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PATTERNS OF SEDIMENT ACCUMULATION IN WATTS BAR RESERVOIR BASED ON ¹³⁷CESIUM¹

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The U.S. Department of Energy has recently undertaken an environmental restoration program designed to achieve remediation of hazardous materials released from the Oak Ridge Reservation (ORR). Contaminants include radionuclides, metals, and organic compounds that were released over the past 50 years from Oak Ridge National Laboratory, the Oak Ridge Gaseous Diffusion Plant, and the Y-12 Plant located on the ORR.

One component of this program is the Clinch River Resource Conservation and Recovery Act Facility Investigation (CRRFI) which focuses on portions of the Clinch and Tennessee Rivers that may have been adversely affected by contaminants released from the ORR. As part of a preliminary scoping study for the CRRFI, Olsen et. al. (1990) measured ¹³⁷Cs activity in 58 sediment cores and 187 surface sediment samples collected from the Clinch River and Watts Bar Reservoir. ¹³⁷Cs was chosen because (1) its release history from ORR is reasonably well known, (2) it is easy and inexpensive to measure by gamma spectrometry, and (3) it is rapidly sorbed to riverborne particulate matter and thus serves as a tracer for the transport and accumulation of other particle-reactive contaminants.

Olsen et. al. (1990) focused on estimating the amount of ¹³⁷Cs retained by Watts Bar Reservoir. Using these data, we have performed additional analyses designed to investigate the relationships between several indicators of ¹³⁷Cs accumulation and various reservoir characteristics. This presentation describes the results of these analyses. In addition, we discuss an independent estimate of the amount of ¹³⁷Cs retained in Watts Bar Reservoir using the Olsen et. al. (1990) data.

METHODS

Data Collection

Two types of coring devices were used to obtain 58 sediment profiles. A gravity corer was generally used in areas where the water depth exceeded 10 m. This device consists of a tube attached to an anchored cable which is then allowed to free-fall to the bottom. The inertia of the corer provides

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the force necessary to penetrate the sediment. In areas where the water depth was less than 10 m, a vibracorer was used. This device consists of a vibrating head attached to an aluminum irrigation pipe. Sediment penetration results from the thixotropic action of the vibrating head. Vibracoring is limited to shallower areas because pipe lengths greater than the depth of the water column are needed with this device. Upon retrieval, sediment profiles were carefully extruded from the corer and sectioned into either 1-, 2-, or 4-cm thickness increments. These sections were placed into plastic-lined aluminum cans, sealed, and returned to the laboratory.

In addition to the cores, 187 surface sediment samples were collected. A Ponar bottom-grab sampler was used to collect these samples. Upon retrieval, the samples were placed into beakers, sealed, and returned to the laboratory. The surface sediment samples were used to develop a map of sediment characteristics and to identify sites best suited for coring.

In the laboratory the core and surface sediment samples were analyzed for ^{137}Cs activity using solid state detectors attached to a computerized gamma spectra acquisition system (Larsen and Cutshall 1981). After counting, each sample was weighed to determine wet weight, oven-air dried (60°C) for several days, and weighed again to determine dry weight. These weights were used to calculate activity concentrations.

Statistical Characterization

Four measures of ^{137}Cs accumulation were used in our statistical characterization. The total activity of each core segment was divided by the cross sectional area of the corer and summed down the core to give a core inventory (pCi cm^{-2}). The peak concentration (pCi g^{-1}) within each core was found by dividing the core segment activities (pCi) by the corresponding dry weights and finding the maximum concentration within the core. Since ^{137}Cs has a well defined release history from the ORR, we calculated a sedimentation rate (cm yr^{-1}) based on the depth of the peak concentration and the elapsed time since the peak discharge occurred from the ORR. Finally a surface concentration of ^{137}Cs (pCi g^{-1}) was obtained by calculating a mass weighted average of the activity concentrations in the top 6 cm of each core.

We used analysis of variance and regression analysis to test for relationships between the ^{137}Cs variables described above and core characteristics such as sediment type and water depth. Exploratory analyses of the data revealed that the two cores taken in the Clinch River had significantly higher peak concentrations and inventories than did the cores from Watts Bar Reservoir. This is most likely due to the fact that significant dilution of the suspended particulate matter containing ^{137}Cs occurs below the confluence of the Clinch and Tennessee Rivers. Consequently, we decided to exclude the Clinch River cores from our statistical analyses. In addition, the six cores collected in the major embayments of Watts Bar Reservoir (Caney Creek, Piney River, and White Creek) were found to have markedly lower concentrations and inventories of ^{137}Cs . The embayment samples were also excluded from our analyses because these samples are located in areas off the main channel of the reservoir.

Estimation of ^{137}Cs Inventory

Olsen et. al. (1990) subdivided the reservoir surface area into polygons based on sedimentary characteristics determined from the surface sediment samples and bathymetry obtained from navigation charts. They used a geographic information system to estimate the amount of ^{137}Cs in the reservoir by averaging the core inventories in each polygon, multiplying these averages by the

polygon areas, and summing the polygon inventories.

