DISCUSSION

This section discusses factors that influence the accumulation of radionuclides in Hanford Reach fish relative to background locations, tissue concentrations, and associated doses estimates that could result from the consumption of fish.

ACCUMULATION OF RADIONUCLIDES

The evaluation of concentrations of man-made radionuclides in Hanford Reach fish indicates that most radionuclides released from Hanford operations during the plutonium production years (1944 through 1989) are no longer measurable using state-of-the-art gamma spectroscopy, or are found at very low concentrations with more sophisticated radiochemical methods. Consequently, it is difficult to demonstrate either a contribution of a radionuclide in fish attributable to Hanford Site releases or trends in fish tissue for most man-made radionuclides. These difficulties are not just analytical, but are also influenced by the complex interactions of the radionuclides between fish and the aquatic environment. These influences are evident in the high variability associated with the fish data and may be explained by the following factors:

1. the environmental chemistry of the radionuclides in the river (in this report, the discussion was restricted to ^{90}Sr and ^{137}Cs)

2. the behavior and movement of the fish species that were sampled and how that is influenced by dams

3. the impact of fallout radioactivity historically deposited in the Columbia River drainage system and its influence on tissue concentrations from background locations and in Hanford Reach fish.

Ideally, a background location should not be impacted by Hanford releases, should sustain adequate populations of fish for sampling requirements, and should be as similar to the Hanford Reach as possible with respect to water chemistry and background radionuclide concentrations in water and sediment. Estimates of Hanford impacts and more realistic dose estimates to consumers of fish can be attained when these factors are understood and quantified. It is not always possible to find sites that ideally fulfill all these criteria, and compromises were made in the selection of background locations. The primary objective in selecting a background site was not to provide a reference for tissue concentrations, but rather to provide a basis for estimating a background radiological dose to consumers. To this end, the influence of fallout was not controlled as rigorously as if the objective would have been to evaluate the incremental increase in radionuclide concentration in fish tissue.

Environmental Chemistry

Environmental chemistry of radionuclides and the influence of water chemistry on environmental fate have been the subjects of much research (reviewed by Coughtrey and Thorne 1983). I will briefly touch on the key aspects of the environmental behavior of ^{90}Sr and ^{137}Cs in freshwater aquatic systems. The aspects of environmental chemistry are important when comparing Hanford Reach fish to background locations, particularly if the background location is different from the Hanford Reach in its chemical and physical character.

Strontium-90 is a chemical analog of calcium and behaves similarly in the environment. It is freely soluble as a divalent cation; consequently, it tends to remain dissolved, is very mobile in aquatic systems, and is prone to be accumulated by organisms that also accumulate calcium. Fish can obtain their dietary requirements for calcium by direct absorption from the water, but may also accumulate calcium from food. Consequently, the potential to accumulate ^{90}Sr is generally inversely related to the amount of calcium in the water (Vanderploeg et al. 1975). Concentrations of ^{90}Sr in fish bone, consequently, are lower in fish inhabiting hard water ecosystems compared to those in soft water systems as a result of dissolved divalent cations, principally, Ca, but also Mg and stable Sr.

Cesium-137 is a monovalent cation that has a high affinity for adsorption to suspended material and clay. Cesium is a chemical analog of K, and ^{137}Cs uptake and accumulation in muscle is inversely related to K concentration in freshwater (Vanderploeg et al. 1975). Releases of ^{137}Cs are rather quickly scavenged by suspended matter (e.g., sediment, plankton) in the river, thereby reducing the potential for direct uptake of soluble ^{137}Cs from the water column by fish. Accumulation by fish is attributed more to food chain transfer processes than direct uptake from the water. There is a greater tendency for ^{137}Cs to be sequestered in sediments where it is less available to fish. Cesium-137 associated with plankton is the first stage of food chain transfer to fish.

While extensive water quality information has been collected on the Hanford Reach and is documented in annual monitoring reports, the sites used for background locations for fish sampling have not been characterized, either in terms of concentrations of radioactivity or chemical character of the water. This limits our ability to explain observed differences in concentrations of radionuclides in fish, particularly whitefish and bass, that were collected from locations potentially dissimilar to the Hanford Reach.

Fish Behavior

Background locations were chosen to provide tissue concentrations to evaluate the potential influence of Hanford Site operations on fish. Resident fish are not restricted in their movements through the Reach and can enter the Snake River or Yakima River as well as move downstream into Lake Wallula (the McNary Dam impoundment). Dams located upstream of Hanford have fish ladders to assist the migration of fish, primarily salmonids, but also other resident species. Grand Coulee Dam is not equipped with fish ladders and represents the closest upstream barrier to fish migration. Consideration must be given to the potential for fish sampled upstream of Hanford as background fish to have previously resided in the Hanford Reach. The salmon data collected in 1988 represent migrating adults whose residence time in the Hanford Reach was unknown, but probably less than 4 months Because adult salmon do not feed when they migrate, the potential to accumulate radionuclides from food chain pathways is insignificant.

