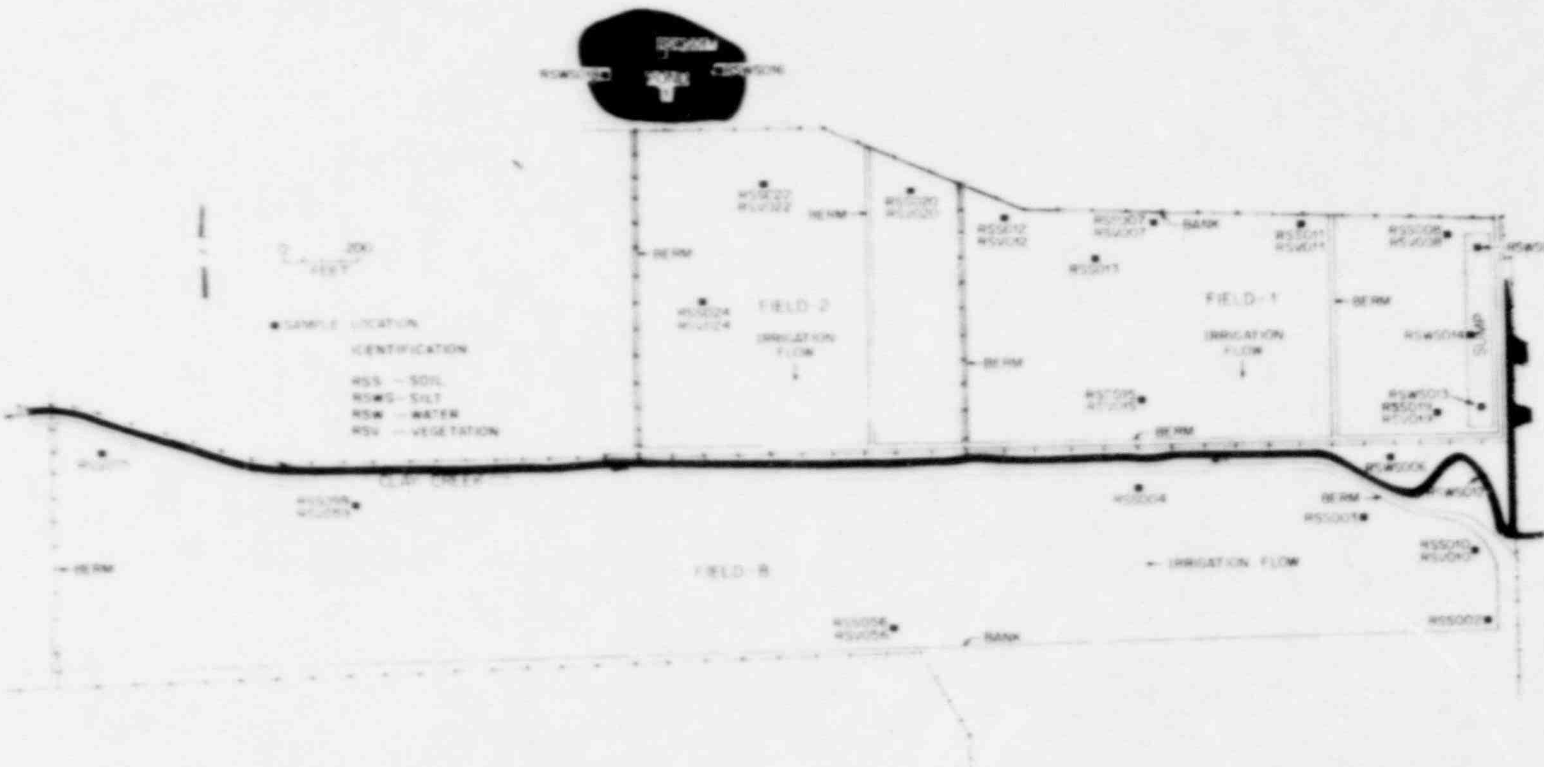

Fig. 4. Sampling locations in irrigated fields along Clay Creek immediately downstream from Sacramento Municipal Utility District

Fig. 5. Sampling locations in irrigated fields along Clay Creek near California Highway 104

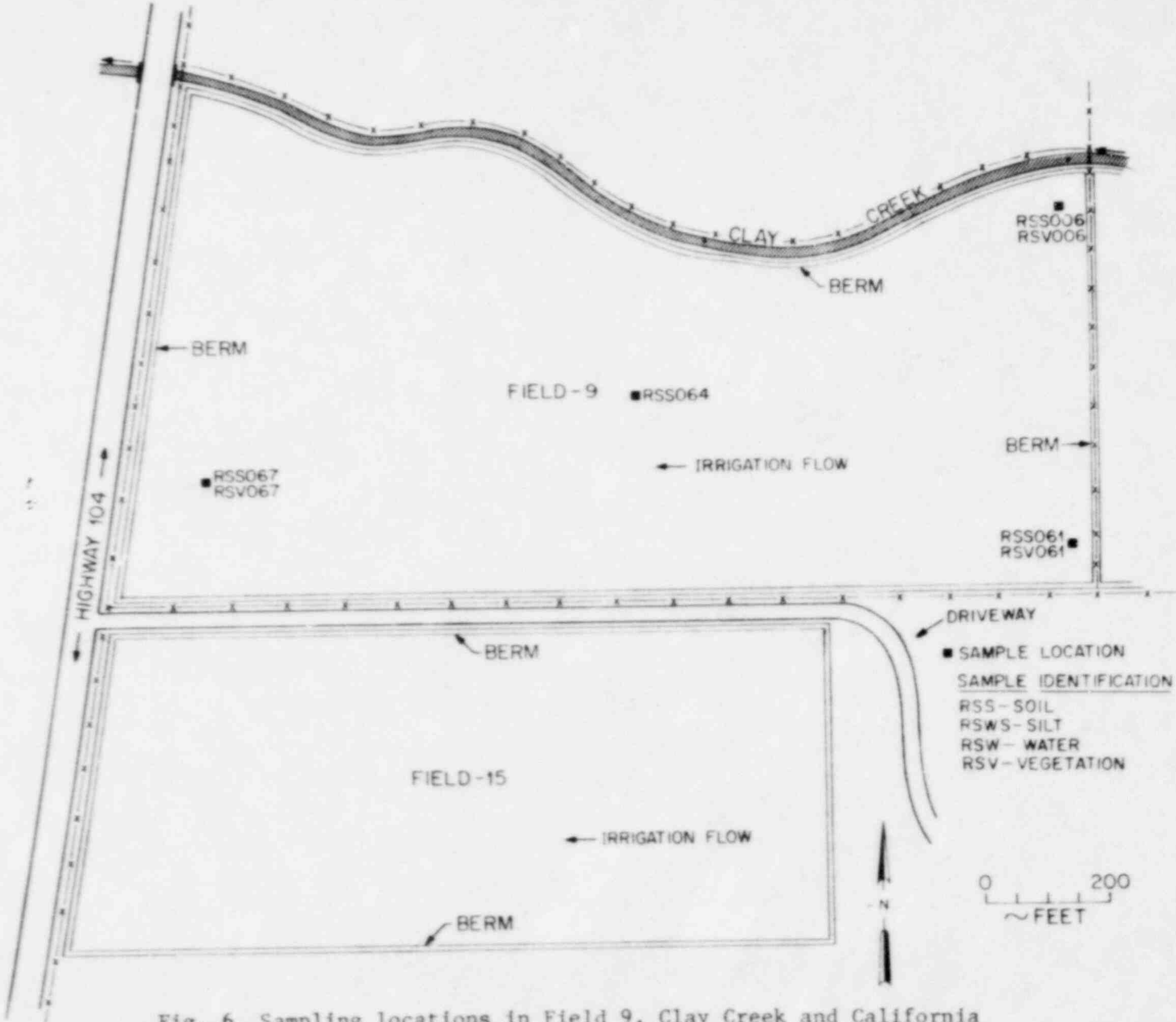

Fig. 6. Sampling locations in Field 9, Clay Creek and California Highway 104.

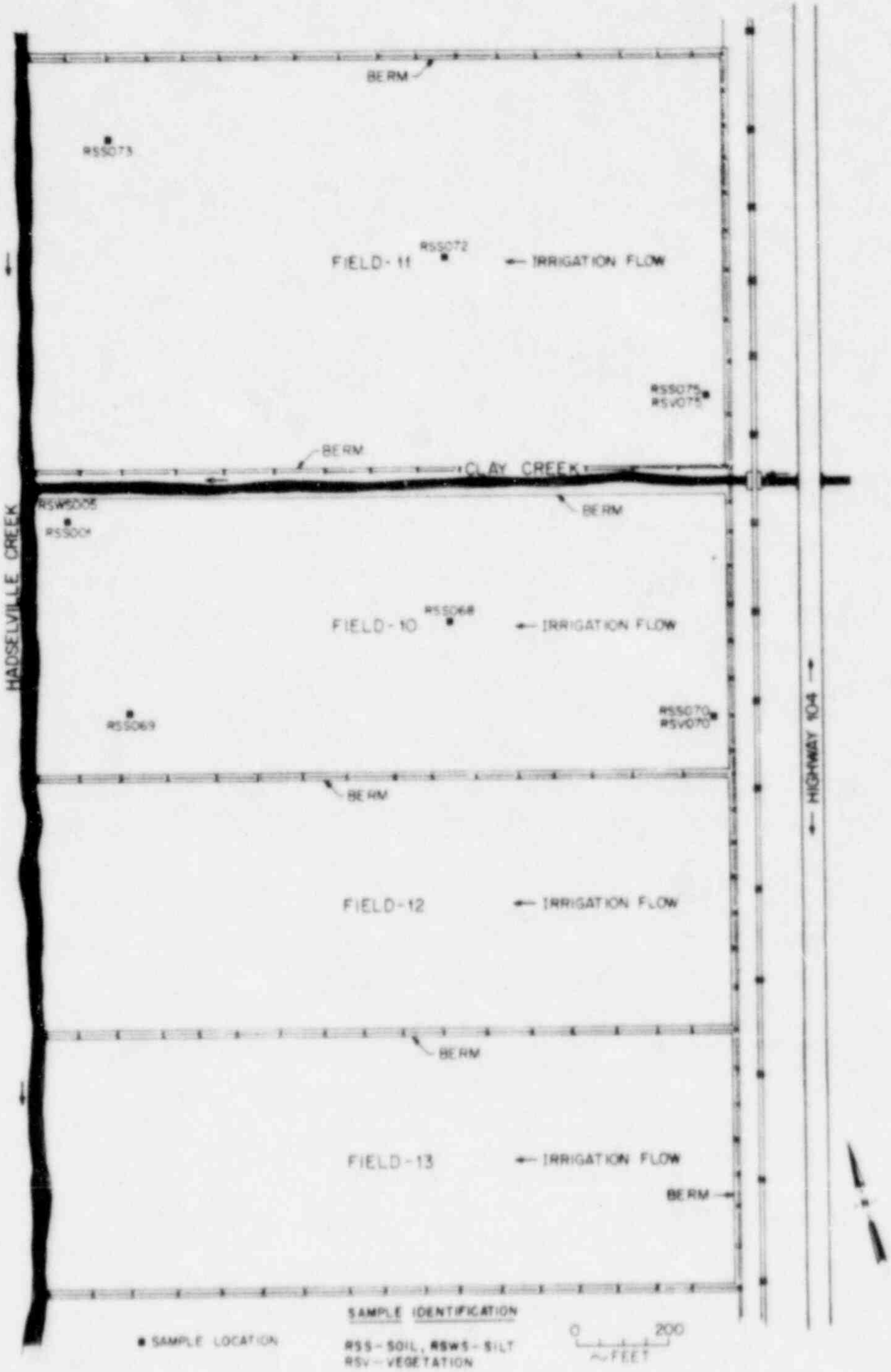

Fig. 7. Sampling locations in irrigated fields at the confluence of Clay and Hadselville Creeks.

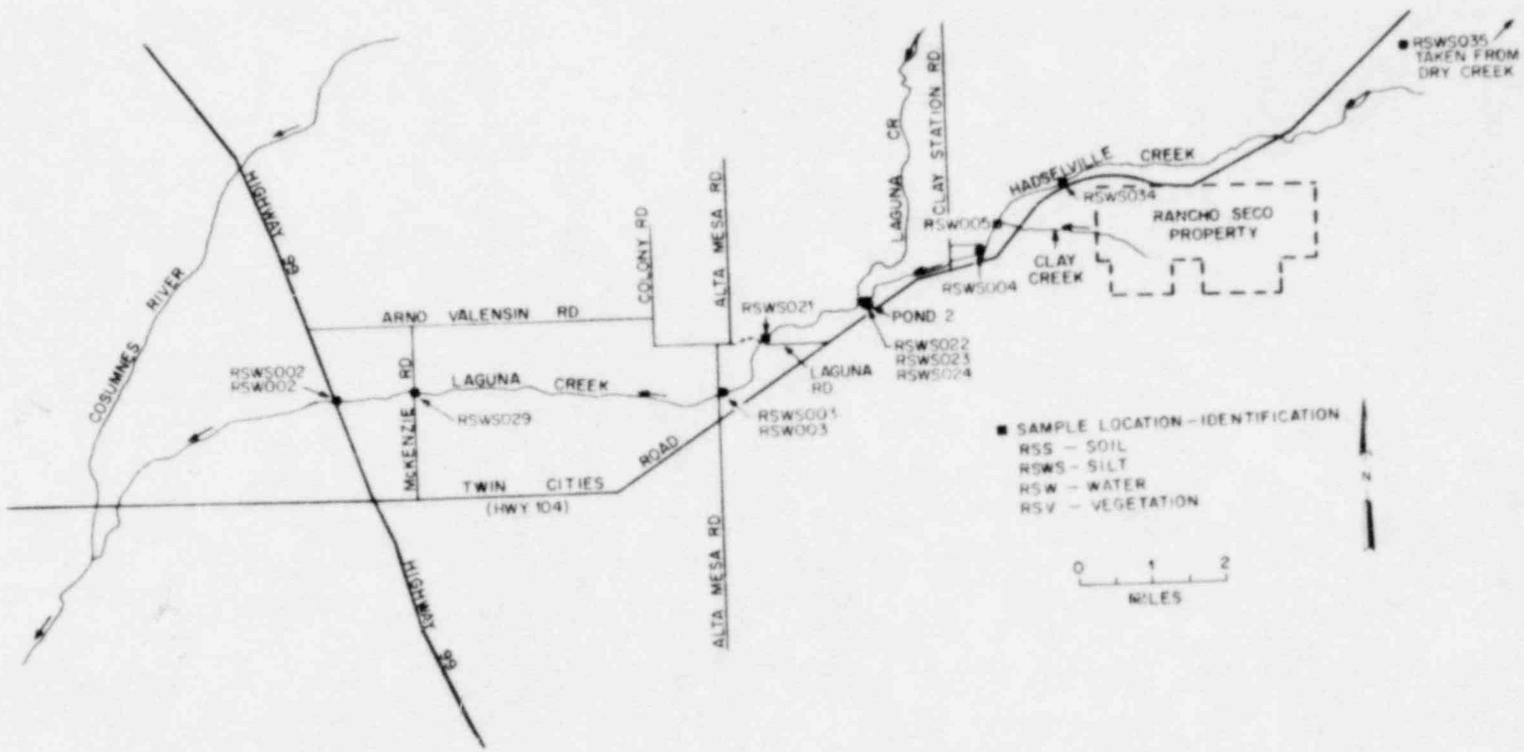

Fig. 8. Plat map showing Rancho Seco Nuclear Power Plant and streams receiving liquid wastes from plant. Water and silt sampling locations are indicated on map

Table 2. Average concentrations of radioactive cesium in soil, vegetation, and silt

Field Number	Soil and silt[a] Average radionuclide concentration (pCi/g, dry wt)		Vegetation[b] Average radionuclide concentration (pCi/kg, wet wt)	
	^{137}Cs	^{134}Cs	^{137}Cs	^{134}Cs
1	2.28	0.84	2240	850
2	1.79	0.55	1220	890
3	1.52	0.59	85	55
4	1.37	0.44	1170	445
5	1.07	0.45	165	70
6	0.36	0.13	<27	<27
7	0.07	0.03	900	365
8	1.82	0.69	2170	840
9	2.97	0.49	2390	920
10	4.29	1.34	Not sampled	
11	1.26	0.38	2680	2270
12[c]	-	-	-	-
13[c]	-	-	-	-
14[d]	75	31	3510	1460
15[c]	-	-	-	-
Sump	57	19	-	-
Pond 1	0.70	0.12	-	-
Pond 2	6.0	2.1	-	-

[a]Average radionuclide concentrations in soil are weighted averages; individual concentration values are weighted according to the fraction of the total area represented by the sample

[b]Average radionuclide concentrations in vegetation are arithmetic averages.

[c]Fields 12, 13, and 15 showed only background levels of external gamma radiation and were not sampled.

[d]Samples collected under water (overflow) on field 14; nonflooded portions of the field were background.

fields in Table 2. Complete analyses results are given in Appendix A, Table A-3.

3.5 SILT SAMPLING

Silt samples were collected from Clay, Hadselville, and Laguna creeks and from ponds and sumps identified as having received water from Clay or Hadselville creeks. Sampling locations are shown in Figs. 3, 4, 7, and 8. As expected, the highest concentrations of radionuclides along the creeks are associated with silt deposits near obstructions or sharp bends in the creeks and appear to be near background levels in stretches of the stream bed where the stream flow is unimpeded and are subject to scouring during periods of high water flow.

