Association of Hanford Origin Radionuclides with Columbia River Sediment

by
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August 1977

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WITH COLUMBIA RIVER SEDIMENT

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SUMMARY

During the past year, the three major objectives of this study have been accomplished: 1) measurement of present radionuclide concentrations in Columbia River sediments and a description of the rates and mechanisms governing the decrease in radioactivity levels in the river sediments between 1971 and 1976; 2) a characterization of the areal and depth distribution of fine grain, silty sediments in the McNary Reservoir by sub-bottom seismic surveying; and 3) obtaining deep piston cores which penetrate the entire thickness of sediment deposits at selected sites in McNary Reservoir to provide radionuclide data for estimating the inventories of radionuclides in the sediment deposits in the McNary Reservoir.

The results of these studies have shown that the short- and intermediate-lived radionuclides have now decayed to insignificant levels, and only a few long-lived radionuclides (i.e., ^{54}Mn , ^{55}Fe , ^{60}Co , ^{137}Cs , $^{152-154}\text{Eu}$, ^{238}Pu , $^{239-240}\text{Pu}$, and ^{241}Am) at trace concentrations remain buried in the sediment deposits. The surface sediments in the McNary Reservoir contain much lower radionuclide concentrations than deeper sediments because of the build-up of 40 to 80 cm of fresh, relatively uncontaminated new sediment deposits since 1971. The naturally occurring radionuclide ^{40}K now accounts for over 48% of the total activity of the surface sediments. The ^{137}Cs , ^{238}Pu , $^{239-240}\text{Pu}$, and ^{241}Am concentrations in McNary Reservoir sediments are typical of the fall-out "background" levels observed in sediments collected upriver from Hanford at Priest Rapids Dam. Deep piston cores that appear to have penetrated the entire sediment layers in the McNary Reservoir clearly show that the deepest sediments (laid down between 1953 and 1960) contain ultra low levels of Hanford origin radionuclides. This indicates that the early operations of the Hanford reactors during peak production years in the late 1950's and early 1960's did not introduce any unusually high concentrations of radionuclides, as compared to later years when more effective measures were taken to minimize the radionuclide releases to the Columbia River.

The sub-bottom seismic surveys of the river bottom in the McNary Reservoir revealed the presence of fine silty sediment deposits 1 to 5 meters thick, which are located along the Oregon side of the river between Port Kelley and McNary Dam and extend from near the shoreline to approximately 500 meters off the Oregon shore. A previously undiscovered major sediment

deposit was also observed along the Washington side of the river just upstream from McNary Dam. The sediment deposits in mid-channel and along most of the Washington side are usually of a sandier nature and are less thick. Using the piston core radionuclide data and the observed distribution of sediments in McNary Reservoir, radionuclide inventories for the photon emitting radionuclides were estimated to range from about 4000 curies for ^{55}Fe to about 9 curies for ^{54}Mn . The inventories of the alpha emitters ^{238}Pu , $^{239-240}\text{Pu}$, and ^{241}Am were estimated to be 0.32, 6.3, and 1.5 curies, respectively.

The future fate of the radionuclides in Columbia River sediments (assuming no new additions) will be a continuing deeper burial by relatively uncontaminated new sediment deposits. Continuing radioactive decay will reduce the spectrum of significant radionuclides to include only those with very long half-lives, i.e., ^{60}Co , ^{137}Cs , $^{152-154}\text{Eu}$, ^{238}Pu , $^{230-240}\text{Pu}$, and ^{241}Am .

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INTRODUCTION

During the peak years of plutonium production at Hanford, thousands of curies of ^{51}Cr and one to tens of curies of other intermediate-lived radionuclides were released each day from the Hanford reactors to the Columbia River and transported downstream.¹ Numerous studies of the radionuclide transport and accumulation processes in the Columbia River were conducted during the years of reactor operations.¹⁻⁸ The primary focus of these studies was to assess the transport, bioaccumulation, and availability to the public of the short- and intermediate-lived radionuclides in the Columbia River and its estuary. These radionuclides (i.e., ^{32}P , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{58}Co , ^{59}Fe , ^{60}Co , ^{65}Zn , ^{95}Zr - ^{95}Nb , ^{106}Ru , and ^{140}Ba) were of major importance in terms of concentration and potential dose to the public.

Immediately following deactivation in January, 1971 of the last reactor (KE) using once-through cooling with treated Columbia River water, an intensive study of the transport and depletion of both short- and long-lived radionuclides in the river was conducted.⁸ This study showed that the sediments were the major repository of Hanford-origin radionuclides, and that, except for ^{55}Fe , ^{60}Co , and $^{152-154}\text{Eu}$, the short- and intermediate-lived radionuclides in the sediments would now have decayed to insignificant amounts. The Columbia River sediments now contain a completely different spectrum of long-lived radionuclides, including ^{60}Co , ^{137}Cs , $^{152-154}\text{Eu}$, and the transuranium radionuclides ^{238}Pu , $^{239-240}\text{Pu}$ and ^{241}Am .

The present document includes data obtained during 1976 which describes the decrease in radioactivity levels in the river sediments and the sedimentation processes which occurred between 1971 and 1976. This study also includes additional new information, obtained by sub-bottom seismic surveying of the McNary Reservoir river bottom, which describes the locations and depths of the fine grain sediment deposits. Deep-sea piston coring techniques were employed to penetrate the deepest sediment deposits behind McNary Dam in order to measure for the first time the radionuclide concentrations and distributions in the very deepest sediments, which were deposited between 1960 and 1953. The combination of these data allows an approximation of the total inventory of radionuclides in the sediments behind McNary Dam, which has been shown during this and earlier studies to be the major reservoir of residual

Hanford origin radionuclides in the Columbia River system. Also, comparison of the data obtained in 1976 with the 1971 data (and in some cases 1972 and 1973 data) allows a description of the changing pattern of radionuclide distributions in the sediments since shutdown of the single-pass cooling production reactors.

HISTORICAL OVERVIEW

The discharge of reactor effluent water from the Hanford reactors to the Columbia River began in 1944 upon start-up of the first of nine production reactors, eight with once-through cooling using treated Columbia River water (see Figure 1). With the deactivation of the last once-through production reactor, KE, in January, 1971, releases of radionuclides to the river by Hanford operations became relatively insignificant. The remaining reactor in operation, N-Reactor, is a dual-purpose reactor producing plutonium as well as 860 megawatts of electrical power. The reactor has a closed primary cooling loop, and the only radioactivity entering the Columbia River from N-Reactor is from very small amounts of radionuclides which migrate through a soil bank to the river from a low level liquid waste disposal trench located several hundred yards from the river.

During operation of the eight reactors with once-through cooling, treated Columbia River water was passed through the reactors and returned to the Columbia River after a few hours' holding time. During passage through the reactors, the cooling water was subjected to the ambient neutron flux which resulted in neutron activation of the various trace elements present in the water. In addition, occasional fuel element failures occurred and trace amounts of irradiated fuel were leached by the cooling water and carried into the Columbia River. The radionuclides discharged to the river in reactor effluent water included neutron activation products, fission products, and traces of transuranium radionuclides. Upon entering the Columbia River, the radionuclides were rapidly dispersed in the river water, sorbed onto detritus and inorganic particulates, or incorporated into the aquatic biota. While the total amounts of radioactivity added to the river were rather large, the flow volume of the river is enormous, and a careful monitoring program assured that the river water radionuclide concentrations at downstream locations of domestic water consumption never exceeded regulation limits.