We also calculated a reservoir inventory based on the Olsen et. al. (1990) polygons. We looked for cores collected in each polygon and determined whether or not there was agreement between the polygon sediment type and the core's sediment type. We also compared the sediment type of the polygon with that of any grab samples collected in the polygon. If there was a core (or cores) collected in the polygon and the sediment types agreed, we chose that core or cores to characterize the polygon. If there were no cores collected in the polygon, we examined sediment type and water depth of any grab samples collected in the polygon. We then chose nearby cores having sediment type, water depth, and location similar to grabs collected in that polygon. If there were no grab or core samples in the polygon, we chose nearby cores having similar sediment type as the polygon. Polygon inventories were calculated by averaging the inventories of the cores assigned to each polygon.

RESULTS AND DISCUSSION

Statistical Characterization

Analysis of variance (ANOVA) showed no significant differences between cores collected by vibracorer and gravity corer for peak concentration ($r^2 < 0.01$; $P = 0.75$), surface concentration ($r^2 = 0.02$; $P = 0.36$), inventory ($r^2 = 0.05$; $P = 0.15$) and sedimentation rate ($r^2 = 0.01$; $P = 0.55$). These results imply that the type of corer does not introduce a bias into the data and therefore allows us to combine measurements from the different sampling gears in subsequent analyses. However, the data were not collected to test this hypothesis.

Linear regression analysis showed that a substantial amount of variance in ^{137}Cs inventory could be explained by the peak concentration ($r^2 = 0.72$; $P < 0.001$). This implies that a large portion of the ^{137}Cs inventory in a core is associated with the peak concentration. We also found a strong relationship between the inventory and the sedimentation rate ($r^2 = 0.78$; $P < 0.001$), implying that areas having higher sedimentation rates will typically have higher ^{137}Cs inventories.

Based on the chemical affinity of ^{137}Cs for fine-grained sediments, we hypothesized that peak and surface concentrations, inventory, and sedimentation rate would be higher for fine-grained sediments than for coarser grained sediments. Each core was assigned to one of three sediment types (soft mud, sandy mud, or eroded soil) based on visual inspection of the core during field collection. An ANOVA on sediment type found significant differences between sediment type for inventory ($r^2 = 0.34$; $P < 0.001$), peak concentration ($r^2 = 0.47$; $P < 0.001$), surface concentration ($r^2 = 0.42$; $P < 0.001$), and sedimentation rate ($r^2 = 0.34$; $P < 0.001$). In all four cases, the soft mud had higher levels than both sandy mud and eroded soil.

Linear regression was used to test for relationships between the four measures of ^{137}Cs accumulation and distance from release source as measured by river mile. We also investigated across-channel effects on ^{137}Cs as measured by distance from shore and water depth. In all cases we did not find that significant amounts of variability in the ^{137}Cs variables were explained by these explanatory variables. It is important to note that the Olsen et. al. (1990) data were not collected to explicitly test these types of effects.

Estimation of ^{137}Cs Inventory

Using the total core inventories, we estimate that Watts Bar Reservoir contains 267 Ci of ^{137}Cs . This is approximately 80 percent of the decay-corrected total of 335 Ci ^{137}Cs released into the Clinch River from White Oak Lake. Olsen et. al. (1990) estimate that the reservoir contains 304 Ci of ^{137}Cs which is approximately 91 percent of the total release. Given the uncertainties in assigning cores to polygons, we feel that these estimates are not significantly different. In order to assess the potential exposure of ^{137}Cs to aquatic biota, we calculated an inventory in the top 16 cm of sediment. We estimate 24 Ci or 7 percent of the total inventory of ^{137}Cs resides in the top 16 cm of sediment.

Accumulation zones for both total and surface inventory estimates occur along the old Clinch River and Tennessee River channels where the impoundment of water has reduced currents and permitted accumulation of sediment and particle-associated contaminants. Nearshore areas in the upper reaches of the reservoir also exhibit high inventories. The sediments in the major embayments contain relatively low inventories of ^{137}Cs suggesting local sediment sources rather than the influx of sediment from the main body of the reservoir.

SUMMARY AND CONCLUSIONS

The lack of difference between samples collected by gravity corer and vibracorer is important since it permits us to combine the data for other analyses. The strong relationship between inventory and peak concentration is important since this indicates that most of the ^{137}Cs retained in the reservoir is associated with the peak discharge from the ORR and that this peak has been effectively trapped by the sediments. The fact that the reservoir contains large areas of fine-grained sediments based on the surface sediment samples, and that these sediments exhibit higher inventories, sedimentation rates, peak, and surface concentrations also supports the hypothesis that most of the ^{137}Cs is trapped in the Watts Bar sediments.

It is important to note that our statistical analyses are exploratory in nature and are based on a data set collected for a different purpose. A major objective of Olsen et. al. (1990) was to estimate the amount of ^{137}Cs retained by Watts Bar Reservoir. Their cores were collected in areas thought to be sediment accumulation zones and do not represent a random sampling of the reservoir. We subsequently used their data for analyses outside of their primary objective. This may account for the lack of relationships we found between our measures of ^{137}Cs accumulation and variables associated with core location. However, we feel that this is an important result in that the data collected in future phases of the CRRFI will use a statistically based sampling design.

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