The maximum concentrations of ^{137}Cs and ^{134}Cs (157 pCi/g and 65 pCi/g, respectively) were observed in Clay Creek near the RSNPP waste outfall and decreased downstream along Clay and Hadselville creeks, approaching background levels in Laguna Creek approximately 19 km downstream from the plant site. Concentrations of ^{137}Cs and ^{134}Cs in water silt along Clay, Hadselville, and Laguna creeks are given in Table 3. Complete analyses results are presented in Appendix A, Table A-4.

3.6 WATER SAMPLING

Water samples were collected from the RSNPP waste outfall, Clay, Hadselville, and Laguna creeks, a sump in field 1, ponds 1 and 2, and from a background station in Dry Creek (see Figs. 3, 7, and 8 for locations). Two water samples (RSW001 from the RSNPP outfall and RSW005 from the mouth of Clay Creek) were subjected to radiochemical analyses. The concentrations of all radionuclides analyzed were at or below the minimum detection amounts (MDA) with the exception of tritium. The plant outfall sample contained 70,000 pCi/L of ^{3}H, and the sample of water from the mouth of Clay Creek showed 9700 pCi of ^{3}H per liter of water. Because of the low levels of radionuclides found in these two samples and high flows observed in the creeks during the time of the survey, the rest of the water samples were not analyzed. Results of water sample analyses are given in Appendix A, Table A-5.

Table 3. Concentrations of ^{137}Cs and ^{134}Cs in silt samples from Clay, Hadselville, and Laguna Creeks.

Sample No.	Sample location: Distance downstream from plant outfall (km)	Concentration[a] of radionuclide (pCi/g): ^{137}Cs	^{134}Cs
	Clay Creek		
RSWS001	0.06 (200 ft)	157 ± 1.7	65 ± 4.9
RSWS012	0.55	86 ± 1.3	35 ± 2.7
RSWS006	0.71	115 ± 1.6	45 ± 3.2
	Hadselville Creek		
RSWS005	3.2	97 ± 1.2	42 ± 2.4
RSWS004	4.0	58 ± 0.73	24 ± 1.9
RSWS034	(Background) 1.6 km upstream from entry of Clay Creek	0.45 ± 0.09	0.06 ± 0.06
	Laguna Creek		
RSWS021	10	4.2 ± 0.11	1.6 ± 0.2
RSWS003	12	2.5 ± 0.08	0.99 ± 0.08
RSWS029	18	0.74 ± 0.07	0.32 ± 0.05
RSWS002	19	0.26 ± 0.06	0.15 ± 0.03

[a]Errors associated with concentrations are 2 σ (95% confidence level).

3.7 BEEF SAMPLING

Beef cattle are raised on land along Clay and Hadselville creeks. These animals drink water from the creeks and graze on fields irrigated with water from the creeks. A cow was purchased from the owner of the irrigated land; the animal was then slaughtered, and samples were shipped to ORNL for analyses. This cow, which was approximately ten years old, had spent most of its life on land bordering on Clay or Hadselville creeks and had been removed from the irrigated pasture seven days prior to slaughter.

Four samples of beef, taken from different parts of the animal, and one liver sample were analyzed by high-resolution gamma spectroscopy. The results of these analyses are given in Table 4.

3.8 HONEY SAMPLING

A sample of honey collected from a hive on a ranch bordering Clay and Hadselville creeks was analyzed by gamma-ray spectrometry. The sample contained very little honey, mostly comb. The gamma-ray spectrum contained only naturally occurring radionuclides with the exception of ^{137}Cs. The ^{137}Cs concentration was found to be 0.006 ± 0.004 pCi/g. The error given is the 2-σ value for counting statistics alone.

3.9 FISH, FROGS, AND GAME BIRDS

To estimate the dose to man from consumption of contaminated fish and other vertebrates that are known to constitute at least a portion of the diet of some local residents, the concentration of radionuclides in the flesh (axial muscle) of both aquatic and terrestrial species was determined. The analyses were conducted on representative species of fish, frogs, and game birds from numerous locations in the vicinity of the RSNPP (Table 1). Results of these analyses are presented in Appendix A, Tables A-6 to A-9.

In the following discussion of these results, two major areas are emphasized: (1) evaluation of the adequacy of the data for purposes of dose assessment and (2) interpretation of differences in the radionuclide concentrations in fish as a function of distance below the source and position in the food web (i.e., trophic level). The

Table 4. Concentration of radionuclides in beef samples from Rancho Seco Nuclear Power Plant environs

Sample	Type	Concentration of radionuclides (pCi/g fresh weight)[a]	
		^{137}Cs	^{134}Cs
RSCM-1	Back strap	0.01	0.005
RSCM-2	Shoulders	0.009	< 0.002
RSCM-3	Rib-eye	0.02	0.004
RSCM-4	Rond	0.009	< 0.004
RSCL-1	Liver	0.006	< 0.003

[a]The counting errors associated with reported concentrations range from ± 20% to ± 120%.

discussion is based on the results of the ^{137}Cs analyses because it contributes the majority of the dose to man from ingestion of contaminated biota (Sect. 4.1.1), because analytical accuracy is high and because most values are above the limit of detection.

3.9.1 Fish

Estimates of the radionuclide concentrations in fish focused on three species: green sunfish (or bluegill at some sites), largemouth bass, and black bullhead that inhabit the streams and small ponds near the RSNPP (Tables 5 and 6, respectively). Based on preliminary information from local anglers and our own sampling by electroshocking, these species comprised the majority of the sport fishery in these small ponds and streams. Black crappie, which were collected at only one site (upper Laguna Creek at Laguna Road), were also included because of their importance as a game fish in other regions of the country.

A valid assessment of the radiological dose to man from ingestion of contaminated fish must take into account the size, as well as the species, of fish that local anglers might keep for consumption. Size is especially important because the concentration of some radionuclides may be higher in the larger (older) individuals in the population. For example, Kolehmainen and Nelson (1969) found a direct linear relationship between total concentration of ^{137}Cs and weight of bluegill over a range of weights from 1 to 70 g ($Y = 9.26 + 0.39X$, $r^2 = 0.998$); concentrations of ^{137}Cs (Y) in bluegill (X) increased by a factor of 4 over this range. In addition, they found no correlation between the concentration of ^{137}Cs and weight in fish greater than 70 g, and they attributed this to the fact that the ^{137}Cs concentration in these larger fish was in a steady state. A regression of the ^{137}Cs concentration in axial muscle and body weight for seven bluegill (weights ranged from 70.7 to 192.7 g) collected from a sump near the SMUD property line in November 1984, (T A-7) indicated that fish exceeding 70 g did not have increased concentrations of ^{137}Cs. The slope of the regression line ($Y = 9.93 - 0.03X$, $r^2 = 0.41$) was not significantly different from zero [t-test, P (probability) >0.05 (Snedecor and Cochran 1967)].

Table 5. Mean concentration (pCi/g, wet wt.) of radionuclides in axial muscle of fish collected from streams downstream of the Rancho Seco Nuclear Power Plant, December 1984. (Less than values ignored in compution of mean; n ~ 3 for each species/site combination)

Sampling site	Species												
	Green sunfish			Largemouth bass			Black crappie				Black bullhead		
	^{137}Cs	^{134}Cs	^{60}Co	^{137}Cs	^{134}Cs	^{60}Co	^{137}Cs	^{134}Cs	^{60}Co		^{137}Cs	^{134}Cs	^{60}Co
Clay Creek	10.03 (1.73)[b]	4.78 (0.77)	0.38 (0.28)	8.96 (1.51)	4.07 (0.78)	0.42 (0.11)		NC[a]			7.16 (0.72)	3.60 (1.01)	0.36 (0.38)
Hadselville Creek	6.58 (3.46)	3.13 (1.28)	0.29 (0.20)		NA[c]			NC			9.21 (1.57)	4.41 (0.65)	0.44 (0.09)
Laguna Creek at Laguna Rd	0.67 (0.27)	0.28 (0.33)	0.28 (0.22)		NA		1.58 (0.37)	0.78 (0.12)	0.15 (0.17)	0.40	0.39 (0.39)	0.46 (0.12)	(0.19)
Laguna Creek at McKenzie Rd	0.13 (0.12)	0.07 (0.02)	0.40 (0.06)		NC			NC			0.09[d]	<0.05[d]	0.23[d]
Dry Creek (control)	0.05 (0.01)	0.12 (0.13)	0.44 (0.34)		NC			NC				NC	

[a]None collected.

[b]Numbers in parentheses indicate standard deviation.

[c]None analyzed; all individuals collected were small.

[d]n = 1.

Table 6. Mean concentration (pCi/g, wet wt.) of radionuclides in axial muscle of fish collected from small ponds near the Rancho Seco Nuclear Power Plant, November-December 1984. (Less than values ignored in compution of mean; n = 3 for each species/site combination)

Sampling site	Green sunfish			Bluegill			Largemouth bass			Black bullhead		
	^{137}Cs	^{134}Cs	^{60}Co	^{137}Cs	^{134}Cs	^{60}Co	^{137}Cs	^{134}Cs	^{60}Co	^{137}Cs	^{134}Cs	^{60}Co
Sump		NC[a]		6.35[b] (2.13)[c]	3.03[b] (1.22)	0.12[b] (0.19)	15.20 (1.34)	7.03 (0.82)	0.50 (0.09)	6.29 (2.67)	3.04 (1.22)	0.18 (0.17)
Pond 1		NC		0.35 (0.27)	0.05 (0.01)	0.60 (0.07)	0.17 (0.06)	0.06 (0.04)	0.21 (0.19)		NC	
Pond 2	0.36 (0.40)	0.17 (0.13)	0.31 (0.26)		NC		3.16 (1.53)	1.33 (0.86)	0.24 (0.09)	0.91 (0.29)	0.41 (0.61)	0.49 (0.13)

[a]None collected.

[b]n = 8.

[c]Numbers in parentheses indicate standard deviation.

The existence of a concentration-vs-size relationship in smaller bluegill (<70 g) emphasizes the importance of limiting the analyses of radionuclide concentrations in fish flesh to the larger individuals in the population. We have assumed that similar relationships between radionuclide concentration and size exist for the other species, although the weight above which concentrations no longer increase with increasing size is not known. Consequently, a minimum size criterion based upon the shape of the curves could not be used to evaluate the adequacy of the fish data used in the dose assessment calculations (Sect. 4.1.1.1) (i.e., to identify those samples with low radionuclide concentrations because the fish were small and not because levels in the environment are low).

As an alternative approach, minimum size criteria were selected for each species based on angler preference (Table 7). Overall, 55% of the fish collected met a minimum size criterion based on quality length, or the size of fish most anglers like to catch [Anderson (1980), as cited in Gabelhouse (1984)]; and 65% of the fish collected were within 1 cm of the criterion. Criteria based on minimum quality-length may approximate the criteria derived from the concentration-vs-size relationship. For example, the minimum quality length for bluegill is 15 cm, total length (or 12 cm standard length). Using the length-weight regression computed for bluegill collected from the sump and pond 2 (Table A-7, footnote c), the estimated weight of a 15-cm bluegill is 68.6 g, very similar to the 70-g criterion based on data in Kolehmainen and Nelson (1969). Such close agreement between the two criteria should be viewed with caution because (1) growth rates of bluegill in the two environments may be different and (2) no data are available for other species.

Similarly, the minimum quality length criteria used in our analysis should be considered as guidelines. Angler preference will vary between individuals and between water bodies because of differences in the availability of fish of quality length to the angler. Because small streams, such as Clay Creek, may have very few largemouth bass that exceed 30 cm (12 in.), local fishermen may keep bass that are less than 30 cm. Although only 50% of the largemouth bass collected in December 1984 exceeded 30 cm, all but one (92%) exceeded 25 cm; therefore, residents might be expected to consume fish of the smaller size. It is

Table 7. Percentage of the fish analyzed for radionuclides that exceeded the minimum quality length proposed by Gabelhouse (1984)

Sampling site	Species					Total (All species combined)
	Green sunfish	Bluegill	Largemouth bass	Black crappie	Black bullhead	
Minimum quality length, cm[a,b]	15(6)	15(6)	30(12)	20(8)	23(9)	
Clay Creek	100		0		33	44
Hadselville Creek	67[c]				100	83
Laguna Creek at Laguna Rd.	67			33[c]	33	44
Laguna Creek near McKenzie Rd.	0				0	0
Dry Creek (control)	67[c]					67
Sump		88[c]	67[c]		67	79
Pond 1		100	100			100
Pond 2	0		33		0[c]	11
Total (all sites combined)	50	91	50	33	44	55

[a]Quality length is defined as the size of a fish most anglers like to catch (Anderson 1980 as cited in Gabelhouse 1984).

[b]Length in inches in parentheses.

[c]Excludes one fish that was within 1 cm of the minimum quality length criterion.

these fish, all the others in Table A-6 exceeded the minimum-quality-length criterion of 12 cm standard length and weighed more than 60 g. Moreover, mean weights at each site exceeded 68 g (range: 69.4 g in Dry Creek to 85.7 g in Clay Creek); these mean weights were similar to the 70-g value reported by Kolehmainen and Nelson (1969) as the weight above which concentration and size were not correlated in the bluegill, a species closely related to the green sunfish. For these reasons, any bias in comparing concentrations of radionuclides in fish with different weight distributions is assumed to be minimal, and adjustment of the concentrations to a standard fish based on regression analyses would not alter the conclusions that follow.

Radionuclide concentrations in green sunfish declined with increasing distance downstream of the source at the RSNPP (Table 5). Although the three sampling stations below the plant were about equidistant apart (4-5 km), the greatest reduction (by a factor of approximately 10) occurred between the Hadselville Creek and upper Laguna Creek sites. Cesium concentrations in green sunfish from Hadselville Creek were only 35% lower than the concentrations in the same species from a site on Clay Creek approximately 0.5 km below the outfall of the plant. Silt concentrations were approximately 25% lower in Hadselville Creek (sites RSWS004 and RSWS005) compared with concentrations in Clay Creek (sites RSWS006 and RSWS012) (Table A-4). Concentrations in black bullhead were actually higher in Hadselville Creek, probably because the individuals were, with one exception, larger at this site. However, the distribution of weights varied between the two sites, thus direct comparisons are difficult. An unambiguous conclusion based on the data from both species is that fish from Hadselvile Creek have cesium levels that are not much lower than the levels in Clay Creek, about 4 km upstream near the SMUD property line. Although concentrations of ^{137}Cs in fish decline sharply below the confluence of Hadselville and Laguna creeks, they are still at least an order of magnitude above background approximately 9 km below the plant (upper Laguna Creek vs Dry Creek sites).

Finally, comparisons between species at a given site indicated that the concentration of ^{137}Cs in piscivorous species (fish-eaters, such as largemouth bass and black crappie) exceeded that of nonpiscivorous not known if the radionuclide concentrations in these bass are near the maximum.

The minimum-quality-length criteria were needed to identify potential bias (underestimates of radionuclide concentrations) in the data base resulting from the inclusion of small fish. Our analyses indicated that, except for the lower Laguna Creek site (near McKenzie Road), an adequate sample (i.e., fish large enough to be kept by anglers) of at least one species was obtained from the other seven sites. Of the four fish analyzed from lower Laguna Creek, only one approached a size that might be included in the catch of local anglers. Radionuclide concentrations in all four fish were very low and similar to the concentrations found in fish from Dry Creek, the control or background site located approximately 17 km east of the power plant. However, the data from the Laguna Creek site are biased low because most of the fish collected at the site were small.

Similar comparisons of the radionuclide concentration in fish from other sampling sites are subject to the same bias because of the differences in fish weights between sites. To correct for such bias, empirical relationships (linear regressions) between concentration and weight must be derived for each species-site combination. For a given species, radionuclide concentration values at each site can be normalized by adjusting them to the concentration in a standard fish (e.g., a 70-g bluegill), using these site-specific regression equations. Such an approach was used by Elwood (1984) and Van Winkle et al. (1984) to make between-site comparisons in the concentrations of mercury, another contaminant in which concentrations in muscle tissue are correlated with fish weight. Because only the three largest individuals of a species were analyzed at each site, a regression analysis of the Rancho Seco data is not appropriate.

Without the support of statistical analyses, comparisons between sampling sites will be less rigorous and, by necessity, conservative (i.e., tending to overpredict the radionuclide concentration or dose). The only species that can be used for such comparisons is the green sunfish, which was similar in size at most of the stream sampling sites, except lower Laguna Creek, as noted previously, and upper Laguna Creek where one of the three individuals was small (Table A-6). Excluding species in three of five possible comparisons; in Clay Creek and pond 1, concentrations of ^{137}Cs were higher in sunfish than in largemouth bass. Numerous studies have reported higher bioaccumulation factors for ^{137}Cs in piscivorous compared to nonpiscivorous species [see review by Vanderploeg et al. (1975)], although the ratio between the two groups varied between study sites. The bioaccumulation factor for ^{137}Cs recommended by Vanderploeg et al. (1975) for piscivorous fishes was approximately three times higher than that for nonpiscivorous species.