FIGURE 1. Operating History of Plutonium Producing Reactors at Hanford 1944 to 1976

Essentially all of the short-lived radionuclides in the river from Hanford origin have now decayed leaving a few long-lived radionuclides. Much information pertaining to the studies of primarily short-lived radionuclides in the river is given in References 1-8.

In 1971, shortly after shutdown of KE reactor, sampling programs were initiated to study the distribution and depletion of radionuclides in Columbia River water, sediments, and biota.^(8,9) As part of this program, sediment cores were collected at selected locations behind McNary, John Day, The Dalles, and Bonneville Dams to determine the transport of radionuclides through the major sedimentation basins located behind each dam. The locations of these sampling stations are shown in Figure 2.

PRESENT STUDY

In 1976, funding was provided to repeat the 1971 measurements of the radionuclide concentrations in the sediments and, in addition, to map the areal and depth distribution of sediments behind McNary Dam using sub-bottom seismic profiling techniques. The areas of greatest sediment accumulation were then sampled by deep-sea piston coring techniques to penetrate the entire sediment overburden laid down since the completion of McNary Dam and the filling of the reservoir in 1953.

This study was intended to assess the present status of Hanford origin radionuclides in the Columbia River, to provide additional information on the long-lived radionuclides, and to provide an estimation of the inventory of radionuclides deposited behind McNary Dam.

SAMPLING AND ANALYTICAL METHODS

A number of sampling locations ranging from Priest Rapids Dam above the Hanford Project to Bonneville Dam, some 360 kilometers downstream from Hanford, have been established as primary sampling stations (see Figure 2). These stations were selected from areas of known fine sediment accumulation, and their sediments contain a record of the radionuclide discharges to the river. Because the McNary Reservoir, located approximately 80 km downstream from the reactors, represents the major repository of radioactive sediments, a more intensified sampling effort was conducted there to better characterize this area.

FIGURE 2. Sediment Sampling Locations - September, 1976

To determine the radionuclide concentrations in surface sediments and in depth profiles down to approximately 55 cm, a 15 cm diameter gravity corer was used throughout this study (see Figure 3). This coring device has been used in previous studies of Columbia River sediments, and has been shown to collect relatively undisturbed, representative sediment cores.

Immediately after sampling, the sediment cores were capped on each end and were frozen in their plastic barrel liners. At the laboratory the cores were then removed, still frozen solid, from the plastic core barrels and 2.5 cm thick slabs were cut from the core by a fine jet of hot water. The outside centimeter of radius was trimmed from each slab to remove any possible contamination from overlying sediment which may have been transported downward during the coring process. The slabs were then thawed, dried at 105°C, pulverized, and then approximately 150 g aliquots were weighed and placed into 2-cm thick by 10-cm diameter plastic counting containers. The concentrations of gamma-emitting radionuclides in the samples were then measured by counting on a large dual coincidence NaI(Tl) gamma-ray spectrometer and on a Ge(Li) diode de-

The transuranium radionuclides ^{238}Pu , $^{239-240}\text{Pu}$ and ^{241}Am were in 100 gram aliquots at LFE Corp., Richmond, California. The plutonium and americium were removed from the sediments by acid leaching, purified by radiochemical separations and electrodeposited on stainless steel discs. The plutonium and americium on the discs were then measured by alpha spectrometry by counting for 1000 minutes or longer on a Si(Li) diode detector or in gridded ionization chambers. Plutonium-236 and ^{243}Am were added to each sample as tracers in determining the chemical yield through the procedure.

In September, 1976 two personnel from the Oceanography Department of the University of Washington were employed to assist us in obtaining deep 5-cm diameter sediment cores (up to 300 cm in length) from known high sedimentation areas using deep-sea piston coring techniques. The objective of the deep coring was to penetrate the entire fine sediment deposits laid down behind McNary Dam since 1953, and thus determine the radionuclide concentrations in the very deepest sediments which had never been measured. Four piston cores, ranging from 218 cm to 295 cm in length (see Figure 4) were obtained at three locations in the McNary reservoir: immediately behind McNary Dam (M-G), at Hat Rock (M-E) and at Port Kelley (M-B). At the laboratory the piston cores were sectioned

FIGURE 3. Gravity Core Sampling in the McNary Reservoir

FIGURE 4. Deep Sediment Piston Core (300 cm) Obtained Behind McNary Dam

into 10-cm long segments, and the sediments were dried, pulverized, packaged and measured for radionuclide contents as described above. At McNary Dam and Port Kelly it appeared that the piston cores (274 cm and 234 cm long, respectively) had penetrated the fine sediment deposits to the original river bed. However, at Hat Rock, where sediment deposits are estimated to be about 300 to 420 cm deep, a 295-cm long piston core did not appear to penetrate the entire thickness of fine deposits.

RESULTS AND DISCUSSION

BACKGROUND RADIONUCLIDE CONCENTRATIONS IN SEDIMENTS

The 38-cm long gravity core collected just above Priest Rapids Dam serves as a "background" sediment sample for comparing sediments collected downstream from Hanford, since it contains only fallout radionuclides from weapons testing origin (see Figure 5). Cesium-137 is the most abundant fallout radionuclide present in the Priest Rapids sediments. Trace amounts of ^{238}Pu , $^{239-240}\text{Pu}$ and ^{241}Am of fallout origin are also present. The ^{137}Cs , Pu and Am concentrations in Priest Rapids sediments are very similar to those observed in sediments from the McNary Reservoir, indicating fallout to be an important source of these radionuclides in river sediments downstream from Hanford. The bottom sediment of the Priest Rapids core (30-38 cm) appears to pre-date the periods of maximum fallout in the early 1960's since the ^{137}Cs , Pu and Am concentrations decrease rapidly to extremely low values below 30 cm. The ^{137}Cs maximum at a depth of 25-28 cm apparently corresponds to sediments deposited in 1961-63, the peak fallout years for this radionuclide. Using ^{137}Cs as a tracer of sediment deposition, a sediment accumulation rate of approximately 1.8 cm/year is estimated, a rate much lower than the accumulation of sediments in the downstream McNary Reservoir, which receives high suspended loads from the Yakima, Snake and Walla Walla Rivers.

RADIONUCLIDE CONCENTRATIONS IN SEDIMENTS DOWNSTREAM FROM HANFORD

The stretch of river between Hanford and the confluence of the Walla Walla River (see Figure 2) is fast moving water, and no major sedimentation occurs in this stretch of the river. However, one small sandy-silt core was obtained near-shore at the old Hanford ferry site (H-A). Cobalt-60, ^{54}Mn and $^{152-154}\text{Eu}$ of Hanford reactor origin were present in concentrations typically observed in

FIGURE 5. Gravity Cores - 1976

the McNary Reservoir, but the plutonium and americium concentrations were much lower (see Figure 5).

A 40-cm long sandy-silt core was collected at Wallula (M-A) which contained very low levels of Hanford origin radionuclides (see Figure 6). The relatively coarse sand deposits in this stretch of the river are typically characterized by low levels of adsorbed radioactivity compared to fine-grained sediments which are found several kilometers downstream.

The naturally occurring gamma-emitter ^{40}K is now the most abundant radionuclide in surface sediments behind McNary Dam, and accounts for approximately 48% of the total radioactivity (see Figure 7). The naturally occurring ^{226}Ra and ^{228}Th account for about 4% and 1.8%, respectively, of the total activity.

