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Trends in Radionuclide Concentrations in Hanford Reach Fish, 1982 through 1992

T. M. Poston

June 1994

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

Environmental monitoring has been conducted at the U.S. Department of Energy's Hanford Site in southeast Washington State since 1945. Fish from the Hanford Reach of the Columbia River, which borders the Site, are monitored annually. The two objectives of this report were 1) to evaluate trends in the concentrations of radionuclides [e.g., ^{90}Sr and ^{137}Cs] in two species of Columbia River fish [smallmouth bass and mountain whitefish] sampled from the Hanford Reach from 1982 through 1992; and 2) to determine the impact of Hanford Site releases on these two species and carp and fall chinook salmon collected during this time frame.

The evaluation found gradual reductions of ^{137}Cs in bass muscle and ^{90}Sr in bass and whitefish carcass from 1982 through 1992. Concentrations of ^{90}Sr in bass and whitefish followed the pattern established by reported Hanford Site releases from 1982 through 1992 and was supported by significnat regression analyses comparing annual releases to sample concnetration. Because data for carp have been collected only since 1990, the data base was inadequate for determining trends. Moreover, fall chinook salmon were only sampled once in this 11-year period.

The fish data were highly variable over the study period, a condition explained by the complex enviromental chemistry of the radionuclides and behavior of the fish. Concentrations of ^{90}Sr and ^{137}Cs in fish samples collected from distant background locations exceeded concentrations in Hanford Reach fish. Such an occurrence is possible because of temporal and spatial differences in atmospheric deposition of nuclear weapons testing fallout at the background locations. Fallout radionuclides may have actually increased exposure of fish to radionuclides at background locations compared to the Hanford Reach. Many other man-made gamma-emitting radionuclides were not observed at measurable concentrations, most notably ^{60}Co. Estimates of the dose from consumption of Hanford Reach fish were less than 0.001 times the National Council on Radiation Protection and Measurements and the U.S. Department of Energy guideline of 100 mrem/yr.

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The author wishes to express his appreciation to D. D. Dauble, D. J. Bates, R. W. Woodruff, R. E. Jaquish and W. L. Templeton for critical reviews of this report, and R. E. Lundgren and A. H. McMakin for editorial assistance. Fish samples were collected by numerous Radiation Protection Technologists over the study period. E. J. Antonio, A. Krupsha, A. T. Cooper, and C. K. Russell assisted with data retrieval and data file formatting.

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INTRODUCTION

The U.S. Department of Energy's (DOE) Hanford Site was established in 1943 in southeastern Washington State for nuclear materials production. Historically, operations at the Site have resulted in the release of radioactivity to the air, ground, and Columbia River. Releases to the ground have resulted in radionuclides like tritium (^{3}H), ^{90}Sr, ^{99}Tc, and ^{129}I, which can migrate with ground water, to be discharged to the Columbia River in seeps and springs (Dirkes 1990; McCormack and Carlile 1984). The discharge of radioactivity to the Columbia River results in the exposure of fish to radioactivity and potential accumulation of radioactivity in fish. Accumulation of radioactivity by fish from reactor effluents was an early concern of Hanford scientists and led to efforts (since 1945) by Site environmental scientists to monitor levels of radioactivity in fish (Denham et al. 1993) that continues today.

Environmental monitoring documents levels of radioactivity in many types of environmental media. Historically, environmental monitoring has included agricultural products, soil, vegetation, air, surface and ground water, wildlife, aquatic organisms, and fish, with the objective of identifying contaminant contributions from the Hanford Site. Monitoring information has been published in monthly, quarterly, and, since 1957, annual reports to summarize the environmental status of the Hanford Site. The most recent edition was published in July 1993 for the 1992 calendar year (Woodruff et al. 1993).

The recent emphasis and shift from nuclear materials production to environmental restoration at the Hanford Site have focused additional attention on environmental radioactivity around the Site. The data are used primarily to estimate the dose to the surrounding public and quantify Hanford Site impacts, e.g., monitoring data have been used extensively for dose estimates from the Hanford Site by the Hanford Environmental Reconstruction Project (HEDR) (Denham et al. 1993; Heeb and Bates 1994; Walters et al. 1992). Data are also used to assess concentrations and trends of radioactive contamination in environmental media , like fish, from the Hanford Reach of the Columbia River.