Several factors may account for the results obtained in Clay Creek and pond 1. First, individuals of the prey species (sunfish) collected at both sites were very large and may not represent the preferred food of the predator (largemouth bass). Bass of the size collected from the two sites may feed on smaller individuals (with correspondingly lower ^{137}Cs concentrations) or on species different from those included in this analysis. Second, ^{137}Cs may not be equally available to the two species because clay particles can alter the efficiency of ^{137}Cs assimilation [Kolehmainen and Nelson (1969)]. Eyman and Kitchings (1975) found that ^{137}Cs accumulation in bluegill and channel catfish can be greatly influenced by sediment composition, particularly the clay and organoclay complexes, which affects the availability of cesium for assimilation. Differences in sediment composition between the eight sampling sites are not known. Although detailed information on food habits (e.g., prey species and size as a function of predator size) and sediment composition were not collected, the available evidence, both from this study and others, suggests that the highest concentrations of ^{137}Cs and ^{134}Cs, which will not have an appreciably different bioaccumulation factor than that of ^{137}Cs (Vanderploeg et al. 1975), should occur in piscivorous species, such as the largemouth bass.

3.9.2 Frogs

The three individuals that were analyzed for radionuclides were collected from the two sites (pond 1 and lower Laguna Creek near McKenzie Road) with the lowest levels of contamination (Table A-4). Consequently, radionuclide concentrations in these frogs may be lower than if they were collected in more highly contaminated sites (Table A-8). The small sample size [one frog at each site, after excluding a very small (37 g), unrepresentative individual from lower Laguna Creek] restricts the use of these data for dose assessment. Because the frogs were collected from sites with the lowest levels of contamination, these data cannot be used to estimate concentrations in frogs at other sites with much higher levels of contamination.

To resolve this problem, radionuclide concentrations in piscivorous fishes could be used to provide an estimate of the maximum concentrations that might be expected in frogs from these sites. The rationale for this approach is the similarity between the recommended bioaccumulation factor (the ratio of the concentration of a radionuclide in fish to its concentration in the water) for cesium in amphibians and that for piscivorous fishes ($\sim 10^4$) [Vanderploeg et al. (1975), Table 1)]. Support for the conservatism of this approach is based on data from pond 2 (Table A-7). The concentration of ^{137}Cs in each of the six fish exceeded that of the large (293 g) bullfrog. Although the sample size is admittedly small, all the samples were taken from very large individuals, so the confounding effect of body weight on concentration is minimized.

3.9.3 Game Birds

Five game birds (three species) were collected at various sites near Clay Creek between 0.5 and 3.0 km downstream of the RSNPP (Table A-9). Concentrations in all samples were relatively low and substantially lower than the concentrations in fish from Clay Creek. Although local sportsmen probably prefer to hunt (and eat) other species of waterfowl (e.g., mallard, teals) than the American coot, these species were uncommon inhabitants of Clay Creek and the small ponds nearby during the sampling periods. Even though the coot has different food habits than many other waterfowl, preferring primarily aquatic vegetation to grasses or grains [Bent (1926)], the data on radionuclide concentrations in this species may approximate or exceed the concentrations found in other waterfowl. Bioaccumulation factors for ^{137}Cs in muscle tissue, for example, were estimated by Pendleton and Hanson (1958) to be 1800 and 2000, for the American coot and mallard, respectively. Moreover, the American coot is a year-round resident in the southern portion of its range [Bent (1926)]. If this includes

Sacramento County, their exposure to contamination would be greater than that of other species that are migrants in this region and breed in more northern latitudes. The winter and breeding ranges of the American coot, on the other hand, include California [Bent (1926)].

4. RADIATION DOSE ASSESSMENT

Radiation doses associated with the liquid radionuclide releases from the RSNPP were estimated for a number of potential pathways of external and internal exposure. Measurements of radionuclide concentrations in environmental media and edible food sources in the vicinity of Rancho Seco indicated that only ^{60}Co, ^{134}Cs and ^{137}Cs would contribute significantly to radiation doses which might be received by an individual. In addition to estimates of dose made directly from measured samples, several model calculations were made to indicate the magnitude of potential pathways of exposure associated with local contaminated land.

4.1 PATHWAYS OF INTERNAL EXPOSURE

Individuals living around Rancho Seco may be internally exposed to radiation doses via ingestion of contaminated foods and inhalation of radionuclides from contaminated land areas. Aquatic species such as fish and frogs living in contaminated waters and terrestial species such as coots, pheasants, and beef cattle on lands contaminated by irrigation or overflow of Clay Creek all represent potential sources of radiation dose to individuals. In addition, the consumption of vegetables grown on contaminated land and the consumpton of drinking water are considered as potential pathways of internal exposure. The resuspension in air of contaminated soil particles or the release of radioactivity from burning of vegetation represent potential dose pathways via inhalation.

All estimates of dose from pathways of internal exposure were made using dose conversion factors and models contained in the latest version of NRC Regulatory Guide 1.109 [USNRC (1977)]. Internal doses are calculated for ingestion or inhalation pathways. The dose from the ingestion pathway is given by [USNRC (1977)].

$$D_i^{ing} = (C_i^f)\ (U_i^f)\ (DFI_i),$$

where

D_i^{ing} = annual dose commitment to an indivivual due to the ingestion of radionuclide i (mrem)

C_i^f = concentration of radionuclide i in ingested food (pCi/kg)

U_i^f = annual intake (usage) of food containing radionuclide i (kg) and

DFI_i = ingestion dose conversion factor for radionuclide i (mrem/pCi).

Similarily, for the inhalation pathway [USNRC (1977)],

$$D_i^{inh} = (C_i^a)\ (R_a)\ (DFA_i),$$

where

D_i^{inh} = annual dose commitment to an individual due to the inhalation of radionuclide i (mrem)

C_i^a = concentration of radionuclide i in air (pCi/m^3);

R_a = annual air intake for individuals (m^3) and

DFA_i = inhalation dose conversion factor for radionuclide i (mrem/pCi).

In this study it was assumed that R_a = 8000 m^3 [Rupp (1984)].

4.1.1 Ingestion

4.1.1.1 Fish

Consumption of local fish represents the primary potential pathway of dose to individuals from RSNPP liquid effluents. Table 8 gives total-body and critical organ (liver) doses resulting from the ingestion of 1 kg of fish for eight locations. These values are based on average radionuclide concentrations in fish caught at the eight locations. Fish from Clay Creek, the sump near the SMUD boundary, and Hadselville Creek at Clay Station Road are the critical locations. Radionuclide concentrations in fish at these locations result in doses of 1.1, 1.3, and 1.0 mrem total-body dose/kg ingested, respectively. Dose to liver, the critical organ, is about 1.4 times greater. Thus, consumption of 14, 16, and 18 kg, respectively, of fish per year from these locations could give an estimated organ dose to an individual which would be at the 25 mrem/year limit given in 40 CFR 190 [USEPA (1977)].

Table 8. Radiation doses from ingestion of fish caught in the vicinity of Rancho Seco

Location	Number of samples	Dose (mrem/kg ingested)	
		Total body	Liver
Clay Creek at SMUD boundary	9	1.1	1.6
Sump	6	1.3	1.8
Pond 1 adjacent to field 2	6	0.03	0.04
Pond 2 near Silva's feedlot	9	0.17	0.24
Hadselville Creek at Clay Station Road	6	1.0	1.4
Laguna Creek at Laguna Road	9	0.12	0.17
Laguna Creek at McKenzie Road	4	0.007	0.01
Dry Creek at Rte. 104 (control)	3	0.02	0.03

Consumption of fish from other ponds in the area or from locations downstream from the Hadselville Creek sampling location appear to pose no problem because it is completely unlikely that an individual would have a yearly consumption of fish great enough (150 to 3500 kg) to exceed the 25-mrem limit.

Radionuclides contributing to the dose from consumption of fish are ^{137}Cs (55.3%), ^{134}Cs (44.5%) and ^{60}Co (0.2%).

4.1.1.2 Frogs and game birds

Based on measured concentrations of radionuclides in frogs and game birds, consumption of these foods would result in very small total-body radiation doses (Table 9). However, frogs were not sampled at the most contaminated locations. If it is assumed that frogs would contain about the same concentrations of radioactivity as fish sampled in these locations (see Sect. 3.9.2) a dose of about 1 mrem/kg ingested would result from consumption of frog flesh in the most contaminated areas.

4.1.1.3 Vegetables

Although vegetables are not currently grown in any of the contaminated, irrigated fields around RSNPP, an estimate was made of potential dose from consumption of leafy vegetables. Using models from Regulatory Guide 1.109 [USNRC (1977)] and average radionuclide concentrations in soil sampled from field 1 (the most contaminated field), it was assumed that an individual eats leafy vegetables grown in this field. The resulting annual dose would be 3×10^{-5} mrem/kg ingested to the total body, 5×10^{-5} mrem/kg ingested to the liver. This estimate is conservative because most of the soil samples taken in field 1 were taken in small areas where relatively high external exposure readings were given when the field was surveyed in a walk-over.

While this pathway of exposure is not currently available, the dose estimate serves to indicate that individual exposures from consumption of vegetables grown on this area would lead to less dose than would consumption of fish from the most contaminated aquatic sampling locations.

Table 9. Radiation doses from ingestion of frogs and game birds caught in the vicinity of Rancho Seco

Source	Number of samples	Dose (millirem/kg ingested)	
		Total body	Liver
Frogs	3	0.01[a](1.1)[b]	0.02[a](1.6)[b]
American coot	2	0.02	0.02
Pheasant	2	0.02	0.03

[a]Dose based on measured activity.

[b]Dose based on assumption that frog flesh contains the same activity as fish flesh.

4.1.1.4 Beef

Two estimates are given of the total-body dose to an individual eating beef from cows allowed to graze on fields 1 and 2 (Table 10). Analysis of beef samples from a cow slaughtered December 27, 1984, indicated very low levels of ^{137}Cs and ^{134}Cs (1.08×10^{-2} and 3.6×10^{-3} pCi/g, respectively). This cow was assumed to have grazed on fields 1 and 2 for several months. The resulting dose of 1.2×10^{-3} mrem/year (total body)/kg of beef ingested is indeed small. Estimated concentrations [USNRC, (1977)] for ^{137}Cs, ^{134}Cs, and ^{60}Co in beef based on average values of grass samples led to an estimated total-body dose of 4.6×10^{-2} mrem/year per kg ingested. This estimate is conservative, however, in that more grass samples were taken in small areas with the heaviest contamination in fields 1 and 2. Also, the model cow is receiving only contaminated pasture in its diet.

It is not likely that consumption of beef from cows allowed to graze in contaminated fields around Rancho Seco would lead to doses greater than 1 mrem/year to an individual.

4.1.1.5 Milk

Although milk cows are not raised on the contaminated fields around Rancho Seco, an estimate of dose via ingestion of milk was made using Regulatory Guide 1.109 models and average concentrations of radionuclide in grass sampled in fields 1 and 2.

Consumption of milk would lead to a total-body dose of 0.14 mrem/l ingested (99.9% due to cesium radionuclides). Because of the relatively high cesium transfer factor from grass to milk, milk consumption leads to higher doses than does consumption of beef. Although these estimates are conservative due to biased sampling of grass, the use of fields 1 and 2 for heavy grazing by milk cows could lead to doses close to the 25 mrem/year limit if it is assumed that all of the milk ingested by the maximally exposed individual comes from cows grazing on these contaminated fields.

Table 10. Radiation doses from ingestion of beef

Source	Dose (millirem/year/per kg ingested)	
	Total-body	Liver
Sampled cow	1.2×10^{-3}	1.7×10^{-3}
Model cow[a]	4.6×10^{-2}	6.3×10^{-2}

[a]Concentration of radionuclides in beef calculated from grass samples in fields 1 and 2.

4.1.1.6 Water

Water from local streams carrying RSNPP liquid wastes is not consumed directly by man. However, an estimate of dose was made which indicates that no serious problem would be anticipated for this potential pathway of exposure. An upper limit of potential dose was estimated by assuming that an individual drinks water at the Rancho Seco outfall. The resulting total-body dose was 7.8×10^{-3} mrem/L ingested with 94.4% from ^{3}H, 5.4% from cesium, and 0.2% from other radionuclides.

4.1.1.7 Honey

Honey collected from a hive on a ranch bordering Clay and Hadselville Creeks contained small concentrations of ^{137}Cs (0.006 pCi/g) and naturally occurring radionuclides. No ^{134}Cs was found in these samples. Ingestion of this honey would result in a total-body dose of 4.3×10^{-4} mrem/kg ingested for the ^{137}Cs. This level of ^{137}Cs could result from weapons fallout [United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (1977)]; thus, it would seem that ingestion of honey poses no significant radiation dose pathway in the RSNPP area.

4.1.2 Inhalation

4.1.2.1 Transuranic Radionuclides

A soil sample taken near the RSNPP outfall contained small amounts of transuranic radionuclides (^{238}Pu, ^{239}Pu, ^{241}Am, and ^{244}Cm). The total activity was 1.1×10^{-2} pCi/g. It is estimated that 1 m^2 of soil would contain 179.2 pCi. Resuspension of these radionuclides into air by an amount of $10^{-9}/m$ [Eckerman and Young (1980)] would lead to a lung dose of 1.2×10^{-6} mrem for an individual breathing 8000 m^3 of air for one year. Any plausible ingestion pathways would lead to even smaller doses. Therefore, transuranic radionuclides seem to pose no significant radiation dose problems. Indeed, the levels of transuranic radionuclides found in the RSNPP environs are consistent with levels reported for weapons fallout [USEPA (1976)].

4.1.2.2 Other Radionuclides

The resuspension into air of nontransuranic radionuclides in soil and subsequent inhalation by an individual represents one pathway of internal exposure around Rancho Seco. A dose estimate for this pathway was made by assuming average soil contamination levels in field 1 and a resuspension value of 10^{-9}/m for aged deposits. Total-body dose to an individual breathing these resuspended radionuclides was estimated to be 3.0×10^{-4} mrem/year. Because no individual would be exposed to this pathway for a full year, a dose of about 3.4×10^{-6} mrem for 100 h of exposure is more realistic. During cultivation, more deposited radioactivity is resuspended (10^{-5}/m) so that an individual spending 100 h/year cultivating field 1 would receive an estimated total-body dose of 3.4×10^{-2} mrem. These inhalation pathways would contribute little to maximum individual doses for persons utilizing contaminated fields around Rancho Seco.

Another potential inhalation pathway is associated with burning contaminated vegetation. Because rice is raised in the Rancho Seco area and the stubble on rice fields is burned, dose from this pathway was estimated. It was conservatively assumed that field 1, with the highest levels of contamination, was used for cultivation of rice. It was further assumed that stubble mass (2.0 kg/m^2) contained the same level of contamination as grass sampled from field 1. Thus a total inventory of 156 μCi of ^{137}Cs, 59 μCi of ^{134}Cs, and 3 μCi of ^{60}Co contained in the 3.5-ha field (8.61 acres) was assumed to be released in a fire of 30 min duration. Using an atmospheric dilution factor of 3.6×10^{-3} s/m^3, an individual 100 m from the fire who inhaled contaminated air for the duration of the fire would receive a total-body dose of 1.3×10^{-2} mrem. Thus, the inhalation pathway associated with burning of contaminated vegetation around Rancho Seco would seem to pose no significant dose problem.

4.2 PATHWAYS OF EXTERNAL EXPOSURE

Two pathways of external exposure are available for individuals around Rancho Seco. These are exposure from contaminated ground and exposure from swimming in contaminated water. Again, using average values of soil contamination in samples from field 1, an annual total-body dose of 73 mrem/year was estimated. Since no individual is exposed for one year, a more realistic dose of 0.83 mrem is estimated for 100 h of exposure per year.

Swimming for 100 h/year in water contaminated to the same degree as water collected at the plant outfall would lead to a total-body dose of 1.6×10^{-3} mrem.

4.3 ALTERNATE DOSE CONVERSION FACTORS

The internal dose conversion factors contained in USNRC (1977) were used in the calculations reported above. However, more recent values based on models proposed by the International Commission on Radiological Protection (1977) are available [Dunning et al. (1981)]. For the principal radionuclides considered in this study, these newer values are lower than the dose conversion factors given in USNRC (1977). For example, use of the values from Dunning et al. (1981) would lower the total-body doses due to ingestion of ^{134}Cs by 44% and those due to ingestion of ^{137}Cs by 31%. For inhalation, reductions in total-body dose would be 53% for ^{134}Cs and 42% for ^{137}Cs. Doses to liver, the critical organ, would be reduced by less--28 to 38%. It may be more appropriate to use the dose conversion factors given by Dunning et al. (1981) than those contained in Regulatory Guide 1.109 [USNRC (1977)] if the risk to persons living near the RSNPP is to be calculated.

5. INVENTORY OF RADIONUCLIDES IN IRRIGATED FIELDS

Soil samples were collected and analyzed from 45 locations in the irrigated fields and silt was collected from three locations each in the sump and ponds 1 and 2. Based on the concentrations of ^{137}Cs and ^{134}Cs found in the soil and silt samples, an estimate of the amounts of these radionuclides remaining in the fields and in the sump and ponds was made.

Each field was divided into areas based on the surface gamma radiation levels observed in each area. Soil sample results from each area were averaged and the averages were weighted according to the fraction of the area of the field represented by the respective areas. Figure 9 shows a typical division of a field into areas for averaging and weighting results. The weighted average concentration for each field was combined with the average sample weight, the area from which the samples were collected, and the area of each field to arrive at an estimate of the quantity of each radionuclide contained in each field. The relationship used in these determinations is as follows:

$$Q = \frac{AK(C_s - C_B)}{10^9 \alpha} ,$$

where

Q = quantity of radionuclides in field in mCi,

A = area of field in ft^2,

K = average weight of sample in g,

C_s = weighted average concentration of radionuclide in pCi/g,

C_B = background concentration of radionuclide in pCi/g, and

α = 0.1964 ft^2, area of sample plug (6-in. diameter).