The major gamma-emitting radionuclides of Hanford origin in Columbia River sediments at McNary are now ^{60}Co (5.27 yr), ^{137}Cs (30.1 yr), and $^{152-154}\text{Eu}$ (13 yr, 8.6 yr) (see Figure 5). The shorter-lived ^{65}Zn , ^{46}Sc and ^{54}Mn , which were in relatively high concentrations shortly after the shutdown of the Hanford reactors, have now decayed to extremely low concentrations. The X-ray emitter ^{55}Fe (2.7 yr) is still the most abundant Hanford origin radionuclide in the sediments, but is of minor importance from radiation dose considerations. During the next decade the ^{55}Fe concentrations will become insignificant compared to the above longer-lived radionuclides. The decrease in concentrations of these radionuclides in the surface sediments behind McNary Dam between April, 1971 and August, 1976 are shown in Table I.

The transuranium alpha-emitting radionuclides ^{238}Pu , $^{239-240}\text{Pu}$ and ^{241}Am are present in surface sediments in extremely low concentrations, as shown in Figure 5, and are typical of concentrations observed in Priest Rapids Dam sediments upstream from Hanford.

The surface sediments in the McNary Reservoir now contain the lowest concentrations of radionuclides in the accumulated silty deposits. This is due to fresh deposits of relatively uncontaminated sediments which have accumulated between 1971 and 1976. The buildup of these relatively uncontaminated sediments since 1971 can be graphically seen in Figure 8 which shows the depth distribution of ^{60}Co in four 6" diameter by 50 cm deep gravity cores collected between April, 1971 and August, 1976. These cores were collected at approximately the same location, 450 meters upstream from McNary Dam on the Oregon side of the river.

FIGURE 6. Gravity Core from McNary Reservoir, Wallula (M-A)

FIGURE 7. Typical Radionuclide Composition in Surface Sediments Behind McNary Dam - September 1976

TABLE 1. Decrease in Concentrations of Radionuclides
in Surface Sediments in McNary Reservoir
Between 1971 and 1976

	<u>Typical Concentrations in D/M/g Dry Sediment</u>	
	<u>April, 1971</u>	<u>August, 1976</u>
^{55}Fe	1100	30 (est.)
^{65}Zn	240	0.14
^{46}Sc	120	0.34
^{60}Co	60	2.7
$^{152-154}\text{Eu}$	51	2.2
^{54}Mn	25	0.32
^{137}Cs	9	2.7
$^{239-240}\text{Pu}$	0.06	0.03

FIGURE 8. Temporal Variation of ^{60}Co Distributions in Sediment Cores from McNary Reservoir (Bouy 3 Site)

In April, 1971 just following the shutdown of KE reactor, the highest ^{60}Co concentrations were observed in the surface sediments, and a sub-surface peak at a depth of approximately 27 cm was observed which correlated with an unusually high river run-off in June, 1967. This high runoff resulted in extensive upstream scouring of the river bottom, which released pre-deposited radioactivity from the stretch of river between Hanford and Richland resulting in increased radionuclide levels being transported to the McNary Reservoir. The core collected in February, 1972, ten months later, shows the addition of about 17 cm of new, less-contaminated sediment deposits; surface concentrations deposited in April, 1971 showed a maximum at 17 cm, and the 1967 maximum peak moved down to about 37 cm. The 1971 peak has made a greater shift downward compared to the 1967 peak because the subsurface sediments become more compacted as a function of depth, whereas the upper 10-15 cm of sediment are relatively flocculent and less dense. The core collected in March, 1973 shows that approximately 27 cm of new, relatively uncontaminated sediments have been deposited over the 1971 sediments of maximum radioactivity. From the August, 1976 core it is evident that the buildup of fresh sediment has now amounted to approximately 40 cm. Thus, it becomes obvious that the fate of the radioactive sediments which were deposited during the years of reactor operations will be a burial by new, relatively uncontaminated sediments. This natural burial process should continue at approximately the same rate unless the sediment accumulation dynamics significantly change.

Two gravity cores were collected in the McNary Reservoir at Refuge Island, approximately 15 km upstream from McNary Dam. One core was collected on the Washington side and the other directly across the river on the Oregon side. The Hanford origin radionuclide composition of the sediments from the Washington side was about 2 to 3 times higher compared to sediments from the Oregon side (see Figures 9 and 10). This presumably is due to the greater dilution of the radioactivity in the sediments on the Oregon side of the river by the higher influx of uncontaminated sediments from the Snake and Walla Walla Rivers. It is known from our past sediment coring experience, and recently verified by the sub-bottom seismic survey (see Appendix), that the major sediment deposits in McNary Reservoir occur on the Oregon side of the river and are of Snake and Walla Walla River origin.

FIGURE 9. Gravity Core from McNary Reservoir, Refuge Island (M-D)

FIGURE 10. Gravity Core from McNary Reservoir, Refuge Island (M-C)

Gravity cores were also collected at Hat Rock (Station M-E) and approximately 4 km upstream from McNary Dam (Station M-F). These cores showed radionuclide depth profiles very similar to that observed at Station M-G just above McNary Dam (See Figures 11 and 12).

With the completion of John Day Dam in 1972 a relatively slack water reservoir was created which serves as a partial repository for suspended sediments transported past McNary Dam. In August, 1976 the first gravity core collected behind John Day Dam (Station JD-A) exhibited a radioactivity depth profile very similar in concentration to that observed in cores collected behind McNary Dam.

The radionuclide concentrations in cores collected behind the Dalles Dam (Stations D-A, D-B and D-C) showed slightly decreased levels compared to sediments from McNary Dam (see Figures 13 and 14). The gravity core collected behind Bonneville Dam at Stevenson, Washington (Station B-A) contained the lowest radionuclide concentrations, and appeared to be a very slowly sedimenting area (see Figure 15). Below a core depth of 20 cm the radionuclide concentrations decreased very rapidly to nearly undetectable levels for all radionuclides. It appears that sediments below a depth of 20 cm were deposited before the Hanford operations, began, and would thus represent the oldest fine sediment deposits we have yet observed in the river.

Piston Cores

Using the Hanford origin radionuclides as tracers of sediment deposition rates, it has been estimated that up to 3 to 7 meters of sediment have accumulated in some areas of the McNary Reservoir. The high sedimentation areas are located on the Oregon side of the river between Wallula Gap and McNary Dam. These sediments are mainly of Snake River and Walla Walla River origin. The radionuclide concentrations in about the deepest third of these sediment layers have, previous to this time, never been measured and would represent sediment deposited between about 1960 and 1953. McNary Reservoir began filling in 1953. During this period all eight of the Hanford reactors were in operation, and conceivably, radionuclide discharges to the river during this time would represent maximum amounts. Thus, deep-sea piston coring techniques were employed to penetrate the entire silty sediment deposits at 3 locations between Wallula Gap and McNary Dam. At two of

FIGURE 11. Gravity Core from McNary Reservoir, Hat Rock (M-E)

FIGURE 12. Gravity Core From McNary Reservoir,
1 1/2 Miles Upstream from Dam (M-F)

FIGURE 13. Gravity Core from The Dalles Dam, Rabbit Island (D-A)

FIGURE 14. Gravity Core from The Dalles Dam (D-C)

FIGURE 15. Gravity Core from Bonneville Dam - Stevenson (B-A)

these locations (M-B and M-G) it appeared that the piston cores had indeed penetrated these deposits since the very bottom of these cores contained coarser sand and debris which would be characteristic of the original river bottom.