The objective of this report is to evaluate radionuclide concentrations in Columbia River fish [smallmouth bass (*Micropterus dolomieui*), carp (*Cyprinus carpio*), mountain whitefish (*Prosopium williamsoni*), and chinook salmon (*Oncorhynchus tshawytscha*)] collected from the Hanford Reach for the years 1982 through 1992. This evaluation addresses two basic issues. What were the trends of radionuclide concentrations in fish in the Hanford Reach, and how do they relate to reported releases of radionuclides to the river? The report specifically addresses ^{90}Sr and ^{137}Cs, as these radionuclides are the only two man-made radionuclides still found in Hanford Reach fish. The data collected during these years were examined for trends over time and relationships to releases of liquid effluents associated with Hanford operations.

The second issue is were concentrations of radionuclides in Hanford Reach fish different compared to background fish collected from areas designated as background locations? The same species of fish found in the Hanford Reach have recently been collected from locations distant, generally upwind, and upstream of the Hanford Site as representative of background concentrations of radioactivity. Results for these background samples are compared with those for samples collected along the Hanford Reach since 1988 or 1990 to measure whether Hanford operations are currently having any effect on radionuclide concentrations in fish. Evaluation of location effects is confounded by the presence of ^{90}Sr and ^{137}Cs fallout from historical weapons testing, which was performed on a global scale in the 1950s and early 1960s.

BACKGROUND

An understanding of the current state of radiological impacts on Hanford Reach fish can be attained by knowledge of past practices and discharges at the Hanford Site. This section provides a brief overview of past practices and how they have influenced exposure of Hanford Reach fish to Site effluents. More comprehensive discussions of past practices can be found in Denham et al. (1993); Heeb and Bates (1994); and Walters et al. (1992). This background discussion consists of three sections: sources and historical releases, releases from 1982 to 1992, and special fish sampling.

SOURCES AND HISTORICAL RELEASES

The largest radioactive releases from Hanford to the Columbia River occurred between 1944 and 1971 when as many as eight single-pass plutonium production reactors were operating. Single-pass reactor designs allow the cooling water to be exposed to a flux of neutrons as it passes through the reactor core. During passage, elements in the water or found on the reactor cooling pipes (scale, corrosion products) may absorb a neutron and transform into a radioactive isotope of the element. This process, called neutron activation, produced the majority of radioactivity discharged to the Columbia River because the cooling water was returned to the Columbia River either directly in the early years of the Site, or, in latter years, after a short detention time in retention basins. Most of the radionuclides produced in this manner had very short half-lives and decayed quickly to stable isotopes, hence the subsequent mitigative addition of retention basins to the effluent discharge systems.

The amount of released radioactivity varied over the years based on the number of reactors on-line, power level of the reactors, basin retention time, seasonal changes in the concentrations of elements in the Columbia River, chemicals used to pretreat cooling water, corrosion rates of reactor piping and fuel element cladding, the frequency of fuel element failures, and water flow of the Columbia River (Walters et al. 1992). Highest releases occurred from 1957 through 1965 when all eight single-pass plutonium production reactors were operating. Estimated releases for the period of 1944 to 1971 are about 41.6 million curies (Heeb and Bates 1994). Much of this released activity consisted of radionuclides with very short half-lives. Phosphorus-32 ($T_{1/2}$ = 14 days) and ^{65}Zn ($T_{1/2}$ = 245 days) were the radionuclides most prone to accumulate in fish flesh during this time. Since the retirement of the last single-pass reactor in 1971, the amount and distribution of discharged radionuclides have changed from predominantly activation products to fission products (Cushing et al. 1980).

N Reactor, which had a closed cooling system, started operation in 1963 and was officially retired in 1989. Radioactivity associated with N Reactor entered the river from contaminated seepage springs rather than direct discharge of single-pass cooling water.

RELEASES 1982 THROUGH 1992

In 1982, 373 curies (Ci) of activity were discharged to the Columbia River (Sula et al. 1983). The primary constituent was tritium (^{3}H; 360 Ci); and ^{60}Co, ^{90}Sr, and ^{137}Cs represented a release of less than 4 Ci combined. Currently, the largest quantities of radioactivity released at Hanford to the Columbia River are found in contaminated ground water associated with the 100 Areas along the Benton County shoreline of the Hanford Reach (Dirkes 1990; McCormack and Carlile 1984). Less than 1.2 Ci were released to the Columbia River in 1992. The releases consisted of about 86% tritium (as tritiated water),

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Tritium in water equilibrates rapidly with fish tissue (NCRP 1979); therefore, ^{3}H has not been monitored in fish tissue, and the concentrations in wet fish tissue would be approximately 90% of the levels reported in Columbia River water, assuming that tissue is 90% water.

Cobalt-60 generally accumulates in kidney, spleen, and liver and does not accumulate in bone or muscle of fish (Poston and Klopfer 1988). The only documented recent discharge of ^{60}Co to the Columbia River is the 100-N springs, and there the relative concentration compared to ^{90}Sr was small. Considering the dilution afforded by the Columbia River and ^{60}Co's relatively short half-life of 5.2 years, only low concentrations of ^{60}Co were infrequently found in fish muscle or carcass over the current study period.