If substantial areas of a field showed the concentration of radioactive contaminants to be at background levels, a weighted average was not used in determining the quantity of cesium in that field, but the quantities of radionuclides were determined for each individual area.

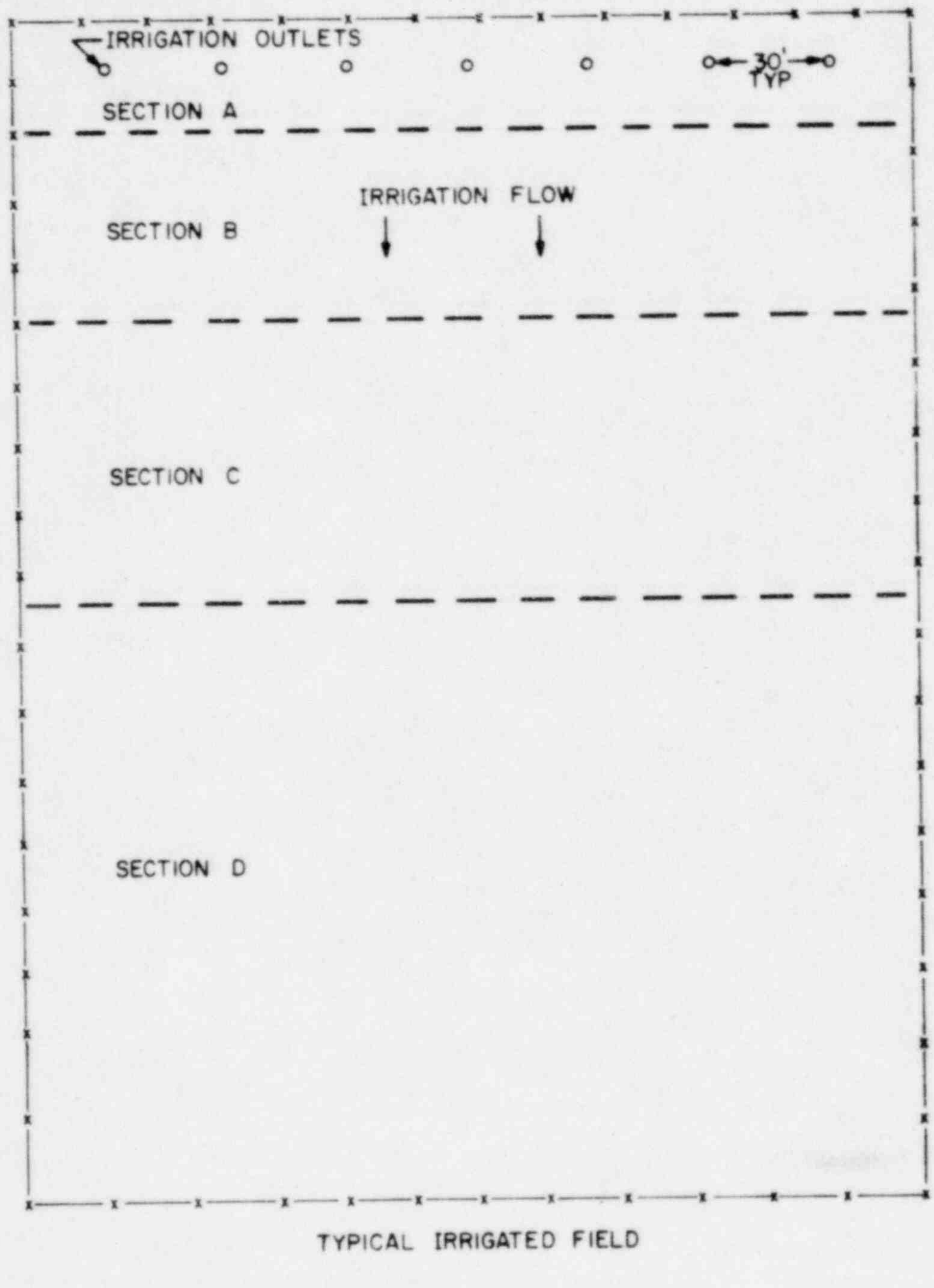

Fig. 9. Typical irrigated field showing division into sections for use in arriving at weighted average radionuclide concentrations.

Table 11 lists the estimated quantities of ^{137}Cs and ^{134}Cs contained in each field, the sump, and ponds 1 and 2. Analyses of depth samples taken from the fields indicates that approximately 85% of the radioactivity is contained in the top two inches of soil. This correction has not been applied to the values in Table 11.

Reported releases from RSNPP during the period 1981-1984 were 280.9 mCi of ^{134}Cs and 520.6 mCi of ^{137}Cs (Table C-1). The quantity of ^{134}Cs, when corrected for decay, becomes 174.1 mCi of ^{134}Cs remaining at the time the survey was carried out. Using the corrected decay value for ^{134}Cs discharged (174.1 mCi) and correcting the total quantities of radionuclides from Table 11 for the 15% of the radioactivity not sampled, the estimated inventory accounts for about 21% of the ^{137}Cs and about 25% of the ^{134}Cs released from the RSNPP during the period 1981-1984.

Table 11. Cesium inventory in fields, sump, and ponds 1 and 2

Location	Quanity of radionuclide(mCi)	
	^{137}Cs	^{134}Cs
Field 1	7.40	3.17
Field 2	2.99	1.07
Field 3	4.18	1.66
Field 4	1.89	0.76
Field 5	1.11	0.66
Field 6	0.72	0.45
Field 7	7.21	2.97
Field 8	6.89	2.81
Field 9	12.31	4.97
Field 10	14.62	4.87
Field 11	6.10	1.69
Field 12	Not sampled	
Field 13	Not sampled	
Field 14	23.50	9.52
Sump	4.81	1.61
Pond 1	0.09	0.02
Pond 2	0.87	0.32
Total	94.68	36.55

6. SUMMARY OF RESULTS

The release of radioactive materials in the liquid waste effluents from the RSNPP has resulted in elevated concentrations of some radionuclides in the immediate environment of the plant. The radioactive contamination in the environment occurs primarily along streams receiving effluents from the plant and in fields irrigated with water from these streams. The highest levels of radionuclides (approximately 375 times background concentration of radionuclides measured) occur immediately below the plant liquid waste outfall and decrease with distance from the plant downstream along Clay and Hadselville Creeks and approach background levels approximately 19 km from the plant in Laguna Creek. The primary contaminants are ^{137}Cs and ^{134}Cs with lesser amounts of ^{60}Co and ^{58}Co.

Radionuclide concentrations in fish also declined with increasing distance downstream of the RSNPP. Concentrations in green sunfish from Clay Creek at the plant boundary were 200 times the background concentration of the radionuclides measured and decreased by 35% in Hadselville Creek, approximately 4 km downstream. Although the same distance separated the Hadselville Creek and upper Laguna Creek sites, concentrations in fish decreased by almost an order of magnitude. The highest cesium concentrations occurred in largemouth bass collected from a sump at the boundary of the RSNPP (mean values of 15.20 and 7.03 pCi/g wet weight for ^{137}Cs and ^{134}Cs, respectively). At three of five sites, cesium concentrations were higher in piscivorous (e.g., largemouth bass) than in nonpiscivorous species.

Elevated external gamma dose rates are associated with the radioactive contamination in the irrigated fields and along streams receiving effluents from the plant. Gamma dose rates up to 38 μR/h at 1 m from the ground were measured along Clay Creek, and the maximum gamma dose rate measured in irrigated fields at 1 m was about 14 μR/h.

Table 12 gives doses estimated for an individual who might be exposed to the currently available pathways. This estimate also serves to indicate the relative importance of the dose from ingestion of fish. Specific pathways of exposure and usage factors were not precisely known for this analysis of current and potential use of contaminated water and

Table 12. Potential radiation doses to an individual from Rancho Seco liquid effluents[a]

Source	Dose (millirem per unit exposure)	
	Toatal body	Liver
Internal		
Consumption of fish (per kg)[b]	1.1	1.6
Consumption of frogs (per kg)[c]	1.1	1.6
Consumption of gamebirds (per kg)	0.02	0.03
Consumption of beef (per kg)[d]	0.001	0.002
Inhalation of resuspended material[e]	0.03	0.05
Inhalation of vegetation fire[f]	0.01	0.02
External		
Contaminated ground[g]	-0.83	0.83
Swimming[g]	0.002	0.002

[a]These doses cannot be added together without considering actual consumption or exposure data.

[b]Average dose for three most contaminated areas.

[c]Assumes frog flesh is as contaminated as fish flesh.

[d]Dose based on measured sample.

[e]100 h/year cultivation.

[f]Duration of fire is 30 min.

[g]100 h/year.

soil around Rancho Seco. However, it seems reasonable to assume that unless some individual is eating 14 to 18 kg of fish per year caught in the sump, Clay Creek, or Hadselville Creek at Clay Station Road, a 25-mrem/year dose limit [USEPA (1977)] is not reached by any individual around Rancho Seco.

No attempt has been made in this study to estimate annual doses associated with each year of release. Rather, this study gives estimates of dose associated with current environmental levels of contamination and potential pathways of exposure. Assuming no further liquid radionuclide releases from the RSNPP, future maximum individual doses should be no greater than those estimated here because of radiological decay and additional dispersion of contamination in the environment.

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APPENDIX A

CONCENTRATIONS OF RADIONUCLIDES IN
ENVIRONMENTAL SAMPLES

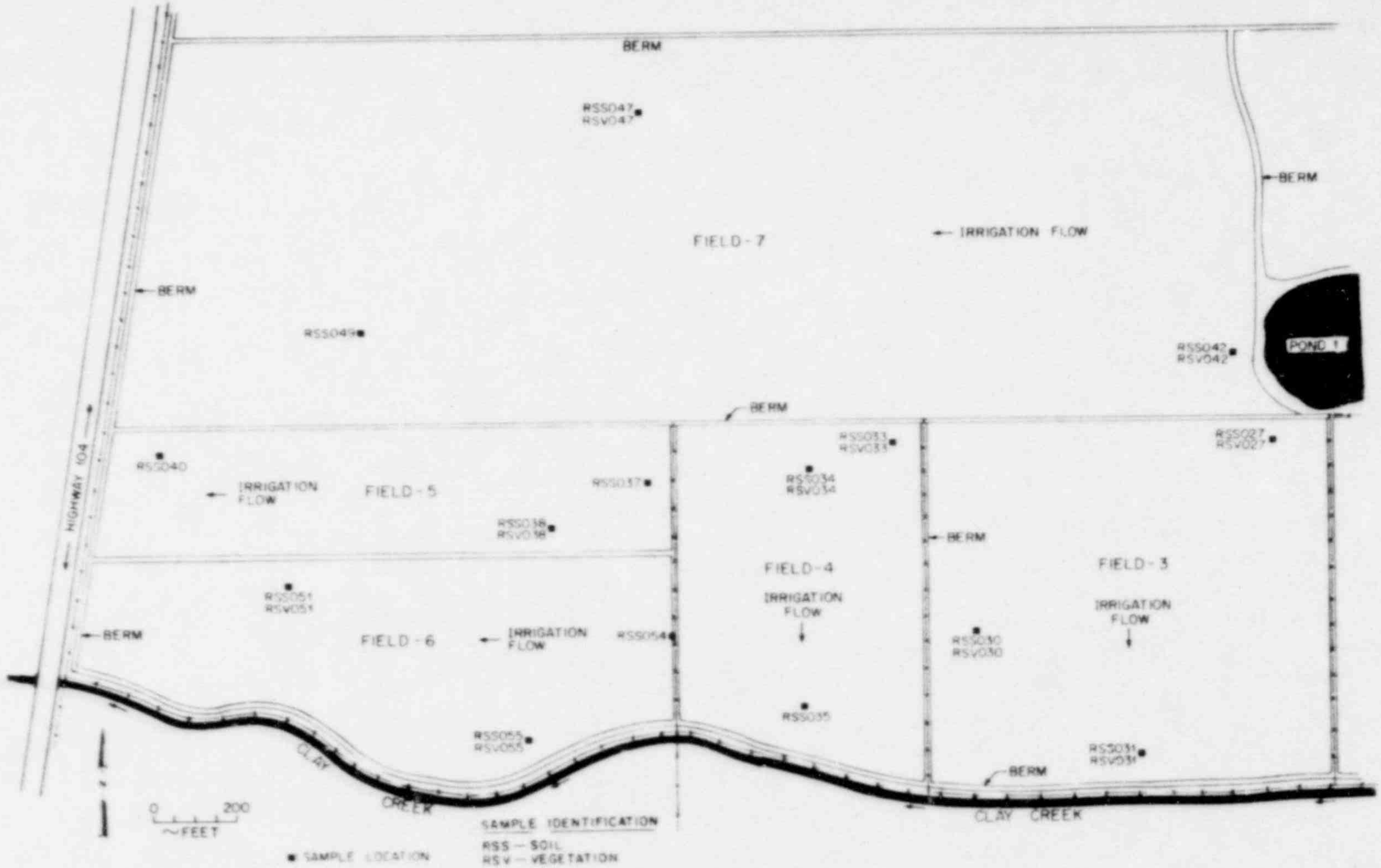

Fig. A-1. California background sampling locations

Table A-1. Concentrations of radionuclides in California background soil samples

Sample number[c]	Concentration[a,b] of radionuclide (pCi/g, dry weight)								
	^{137}Cs	^{134}Cs	^{60}Co	^{58}Co	^{54}Mn	^{226}Ra	^{238}U[d]	^{232}Th	^{40}K
CA4	0.79 ± 0.19	<0.1	<0.11	<0.13	<0.09	1.4 ± 0.21	1.07	1.5 ± 0.63	27 ± 2.6
CA5	1.3 ± 0.12	0.07 ± 0.08	<0.07	<0.08	<0.06	1.1 ± 0.17	1.13	1.2 ± 0.59	19 ± 1.6
CA6	0.02 ± 0.04	0.03 ± 0.04	<0.03	<0.04	<0.03	0.98 ± 0.13	0.92	1.0 ± 0.33	17 ± 0.86
CA7	0.61 ± 0.08	0.06 ± 0.08	<0.05	<0.05	<0.04	1.1 ± 0.22	1.28	1.5 ± 0.59	2.1 ± 0.69
CA8	0.33 ± 0.09	<0.05	<0.06	<0.07	<0.05	0.73 ± 0.14	0.77	0.63 ± 0.21	12 ± 1.5
CA9	0.23 ± 0.05	0.05 ± 0.09	<0.03	<0.04	<0.03	0.55 ± 0.11	0.49	0.46 ± 0.19	9.7 ± 0.67
CA10	0.26 ± 0.99	<0.06	<0.06	<0.08	<0.05	0.55 ± 0.09	0.46	0.47 ± 0.39	9.5 ± 1.2
CA11	0.07 ± 0.05	0.03 ± 0.03	<0.03	<0.04	<0.03	0.78 ± 0.13	0.68	0.74 ± 0.17	13 ± 0.76
CA12	0.89 ± 0.15	<0.03	<0.04	<0.04	<0.03	0.89 ± 0.15	0.73	1.13 ± 0.40	23 ± 0.94
CA13	0.11 ± 0.05	0.07 ± 0.12	<0.03	<0.04	<0.03	1.16 ± 0.13	0.56	0.82 ± 0.29	14 ± 0.82
CA14	0.29 ± 0.09	<0.06	<0.06	<0.07	<0.05	0.65 ± 0.04	0.53	0.76 ± 0.46	23 ± 1.5
CA15	<0.04	<0.03	<0.04	<0.05	<0.03	0.40 ± 0.07	0.37	0.78 ± 0.37	35 ± 1.0

[a]Indicated counting error is at the 95% confidence level ($\pm 2\sigma$).
[b]Concentration values preceded by < are below the minimum detectable amounts (MDA).
[c]For location see Fig. A-1.
[d]Errors associated with ^{238}U concentrations are ± 5% (2σ).