Bass

Movements of bass have been documented in the Hanford Reach in radiotagging studies (Montgomery and Fickeisen 1978). Bass were collected and tagged in F Slough, White Bluffs Slough, and the Hanford Townsite Slough during the breeding season in May and June in 1977. Most radio-tagged bass resided in the main channel of the river close to the sloughs after spawning. They slowly disperse downstream through the summer. All fish radiotagged in the Hanford Reach sloughs during this study remained in the Reach, with the most distant fish collected by a fisher 63 km (40 mi) downstream in Lake Walulla.

The potential for upstream migration of bass over Priest Rapids Dam is small. Mullan et al. (1986) report that too few bass move over dams upstream of McNary to be tabulated. Bass prefer warmer water, and their distribution is limited more to the downstream reservoirs by water temperature. The Sunnyside pond was selected for background bass collection because of the large resident population of bass and its location upwind of Hanford. From this perspective, Sunnyside was a reasonable location for estimating background bass concentrations; however, it cannot directly address Hanford effects because the pond has its own separate ecosystem, levels of fallout radioactivity in the pond are not known, and the water characteristics of the pond are not known.

Carp

Carp are also known to pass over dam ladders; however, their movements are more or less random. Maximum passage over Priest Rapids Dam occurred in 1966 with about 24,000 fish. Passage steadily decreased in subsequent years to less than 2000 fish in 1983 (Mullan et al. 1986). More importantly, migration over Wanapum Dam was very low, indicating that the carp collected at Vantage are most likely truly distinct from Hanford Reach populations.

The selection of Vantage as a background location balances concern for isolation from Hanford with concern for the need to provide realistic upstream conditions that are not adversely influenced by high background radioactivity.

Whitefish

Whitefish migrate seasonally upstream to eventually spawn in tributaries or the main stem of the Columbia. River. Ladder counts for Priest Rapids Dam ranged from initially 80,000 in 1963 to about 17,000 in 1983 (Mullan et al. 1986). For this reason, the distant Kettle River background location was selected because it was the closest upstream location that has a nonpassable barrier (Grand Coulee Dam) separating it from the Hanford Reach. However, precipitation in the Kettle River basin is about three to four times the level at Hanford, implying that historical fallout would also be elevated in this region. High historical fallout is the most reasonable explanation for the elevated ^{90}Sr observed in whitefish carcass collected from the Kettle River.

A significant concern in the fish monitoring program is whether the fish collected are representative of fish from the area sampled. The amount of residence time fish sampled from the Hanford Reach have spent in the area cannot be quantified. Most collections of whitefish occurred during the peak migration period from October through January. Moreover, whitefish collected from Priest Rapids and the 100-N to 100-D Areas most likely represent the same general group of fish. These fish represent the population that would be harvested by fishers and are suitable to estimate doses for fishers. The potential variations introduced by migration are less of a concern for carp and bass. For the overall evaluation of trends over the past 11 years, these perturbations may introduce additional uncertainty, but do not invalidate the data for assessing trends or Hanford effects.

Radioactive Fallout

The preceding discussion on fish movement and environmental chemistry highlights a key observation in this study. In carp and whitefish carcasses, the levels of ^{90}Sr in background samples significantly exceeded the concentrations in Hanford Reach fish from the same period. This is not a contradiction if the environmental concentrations of ^{90}Sr in the fish's habitat were higher than for Hanford

Reach fish. The environmental conditions and concentrations of ^{90}Sr of background fish habitat was not measured, and bioaccumulation processes cannot be quantified.

The most plausible explanation for the elevated concentrations of ^{90}Sr is historical fallout from atmospheric weapons testing in the 1950s and 1960s. Fallout levels correspond with increased precipitation, and there is a reasonable likelihood that exposure concentrations of Kettle River fish were actually greater than those of Hanford Reach fish as a result of fallout. The primary Hanford Site source of ^{90}Sr in the Columbia River during this time was the 100-N Area springs, which discharge to the river around RM 380. However, the largest source of ^{90}Sr and ^{137}Cs in the Columbia River is watershed runoff from the river's many tributaries. There are no major tributaries to the Columbia River between the confluence of the Wenatchee River (RM 468) and the confluence of the Yakima River at RM 335; consequently, the 112 km (70 mi) stretch upstream from Priest Rapids Dam should be relatively consistent in its makeup of fallout radioactivity.