Reported releases of ^{90}Sr and ^{137}Cs from 1982 through 1992 indicate maximum releases primarily from ground-water seeps in 1984 through 1986 compared to the preceding and following years (Figure 1). Monitored concentrations in water of ^{90}Sr upstream and downstream from the Hanford Site indicate only a slight potential for a Hanford impact (Dirkes 1994). In many of the years, there was no measured difference between samples from upstream and downstream locations. It was difficult to measure this difference because of elevated background concentrations in the Columbia River upstream of Hanford from historical radioactive fallout deposited in the Columbia River watershed as a result of atmospheric weapons testing.

FISH SAMPLING

Since 1945, fish have been a primary focus of Hanford Site monitoring efforts because of the direct discharges of liquid effluent to the Columbia River. In the mid-1950s, sampling efforts shifted from whole-body analysis of feral and sport fish to filets (muscle) of sport fish. A major effort was expended in the 1960s both to quantify levels of radioactivity in fish and to characterize the recreational sport fish harvest and consumption from the Hanford Reach and Lake Walulla (McNary Dam impoundment) immediately downstream of the Site (Soldat 1970). During the 1982-through-1992 time frame, special sampling was performed for salmon and sturgeon in addition to the routine sampling of bass, whitefish, and carp.

Salmonids represent a group of fish of great interest among sport fishers; however, historical data on concentrations of radioactivity in adult salmon or steelhead indicate little propensity to accumulate radionuclides from the Columbia River (Foster et al. 1965, 1966, 1967). These observations were also borne out in samples of salmon intermittently collected in the 1960s and 1970s (Eberhardt et al. 1989; Watson et al. 1970). Salmon were sampled in 1988 at White Bluffs (between the 100-D and 100-F Areas) and Priest Rapids, and are discussed in that annual report (Jaquish and Bryce 1989).

Concentrations of the radionuclide burden of white sturgeon (*Acipenser transmontanus*) have decreased significantly since the 1960s. There were no significant differences in concentrations of ^{90}Sr or ^{137}Cs in sturgeon cartilage or muscle collected from the Hanford Reach and locations upstream and downstream of the Site (Dauble et al. 1993). Trends from 1972 through 1988 in other species of wildlife and fish monitored at the Hanford Site have been reported (Eberhardt et al. 1989). Generally, data from the early 1970s show measurable concentrations of ^{60}Co and ^{65}Zn that decreased to less-than-detection

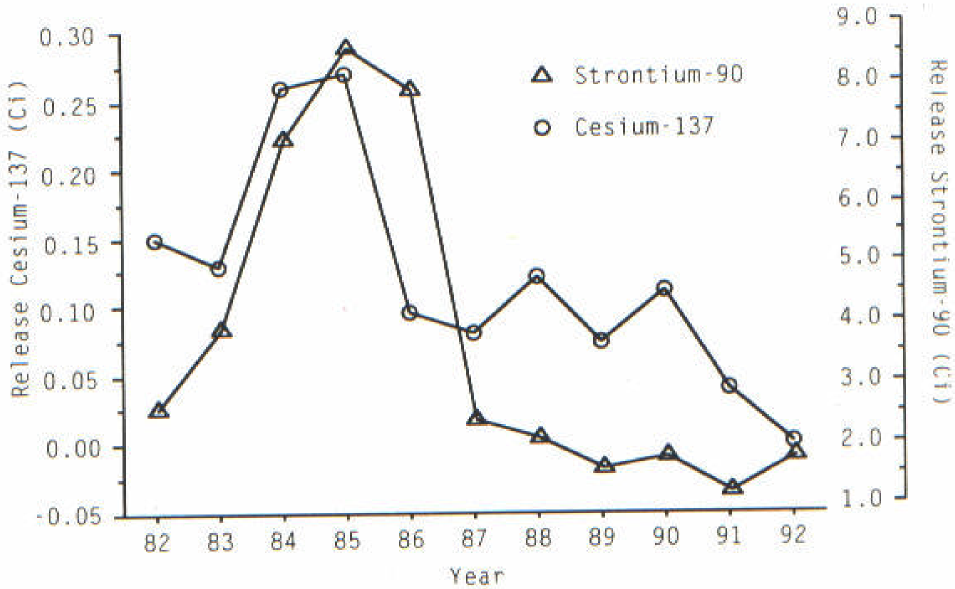

FIGURE 1. Estimated Annual Releases (Curies) to the Columbia River from the 100 Areas (Source: Hanford Site monitoring reports)