Table A-2. Concentrations of radionuclides in soil samples

Sample number[c]	Depth (in.)	Concentration[a,b] of radionuclide (pCi/g, dry weight)								
		^{137}Cs	^{134}Cs	^{60}Co	^{58}Co	^{54}Mn	^{226}Ra	^{238}U	^{232}Th	^{40}K
Field 1										
RSS007	0–4	22 ± 0.36	7.3 ± 0.95	2.7 ± 0.21	<15	0.49 ± 0.11	<0.24	0.89 ± 15%	0.64 ± 0.20	8.3 ± 1.4
RSS008	0–4	33 ± 0.68	10.5 ± 1.4	8.4 ± 0.41	<0.17	1.3 ± 0.21	<0.41	1.15 ± 15%	0.54 ± 0.54	7.0 ± 1.9
RSS011A	0–2	45 ± 0.72	14 ± 0.94	7.4 ± 0.57	<0.15	1.07 ± 0.19	<0.41	–	<0.68	8.5 ± 1.8
RSS011B	2–4	6.6 ± 0.15	1.4 ± 0.12	1.4 ± 0.12	<0.06	0.22 ± 0.06	0.67 ± 0.16	–	0.75 ± 0.63	7.5 ± 0.91
RSS011C	4–6	0.5 ± 0.07	0.13 ± 0.05	0.09 ± 0.006	<0.05	<0.03	0.71 ± 0.10	–	0.75 ± 0.33	6.8 ± 0.79
RSS011D	6–8	0.18 ± 0.04	0.06 ± 0.04	0.02 ± 0.012	<0.03	<0.02	0.76 ± 0.03	–	0.72 ± 0.24	7.5 ± 0.55
RSS011E	8–12	0.13 ± 0.04	<0.02	<0.03	<0.03	<0.02	0.87 ± 0.06	–	0.76 ± 0.22	7.9 ± 0.61
RSS012A	0–2	59 ± 0.43	20 ± 2.0	7.6 ± 0.24	<0.09	1.2 ± 0.11	0.84 ± 0.21	–	0.74 ± 0.24	7.4 ± 0.91
RSS013A	0–2	8.3 ± 0.22	3.4 ± 0.36	0.68 ± 0.02	<1.95	0.13 ± 0.15	0.50 ± 0.17	–	0.62 ± 0.14	6.06 ± 1.01
RSS015A	0–4	0.31 ± 0.08	0.11 ± 0.08	0.04 ± 0.05	<0.05	<0.04	0.54 ± 0.11	–	0.67 ± 0.48	5.4 ± 0.79
RSS019A	0–3	0.27 ± 0.08	<0.04	0.09 ± 0.03	<0.05	<0.04	0.71 ± 0.15	–	0.52 ± 0.59	6.2 ± 0.89
Field 2										
RSS020A	0–2	46 ± 0.58	17 ± 1.3	5.5 ± 0.17	<0.13	0.98 ± 0.15	0.89 ± 0.13	–	0.76 ± 0.14	7.5 ± 1.5
RSS020B	2–4	10 ± 0.18	2.1 ± 0.21	2.7 ± 0.11	<0.07	0.38 ± 0.07	0.75 ± 0.34	–	0.88 ± 0.4	8.7 ± 0.94
RSS020C	4–6	4.3 ± 0.11	0.92 ± 0.13	0.95 ± 0.06	<0.05	0.13 ± 0.04	0.82 ± 0.08	–	0.80 ± 0.24	8.6 ± 0.73
RSS020D	6–8	1.3 ± 0.14	0.31 ± 0.04	0.20 ± 0.02	<0.06	0.04 ± 0.05	0.78 ± 0.43	–	0.74 ± 0.22	8.8 ± 1.2
RSS020E	8–10	0.73 ± 0.07	0.16 ± 0.11	0.09 ± 0.014	<0.04	<0.03	0.74 ± 0.08	–	0.61 ± 0.41	8.7 ± 0.92
RSS022A	0–2	2.1 ± 0.16	0.60 ± 0.15	0.13 ± 0.11	<0.08	<0.07	0.50 ± 0.05	–	0.44 ± 0.36	3.5 ± 1.4
RSS024A	0–2	0.83 ± 0.08	0.20 ± 0.07	<0.05	<0.05	<0.04	0.57 ± 0.10	–	0.66 ± 0.53	6.0 ± 0.80
Field 3										
RSS027A	0–2	17 ± 0.34	5.8 ± 0.58	1.6 ± 0.18	<0.08	0.27 ± 0.09	0.50 ± 0.11	–	0.41 ± 0.12	4.7 ± 1.12
RSS030A	0–2	0.57 ± 0.09	0.18 ± 0.14	<0.05	<0.05	<0.04	0.57 ± 0.12	–	0.80 ± 0.37	6.7 ± 0.90
RSS031A	0–3	0.09 ± 0.08	<0.05	<0.06	<0.06	<0.04	0.42 ± 0.07	–	0.58 ± 0.54	4.4 ± 0.97
Field 4										
RSS033A	0–2	28 ± 0.43	9.1 ± 0.72	3.2 ± 0.19	<0.11	0.39 ± 0.12	<0.28	–	0.84 ± 0.89	6.7 ± 1.52
RSS034A	0–3	2.5 ± 0.09	0.83 ± 0.10	0.11 ± 0.02	<0.04	0.02 ± 0.04	0.39 ± 0.18	–	0.51 ± 0.31	4.7 ± 0.72
RSS035A	0–2	0.35 ± 0.07	0.10 ± 0.06	<0.04	<0.04	<0.03	0.67 ± 0.08	–	0.55 ± 0.37	5.7 ± 0.72
Field 5										
RSS037A	0–2	12 ± 0.25	4.6 ± 0.49	0.5 ± 0.06	<0.05	0.09 ± 0.05	0.51 ± 0.09	–	0.58 ± 0.29	5.4 ± 0.85
RSS037B	2–4	0.24 ± 0.06	0.11 ± 0.02	<0.04	<0.04	<0.03	0.53 ± 0.14	–	0.72 ± 0.35	5.8 ± 0.70
RSS038A	0–2	0.81 ± 0.08	0.31 ± 0.03	0.02 ± 0.003	<0.04	<0.03	0.66 ± 0.098	–	0.83 ± 0.34	6.9 ± 0.75
RSS040A	0–2	0.06 ± 0.05	<0.04	<0.04	<0.04	<0.03	0.70 ± 0.08	–	0.64 ± 0.14	8.0 ± 0.90

Table A-2 (continued)

Sample number[c]	Depth (in.)	Concentration[a,b] of radionuclide (pCi/g, dry weight)								
		^{137}Cs	^{134}Cs	^{60}Co	^{58}Co	^{54}Mn	^{226}Ra	^{238}U	^{232}Th	^{40}K
Field 6										
RSS051A	0-2	0.04 ± 0.03	<0.02	<0.02	<0.02	<0.02	0.47 ± 0.03	-	0.52 ± 0.16	5.8 ± 0.47
RSS054A	0-2	20 ± 0.41	7.9 ± 0.82	1.4 ± 0.008	<0.10	0.21 ± 0.11	<0.3	-	0.79 ± 0.44	6.4 ± 1.53
RSS054B	2-4	0.82 ± 0.07	0.31 ± 0.06	0.07 ± 0.04	<0.03	0.02 ± 0.03	0.69 ± 0.10	-	0.74 ± 0.23	6.5 ± 0.62
RSS054C	4-6	0.34 ± 0.06	0.13 ± 0.06	<0.03	<0.03	<0.03	0.67 ± 0.07	-	0.75 ± 0.25	6.6 ± 0.63
RSS055A	0-2	0.42 ± 0.07	0.13 ± 0.06	<0.04	<0.04	<0.03	0.57 ± 0.14	-	0.48 ± 0.21	6.1 ± 0.80
Field 7										
RSS042A	0-2	10 ± 0.43	4.1 ± 0.12	0.43 ± 0.07	<0.14	<0.13	0.57 ± 0.23	-	0.58 ± 0.55	7.8 ± 2.6
RSS047A	0-2	0.08 ± 0.04	<0.03	<0.03	<0.03	<0.02	0.46 ± 0.05	-	0.44 ± 0.29	6.3 ± 0.58
RSS049A	0-2	0.08 ± 0.05	<0.03	<0.04	<0.04	<0.03	0.54 ± 0.10	-	0.48 ± 0.17	6.4 ± 0.85
Field 8										
RSS002	0-4	33 ± 0.84	13 ± 0.91	6.0 ± 0.03	1.4 ± 0.32	0.64 ± 0.27	<0.64	0.69 ± 15%	<0.78	7.3 ± 2.6
RSS003	0-4	1.2 ± 0.10	0.36 ± 0.07	0.05 ± 0.004	<0.04	<0.04	0.53 ± 0.04	0.52 ± 15%	0.52 ± 0.15	5.4 ± 0.90
RSS004	0-4	0.27 ± 0.06	<0.04	<0.04	<8.6	<0.03	0.53 ± 0.12	0.41 ± 15%	0.48 ± 0.28	5.8 ± 0.76
RSS005	0-4	0.23 ± 0.08	<0.04	<0.04	<9.3	<0.04	0.50 ± 0.05	0.51 ± 15%	0.51 ± 0.20	5.5 ± 0.72
RSS010	0-4	30 ± 0.54	12 ± 0.91	4.0 ± 0.13	1.6 ± 0.15	0.46 ± 0.11	<0.29	0.61 ± 15%	0.52 ± 0.49	5.3 ± 2.8
RSS056A	0-2	<0.04	0.02 ± 0.03	<0.03	<0.03	<0.02	0.59 ± 0.09	-	0.58 ± 0.17	6.06 ± 0.6
RSS059A	0-2	0.05 ± 0.04	0.03 ± 0.03	<0.03	<0.03	<0.02	0.64 ± 0.07	-	0.62 ± 0.23	7.1 ± 0.63
Field 9										
RSS006	0-4	12 ± 0.41	4.9 ± 0.68	1.4 ± 0.05	<16	0.22 ± 0.12	0.45 ± 0.13	0.85 ± 15%	0.66 ± 0.30	5.5 ± 1.7
RSS061A	0-2	58 ± 0.87	23 ± 1.0	5.5 ± 0.00005	0.74 ± 0.21	1.2 ± 0.24	<0.6	-	<0.69	6.1 ± 1.72
RSS061B	2-4	21 ± 0.33	5.8 ± 0.57	6.8 ± 0.30	<0.095	0.93 ± 0.12	<0.22	-	0.66 ± 0.48	6.8 ± 1.2
RSS061C	4-6	9.3 ± 0.14	2.2 ± 0.25	3.5 ± 0.24	<0.04	0.41 ± 0.05	0.71 ± 0.08	-	0.63 ± 0.18	7.5 ± 0.56
RSS061D	6-8	3.7 ± 0.98	1.03 ± 0.14	1.09 ± 0.04	<0.05	0.14 ± 0.04	0.76 ± 0.14	-	0.63 ± 0.30	6.8 ± 0.62
RSS064A	0-2	1.1 ± 0.15	0.32 ± 0.04	<0.07	<0.07	<0.05	0.60 ± 0.19	-	0.64 ± 0.46	6.9 ± 1.23
RSS067A	0-3	0.26 ± 0.06	0.04 ± 0.04	<0.03	<0.40	<0.03	0.58 ± 0.09	-	0.46 ± 0.15	6.8 ± 0.69
Field 10										
RSS001	0-4	7.7 ± 0.20	1.7 ± 0.21	4.9 ± 0.25	<0.09	0.33 ± 0.09	0.70 ± 0.03	0.94 ± 15%	0.66 ± 0.88	9.0 ± 1.3
RSS068A	0-2	0.81 ± 0.09	0.09 ± 0.06	<0.05	<0.04	<0.04	0.73 ± 0.13	-	0.55 ± 0.32	10 ± 0.96
RS0069A	0-2	2.0 ± 0.16	0.42 ± 0.11	1.3 ± 0.14	<0.07	0.06 ± 0.08	0.80 ± 0.12	-	0.79 ± 0.24	13 ± 1.7
RSS070A	0-2	41 ± 0.56	16 ± 1.2	3.6 ± 0.10	<0.11	0.58 ± 0.13	<0.34	-	0.77 ± 0.18	8.0 ± 1.5

Table A-2 (continued)

Sample number[c]	Depth (in.)	Concentration[a,b] of radionuclide (pCi/g, dry weight)								
		^{137}Cs	^{134}Cs	^{60}Co	^{58}Co	^{54}Mn	^{226}Ra	^{238}U	^{232}Th	^{40}K
Field 11										
RSS072A	0-2	0.38 ± 0.05	0.06 ± 0.03	<0.03	<0.03	<0.02	0.79 ± 0.08	-	0.71 ± 0.23	15 ± 0.79
RSS073A	0-2	0.18 ± 0.07	<0.04	<0.05	<0.04	<0.04	0.90 ± 0.11	-	0.78 ± 0.32	14 ± 1.0
RSS075A	0-2	15 ± 0.39	5 ± 0.53	2.2 ± 0.30	<0.10	0.30 ± 0.10	0.98 ± 0.16	-	0.83 ± 0.20	13 ± 1.5
Field 14										
RSS078A	0-3	<0.06	<0.04	<0.05	<0.05	<0.04	1.02 ± 0.2	-	0.84 ± 0.43	8.6 ± 0.93
RSS079A	0-4	<0.71	<0.04	<0.04	<0.04	<0.03	0.48 ± 0.08	-	0.35 ± 0.13	4.7 ± 0.83

[a]Indicated counting error is at the 95% confidence level ($\pm 2\sigma$).

[b]Concentration values preceded by < are below the minimum detectable amount (MDA).

[c]For location see Figs. 2-6.

Table A-3. Concentrations of radionuclides in vegetation samples

Sample number[c]	Concentration[a,b] of radionuclide (pCi/kg, wet weight)												
	^{137}Cs	^{134}Cs	^{60}Co	^{58}Co	^{54}Mn	^{141}Ce	^{144}Ce	^{89}Sr	^{90}Sr	^{7}Be	^{40}K	^{110m}Ag	^{131}I
<u>Field 1</u>													
RSV007	5940 ± 270	2214 ± 135	72.9 ± 10.8	–	15.7 ± 5.4	<11	<54	<270	<270	2970 ± 270	1971 ± 189	–	<8.1
RSV008	3240 ± 270	1107 ± 81	51.3 ± 8.1	–	26 ± 5.4	<11	<54	<270	<270	2376 ± 189	2619 ± 189	–	<5.4
RSV011	2376 ± 162	1053 ± 81	40.5 ± 2.7	–	–	–	–	–	–	–	–	–	–
RSV012	1782 ± 108	675 ± 54	8.1 ± 0.81	–	–	–	–	–	–	–	–	–	–
RSV015	19 ± 1.9	<27	<27	–	–	–	–	–	–	–	–	–	–
RSV019	70 ± 5.4	<27	<27	–	–	–	–	–	–	–	–	–	–
<u>Field 2</u>													
RSV020	2295 ± 135	1188 ± 81	95 ± 5.4	–	–	–	–	–	–	–	–	–	–
RSV024	146 ± 8.1	594 ± 54	24 ± 2.43	–	–	–	–	–	–	–	–	–	–
<u>Field 3</u>													
RSV027	208 ± 13.5	116 ± 8.1	<27	–	–	–	–	–	–	–	–	–	–
RSV030	<27	<27	<27	–	–	–	–	–	–	–	–	–	–
RSV031	<27	<27	<27	–	–	–	–	–	–	–	–	–	–
<u>Field 4</u>													
RSV033	2079 ± 135	756 ± 54	40.5 ± 5.4	–	–	–	–	–	–	–	–	–	–
RSV034	251 ± 16.2	135 ± 8.1	<27	–	–	–	–	–	–	–	–	–	–
<u>Field 5</u>													
RSV038	165 ± 11	70 ± 5.4	<27	–	–	–	–	–	–	–	–	–	–
<u>Field 6</u>													
RSV051	<27	<27	<27	–	–	–	–	–	–	–	–	–	–
RSV055	<27	<27	<27	–	–	–	–	–	–	–	–	–	–
<u>Field 7</u>													
RSV042	1782 ± 162	702 ± 81	89 ± 46	–	–	–	–	–	–	–	–	–	–
RSV047	15 ± 14	<24	<27	–	–	–	–	–	–	–	–	–	–
<u>Field 8</u>													
RSV010	6480 ± 540	2457 ± 162	1107 ± 81	1215 ± 81	165 ± 19	<11	<54	<135	<135	2970 ± 270	3780 ± 270	270 ± 27	<14
RSV056	10 ± 9.7	<27	<27	–	–	–	–	–	–	–	–	–	–
RSV059	<27	<27	<27	–	–	–	–	–	–	–	–	–	–

Table A-3 (continued)

Sample number[c]	Concentration[a,b] of radionuclide (pCi/kg, wet weight)												
	^{137}Cs	^{134}Cs	^{60}Co	^{58}Co	^{54}Mn	^{141}Ce	^{144}Ce	^{89}Sr	^{90}Sr	^{7}Be	^{40}K	^{110m}Ag	^{131}I
Field 9													
RSV006	1458 ± 81	540 ± 27	75.6 ± 11	25 ± 6.5	–	<11	<54	<270	<270	3240 ± 270	5130 ± 270	10.5 ± 7.8	<5.4
RSV061	5670 ± 540	2187 ± 189	143 ± 59	–	92 ± 46	–	–	–	–	–	–	–	–
RSV067	<27	<27	<27	–	–	–	–	–	–	–	–	–	–
Field 11													
RSV075	2673 ± 216	2268 ± 81	54 ± 32.4	–	–	–	–	–	–	–	–	–	–
Field 14													
RSV001	3510 ± 270	1458 ± 108	324 ± 27	211 ± 24	84 ± 16.2	<11	<54	<270	<270	1809 ± 243	7560 ± 540	37.8 ± 18.9	<14

[a]Indicated counting error is at the 95% confidence level (± 2σ).

[b]Concentration values preceded by < are below the minimum detectable amount (MDA).

[c]For location see Figs. 2-6.