Figures 16, 17, 18 and 19 show the depth distributions of a number of radionuclides in piston cores collected at these locations. The characteristic ^{60}Co peaks seen in the 15-cm diameter by 50-cm deep gravity cores (compare with Figure 5) can easily be identified in the upper 100 cm of the McNary #2 piston core. In addition, a ^{60}Co concentration maxima exists at a depth of about 120 cm, which corresponds to sediment deposited about 1963. This date can be derived from the depth distribution of ^{137}Cs , which shows a broad maxima peaking at a depth of about 120 cm. A large fraction of the ^{137}Cs in the river sediments originated from fallout from nuclear weapons testing. The peak fallout year was 1963 and the ^{137}Cs maxima in the sediments corresponds with sediments deposited during that period.

It is reassuring to note that the ^{60}Co , ^{137}Cs , $^{152-154}\text{Eu}$ and transuranic radionuclide concentrations in the bottom 100 cm of the piston cores are very low. This indicates that no abnormally high discharges of radionuclides to the river from the Hanford reactors occurred during the early years of their operation at peak plutonium production. These very low concentrations of radionuclides in the Columbia River sediments are truly remarkable, considering the large quantities of radioactivity which were released to the river during the years of reactor operations.

From studies of sedimentation rates using radionuclide ratios, and from the observed rapid buildup of new sediments at the Hat Rock (M-E) piston coring site, it has been estimated that this location is the fastest sedimenting area of the river observed thus far. Sedimentation rates of 16 to 30 cm/yr have been estimated for this location (sedimentation rates are variable from year to year and appear to be directly related to annual runoff volumes). It appears obvious from the depth distributions of radionuclides in the bottom portion of the Hat Rock piston core (295 cm long) that this core had not penetrated the entire fine sediment deposits to the original river bed (see Figure 17). No rapid decrease in radionuclide concentrations was observed in the bottom sediment sections as observed in the McNary Dam and Port Kelley piston cores, which might indicate the presence of the original river bed. However, from the depth

FIGURE 16. Piston Core from McNary Reservoir - Port Kelley (M-B)

FIGURE 17. Piston Core from McNary Reservoir - Hat Rock (M-E)

FIGURE 18. Piston Core #1 from McNary Dam (M-G)

FIGURE 19. Piston Core #2 from McNary Dam (M-G)

distributions of the radionuclides in the other piston cores it appears certain that the bottom sediments at the Hat Rock location would contain very low levels of radioactivity.

RADIONUCLIDE INVENTORY IN McNARY RESERVOIR

With the acquisition of the radionuclide concentrations in the piston cores and from the characterization of sediment deposits from the sub-bottom seismic survey, an estimate of the total quantities of gamma-emitting radionuclides in the sediment of McNary Reservoir can now be made. If we assume that the deepest silty sediment deposits extend approximately 500 meters from the Oregon shore (this estimate is based on seismic profiling of the river bottom) at an average sediment depth of 3 meters throughout the 40 km stretch of river between Wallula Gap and McNary Dam, and assuming a sediment density of 2.4 g/cm^3 , then approximately $1.4 \times 10^{14} \text{ g}$ of sediment are present in this stretch of the river. The average concentration of the following radionuclides, in D/M/g, was measured in the piston cores from top to bottom to be: ^{40}K - 30; ^{55}Fe - 70 (estimated); ^{60}Co - 9.6; ^{137}Cs - 7.5; $^{152-154}\text{Eu}$ - 8.2; $^{239-240}\text{Pu}$ - 0.10, ^{238}Pu - 0.0050; ^{54}Mn - 0.15; ^{241}Am - 0.023; ^{228}Th - 1.0; ^{226}Ra - 3.0; and ^{65}Zn - <0.3 . Multiplying these average concentrations by the total sediment deposits gives the following radionuclide inventories in total curies (see Figure 20): ^{40}K - 1900; ^{55}Fe - 4000; ^{60}Co - 600; ^{137}Cs - 470; $^{152-154}\text{Eu}$ - 520; $^{239-240}\text{Pu}$ - 6.3; ^{54}Mn - 9.4; ^{241}Am - 1.5; ^{228}Th - 63; ^{226}Ra - 190; and ^{65}Zn - 18. When distributed throughout the vast sediment deposits behind McNary Dam these inventories are present in very dilute concentrations in the sediments.

If we assumed that the remaining 1000 meters across the river was characterized by a silty bottom one meter thick (a very liberal estimate based on current knowledge), this would increase the radionuclide inventories by only 25%.

SUB-BOTTOM SEISMIC SURVEY OF McNARY RESERVOIR BOTTOM

Previous studies have shown that the sediment deposits behind McNary Dam represent a significant repository of Hanford origin radionuclides (1,3,8). Inventories of ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{60}Co and ^{65}Zn contained in the sediment deposits between Pasco and McNary Dam and between Pasco and Vancouver were estimated in 1966 (1,3). However, these inventory estimates were concerned

NOTE: PERCENTAGES IN PARENTHESES REPRESENT THE FRACTION OF THE TOTAL RADIOACTIVITY CONTRIBUTED BY EACH RADIONUCLIDE.

FIGURE 20. Estimated Inventories of Radionuclides (in Curies) Associated with Sediment Deposits Behind McNary Dam September 1976

with only the upper few tens of centimeters of sediments, since the concentrations of the short-lived radionuclides decreased fairly rapidly with sediment depth and the deep sediments were ignored. In order to estimate the inventories of the long-lived radionuclides now contained in McNary Reservoir sediments it is necessary to know the extent of the areal and vertical distributions of sediments and their radionuclide concentrations from top to bottom. From our previous sediment sampling experience and from estimates of sedimentation rates calculated from the change in radionuclide concentration ratios as a function of sediment depth, we knew that as much as 3 to 7 meters of sediment had accumulated in rapidly sedimenting areas of the McNary Reservoir. We also knew that these highly sedimenting areas were located along the Oregon side of the Columbia River between Port Kelley and McNary Dam. However, we did not know any of the details concerning the extent of the areal and vertical distributions of sediments throughout the entire McNary Reservoir. This information is essential for estimating radionuclide inventories in the sediment deposits.

Therefore, Holosonics, Inc. of Richland, Washington was employed to conduct a sub-bottom seismic survey of the McNary Reservoir bottom to characterize the sediment deposits. A detailed report prepared by Holosonics, Inc. is included in the Appendix, which describes the techniques employed and the results that were obtained.

In general, the Holosonics survey verifies what we had conceived the sediment distribution would resemble (see Figure 21). The seismic survey did reveal the presence of deep pockets of sediments in roughly contoured areas near the Oregon side of the river. A major discovery was the presence of fine sediment deposits along a section of the Washington side of the river several kilometers above McNary Dam.

The average thickness of the fine sediment deposits along the Oregon side of the river is approximately 3 meters. This value was used in computing the mass of the major fine-grained sediment deposits in the reservoir.

CONCLUSIONS

The Columbia River has shown the ability to safely and efficiently assimilate the residual radioactivity remaining in the river sediments from past Hanford operations.