limits through the 1970s into the early 1980s. For example, from 1982 through 1992, 134 whitefish muscle samples were collected and analyzed for ^{60}Co. During this time, only one sample collected between the 100-N and 100-D Areas had a measurable concentration of 0.05 ($\pm$ 50%) pCi/g wet. Twenty-seven samples (about 20% of all samples) had concentrations of ^{60}Co in which the total analytical error ranged from 50% to 100% of the concentration. Collectively, concentrations of ^{60}Co were generally not measurable in whitefish filets, and no conclusions can be drawn regarding trends in the concentration of ^{60}Co in whitefish muscle. Decreases in the amounts of radionucides in fish were attributed to reduced discharges of radioactive effluents and radioactive decay (Eberhardt et al. 1989).

Fish have been monitored quite extensively over the past 40 years as the basis for estimating the potential radiation dose to consumers of Columbia River fish. Estimated dose rates from the consumption of sport fish in the mid-1960s ranged from 80 to 100 mrem (Foster et al. 1965, 1966, 1967) and are considerably higher (>100 times) than present dose estimates because of the presence of ^{32}P and ^{65}Zn in fish flesh in the 1960s. Additionally, the monitoring data document exposure of fish to contamination in the Columbia River. The evaluation of fish data over periods of time provides valuable insight into trends and contributes further to our understanding of the environmental behavior and potential impact of radionuclides in the Columbia River.

SAMPLING AND ANALYSIS

The methods used to collect and prepare fish samples and conduct radiochemical analysis are discussed below.

FISH COLLECTION AND SAMPLE PREPARATION

This report evaluates radionuclide levels in four species of fish collected from the Hanford Reach from 1982 through 1992 (Figure 2). The species were smallmouth bass, carp, mountain whitefish, and fall chinook salmon. Fish collection procedures are documented in Surface Environmental Surveillance Project records and are based on standard methods (Nielsen and Johnson 1983); collection methods were rod and reel, gill netting, and electroshocking. The primary sample was a filet that was removed by methods routinely used by fishers (i.e., the muscle was removed from the backbone and skinned). While considered a muscle sample, filets may contain small bones that extend laterally from the spinal column into the musculature. Kettle River whitefish filets were combined into one sample from two fish because of their small size. Fish muscle is the target tissue of ^{137}Cs accumulation.

The remainder of the fish was eviscerated and submitted as a carcass sample. In large specimens, the head was removed. Carcass samples are predominately bone, the target tissue for ^{90}Sr accumulation.

Bass were collected from F Slough [100-F Area, river mile (RM) 367] for several reasons:

- F Slough is located downstream of 100-N Area springs, which contain ^{90}Sr (Figure 2).
- F Slough is one of three sloughs that support spawning bass from RM 358 to 367.
- Slack water in the slough allows accumulation of sediment that may affect exposure of fish to sediment-bound radionuclides.
- Bass are a popular sport fish subject to harvest that congregate in the slough in the spring to breed, thus facilitating sample collection.

In 1982, a small number of bass were collected from the Hanford Townsite shoreline (5) at RM 360 to 363 and from Priest Rapids (1) at RM 390 to 395. These bass samples were not included in the analysis because their collection ceased after the first year of the study period. Bass were sampled at F Slough annually from 1983 to 1990, when the scheduling was modified to a biannual cycle with collections on even-numbered years (Table 1). Background samples of bass were collected from a pond near Sunnyside, Washington, in 1991.

Routine carp sampling was initiated in 1990 with sampling at the 100-N Area and Vantage, Washington (background location), and expanded to the 300 Area in 1991. Carp were selected for analysis because they are a food fish for specific ethnic groups. Also, carp are omnivorous bottom feeders. Bottom-feeding species are likely to accumulate radioactivity to greater levels than higher trophic-level species (Poston and Klopfer 1988). The 300 Area (RM 340 to 344) and 100-N Area