Table A-4. Concentrations of radionuclides in silt samples

Sample number[c]	Concentration[a,b] of radionuclide (pCi/g, dry weight)								
	^{137}Cs	^{134}Cs	^{60}Co	^{58}Co	^{54}Mn	^{226}Ra	^{238}U	^{232}Th	^{40}K
Clay Creek									
RSWS001	157 ± 1.7	65 ± 4.9	24 ± 2.2	16 ± 0.60	4.6 ± 0.48	<1.0	1.2 ± 1%	<1.3	7.0 ± 3.0
RSWS006	115 ± 1.62	45 ± 3.2	13 ± 1.7	3.4 ± 0.46	1.4 ± 0.37	<1.07	1.1 ± 1%	<1.09	8.3 ± 3.1
RSWS009[d]	54 ± 0.78	22 ± 1.6	2.9 ± 0.34	0.18 ± 0.11	0.6 ± 0.16	0.69 ± 0.4	–	0.98 ± 0.19	6.13 ± 1.43
RSWS010[d]	33 ± 0.51	12 ± 0.70	1.95 ± 0.11	<0.10	0.33 ± 0.11	1.01 ± 0.25	–	0.69 ± 0.39	6.01 ± 1.3
RSWS011[d]	57 ± 1.2	23 ± 1.8	1.9 ± 0.12	1.04 ± 0.36	0.83 ± 0.27	1.02 ± 0.26	–	0.92 ± 0.20	7.8 ± 2.8
RSWS012	86 ± 1.3	35 ± 2.7	15 ± 0.37	2.6 ± 0.32	1.44 ± 0.38	<0.99	–	<1.18	5.9 ± 2.4
Hadselville Creek									
RSWS004	58 ± 0.73	24 ± 1.9	3.3 ± 0.16	0.62 ± 0.12	0.48 ± 0.15	<0.48	0.53 ± 1%	0.86 ± 0.44	13 ± 1.6
RSWS005	97 ± 1.18	42 ± 2.4	10 ± 0.35	1.4 ± 0.38	1.0 ± 0.31	<0.83	1.24 ± 1%	0.78 ± 0.23	9.0 ± 2.5
RSWS034	0.45 ± 0.09	0.06 ± 0.06	<0.05	<0.05	<0.04	0.89 ± 0.07	–	0.84 ± 0.27	16 ± 1.3
Laguna Creek									
RSWS002	0.26 ± 0.06	0.15 ± 0.03	<0.04	<0.04	<0.03	0.67 ± 0.05	0.67 ± 1%	0.66 ± 0.18	8.9 ± 0.71
RSWS003	2.5 ± 0.08	0.99 ± 0.08	0.04 ± 0.02	<0.02	0.02 ± 0.03	0.55 ± 0.05	0.81 ± 1%	0.65 ± 0.27	12 ± 0.66
RSWS021	4.2 ± 0.11	1.64 ± 0.2	0.08 ± 0.03	<0.04	0.01 ± 0.04	0.54 ± 0.25	–	0.48 ± 0.33	11 ± 0.81
RSWS029	0.74 ± 0.07	0.32 ± 0.05	<0.04	<0.04	<0.03	0.64 ± 0.13	–	0.65 ± 0.29	9.8 ± 0.79
Sump									
RSWS013	16 ± 0.29	5.5 ± 0.38	4.0 ± 0.18	<0.08	0.22 ± 0.08	0.51 ± 0.05	–	0.42 ± 0.15	6.1 ± 0.93
RSWS014	78 ± 1.16	27 ± 2.0	12 ± 0.86	0.43 ± 0.23	0.74 ± 0.26	0.64 ± 0.39	–	0.89 ± 0.24	7.2 ± 1.8
RSWS015	73 ± 0.79	25 ± 2.4	12 ± 1.3	<0.18	0.74 ± 0.21	<0.64	–	<0.54	7.4 ± 1.8
Pond 1									
RSWS016	0.72 ± 0.05	0.19 ± 0.02	0.05 ± 0.01	<0.02	<0.02	0.57 ± 0.09	–	<0.69	7.6 ± 0.65
RSWS017	0.41 ± 0.05	0.07 ± 0.04	0.02 ± 0.02	<0.02	<0.02	0.57 ± 0.11	–	0.71 ± 0.28	6.5 ± 0.59
RSWS018	0.97 ± 0.09	0.18 ± 0.22	0.14 ± 0.04	<0.06	<0.04	0.72 ± 0.26	–	1.1 ± 0.41	6.7 ± 0.92
Pond 2									
RSWS022	4.26 ± 0.12	1.64 ± 0.13	0.35 ± 0.03	<0.07	<0.04	0.49 ± 0.33	–	0.64 ± 0.33	15 ± 0.96
RSWS023	10 ± 0.24	3.7 ± 0.59	1.2 ± 0.13	<0.09	0.13 ± 0.08	<0.19	–	1.0 ± 0.98	12 ± 1.4
RSWS024	3.7 ± 0.16	0.97 ± 0.16	0.42 ± 0.03	<0.06	0.04 ± 0.06	0.93 ± 10	–	0.91 ± 0.29	11 ± 1.3
Background									
RSWS035	<0.02	0.02 ± 0.02	<0.02	<0.02	<0.02	0.41 ± 0.08	–	0.38 ± 0.14	8 ± 0.47

[a]Indicated counting error is at the 95% confidence level (± 2σ).
[b]Concentration values preceded by < are below minimum detectable amounts (MDA).
[c]For location see Figs. 2, 3, 6, and 7.
[d]Overflow from Clay Creek into Field 14.

Table A-5. Concentrations of radionuclides in water samples

Sample number[c]	Concentration[a,b] of radionuclide (pCi/L)											
	^{137}Cs	^{134}Cs	^{60}Co	^{58}Co	^{141}Ce	^{144}Ce	^{89}Sr	^{90}Sr	^{3}H	^{14}C	^{131}I	Gross alpha
RSW001	<2.7	<1.9	<2.7	<2.7	<2.7	<2.7	<8.1	3 ± 4	70,200 ± 2,700	<810	<2.7	32.4 ± 57
RSW005	<2.2	<2.2	<2.7	<1.9	<2.7	<2.7	<5.4	1.6 ± 3.8	9,720 ± 1,350	<810	<2.7	16.2 ± 24

[a]Indicated counting error is at the 95% confidence level (± 2σ).
[b]Values indicated are less than minimum detectable amounts (MDA).
[c]For location see Figs. 2, 6, and 7.

Table A-6. Concentration of radionuclides in axial muscle of fish collected at various sites downstream of the Rancho Seco Nuclear Power Plant, December 1984

Site	Species	Sex[a]	Total length (cm)	Standard length (cm)	Weight (g)	Concentration (pCi/g, wet wt) ^{137}Cs	^{134}Cs	^{60}Co
Clay Creek	Green sunfish (*Lepomis cyanellus*)	M	17.4	14.8	101.1[b]	12.02	5.66	0.48
		U	16.8	14.2	89.7[b]	9.17	4.20	0.59
		F	15.2	12.8	66.3[b]	8.89	4.48	<0.06
	Largemouth bass (*Micropterus salmoides*)	ND	27.5	22.9	384.2	8.17	3.28	0.54
		ND	25.1	20.5	283.4	10.70	4.84	0.34
		ND	17.4	14.3	69.4	8.02	4.10	0.38
	Black bullhead (*Ictalurus melas*)	U	32.7	28.3	464.1[c]	6.33	2.50	0.79
		U	17.8	14.8	64.4[c]	7.53	3.81	0.23
		U	17.0	14.5	60.5[c]	7.63	4.48	<0.07
Hadselville Creek	Green sunfish	M	18.5	16.1	129.2[b]	10.48	4.60	0.41
		F	15.8	13.4	75.8[b]	3.87	2.54	<0.06
		M	14.1	13.4	75.8[b]	5.38	2.26	0.40
	Black bullhead	U	28.0	23.6	266.8[c]	9.80	3.97	0.55
		U	26.8	23.2	253.3[c]	10.40	5.15	0.38
		U	23.0	19.8	156.3[c]	7.43	4.10	0.40
Laguna Creek at Laguna Rd	Green sunfish	M	14.9	12.5	71.3	0.81	0.66	<0.05
		M	15.0	12.3	69.4	0.84	0.12	0.48
		F	12.3	10.2	38.2	0.36	0.06	0.30
	Black crappie (*Pomoxis nigromaculatus*)	F	21.9	17.5	163.0	1.46	0.70	0.35
		M	19.5	15.4	115.2	1.28	0.71	<0.04
		F	14.5	11.1	40.3	2.00	0.92	0.06

Table A-6 (continued)

Site	Species	Sex[a]	Total length (cm)	Standard length (cm)	Weight (g)	Concentration (pCi/g, wet wt)		
						^{137}Cs	^{134}Cs	^{60}Co
	Black bullhead	U	15.7	13.4	50.8	0.09	<0.05	0.23
Dry Creek (control)	Green sunfish	M	16.3	13.9	85.4[d]	<0.06	0.27	0.05
		M	15.2	12.4	62.1[d]	<0.05	0.05	0.60
		M		12.3	60.6[d]	0.05	0.05	0.66

[a]F = female; M = male; U = unknown; ND = not determined.

[b]Estimated by: $\log_{10}W$ (fish weight in g) = −1.3953 + 2.9055 $\log_{10}L$ (standard length in cm), r^2 = 1.00 and n = 26.

[c]Estimated by: $\log_{10}W$ (fish weight in g) = −1.7577 + 3.0475 $\log_{10}L$ (standard length in cm), r^2 = 0.99 and n = 20.

[d]Estimated by: $\log_{10}W$ (fish weight in g) = −1.4208 + 2.9390 $\log_{10}L$ (standard length in cm), r^2 = 1.00 and n = 8.

Table A-7. Concentration of radionuclides in axial muscle of fish collected from three small ponds near the Rancho Seco Nuclear Power Plant

Site	Species	Sex[a]	Total length (cm)	Standard length (cm)	Weight (g)	Concentration (pCi/g, wet wt) ^{137}Cs	^{134}Cs	^{60}Co
Sump	Bluegill	F	15.0[b]	12.5	70.7	11.10	5.77	<0.05
	(*Lepomis*	M	16.2[b]	13.1	83.8	6.50	2.96	0.08
	macrochirus)	U	16.2[b]	13.2	89.2	5.76	3.09	<0.04
		F	16.7[b]	13.1	76.9	6.85	3.07	<0.05
		U	18.4[b]	14.6	148.6	5.72	2.55	<0.04
		F	18.5[b]	15.0	130.9	6.02	2.90	<0.04
		F	21.1[b]	16.8	192.7	4.87	2.40	<0.05
		M	14.4	11.6	61.8[c]	3.94	1.51	0.59
	Largemouth	M	39.0	33.5	1,120.0[d]	14.42	7.19	0.40
	bass	F	33.4	27.2	583.6[d]	16.75	7.76	0.53
	(*Micropterus*	M	29.3	24.3	410.2[d]	14.44	6.14	0.57
	salmoides)							
	Black	M	27.9	23.6	266.8[e]	6.47	2.88	0.37
	bullhead	F	23.2[b]	19.5	146.8	8.87	4.33	<0.04
	(*Ictalurus*	U	20.0	17.2	101.8[e]	3.54	1.91	0.14
	melas)							
Pond 1	Bluegill	F	21.0	16.6	176.9	0.26	<0.05	0.61
		F	18.7	14.5	143.0	0.14	<0.05	0.52
		F	17.5	13.5	91.6	0.66	<0.06	0.66
	Largemouth	F	38.8	31.2	886.9	0.24	0.06	<0.03
	bass	F	36.2	30.0	687.1	0.13	0.10	0.19
		M	35.8	29.5	785.3	0.13	<0.03	0.40
Pond 2	Green	U	11.5	9.5	34.1	<0.06	0.32	0.11
	sunfish	U	10.8	8.8	28.7	0.21	<0.07	0.21
	(*Lepomis*	U	9.6	7.8	18.9	0.81	<0.11	0.61
	cyanellus)							

Table A-7 (continued)

Site	Species	Sex[a]	Total length (cm)	Standard length (cm)	Weight (g)	Concentration (pCi/g, wet wt)		
						^{137}Cs	^{134}Cs	^{60}Co
	Largemouth bass	M	33.0	27.8	754.6	4.48	1.90	0.27
		F	25.7	21.2	263.8	3.52	1.76	0.14
		M	25.5	21.2	264.6	1.48	0.34	0.31
	Black bullhead	U	22.5	19.0	162.2	0.78	<0.06	0.55
		U	18.6	15.8	92.9	0.71	0.06	0.58
		U	14.1	11.9	35.1	1.25	1.11	0.34

[a]F = female; M = male; U = unknown.

[b]Fish collected on November 14, 1984; all other fish were collected on December 10-12, 1984.

[c]Estimated by: $\log_{10}W$ (fish weight in g) = −1.4773 + 3.0704 $\log_{10}L$ (standard length in cm), r^2 = 1.00 and n = 21.

[d]Estimated by: $\log_{10}W$ (fish weight in g) = −1.7219 + 3.1285 $\log_{10}L$ (standard length in cm), r^2 = 1.00 and n = 17.

[e]Estimated by: $\log_{10}W$ (fish weight in g) = −1.7577 + 3.0475 $\log_{10}L$ (standard length in cm), r^2 = 1.00 and n = 20.

Table A-8. Concentration of radionuclides in axial muscle of frogs from two sites near the Rancho Seco Nuclear Power Plant, December 1984

Site	Species[a]	Weight (g)	Concentration (pCi/g, fresh wt)		
			^{137}Cs	^{134}Cs	^{60}Co
Pond 1	bullfrog (<u>Rana catesbeiana</u>)	292.8	0.06	<0.04	0.25
Laguna Creek near McKenzie Road	ND	98.7	<0.06	0.11	0.27
	ND	37.3	0.23	<0.08	0.31

[a]ND = not determined.

Table A-9. Concentration of radionuclides in axial muscle of game birds collected at several sites near the Rancho Seco Nuclear Power Plant, December 9 and 13, 1984

Species	Sex[a]	Weight (g)	Collection site	Concentration (pCi/g, wet wt)		
				^{137}Cs	^{134}Cs	^{60}Co
American coot (*Fulica americana*)	ND	539	Sump	<0.08	0.08	1.21
American coot	ND	588	Pond 1	<0.07	0.27	0.14
Wilson's snipe (*Capella delicata*)	ND	1017	Clay Creek near SMUD boundary	<0.07	0.13	0.33
American bitttern[b] (*Botaurus lentiginosus*)	ND	630	Clay Creek west of Rte 104	0.95	0.42	0.42
Pheasant (*Phasianus colchicus*)	M	1010	Field just north of Clay Creek and west of Rte 104	0.31	<0.07	0.68
Pheasant	M	967	Field just south of Clay Creek and east of Rte 104	0.21	<0.06	0.21

[a]M = male; ND = not determined.

[b]Not a game bird; species was collected because its diet, although varied, consists of small fish (Bent 1926).

APPENDIX B

QUALITY CONTROL PROCEDURES

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The radiological survey and analyses of environmental samples from the Rancho Seco Nuclear Power Plant environs was carried out within the general guidelines of Oak Ridge National Laboratory Quality Assurance Procedures.

The radiochemical analyses of environmental samples performed by the Analytical Chemistry Division were carried out within the controls provided by the division's Quality Assurance Program (copy attached). In accordance with this program, the analytical laboratories within the division submit quarterly quality-control reports to the division Quality Control Coordinator. The Rancho Seco environmental samples were analyzed by the low-level analytical laboratory of the Analytical Chemistry Division. The control results from this laboratory for the fourth quarter of 1984, covering the time in which Rancho Seco samples were analyzed, is attached.

Portable instruments used in the field to measure gamma radiation levels are calibrated at six-week intevals in the calibration facility of the Environmental and Occupational Safety Division of Oak Ridge National Laboratory. The sources used are National Bureau of Standards (NBS) or are traceable to NBS standards. In addition, each portable instrument is checked in the field daily for proper operation using uranium check sources.

High resolution gamma spectrometry instruments (GeLi) used by the Radiological Survey Activities (RASA) group of the Health and Safety Research Division (HASRD) to assay environmental samples are calibrated routinely using NBS traceable sources. In addition, a number of samples are routinely submitted to other counting facilities within ORNL for independent assay. Table B-1 gives the results of a group of Rancho Seco samples that were analyzed by two independent counting facilities.

For the aquatic sampling program, the Environmental Sciences Division used a NaI(Tl) gamma spectrometry system. Duplicate samples were taken from eight of the 52 fish (15%) collected in December and submitted to the Analytical Chemistry Division also for analyses. All samples were analyzed for ^{137}Cs, ^{134}Cs, and ^{60}Co and scanned for other gamma ray-emmitting radionuclides by the Analytical Chemistry Division using a GeLi detector. Table B-2 gives the results of these two independent concentration measurements.

Table B-1. Comparison of gamma spectrometry results of soil sample analyses performed by two independent laboratories

Sample number	Concentration of radionuclide (pCi/g, dry weight)									
	^{137}Cs		^{134}Cs		^{60}Co		^{58}Co		^{54}Mn	
	RASA[a]	AC[b]	RASA[a]	AC[b]	RASA[a]	AC[b]	RASA[a]	AC[b]	RASA[a]	AC[b]
RSS001	7.7 ± 0.20	7.7	1.7 ± 0.21	1.7	4.9 ± 0.25	4.6	<0.09[c]	–	0.33 ± 0.09	0.37
RSS002[d]	33 ± 0.84	34	13 ± 0.91	12	6.0 ± 0.03	5.7	1.4 ± 0.32	0.37	0.64 ± 0.27	0.63
RSS006	12 ± 0.41	13	4.9 ± 0.65	4.5	1.4 ± 0.05	1.4	<16[c]	0.07	0.22 ± 0.12	0.24
RSS007	22 ± 0.36	22	7.3 ± 0.95	6.7	2.7 ± 0.21	2.5	<15[c]	–	0.49 ± 0.11	0.50
RSWS001[e]	155 ± 1.7	140	65 ± 4.9	57	29 ± 2.2	26	16 ± 0.60	14	4.6 ± 0.48	3.8
RSWS002	0.26 ± 0.06	0.26	0.15 ± 0.03	0.13	<0.04[c]	–	<0.04[c]	–	<0.03[c]	–
RSWS006[f]	115 ± 1.6	100	45 ± 3.2	40	13 ± 1.6	11	3.4 ± 0.46	3.2	1.4 ± 0.37	1.4

[a]Analyses performed in the Radiological Survey Activities (RASA) Group counting facility at Oak Ridge National Laboratory. Errors associated with these concentrations are 2σ (95% confidence level).