The influence of fallout radioactivity was evident in measurements of ^{90}Sr and ^{137}Cs in water at Priest Rapids and downstream of the Hanford Site at the Richland pumphouse (Dirkes 1994). Annual average concentrations of ^{90}Sr ranged from 0.07 to 0.29 pCi/L at the Richland pumphouse or 300 Area water sample collection locations compared to a range of 0.08 to 0.24 pCi/L at upstream (100-B or Vernita Bridge) sampling locations. Statistically, there was no difference between locations from 1980 to 1989, indicating that contributions from the Hanford Site are not of sufficient magnitude to produce a demonstrable effect. In comparison, the monitored concentrations of ^{90}Sr in bass and whitefish reflect the reported discharges of ^{90}Sr over the years 1982 through 1992 (see Figure 1). Specifically, the results suggest an increase followed by a decline, as indicated in carcass data from bass and whitefish and corroborated by second-order regression models and simple regression of site releases and log-transformed median tissue concentrations. The measurements of ^{137}Cs in fish are generally too low to draw any firm conclusion on impacts from the Hanford Site in water or fish.

TISSUE CONCENTRATIONS

Carcass samples were analyzed for ^{90}Sr because carcass contains a large amount of calcified bone tissue, and ^{90}Sr is a chemical analog to calcium (Poston and Klopfer 1988). Concentrations of ^{90}Sr reported in muscle samples may, in fact, represent residual levels in fish bone that were not removed during the filleting process. The 100-N Area springs source probably accounts for the wider range of ^{90}Sr observed in Hanford Reach fish carcasses. A few 1990 carp had relatively high concentrations of ^{90}Sr in their carcasses. These fish had clam shells (*Corbicula* sp.) in their stomachs. A clam shell from 100-N Area springs in 1990 had 266 ($\pm$ 20%) pCi ^{90}Sr/g (Woodruff et al. 1992); the flesh contained 0.05 pCi/g (Woodruff et al. 1991). These observations suggest a possible food chain pathway to carp; however, the extent of contamination from the 100-N Area springs is small, and the potential for carp to feed on clams residing in the area effected by the springs is also relatively small. Consequently, the potential for contamination of many fish is small, as indicated in the monitoring data.

Cesium-137 was evaluated in the muscle of bass, carp, and whitefish. Because ^{137}Cs is a chemical analog of potassium, it accumulates in muscle tissue and is a concern for potential dose to consumers of fish (Poston and Klopfer 1988). The demonstrated decreasing trend in median ^{137}Cs in bass muscle, while significant, is somewhat compromised by the high percentage of nonmeasurable concentrations. The fact that ^{137}Cs generally was not measured in fish illustrates the dilution of the Columbia River and the overall low concentrations of ^{137}Cs in seep water and permitted discharges to the river at the Hanford Site. As was noted with ^{90}Sr, atmospheric fallout has contributed to elevated environmental concentrations of ^{137}Cs, but there was no indication of elevated levels of ^{137}Cs in background fish relative to Hanford Reach fish in this study.

The significance of fish tissue concentrations lies in its potential for the radionuclides to impact human populations. Native American's or ethnic groups may harvest, cook, or prepare fish in ways that influence human exposure. For example, a diet dominated by salmon would contribute less radioactivity to radiological dose than a diet dominated by resident species because the anadramous life cycle of salmon reduces the residence time in the Columbia River and the non -feeding adults do not accumulate radioactivity via the food chain. Consumption of fish muscle is the most direct pathway to humans. Fish carcass and its associated burden of ^{90}Sr would most likely be discarded. Canning, poaching, or pickling fish, however, will soften bones so that they could be consumed without discomfort. Fish carcass could also be used for fertilizer in home gardens, which would lead to an indirect consumption pathway. The potential dose impact of fish consumption is summarized in the next section, Dose Considerations.

DOSE CONSIDERATIONS

Each year, the Hanford Site environmental monitoring report addresses the estimated dose to the maximally exposed individual (MEI). The MEI is a hypothetical person that receives the highest possible dose from all environmental pathways. In 1982, the dose resulting from the consumption of 40 kg of Columbia River fish in combination with other modeled river pathways (i.e., immersion in water, exposure to the shoreline) was 0.04 mrem to the whole body and 0.1 mrem to bone (Sula et al. 1983). In 1992, the reported estimated dose to the MEI resulting from river recreation and fish consumption was 0.006 mrem (Woodruff et al. 1993). While assumptions in the dose modeling were different in 1982 compared to 1992, the overall trend in estimated doses is downward.