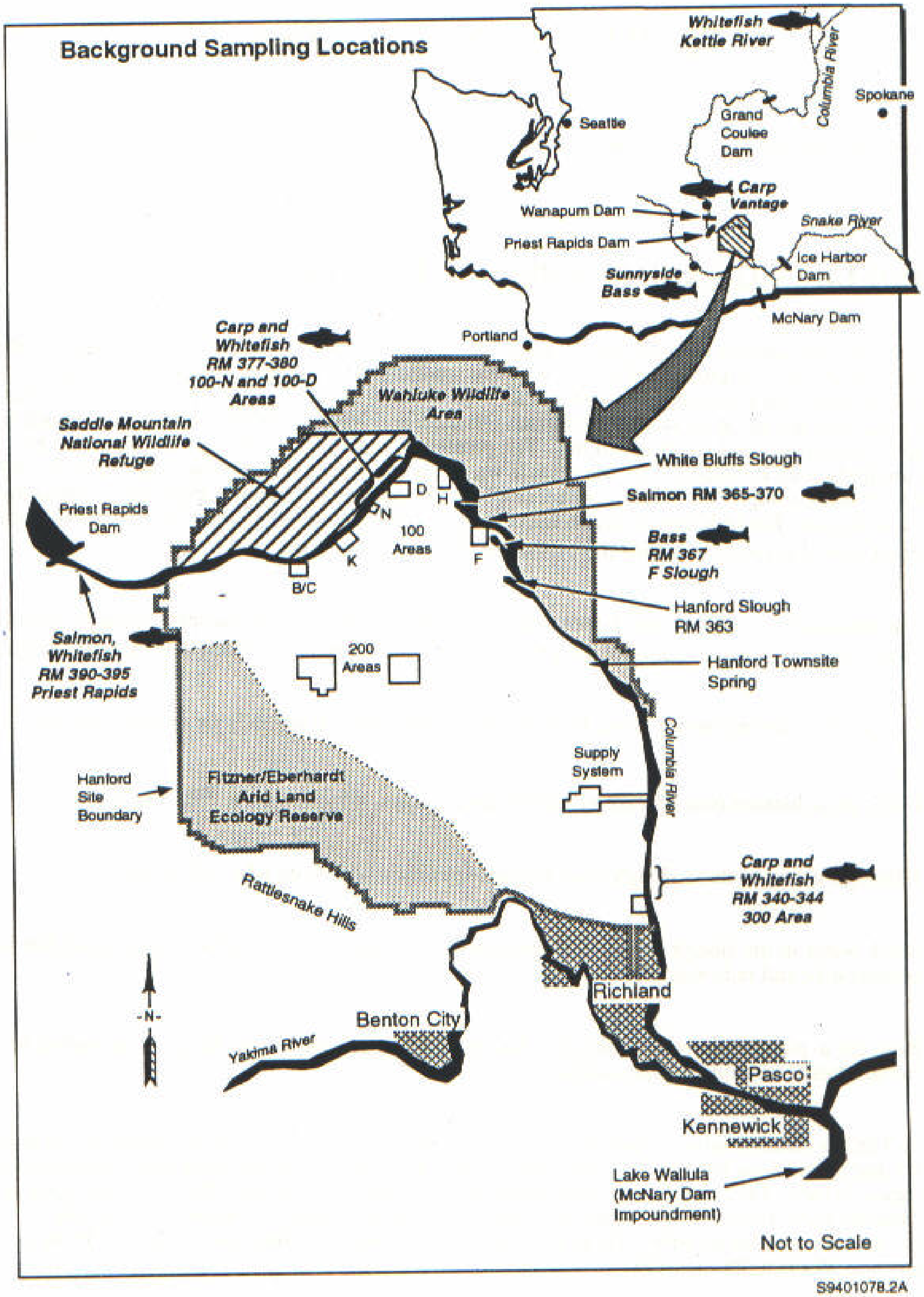

FIGURE 2. Sampling Locations for Hanford Reach and Background Fish

TABLE 1. Species, Locations, and Number of Fish Sampled from 1982 Through 1992

		Year										
Species	Location	82	83	84	85	86	87	88	89	90	91	92
Bass	F Slough	-(a)	5	5	5	5	5	5	5	5	-	5
Bass	Sunnyside	-	-	-	-	-	-	-	-	-	20	-
Bass	Hanford TS(b,c)	5	-	-	-	-	-	-	-	-	-	-
Bass	Priest Rapids(c)	1	-	-	-	-	-	-	-	-	-	-
Carp	100-N Area	-	-	-	-	-	-	-	-	6	4	1
Carp	300 Area	-	-	-	-	-	-	-	-	-	5	5
Carp	Vantage	-	-	-	-	-	-	-	-	3	10	-
Whitefish	Priest Rapids	9	5	5	5	5	5	5	5	5	-	-
Whitefish	100-D Area	9	14	10	10	10	10	10	6	10	5	-
Whitefish	100-N Area	-	-	-	-	-	-	-	-	5	1	10
Whitefish	300 Area	-	-	-	-	-	-	-	-	5	2	10
Whitefish	Kettle River	-	-	-	-	-	-	-	-	-	9	-
Whitefish	Hanford TS(c)	5	7	-	-	-	-	-	-	-	-	-
Whitefish	Ringold(b,c)	7	5	-	-	-	-	-	-	-	-	-
Salmon	100-D Area	-	-	-	-	-	-	5	-	-	-	-
Salmon	Priest Rapids	-	-	-	-	-	-	5	-	-	-	-

(a) Dash indicates no samples were collected.
(b) Hanford Townsite at RM 360 to 363, Ringold at RM 350 to 354.
(c) Samples not used in analysis.