[b]Analyses performed by the Analytical Chemistry Division of Oak Ridge National Laboratory. The overall uncertainty in the concentrations of major constituents is ± 10% (2σ); the uncertainty of minor constituents is of the order of ± 25%.

[c]Concentrations are less than the minimum detectable amount (MDA).

[d]^{110m}Ag – 4.8 pCi/g.

[e]^{110m}Ag – 1.3 pCi/g.

[f]^{110m}Ag – 0.66 pCi/g.

Table B-2. Comparison of radionuclide concentrations in duplicate tissue samples analyzed by the Environmental Sciences Division, and in parentheses with 95% confidence interval, the Analytical Chemistry Division

Sample Number	Sample Description	Sample Location	Concentration (pCi/g)		
			^{137}Cs	^{134}Cs	^{60}Co
1	Coot	Sump	<0.08 (<0.19)	0.08 (<0.14)	1.21 (<0.16)
2	Pheasant	Hadselville Creek	0.21 (<0.11)	<0.06 (<0.11)	0.21 (<0.11)
3	Black bullhead	Laguna Cr. at Laguna Rd.	0.84 (0.92 ± 0.22)	0.35 (0.38 ± 0.16)	0.53 (<0.11)
4	Frog	Pond 1	0.06 (<0.08)	<0.04 (<0.05)	0.25 (<0.08)
5	Largemouth bass	Pond 1	0.24 (0.32)	0.06 (<0.08)	<0.03 (<0.11)
6	Largemouth bass	Sump	16.75 (17.82 ± 1.08)	7.76 (6.75 ± 0.54)	0.53 (<0.11)
7	Black bullhead	Clay Creek	6.33 (7.29 ± 0.54)	2.50 (2.56 ± 0.27)	0.79 (0.12 ± 0.10)
8	Green sunfish	Dry Creek	<0.06 (<0.08)	0.27 (<0.08)	0.05 (<0.08)

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OAK
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UNION
CARBIDE

QUALITY ASSURANCE PROGRAM

ANALYTICAL CHEMISTRY DIVISION

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Oak Ridge National Laboratory

QUALITY ASSURANCE PROGRAM

QUALITY ASSURANCE PROCEDURE	
PROCEDURE NO.	QA- ACD-1
DATE	8-1-83
PAGE	1 of 1
SUPERSEDES ISSUE DATED	

TITLE: ANALYTICAL CHEMISTRY DIVISION QUALITY ASSURANCE PROGRAM POLICY STATEMENT

In accordance with the Quality Assurance Program goals established by the Director of the Oak Ridge National Laboratory (ORNL), it is the policy of the Analytical Chemistry Division (ACD) to establish, maintain, and enforce an effective quality assurance program. This effort is designed to meet the requirements of the ORNL Quality Assurance Program and has been prepared to be consistent with the applicable parts of the following documents: DOE Order 5700.6, ANSI NQA-1, and the ORNL QA program.

The work of the Analytical Chemistry Division includes basic research, applied research, development and support activities. It is the policy of the Analytical Chemistry Division to maintain a quality assurance program that will aid in ensuring reliable results and in the efficient and safe operation of all facilities used by members of the division.

The Director of the Analytical Chemistry Division has responsibility for the execution of the Quality Assurance Program defined here. The ACD Quality Assurance Coordinator is responsible for preparation of this Quality Assurance Program Manual. The ACD managers are responsible for implementation of the Quality Assurance Program with assistance from the Quality Assurance Coordinator. All staff members are responsible for applying the appropriate quality assurance procedures in their work. Implementation of the Quality Assurance Program will be checked periodically by the Division Director through audits conducted by the Quality Assurance Coordinator.

Oak Ridge National Laboratory
operated by
Union Carbide Corporation
Nuclear Division

Approved By: W. D. Shults

OAK RIDGE NATIONAL LABORATORY QUALITY ASSURANCE PROGRAM	QUALITY ASSURANCE PROCEDURE
	PROCEDURE NO. QA-ACD-1
	DATE 8-1-83
	PAGE 1 OF 5
	SUPERSEDES ISSUE DATED

TITLE: ANALYTICAL CHEMISTRY DIVISION QUALITY ASSURANCE PROGRAM

1. Mission of the Division

The Analytical Chemistry Division (ACD) engages in research, development, and support activities in analytical chemistry science. The mission of the division is threefold: (1) to provide analytical expertise in support of Laboratory programs, (2) to conceptualize, develop, and carryout R/D programs that are analytical in nature, and (3) to provide high quality analytical chemistry support services.

2. Conduct of Division Activities

2.1 Research/Development Programs

The R/D programs in ACD are planned activities with stated objectives. The work is performed by a group of professional scientists and a small number of trained technicians under the direction of a group or task leader. The experiments progress stepwise so that failure at one point does not threaten the program. Controls fall into three areas: (1) peer review in either formal or informal meetings, (2) mandated quality assurance actions by the sponsoring agency, and (3) internal and external audits.

2.2 Support Programs

These programs encompass the more routine analytical measurements performed in support of Laboratory projects or work for others. The work is performed by professional scientists and trained technicians under the direction of a group or task leader. The tests performed are part of a larger program and as such do not constitute a large risk to failure. Controls fall into four areas: (1) quality control samples prepared by ACD to be similar to process samples, (2) standard reference materials prepared by recogized authorities such as the National Bureau of Standards and USDOE New Brunswick Laboratory, (3) controls prepared to simulate process material, and (4) internal and external audits.

OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE CORPORATION NUCLEAR DIVISION	Approved By: W. D. Shults

3. Responsibilities

3.1 The Division Director

3.1.1 Appoints a division Quality Assurance Coordinator (QAC).

3.1.2 Authorizes preparation of documents related to quality assurance when appropriate.

3.1.3 Implements QA procedures within the division.

3.1.4 Provides the division QAC information on new projects.

3.2 The Division Quality Assurance Coordinator

3.2.1 Coordinates and assists in the preparation of quality assurance related documents.

3.2.2 Arranges for review and approval of appropriate documents by the Division Director and the ORNL Quality Assurance Program Director.

3.2.3 Informs the Division Director of Quality Assurance activities within the division.

3.2.4 Maintains a file of ORNL and division QA procedures, ORNL Master Analytical Methods, Quality Assurance Assessments (QAA) and plans, quality failure and audit reports.

3.2.5 Reviews and approves division QA assessments and QA plans.

3.2.6 Performs internal audits and assists others in performing audits.

3.2.7 Interprets quality assurance procedures for the division.

3.2.8 Produces an annual report of QA actions.

3.3 Section Head

3.3.1 Implements QA procedures within the section.

3.3.2 Reviews and approves section QA plans.

3.3.3 Reviews Group/Task Leader actions to ensure that these responsibilities are discharged.

3.4 Group/Task Leader

3.4.1 Plans the R/D or support program for the group assisted by the scientists involved.

3.4.2 Prepares needed Quality Assurance Assessments, Plans, and Procedures for these programs.

3.4.3 Informs the QAC of any new programs, procedures, or equipment not covered by existing QAAs.

3.4.4 Bears responsibility for the quality assurance of the program.

3.4.5 Initiates a Quality Investigation Report (QIR) in the event of any significant failure occurring during operations.

4. Quality Assurance Education

Each employee of the Analytical Chemistry Division will be informed of the purpose, need, and scope of this Quality Assurance Program. Orientation sessions by the QAC will be provided to inform new employees of their roles in providing assurance of quality. The QAC will make periodic reports to ACD supervisory personnel on current QA procedures and directions. The division will comply with guidelines described in QA-L-1-102 and participate in activities such as QA week and video tape presentations.

TITLE: ANALYTICAL CHEMISTRY DIVISION QUALITY ASSURANCE PROGRAM

5. Implementation

5.1 This program is to be used as a supplement to the Laboratory's Quality Assurance Manual. No part of this document supersedes nor may be used as a substitute for those requirements given in UCC-ND SPP D-2-16, ORNL Supplement to D-2-16 and the ORNL Quality Assurance Manual.

5.2 A QA Assessment shall be completed for all projects to identify and evaluate the risk of potential significant quality problems (failure modes), and for each quality problem with an acceptable risk provide a rationale for the determination. For each potential quality problem with an unacceptable risk, define the planned preventative action(s) required to provide confidence that the problem is unlikely to occur or to minimize the consequences of the problem if it does occur, and to specify the responsibility and schedule for carrying out the preventative actions(s). ORNL QA procedure L-1-103 (Rev. 8), provides guidance in this evaluation.

5.3 For all programs and activities the Group/Task Leader will be responsible for application of the following elements in order to meet quality assurance requirements.

5.3.1 All ACD and ORNL quality related standard practice procedure and manuals shall be observed.

5.3.2 UCCND Standard Practice Procedure D-5-5 and ORNL QA procedure QA-L-3-100 (Rev. 3) shall be observed in recording research/development data and in document control.

5.3.3 All laboratory equipment and instruments shall be identified, calibrated periodically and appropriate records shall be maintained. ORNL QA-L-14-100 (Rev. 3) describes these requirements. Those instruments from which reportable data is obtained are of particular importance.

5.3.4 Results of research shall be published in ORNL documents, and in scientific journals, and presented at scientific meetings when appropriate.

5.3.5 Any significant changes in the program or activity shall be discussed with the QAC to determine whether additional quality assurance procedures should be implemented.

5.3.6 All significant quality problems shall be investigated, documented for management review and, when appropriate, corrective action taken. QA-L-6-101 (Rev. 3) describes these procedures and references the needed QA procedures for quality investigation reports, nonconforming items and others.

5.3.7 The retention and disposition of quality related records shall follow the procedures described in QA-L-16-100.

5.3.8 Purchase of standard and special items shall be accomplished in a manner to ensure adequate quality. QA-L-9-100 (Rev. 2) describes these procedures and references appropriate QA procedures for procurement, inspection, quality problems and others.

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NATIONAL
LABORATORY

MARTIN MARIETTA

Analytical Chemistry Division

General and Environmental Analysis Section

Quarterly Quality Control Report

October–December 1984

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

January 11, 1985

To: T. G. Scott, Low Level Radiochemical Analytical Laboratory

From: P. L. Howell, Quality Control Coordinator

Subject: Control Results for Fourth Quarter 1984

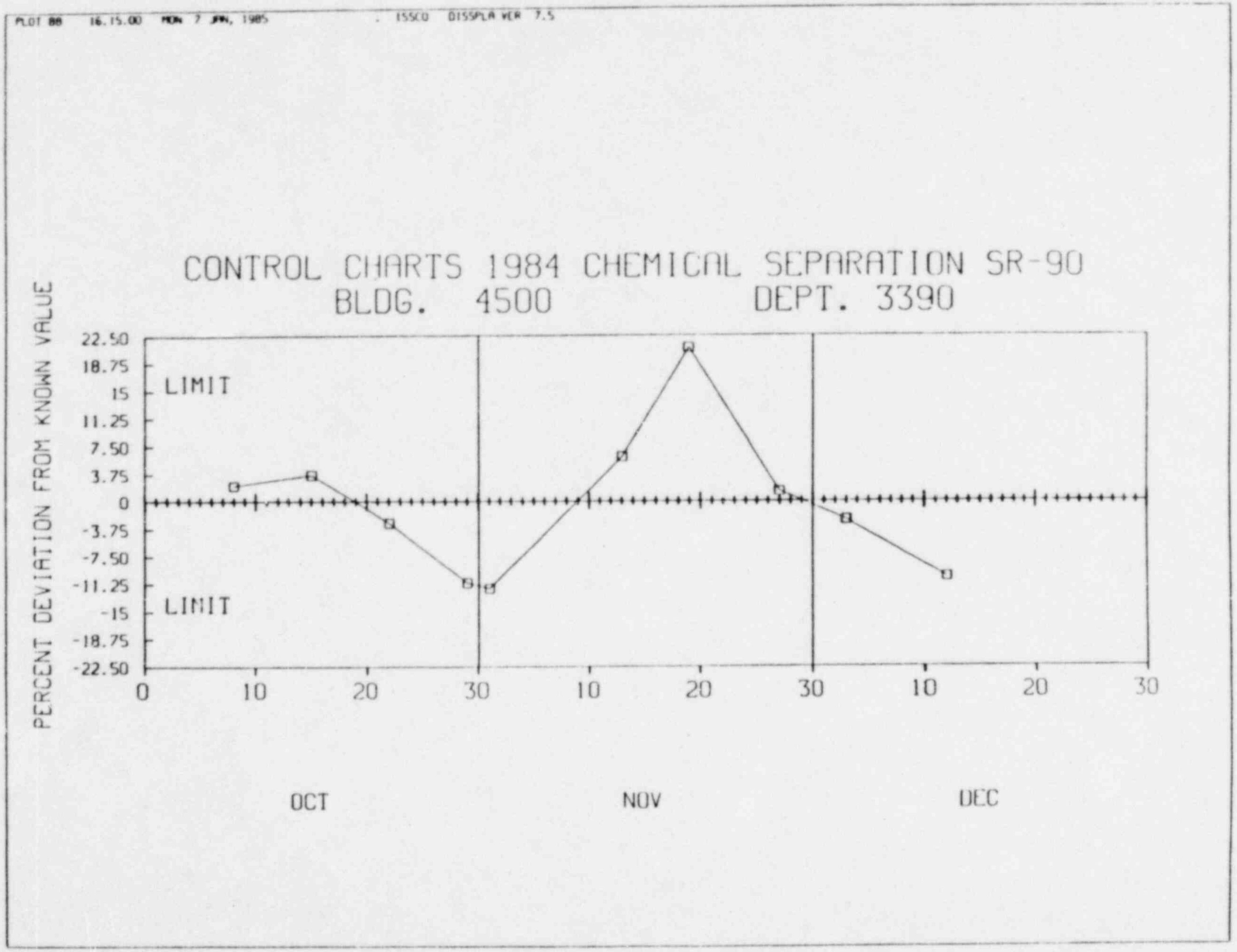
CONTROL RESULTS FOR 4TH QUARTER 1984 LAB:4500B

METHOD:DETER:CCODE	NUM OF TESTS	LIMIT OF ERROR	2S% FOUND	CALC 'T'	% BIAS	NUM. OUT CNTRL	BIAS SIGNIF
CHEM SEP:SR-90:RSRY5	11	+15.00	+18.885	-0.2180	-0.62	1	NO
G-SPEC:CO-60:RCC5:	14	+8.00	+3.176	+2.1528	+0.92	0	NO
G-SPEC:CS-137:RCC5:	12	+6.00	+1.407	+8.7183	+1.80	0	YES
LIQ SCINT:H-3:RTR1B:	3	+10.00	+0.036	+247.4358	+2.70	0	YES
	40					1	

$$\text{Quality level} = \frac{\text{No. results in control}}{\text{Total No. results}} \times 100$$

Quality level for the Low Level Radiochemical Analysis Laboratory for 4th quarter 1984 was 98%.

cc: W. R. Laing
D. A. Lee
R. K. Owenby
L. M. Roseberry
J. R. Stokely (2)