The DOE guideline for public exposure, which is based on the National Council on Radiation Protection and Measurements' recommendations (NCRP 1987), is 100 mrem (U.S. DOE 1990). Estimates of background radiation to humans from natural sources of radiation are approximately 300 mrem. The DOE field office is notified when a fish tissue concentration reaches a level that would result in a 1.0-mrem dose to a human consumer (U.S. DOE 1991). This 1.0-mrem dose would be attained from the consumption of 40 kg of fish in a year that contained either 0.18 pCi ^{90}Sr/g fish or 0.54 pCi ^{137}Cs/g of fish. Under an assumption that fish carcasses would be consumed, recent monitoring data suggests that estimated doses would actually be higher in background fish than those observed in some populations of Hanford Reach fish. This observation illustrates how low tissue concentrations are in some Hanford Reach fish and provides a measure of comparison for estimated doses resulting from the consumption of fish collected at background locations. Concentrations of radioactivity measured in bass, carp, and whitefish over the past 11 years do not constitute a significant radiological dose to the fish-eating public. Consumption of salmon collected from the Reach also contributes little to the estimated dose resulting from Hanford Site activities.

The DOE has established a guideline dose rate of 1.0 rad/d for aquatic life (U.S. DOE 1990). Based on a maximum carcass concentration of ^{90}Sr in carp in 1992 (Woodruff et al. 1993), the estimated dose rate was 0.01 mrad/d, or 100,000 times lower than the DOE standard. In 1991, the maximum calculated dose was to a whitefish and it was 0.001 rad/d (Woodruff et al. 1992). A worst-case estimate was also prepared for carp residing around 100-N springs that consumed clams residing in the spring area. The hypothetical maximum dose rate from internal accumulation of radioactivity from the clam under dietary equilibrium was 0.05 mrad/d (Poston and Soldat 1992). These recent examples of dose calculations indicate that present concentrations of man-made radionuclides in Hanford Reach fish do not result in notable radiological doses to these fish. For some species of background fish, where background concentrations of ^{90}Sr exceeded Hanford Reach fish concentrations, estimated doses in background would be comparable or slightly exceed estimated doses of Hanford Reach fish.

CONCLUSIONS

This evaluation address two basic questions. What were the trends of radionuclide concentrations in fish from the Hanford Reach, and how do they relate to reported Site releases of radionuclides to the river? The second question is were concentrations of radionuclides in Hanford Reach fish different compared to fish collected from locations designated as background locations? Based on the statistical analysis of data on bass, carp, whitefish, and salmon, this report draws the following conclusions about trends and location effects.

Trends. Overall, radionuclides have decreased over the 11-year study period. Most man-made gamma-emitting radionuclides previously found in Hanford Reach fish are no longer found at measurable concentrations because of their short half-lives. Strontium-90 and Cesium-137 are the only man-made radionuclides that were measured. The general reduction of ^{90}Sr and ^{137}Cs was punctuated with a moderate increase and subsequent decline that paralleled reported releases of ^{90}Sr to the river. The same pattern was evident for ^{137}Cs in fish but high variability in the data and very low concentrations of ^{137}Cs (less than detection levels) in fish samples weaken the statistical comparison.

Location Effects. Regression analysis of ^{90}Sr in fish carcass samples clearly demonstrates a relationship between bass and whitefish carcass concentrations and reported releases. Tissue concentrations since 1988, however, have declined to a level where they generally are comparable or in some cases less than background location samples. This conclusion is based on only 1 or 2 years of background location data for bass, carp, or whitefish, which is statistically limited and will improve with additional sample collection at background locations in the future. That background fish carcass samples contain concentrations of ^{90}Sr exceeding Hanford Reach fish concentrations illustrates the magnitude of current Hanford operations on resident fish populations.

While the ability to monitor trends in fish samples and relate them to releases is quite noteworthy; the monitored concentrations of ^{90}Sr and ^{137}Cs in fish currently are very low and posed no known risk to human consumers of Hanford Reach fish or to the fish themselves. The results of this report have value for documenting concentrations of radionuclides against which future monitoring results can be compared, particularly for clean-up and remediation activities that impact the Columbia River.

One of the purposes of monitoring fish in the Columbia River is to estimate human doses resulting from the hypothetical consumption of Hanford Reach fish. Past and continued monitoring of Hanford Reach fish assures the public that these fish are safe to eat. This assessment of concentrations of ^{90}Sr and ^{137}Cs in fish indicates that the monitoring program should be reviewed to determine the direction and level of effort needed to meet public assurance objectives and how questions regarding trends and Hanford effects can be better addressed.

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