(RM 380) were sampled because of concern of seeps releasing contaminants into the river. Tritium, ^{60}Co, and ^{90}Sr are the primary radionuclides of interest in the 100-N Area springs. The 300 Area springs contain elevated levels of ^{3}H and uranium isotopes. Additionally, because ^{99}Tc was present in Hanford Townsite springs (Woodruff et al. 1993), ^{99}Tc was also analyzed in 300 Area carp muscle.

Fall chinook salmon were collected once in 1988 because of interest raised at that time.

Whitefish were collected every year of the study period (see Table 1). Whitefish were sampled because they are a bottom-feeding sport fish that historically has accumulated some of the highest levels of radioactivity in the Hanford Reach. Whitefish results from the 100-D Area (RM 377) were combined with results from the 100-N Area for evaluation because the 100-D and 100-N Areas are both influenced by the 100-N Area springs. From 1982 through 1990, whitefish were collected from the Vernita Bridge upstream to Priest Rapids Dam. There is no certainty that these fish have always resided in this area and that they had not resided in other sections of the Hanford Reach. However, this is the location most likely to be fished for whitefish immediately upstream from the Hanford Site. In 1982 and 1983, whitefish were collected from Ringold (RM 350 to 354) and the Hanford Townsite. These whitefish samples were not included in this analysis because their collection ceased after the first 2 years of the study period. Background samples of whitefish were collected from the Kettle River in northeastern Washington in 1991.

Trends of radioactivity in fish were evaluated in bass collected from F Slough and whitefish collected from Priest Rapids and the 100-N to 100-D Areas from 1982 through 1992 (see Table 1). Location effects were evaluated for bass and carp using data collected from 1990 through 1992 and for whitefish from 1988 through 1992.

RADIONUCLIDE ANALYSES

Fish filet samples are analyzed by gamma spectroscopy for a large number of gamma-emitting radionuclides (Woodruff et al. 1993). Routinely, only ^{7}Be, ^{40}K, and ^{137}Cs were detected in fish. Cobalt-60 was infrequently detected in the early 1980s, but decay and very small releases to the environment have reduced ^{60}Co to undetectable levels in fish samples. Radiochemical methods are also used to measure ^{90}Sr in carcass and muscle samples. In 1991 and 1992, some samples of carp and whitefish from the 300 Area were analyzed for ^{99}Tc or uranium isotopes. Technetium-99 and uranium results are listed in Appendix A; however, it was not possible to address trends as the time frame covers only the most recent 2 years.

All results were reported as pCi/g wet weight. Minimum detectable concentrations (MDC on a wet-weight basis) for ^{60}Co, ^{90}Sr, and ^{137}Cs were 0.01, 0.005, and 0.015 pCi/g, respectively. The ^{137}Cs MDC was adjusted to 0.02 pCi/g for fish samples analyzed in 1991 and 1992. The MDCs for other gamma-emitting radionuclides ranged from 0.02 to 0.2 pCi/g. Technetium-99 has an MDC of 1.0 pCi/g, and uranium isotopes have an MDC of 0.02 pCi/g. These MDCs are a contractual guideline that the analytical facilities are obligated to meet by adjusting sample count time and aliquot size.

Analyses whose results are reported herein were performed by two laboratories. Fish samples collected before 1990 were analyzed by U.S. Testing, Inc. (UST), Richland, Washington. Samples collected in 1990 and after were analyzed by IT Analytical Services, Richland, Washington, which acquired the UST facilities in 1991. The methods used for radiochemical analyses are summarized by Jaquish and Bryce (1990).

DATA ANALYSIS

The data for each species and radionuclide combination were screened to determine whether an adequate number of measurements were present for a statistical evaluation. The data were electronically retrieved from PNL's Surface Environmental Surveillance Project (SESP) data base and transferred to Excel (Microsoft Corp.) and StatView (Abacus Concepts, Inc.) software for data analysis.

SCREENING OF DATA

To determine the suitability of the data for analysis, each analytical result for ^{60}Co, ^{90}Sr, and ^{137}Cs was evaluated by calculating the ratio of the two sigma analytical error (combined counting error and radiochemical analytical error) to the concentration. Four categories of the resulting ratio were determined: 1) values less than 0 indicated a negative analytical result; 2) values between 0 and 0.50 indicated a result with an associated two sigma analytical error of $\pm$ 50% or less, hereafter referred to as "definitive results;" 3) values between 0.50 and 1.00 indicated a result with an error between 50% and 100% of the result; and 4) values greater than 1.0 indicated an estimate of the two sigma analytical error in excess of 100% of the concentration. Generally, only data types with a preponderance of values (>40% of all values for a given analyte and tissue) in Categories 2 and 3 were considered for further statistical analysis using all the reported values. Collectively, Categories 2 and 3 concentrations are referred to as "measured" values in the text. Some analyses in 1982 and 1983 had only the two sigma counting error reported, in which case that was used to calculate the ratio.