In fast-flowing stretches of the river between Hanford and Wallula Gap (and other locations downstream from McNary Dam) the radionuclides associated with

FIGURE 21. Sub-bottom Seismic Survey Tracks in McNary Reservoir. Dark-shaded Areas Represent Major Deposits of Fine-Grained Sediments.

bottom deposits are scoured from the river during the spring freshets and deposited in relatively slack water regions of the river, primarily behind McNary Dam. Following the shut-down of the Hanford reactors no major releases of radionuclides to the river has occurred (N-Reactor occasionally releases very small amounts of specific radionuclides), and the areas of high sedimentation are now being blanketed with relatively uncontaminated sediment deposits. The following conclusions can be drawn regarding the fate of the remaining inventory of radionuclides contained in the sediments:

- 1) Surface sediments behind McNary Dam now contain extremely low concentrations of Hanford origin radionuclides due to dilution with uncontaminated sediments and to radioactive decay. The major gamma-emitters are now ^{60}Co , ^{137}Cs and $^{152-154}\text{Eu}$. Trans-uranium radionuclides (Pu and Am) are present in the sediments at near-fallout levels.
- 2) Since the shut-down of the last reactor with single pass cooling in 1971 approximately 40 to 80 cm of new, relatively uncontaminated sediments have now covered the most radioactive sediments.
- 3) Sub-bottom seismic surveys reveal that approximately 3-meter thick silty sediment deposits have accumulated in the McNary Reservoir between Wallula Gap and McNary Dam on the Oregon side of the river since the creation of the McNary Reservoir in 1953. Occasionally deeper sediment deposits appear to occur in pockets. The average sedimentation rate between 1953 and 1976 for these locations varied from about 5 to 18 cm/yr. The mid-channel and Washington side sediments appear to be composed mainly of coarser sands, possibly old sand bars from the original river bed.
- 4) Radionuclide concentrations in deep piston core sediments indicate that no unusually high radioactivity releases to the river occurred during the early peak years (1953-1963) of operations at Hanford.
- 5) Total inventories of gamma-emitting radionuclides in the major sediment deposits behind McNary Dam have been estimated to range from approximately 600 curies for ^{60}Co to 9.4 curies for ^{54}Mn . The $^{239-240}\text{Pu}$ inventory is estimated to be about 6.3 curies. The X-ray emitter ^{55}Fe inventory is estimated at 4000 curies.

- 6) The buried inventory of sediment associated residual radio-nuclides in McNary Reservoir poses no radiological hazard to human or animal populations.

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APPENDIX A

HOLOSONICS, INC. REPORT ON:

Sub-bottom Seismic Survey
Port of Walla Walla to
McNary Dam, Columbia River

SUBBOTTOM SEISMIC SURVEY
PORT OF WALLA WALLA TO
McNARY DAM, COLUMBIA RIVER

Submitted To:

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Submitted By:

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June 8, 1977

SUMMARY OF
CONCLUSIONS AND RECOMMENDATIONS

- A. Fine grained sediments (silt) were located adjacent to the Oregon shore line between Twin Sisters and McNary Dam as shown in Appendix A.
- B. Coarser grained sediments (Sand) were located above Twin Sisters and are present across the entire area surveyed.
- C. Surveys run parallel to the river channel (Numbers 1, 2, 3, 4, 1A, 2A, 3A and 4A) were chiefly used in data reduction. Cross surveys transects A through G and A', AA, AA') were of lesser value in sediment locations.
- D. By providing minor modifications to the survey system as presented, a more effective system can be provided.

INTRODUCTION

The earth and planetary chemistry section of Battelle Pacific Northwest Laboratories is conducting a program to study the transport and depletion of radionuclides in the Columbia River. In the conduct of this study, it is necessary to secure sediment samples from the river bottom which in turn will be subjected to laboratory analyses. To more efficiently define locations where such samples should be obtained, a thorough knowledge of sediment deposits should be known. Because of the lack of detailed data on the locations and thickness of those deposits, Holosonics' Field Services Department in conjunction with Battelle Pacific Northwest Laboratories, has conducted a series of sub-bottom seismic surveys on the Columbia River. The surveys were designed to determine areas of maximum sediment build-up to assist in the location of future sampling points.

A total of four, 26-mile traverses were performed parallel to the river channel. A total of nine transects were performed at right angles to the river axis at locations determined by Battelle Pacific Northwest Laboratories. From these surveys, a usable sediment inventory has been obtained.

Project Methodology

To accomplish the delineation of the deposits, Holosonics' Field Services Department provided a water-borne acoustical surveying technique. This technique, effectively reflection seismology, involves the use of a specially designed acoustic transceiver system.

The technique employs the use of an acoustical element (transmitter) pulled by a boat. The transmitter is activated, generating an acoustic pulse which in turn penetrates

the subsurface beneath the river. When the pulse strikes an acoustic impedance mismatch, a signal is reflected back to the receiver. These signals are then processed and displayed on a permanent time history record. Knowledge of the approximate acoustic wave velocity (compressional wave) allows for the conversion of the time-history data into depths of the reflecting horizons. By obtaining numerous depth soundings on a traverse in the river, a profile of the subsurface conditions can be obtained.

The penetration of the acoustic waves into the sediments is controlled by the acoustic frequency and attenuation characteristics of the sediment. Further, the resolution of specific boundary conditions is controlled by the acoustic frequency. Therefore, a survey frequency must be chosen which enables best penetration with maximum resolution. For these surveys a frequency of 7.5kHz was chosen as optimum.

During actual surveys a constant boat speed is obtained and its direction of traverse is recorded. The acoustic instruments are then pulsed at a constant rate and reflected data is recorded. The pulse rate and pulse package width is optimized based on water depth and assumed sediment thickness. In these surveys a pulse rate of 8 pulses per second with a .2ms pulse width was determined to be optimum.

Once these optimum boundary conditions are established, changes in the quality of recorded data can be made by receiver gain and recorder contrast controls. During the survey, the seismic observer monitors the recorded data and adjusts the instrument to maintain quality data reception.

Survey Equipment

The survey equipment consists of three major subsystems. An EDO Western Precision Bathymetric/Seismic Recorder Model 550A, an EDO Western Model 6269 Hull Mount Cone Transducer and Holosonics' MAP system (Mineral Acoustic Prospecting) Model 75A High Energy Acoustic Transceiver. Figure 1 shows a block diagram of the survey system.

The MAP System Model 75A provides electrical energy at a specific frequency, power level and pulse width to the cone transducer. Further, the system also provides a series of amplifiers and filters for conditioning the received signals before they are displayed on the seismic recorder.

The bathymetric/seismic recorder receives the data from the MAP System and records the received signal through amplitude discrimination on heat sensitive paper. This system also provides command signals to the transceiver to ensure proper firing sequence of the transducer.

The hull mounted cone transducer provides the acoustic wave package and serves as the receiver for the reflected acoustic signals. The transducer is designed to have a specific beam pattern to ensure proper data reception. Figure 2 shows the beam calibration for the particular transducer used for this project.

The transducer was mounted on a tubular frame and was located on the side of the survey boat by means of control ropes and an existing boom. The bottom of the transducer was located approximately three feet underwater and in a fixed position to ensure no cavitation and eliminate minor effects from the survey boat.

SUB-BOTTOM PROFILING SYSTEM

FIGURE 1

ACOUSTIC CALIBRATION FACILITY NO. II

Figure 2
Model 6269
Serial 123

Report —
S.C. 2789
Date 3-30-75

Frequency 7.0 kHz
Directivity-Trans X Rec. —
Transducer Orientation Horz.
Test Depth 9 ft.
Test Distance 12 ft.

$TAIU = 67.4db$
 $RA = -68.2db$
 $Z = 47.5-J43$
 $TA/w = 86.8db$

Standard Model NRL H-23
Water Temperature 35 °F
Remarks —

FIGURE 2

Field Program

The conduct of the sub-bottom surveys consumed eight days starting April 11, 1977 and concluding on April 20, 1977. The initial three days were spent in calibration, system performance check, correcting minor malfunctions and waiting for suitable weather conditions.