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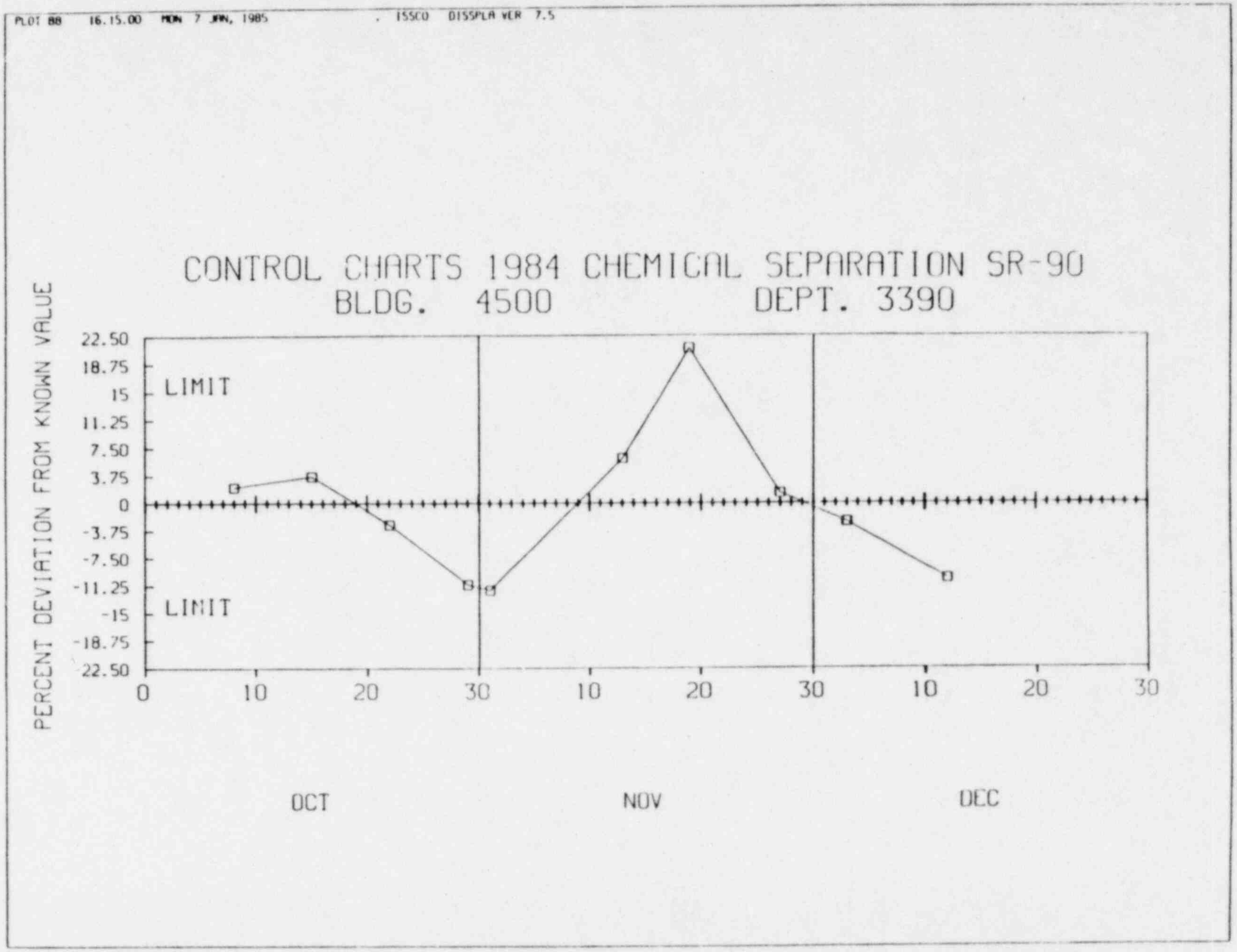
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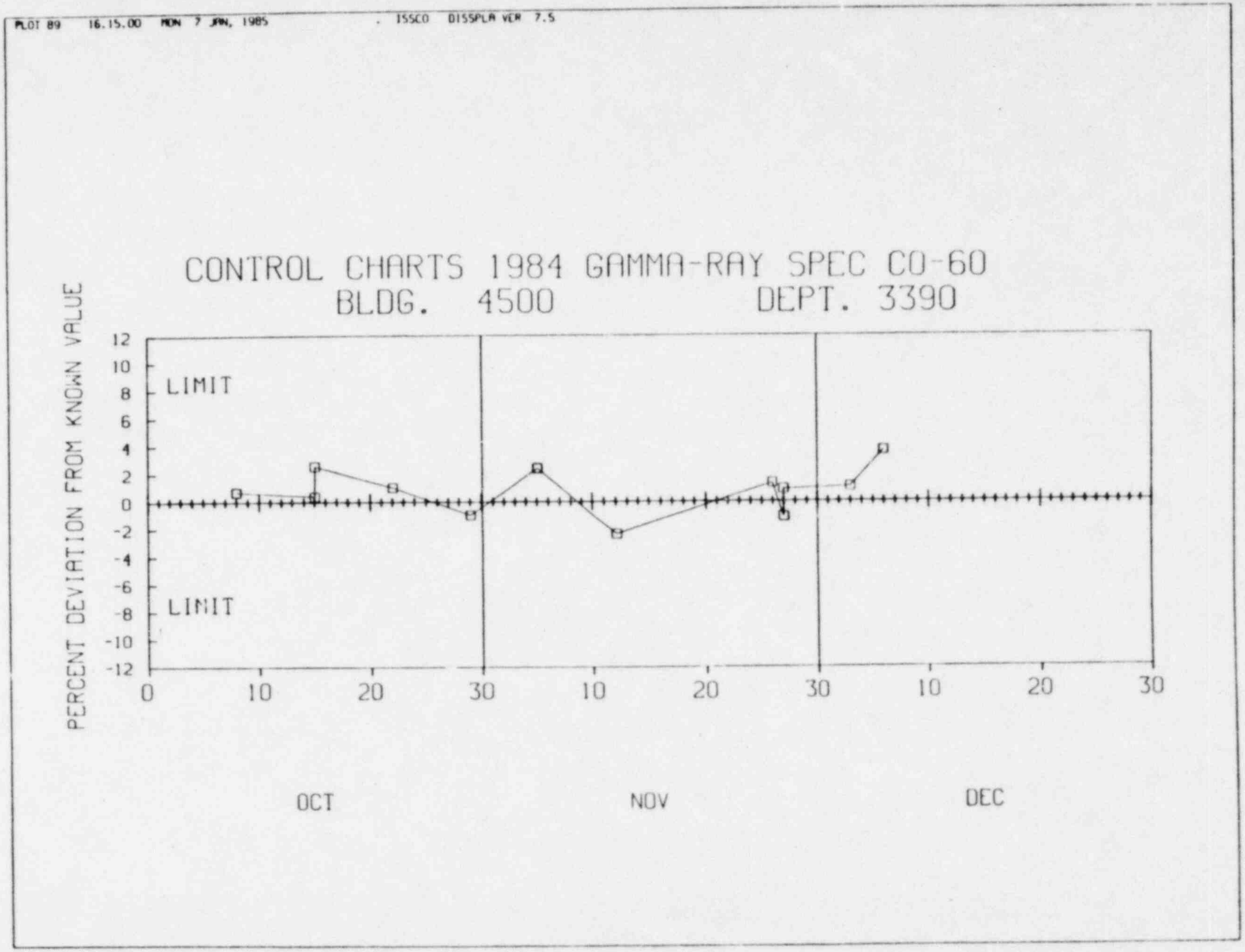
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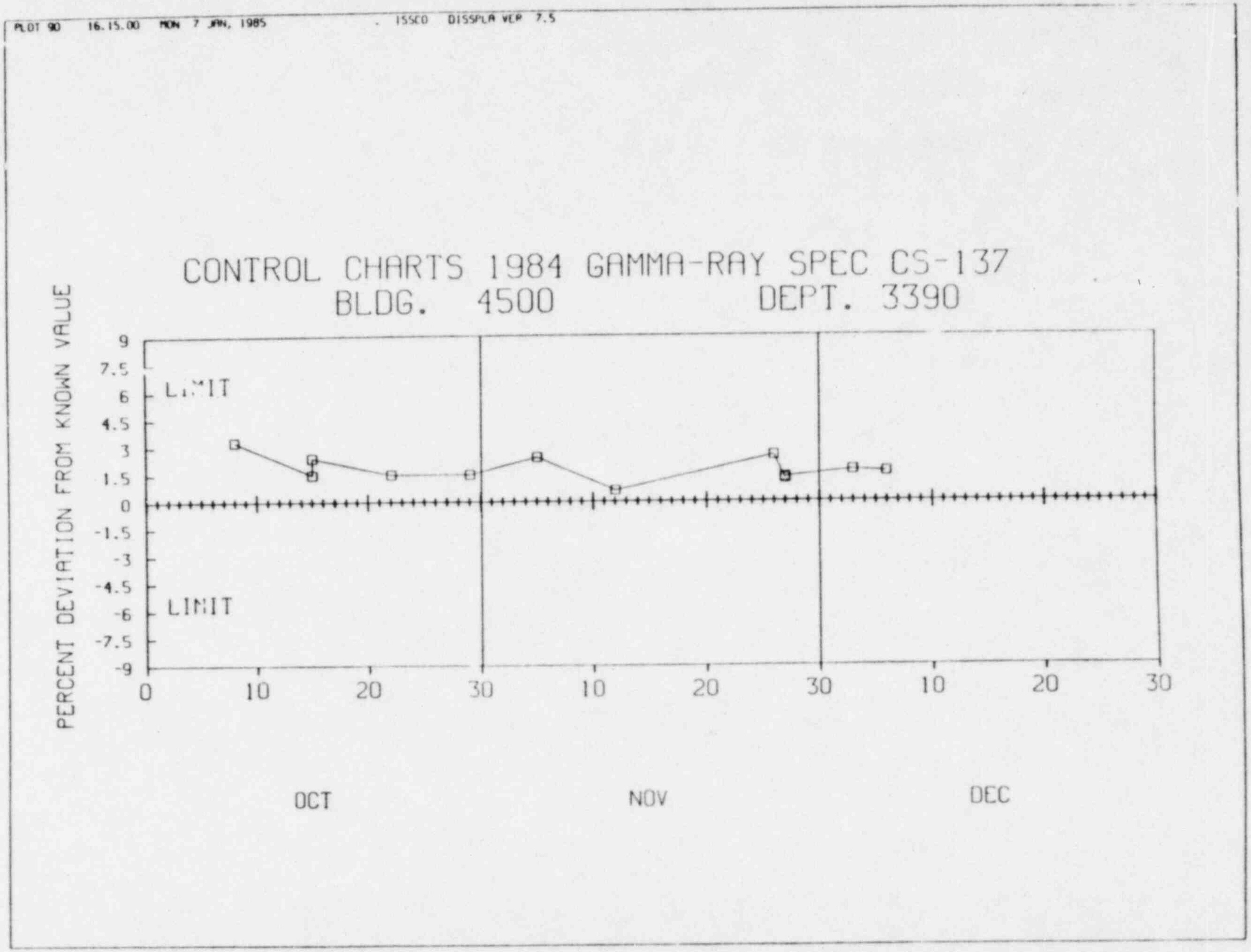
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APPENDIX C

RELEASE DATA

Table C-1. Liquid effluent releases (Ci) from the Rancho Seco Nuclear Power Plant [SMUD (1985)]

Nuclide	1980	1981	1982	1983	1984
^{3}H	1.47 E-02[a]	8.35 E+01	6.46 E+01	7.43 E+01	2.97 E+02
^{24}Na	0	0	1.40 E-04	4.15 E-04	5.95 E-04
^{51}Cr	0	0	6.71 E-03	0	–
^{54}Mn	0	4.22 E-02	1.05 E-02	5.13 E-03	2.45 E-03
^{59}Fe	0	3.92 E-04	2.32 E-03	0	0
^{57}Co	0	1.47 E-04	0	0	0
^{58}Co	0	3.04 E-01	1.26 E-01	3.22 E-02	1.13 E-02
^{60}Co	0	6.09 E-02	2.21 E-02	1.53 E-02	1.94 E-02
^{95}Zr	0	4.53 E-03	2.15 E-03	0	1.26 E-04
^{131}I	0	3.47 E-02	1.58 E-02	3.67 E-02	1.23 E-01
^{133}I	0	4.70 E-03	1.39 E-03	6.88 E-04	1.71 E-02
^{135}I	0	0	1.27 E-04	1.77 E-03	1.87 E-03
^{134}Cs	1.34 E-03	4.95 E-02	9.61 E-03	6.99 E-02	1.53 E-01
^{136}Cs	0	0	3.07 E-04	1.71 E-03	4.28 E-03
^{137}Cs	2.43 E-03	8.92 E-02	1.87 E-02	1.16 E-01	3.01 E-01
^{110m}Ag	0	6.34 E-04	1.25 E-05	0	1.45 E-03
^{140}Ba	0	1.36 E-02	1.26 E-04	0	0
^{90}Sr	0	0	0	1.08 E-03	0
^{133}Xe	0	0	3.81 E-04	0	3.39 E-02
^{135}Xe	0	0	1.62 E-04	0	4.97 E-03

[a] 1.47 E-02 = 1.47×10^{-2}

REFERENCE

Sacramento Municipal Utility District. 1985. Radiation Exposure, Environmental Protection Effluent and Waste Disposal, January-December 1984 Annual Report, Rancho Seco Nuclear Generating Station Unit No. 1, Clay Station, California, LIcense Number DPR-54.

Table C-1. Liquid effluent releases (Ci) from the Rancho Seco Nuclear Power Plant [SMUD (1985)]

Nuclide	1980	1981	1982	1983	1984
^{3}H	1.47 E-02[a]	8.35 E+01	6.46 E+01	7.43 E+01	2.97 E+02
^{24}Na	0	0	1.40 E-04	4.15 E-04	5.95 E-04
^{51}Cr	0	0	6.71 E-03	0	–
^{54}Mn	0	4.22 E-02	1.05 E-02	5.13 E-03	2.45 E-03
^{59}Fe	0	3.92 E-04	2.32 E-03	0	0
^{57}Co	0	1.47 E-04	0	0	0
^{58}Co	0	3.04 E-01	1.26 E-01	3.22 E-02	1.13 E-02
^{60}Co	0	6.09 E-02	2.21 E-02	1.53 E-02	1.94 E-02
^{95}Zr	0	4.53 E-03	2.15 E-03	0	1.26 E-04
^{131}I	0	3.47 E-02	1.58 E-02	3.67 E-02	1.23 E-01
^{133}I	0	4.70 E-03	1.39 E-03	6.88 E-04	1.71 E-02
^{135}I	0	0	1.27 E-04	1.77 E-03	1.87 E-03
^{134}Cs	1.34 E-03	4.95 E-02	9.61 E-03	6.99 E-02	1.53 E-01
^{136}Cs	0	0	3.07 E-04	1.71 E-03	4.28 E-03
^{137}Cs	2.43 E-03	8.92 E-02	1.87 E-02	1.16 E-01	3.01 E-01
^{110m}Ag	0	6.34 E-04	1.25 E-05	0	1.45 E-03
^{140}Ba	0	1.36 E-02	1.26 E-04	0	0
^{90}Sr	0	0	0	1.08 E-03	0
^{133}Xe	0	0	3.81 E-04	0	3.39 E-02
^{135}Xe	0	0	1.62 E-04	0	4.97 E-03

[a] 1.47 E-02 = 1.47×10^{-2}

REFERENCE

Sacramento Municipal Utility District. 1985. Radiation Exposure, Environmental Protection Effluent and Waste Disposal, January-December 1984 Annual Report, Rancho Seco Nuclear Generating Station Unit No. 1, Clay Station, California, LIcense Number DPR-54.

APPENDIX D

ADDITIONAL PARTICIPANTS IN THIS PROJECT

The authors of this report have been the Principal Investigators on this project. However, there were many other persons who made significant contributions to this project. Listed below are some of these additional persons and the area in which they contributed to this project.

Field Sample Collection

D. K. Cox - Environmental Sciences Division, ORNL

W. C. Kyker - Environmental Sciences Division, ORNL

J. L. Malone - Environmental and Occupational Safety Division, ORNL

B. Millar - Private Consultant, Colusa, California

J. A. Roberts - Health and Safety Research Division, ORNL

W. H. Shinpaugh - Health and Safety Research Division, ORNL

Sample Preparation and Analysis

A. C. Butler - Health and Safety Research Division, ORNL

B. S. Ellis - Health and Safety Research Division, ORNL

J. S. Eldridge - Analytical Chemistry Division, ORNL

J. F. Emery - Analytical Chemistry Division, ORNL

M. L. Frank - Environmental Sciences Division, ORNL

G. A. Moore - Operations Division, ORNL

S. W. Nichols - Environmental and Occupational Safety Division, ORNL

T. G. Scott - Analytical Chemistry Division, ORNL

This project could not have been brought to a timely and successful completion without the contributions of these persons.

APPENDIX E

RADIATION UNITS USED IN THIS REPORT

The radiation doses and exposures presented in this report are given in terms of older units rather than in terms of the International System of Units (SI). Given below is a table which contains the relations between the various radiation quantities in each system. This table is provided to assist the reader in converting from one set of units to the other.

Quantity	New SI unit and symbol	Basic SI dimensions	Old unit and symbol	Conversion
Exposure		coulomb per kilogram, $C\ kg^{-1}$	roetgen (R)	$1\ C\ kg^{-1} = 3.9 \times 10^3\ R$
Absorbed dose	Gray (Gy)	joules per kilogram, $J\ kg^{-1}$	rad(rad)	1 Gy = 100 rad
Dose equivalent	Sievert (Sv)	joules per kilogram, $J\ kg^{-1}$	rem (rem)	1 Sv = 100 rem
Activity	Becquerel	per second, (Bq) s^{-1}	curie (Ci)	$1\ Bq = 2.7 \times 10^{-11}\ Ci$

NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1. REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)
NUREG/CR-4286
ORNL/TM-6183

2. TITLE AND SUBTITLE
Evaluation of Radioactive Liquid Effluent Releases from the Rancho Seco Nuclear Power Plant

3. LEAVE BLANK

4. DATE REPORT COMPLETED
MONTH: December YEAR: 1985

5. AUTHOR(S)
C. W. Miller, W. D. Cottrell, J. M. Loar, J. P. Witherspoon

6. DATE REPORT ISSUED
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7. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
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Health and Safety Research Division
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8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER
A9468

10. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Pressurized Water Reactor Licensing-B
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a. TYPE OF REPORT
Technical

b. PERIOD COVERED (Inclusive dates)

12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

A project has been carried out by Oak Ridge National Laboratory (ORNL) to estimate the concentrations of radionuclides in the environment that have resulted from the release of radioactive materials in the liquid waste effluents from the Rancho Seco Nuclear Power Plant (RSNPP) and to estimate possible radiation doses to man resulting from current environmental concentrations. To carry out the objectives of this project, two visits were made to the RSNPP site by scientists from ORNL during November and December of 1984 to conduct an environmental sampling program around the site. Elevated levels of some radionuclides were found in the immediate environment of the plant. This radioactive contamination occurs primarily along streams receiving effluent from the plant and in fields irrigated with water from these streams. The primary contaminants are ^{137}Cs and ^{134}Cs with lesser amounts of ^{60}Co and ^{58}Co. Specific pathways of exposure and usage factors were not precisely known for the dose assessment of current and potential use of contaminated water and soil around the RSNPP. The ingestion of fish is the single most important pathway identified in this analysis.

14. DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS
nuclear power plant
pressurized water reactor
liquid wastes
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dose
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b. IDENTIFIERS/OPEN-ENDED TERMS

15. AVAILABILITY STATEMENT
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