STATISTICAL ANALYSIS

Data were graphically presented in box plots that show the 10th, 25th, median (50th percentile), 75th, and 90th percentiles for each year and location as well as individual concentrations that lie above or below the 90% or 10% levels, respectively (Figure 3). Median concentrations were reported because they are not as radically influenced by outliers and may provide a more accurate estimate of the central tendency of environmental data compared to mean concentrations when sample sizes are small.

Parametric statistical analyses were used to evaluate trends, location effects, and the relationship between bass and whitefish concentrations of radionuclides to reported annual releases to the Columbia River from 1982 through 1992 (Figure 4).

Generally, radionuclide concentrations are log-normally distributed in environmental media (Eberhardt and Gilbert 1980), i.e., the data are generally skewed, but a log-transformation will produce a more normal bell-shaped distribution. Distributions of log-transformed and non-transformed data for each combination of fish, tissue, and location were compared to determine whether log-transformation was appropriate. In nearly all cases, log-transformation produced a more normal distribution of data than the non-transformed data. Negative values are lost when a log-transformation is applied to the data, hence biases can be introduced into the evaluation. Where analysis of variance (ANOVA) was used to determine location effects or differences in concentrations among years, the statistical result (i.e., significance) was unaffected by log-transformation except for values for ^{137}Cs in muscle, for which there was a larger proportion of negative values in certain species and locations. All ANOVA tables are located in Appendix B.

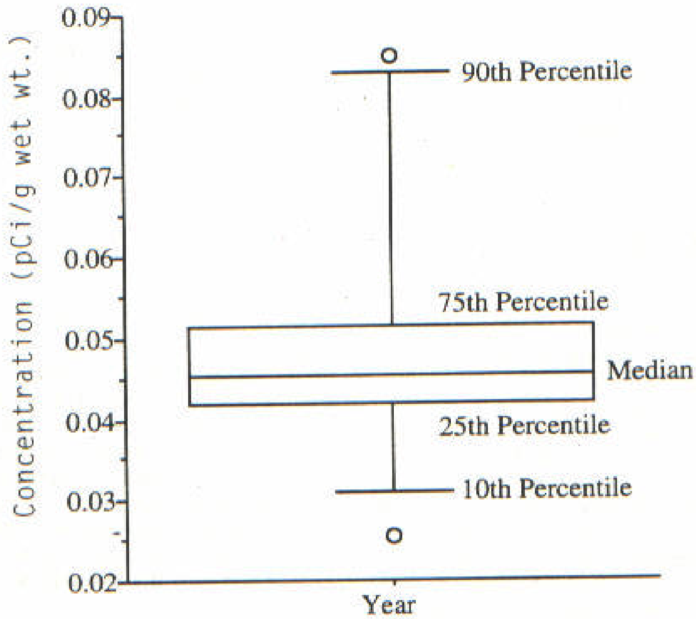

FIGURE 3. Example Box Plot (circles indicate results either above or below the 90th and 10th percentiles, respectively)

Trend Effects

Trends were initially evaluated by conducting a Model I (simple) regression of log-transformed median values by year for bass and whitefish at each location where 9 or more years of data were available (Sokal and Rohlf 1981). Both a Model I and a second-order polynomial regression by year were performed. The second-order polynomial was used because the reported releases of ^{90}Sr and ^{137}Cs indicated a parabolic shape (see Figure 1), which is expressed better by a two-term regression model than a single linear model. Additionally, the log-transformed median was regressed against reported releases to the river (see Figure 1) to determine whether there was a significant Model II regression. Analysis of bass and whitefish followed this general pattern. Carp and salmon data were not used to evaluate trends because they were only collected for 3 and 1 years, respectively. The ANOVA tables for regression analysis are located in Appendix B.

Location Effects

The statistical analyses for location effects involved ANOVA initially by location, then by year within location if the analysis was significant, as indicated by a P value of <0.05. Evaluation of location effects was limited to 3 years for bass and carp (1990 through 1992), and 5 years for whitefish (1988 through 1992). Comparisons among years were performed to identify years that were significantly different than other years for a particular location over the 11-year study period and to support in part the regression analysis conducted for trends.