A total of 17 surveys were then conducted from April 14 to April 20th. Eight of the surveys were performed parallel to the river channel as follows:

- April 14 - Survey #1

Twin sisters to McNary Dam, 100 yards off the Oregon shore line, 21 miles length

- April 15 - Survey #2

Twin Sisters to McNary Dam, 200 yards off the Oregon shore line, 21 miles length

- April 18 - Survey #3

Twin Sisters to McNary Dam, mid-channel, 21 miles length

- April 19 - Survey #4

Twin Sisters to McNary Dam, 200 yards off Washington shore line, 21 miles length

- April 20 - Surveys 1-A, 2-A, 3-A, 4-A

Continuation of Surveys #1 through #4 upstream from Twin Sisters adjacent to the Port of Walla Walla, 20 miles total length

A total of nine surveys were performed at right angles to the river axis from April 15 to April 20th as follows:

- April 15 - Transect A - McNary Dam, 100 yards upstream from buoy line
- April 15 - Transect B - Center of McNary Park, swimming lagoon
- April 18 - Transect C - Hat Rock State Park, at navigation range marker
- April 18 - Transect AA - McNary Dam, halfway between buoy line and powerhouse
- April 18 - Transect AA' - McNary Dam, halfway between Transect AA and powerhouse
- April 19 - Transect F - Port Kelley
- April 19 - Transect F - Port Kelley
- April 19 - Transect E - Juniper
- April 19 - Transect E - Juniper
- April 19 - Transect D - Upstream end of Refuge Island
- April 19 - Transect D - Upstream end of Refuge Island
- April 19 - Transect A'' - McNary Dam upstream from buoy line (same as Transect A)
- April 20 - Transect G - Adjacent to Port of Walla Walla

Included in Appendix A, "River Charts" are the locations of all surveys performed.

Survey Data

Appendix B contains pertinent examples of original field data obtained during the field surveys. Located along the top edge of these survey records are tic marks and data concerning the lateral extent and sediment thickness as analyzed by Holosonics' Field Services Department staff.

Appendix A "River Charts" also contains plotted data as to sediment (silt and sandy silt) locations based on our analyses of survey data and geologic interpretation, and results of field sampling programs conducted by Battelle Pacific Northwest Laboratories.

Contained in Tables I through IV is a sediment inventory taken from the field data. The location (yardage from survey control points) is based on our calibration of boat speed and location, versus record length. The actual locations of the sediment deposits will vary from tabulated data due to inaccuracies of boat speed and absolute location of boat. However, by using field records, the location of deposits can be duplicated to approximately ± 20 yards. Also contained with the sediment inventory is our estimate of sediment type base of field data and geologic interpretation.

During data analysis it became apparent to our staff that the cross surveys were of lesser value than the down river traverses. This is due to the spacing of the cross transects which does not allow correlation between adjacent sets of data. These surveys contain valuable data and provide a basic understanding of the river system necessary to any interpretation. However, the data could not be used to any great extent for sediment deposit location (except at McNary Dam) and all results are based on down river traverses.

Survey Results

As can be seen in Appendix A, our interpretation shows silt and sandy silt type deposits located generally along the Oregon shore line. These deposits are felt to be located on the low angle slopes adjacent to the shore line and generally

do not extend to the center line of the river. The central section and Washington side of the river except as plotted in Appendix A, is composed of silty sand, sand and coarse aggregate or rocky bottom deposits.

Generally, the area surveyed, lying upstream from Port Kelley, is composed mostly of sand and contains large ripple marks as shown in Appendix A & B.

All sediment thicknesses are based on the assumed primary wave velocity of 5000 feet per second. This velocity should be verified by laboratory tests on core samples from actual river deposits.

TABLE I
SURVEY #1

100 Yards Off Oregon Shore Line - Twin Sisters to McNary Dam

<u>LOCATION*</u>	<u>LENGTH</u>	<u>THICKNESS**</u>	<u>PROBABLE SEDIMENT TYPE</u>
1- 1 + 1,180 yds.	100 yds.	6-8'	Silty <i>Twin Sisters</i>
1- 2 + 380 yds.	1,440 yds.	2-3' to 10-12'	Silty
1- 3 + 960 yds. to	-		
1- 4 + 40 yds.		2' up to 12' pock.	Silty
1- 6 ± 80 yds.	-	3-4'	Silty
1- 6 + 440 yds.	600 yds.	9'	Silty
1- 7 + 960 yds.	360 yds.	5-6'	Silty
1- 8 + 100 yds.	200 yds.	1-2'	Silty
1- 9 - 360 yds.	360 yds.	2-8'	Silty
1-10 + 650 yds.	200 yds.	5-7'	Silty
1-11 + 660 yds. to			
1-12 + 770 yds.	-	8-15'	Silty
1-14 + 280 yds. to			
1-15 + 190 yds.	-	Start 3-4', Center 15-18', End 4-6'	Silty
1-15 + 190 yds. to			
1-16 + 50 yds.		2-4'	Silty
1-16 + 960 yds. to			
1-17 + 50 yds.	-	1-2'	Silty
1-19 + 660 yds. to			
1-21	-	4-8'	Silty Sand to Sand
1-21 + 140 yds.	680 yds.	1-3'	Silt to Sandy Silt
1-21 + 720 yds.	480 yds.	8-10'	Silt to Sandy Silt
1-22 + 480 yds.	480 yds.	5-10'	Silt to Sandy Silt
1-23	800 yds.	8-14'	Silty to Sand Silt

Twin Sisters

Port Kelley

Port Kelley to Juniper

Juniper to Hat Rock

Hat Rock

*Based on our calibration of field data
**Vp assumed at 5000 ft/sec.

TABLE I
SURVEY #1
100 Yards Off Oregon Shore Line - Twin Sisters to McNary Dam
(CONTINUED)

<u>LOCATION*</u>	<u>LENGTH</u>	<u>THICKNESS**</u>	<u>PROBABLE SEDIMENT TYPE</u>
1-25 + 420 yds.	500 yds.	2'	Silty
1-27 to 1-27	-	1-3'	Silty
1-27	800 yds.	Var. to 15'	Silty
1-27 + 800 yds. to 1-28 - 350 yds.	-	Var. to 20'	Silty
1-28 + 720 yds.	400 yds.	10-12'	Silty
1-28 + 1,120 yds. to End of Survey		10-15' with thin pockets at irregular intervals	Silty

Hat Rock
to
McNary Dam
- Bay 3

*Based on our calibration of field data

**Vp assumed at 5000 ft/sec

TABLE II

SURVEY #2

200 Yards Off Oregon Shore Line - Twin Sisters to McNary Dam

<u>LOCATION*</u>	<u>LENGTH</u>	<u>THICKNESS**</u>	<u>PROBABLE SEDIMENT TYPE</u>
2- 1	800 yds.	8-12'	Sandy Silt to Silt
2- 3 + 100 yds. to			
2- 4 + 60 yds.	-	Var. 4-10'	Silty
2- 7	1,000 yds.	6-12'	Silty
2- 8 to 2-9	-	2-4'	Silty
2- 9 + 850 yds. to			
2-10 + 1,100 yds.		4-8'	Silty
2-10 + 1,100 yds. to			
2-14 + 400 yds.		1-3'	Sand Silt to Silty Sand
2-14 + 400 yds. to			
2-14 + 2,700 yds.		2-5' w/ 10-15' Pockets	Sandy Silt to Sand
2-14 + 2,700 yds. to			
2-16 + 1,500 yds.	-	2-3'	Sandy Silt to Sand
2-16 + 1,500 yds.	500 yds.	5-7'	Silty Sand to Silt
2-16 + 2,000 yds. to			
2-21	-	2-3'	Silty
2-22 to 2-23	200 yds.	2-3'	Silty
2-23 - 200 yds. to			
2-23 + 200 yds.		4-5' Local Pockets	Silty
2-24 to End	-	5-12' Thick pocket in 1-3' General Thickness	

Port
Kelley
to
Juniper

Juniper
to
Hat Rock

Hat Rock
to
McNary

*Based on our calibration of field data

**Vp assumed at 5000 ft/sec.

TABLE III
SURVEY #3
Mid-Channel - Twin Sisters to McNary Dam

<u>LOCATION*</u>	<u>LENGTH</u>	<u>THICKNESS**</u>	<u>PROBABLE SEDIMENT TYPE</u>	
3- 1	1,300 yds.	5-9'	Silty Sand to Sand	} Port Kelley to Juniper
3- 1 + 1,300 yds. to 3- 6	-	Var. up to 8'	Sand	
3- 8	1,500 yds.	1-3'	Sand	
3- 9 - 150 yds. to 3-10	-	5-12' Pockets	Sand Maybe Some Silt	} Juniper to Hat Rock
3-10 to 3-14	-	4-5' Occasional 12' Pockets	Sand Maybe Some Silt	
3-14 + 400 yds at Hat Rock State Park Transect C	-	Weak Indication of 12' Pockets	Sand Maybe some Silt	
3-14 + 1,100 yds.	-	4-5' Pockets	Sand	} Hat Rock to McNary Dam
3-14 + 1,400 yds.	200 yds.	3-4'	Sand Pockets Grading To Silt	
3-15 - 100 yds. to 3-15 + 200 yds.	-	3-10' Variable	Sand & Silt	
3-15 + 1,150 yds.	500 yds.	10'	Sandy Silt to Silt	
3-15 + 1,650 yds. to 3-17 - 100 yds.	-	2-4'	Sandy	
3-17 - 100 yds. to 3-17 + 600 yds.	-	5-8'	Sandy Silt To Silt	
3-17 + 600 yds.	400 yds.	10-12'	Sand	
3-17 - 1,000 yds. to End	-	Rough Bottom with Some Local Pockets of Sand	Rock & Sand	

*Based on our calibration of field data

**vp assumed at 5000 ft/sec.

TABLE IV

SURVEY #4

200 Yards Off Washington Shore - Twin Sisters to McNary Dam

<u>LOCATION*</u>	<u>LENGTH</u>	<u>THICKNESS**</u>	<u>PROBABLE SEDIMENT TYPE</u>
4- 1 to 4-2 - 200 yds.		2-4'	Sand
4- 4 + 900 yds. to			
4- 5 + 300 yds.	-	5-10'	Sand
4- 5 + 300 yds.	200 yds.	10-12'	Sand
4- 5 + 500 yds.	900 yds.	6-10' Grading to 3-6'	Sand
4- 6 + 900 yds.	700 yds.	-	Rock Bottom w/Sand and Gravel
4-10 - 650 yds. to			
4-19 - 1,400 yds.	-	5-8'	Sand
4-10 + 1,400 yds.	75 yds.	3-5' Pockets to 12'	Sand
4-12 + 750 yds. to			
4-13 + 300 yds.		5-10' Variable	Sand & Silt
4-13 + 300 yds. to			
4-15	-	2-5' Variable	Sandy Silt
4-17 - 1,100 yds. to			
4-18 + 800 yds.	-	5-15'	Silt
4-18 to Finish	-	Variable to None	Sand & Silt

Port Kelley
to
Juniper

Juniper
to
Hat Rock

Hat Rock
to
McNARY
Dam

*Based on our calibration of field data

**Vp assumed at 5000 ft/sec.

TABLE V

All Locations are Referenced From Oregon Shore Line

<u>LOCATION</u>	<u>THICKNESS</u>	<u>PROBABLE SEDIMENT TYPE</u>
SURVEY A		
0 yds. to 500 yds.	10-12'	Silty
600 yds. to 1300 yds.	2-6'	Silty
1400 yds. to 1550 yds.	3-9'	Silty
1600 yds. to 1800 yds.	3-4'	Silty
SURVEY AA		
0 yds. to 550 yds.	6-12'	Silty
630 yds. to 680 yds.	2-4'	Silty
770 yds. to 1020 yds.	6-7'	Silty
1020 yds. to 1530 yds.	10-12'	Silty
SURVEY AA'		
0 yds. to 730 yds.	2-6'	Silty
700 yds. to 1225 yds.	2-4'	Silty

CONCLUSIONS

Based on sub-bottom surveys and geologic interpretation it is our opinion that the majority of fine grained sediments are located adjacent to the Oregon shore line and are located on the bench (low angle) structures.

During the conduct and analyses of surveys it became apparent that the acoustic nature of the sediment deposits were complex. That is, the impedance mismatch (ultimately the reflection co-efficient) of the river deposited silts overlying the terrestrial silts in those areas where the pool inundated the surrounding land is very low. This low mis-match creates a low amplitude (relative) return signal which is difficult to record. Further, the attenuation of some of the silt deposits appears to be high at the frequency used (7.5 kHz).

These two acoustic characteristics coupled with the large variation in water depth, compound the data complexity and make interpretation difficult. Further, profiling in shallow water approximately fifteen feet or less adds further complexity to data reduction because the return signals are located within the instrument ringdown and multiple reflections of the first bottom. Although these conditions essentially degrade the sub-bottom data, their effect can be reduced or eliminated by providing modification to the survey techniques and systems as outlined under recommendations.

The sub-bottom profiling technique has the ability to delineate these and other sediment deposits with the help of geologic analyses and data from actual sampling programs. It is felt that this survey technique and systems with minor modification can provide enhanced data on sediment location

which would not require extensive geologic analyses or pre-survey sampling if the recommendations contained below are followed.

Recommendations

To provide complete sub-bottom profiling capabilities for the Columbia River sediment deposits, the following recommendations and modifications are suggested:

- Provide greater control on position of survey vehicle. This will allow for more accurate reconstruction of data points for sampling programs.
- Provide a dual frequency (3.5 and 7.5 kHz) profiling system. This will effectively eliminate attenuation problems and reduce the effect of low impedance mismatch at boundaries.
- Obtain occasional core samples for acoustic velocity control.
- Conduct additional cross river surveys to enable better correlation of data.
- Provide a calibration site near McNary Dam for periodic system check.
- In shallow water areas, readjust the instrumentation from normal settings to enhance the signals contained in the ringdown and first bottom multiple.

APPENDIX A

Shown in Figures 1, 2 and 3 are the locations of all surveys conducted for this project and approximate boundaries of major sediment build-up (silt and sandy silt).

LEGEND

- Traverses Run Parallel to River Channel
- Transects Run Perpendicular to River Channel
- Major Sediment Areas

COLUMBIA RIVER—MCHARY DAM TO HAT ROCK

APPENDIX B

The following contains a brief description of data reduction methods and examples of data obtained during the surveys.

Data Reduction

Subbottom profiling data is reduced in the same fashion as standard land born seismic reflection surveying. That is, a series of time-history records are obtained at discrete points along a survey line and correlation is made between records based on arrival times of significant signal sets.