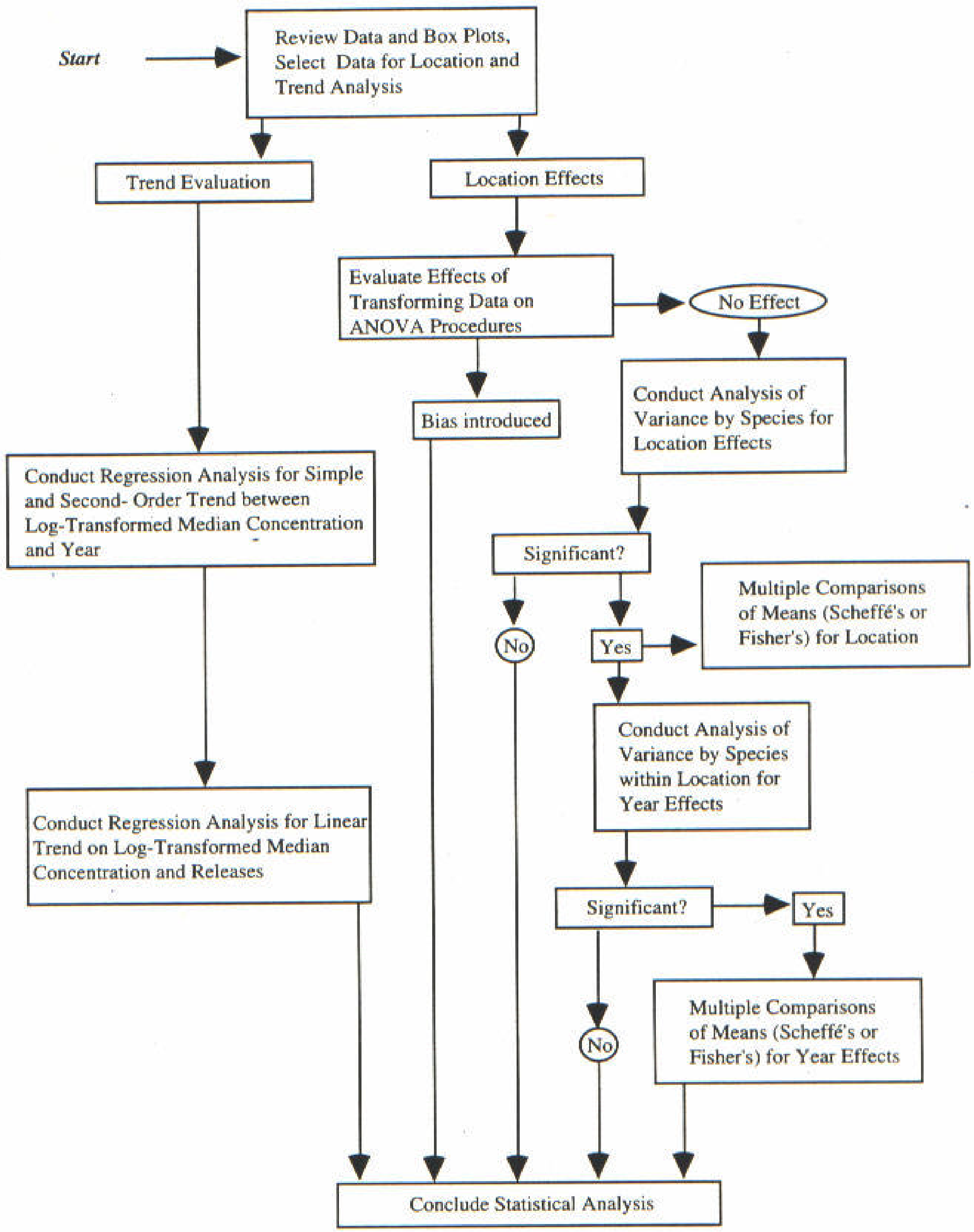

FIGURE 4. Flow Chart for Data Analysis

The ANOVA was followed by a multiple comparison of means when significant for either location effects or year effects. Either Fisher's Protected Least Significant Differences (PLSD) test or Scheffé's correction for multiple comparisons of means was used, depending on whether the comparison was judged as a planned comparison or a post-hoc comparison. Planned comparisons involved data sets in which the collections at a particular location were planned, documented, and generally completed as planned. Fisher's PLSD test was used on comparisons among years for bass collected at F Slough and whitefish collected at Priest Rapids and the 100-N to 100-D Areas. Generally, Scheffé's correction was used because of the addition of several new study areas over a short period of time or when the numbers of fish collected were radically different from what had been planned. Fisher's test is less conservative than Scheffé's; i.e., it is more likely to show a difference between treatments.