Figure B-IA shows a hypothetical cross-section of a survey area. In this example, the transmitter-receiver element is located at the water surface and is towed from left to right. Ray paths are provided to show acoustic wave propagation. Ray path Number 2 is a continuation of Path 1 showing ringing in the surface layer (water layer). Additional ringing of this type will occur between Boundary A & B in the sediment layer but is not shown to avoid confusion.

Figure B-IB shows the time-history record received by the instrument before signal processing (this signal would be symmetrical about the Y-axis in real field data). The location (time) of each received signal is a function of wave propagation velocity and path length. Each significant set of signals is identified by the ray path traversed and the boundary at which it reflects. Signal A-2 indicates a multiple reflection (ghost) from Boundary A caused by the ringing of the waves in the surface layer.

The received waves are then processed by amplitude discrimination and displayed by the bathymetric/seismic recorder in thirteen shades of gray. Therefore, each tick

FIGURE B-1A

FIGURE B-1B

mark shown on the records represents the amplitude of individual waves received by the system. If the arrival times of the individual waves is consistent along the traverse, then they appear as linear features. The linear features can be interpreted as either the river bottom or boundary conditions present in the sediments as shown in Figures B-I A & B.

Figure B-II shows field data with the reflecting boundaries highlighted. The parallel line at the boundaries are created because the actual transmitted energy is a wave packet and the recorder amplitude discriminates each individual wave in the packet.

FIGURE B-II FIELD RECORD SHOWING FIRST ARRIVAL AND
MULTIPLE REFLECTIONS

RIVER BOTTOM

SEDIMENT REFLECTION

MULTIPLE REFLECTION
OF BOTTOM

A-27-

SURVEY #1

APPROXIMATELY 350 YDS. DOWNSTREAM FROM STATION 1-2 NEAR PORT KELLEY: THIS AREA CONTAINS 6 TO 8 FEET OF SEDIMENT BUILD-UP. THE RECEIVED REFLECTIONS ARE PARTIALLY MASKED BY THE TRANSDUCER RING DOWN DUE TO HIGH GAIN AND POWER LEVEL SETTINGS. AVERAGE WATER DEPTH IS 10 FT.

RIVER BOTTOM

SEDIMENT REFLECTION

MULTIPLE REFLECTION
OF BOTTOM

STATION 1-20

SURVEY #1

LOCATED AT STATION 1-20 NEAR HAT ROCK STATE
PARK; THIS AREA CONTAINS SAND DEPOSITS 4
FEET THICK AS DETERMINED FROM SUB-BOTTOM
SURVEYS AND FIELD OBSERVATIONS. NOTICE THE
LACK OF MULTIPLE REFLECTIONS (GHOSTS) IN
SOME AREAS WHILE PRESENT IN OTHERS. THIS
IS DUE TO THE VARIABLE ACOUSTIC NATURE OF
THE SEDIMENTS PRESENT. AVERAGE WATER DEPTH
IS LESS THAN 10 FEET.

AT HAT ROCK STATE PARK SAMPLE LOCATION: SEDIMENT THICKNESS IS 8 TO 14 FEET AS DETERMINED BY SUBBOTTOM SURVEYS. REFLECTIONS ARE WEAK IN THIS AREA AND ARE PROBABLY DUE TO HIGH ATTENUATION AND SCATTERING OF ACOUSTIC SIGNALS BY THE SEDIMENTS. THIS LOCATION WOULD BE VERY USEFUL AS A CALIBRATION POINT FOR FUTURE SURVEYS. AVERAGE WATER DEPTH IS 35 FEET.

SURVEY #1

RIVER BOTTOM

SEDIMENT REFLECTION

MULTIPLE REFLECTION
OF BOTTOM

MULTIPLE REFLECTION OF
SEDIMENT BOUNDARY

SURVEY #1

AT GRAIN ELEVATORS UPSTREAM FROM McNARY DAM, DOWNSTREAM 480 YDS. FROM STATION 1-29: THIS IS TYPICAL OF FINE GRAINED SEDIMENTS NEAR McNARY. NOTICE SEVERAL REFLECTIONS OF SEDIMENT IN THE LEFT HAND SECTION. THIS LOCATION WOULD BE VERY USEFUL AS A CALIBRATION POINT FOR FUTURE SURVEYS. AVERAGE WATER DEPTH IS 35 FEET.

RIVER BOTTOM

SEDIMENT REFLECTION

MULTIPLE REFLECTION OF
SEDIMENT BOUNDARY

MULTIPLE REFLECTION
OF BOTTOM

SURVEY #2

DOWNSTREAM 800 YDS. FROM STATION 2-15: THIS
SHOWS TYPICAL, THIN SAND & SILT DEPOSITS WITH
NO INDICATIONS OF THICKER AREAS. AVERAGE
WATER DEPTH IS 60 FEET.

RIVER BOTTOM

SEDIMENT BOUNDARY

(SEDIMENT REFLECTION
POSSIBLE HERE)

MULTIPLE REFLECTION
OF BOTTOM

MULTIPLE REFLECTION OF
SEDIMENT BOUNDARY

SURVEY #2

200 YDS. UPSTREAM FROM McNARY DAM: NOTICE THE BUILD-UP OF SEDIMENT IN THE SMALL DEPRESSIONS AND THE PRESENCE OF THIN SEDIMENT THROUGHOUT THE ENTIRE AREA. SOME INDICATIONS ARE PRESENT FOR DEEPER SEDIMENTS AS NOTED. AVERAGE WATER DEPTH IS 33 FEET.

buoy D

10
36'

A-33

RIVER BOTTOM

SEDIMENT REFLECTION

MULTIPLE REFLECTION
OF BOTTOM

MULTIPLE REFLECTION OF
SEDIMENT BOUNDARY

SURVEY #2

AT SAMPLE POINT, BUOY D: THIS RECORD WAS TAKEN WHILE CIRCLING AND DRIFTING AROUND THE SAMPLE AREA. NOTICE THE INCLINED LINEAR STRUCTURE PRESENT WHICH INDICATES A MINIMUM SEDIMENT THICKNESS OF 5 TO 12 FEET. THIS AREA WOULD ALSO BE IDEAL AS A CALIBRATION POINT FOR FUTURE SURVEYS. AVERAGE WATER DEPTH IS 38 FEET.

RIVER BOTTOM

SEDIMENT REFLECTION

WEAK REFLECTION
SECOND SEDIMENT BOUNDARY

MULTIPLE REFLECTION
OF BOTTOM

WEAK REFLECTION
SECOND SEDIMENT BOUNDARY

SURVEY #2

UPSTREAM 100 YDS. FROM STATION 3-16: THIS RECORD SHOWS TYPICAL SILT AND SAND DEPOSITS FOUND IN THE CENTER SECTION OF THE RIVER. NOTICE A WEAKER REFLECTION WHICH INDICATES A SECOND SEDIMENT BOUNDARY WHICH IS DEEPER THAN THE MAJOR DEPOSITS. THIS MAY BE DUE TO UNDERLYING DEPOSITS OF SILT. AVERAGE WATER DEPTH IS 43 FEET.

SURVEY #3

UPSTREAM 800 YDS. FROM McNARY DAM: THIS RECORD SHOWS A ROUGH SAND AND GRAVEL BOTTOM WITH A FINE SEDIMENT FILLED CHANNEL. NOTICE THE WEAK REFLECTION INDICATING A POTENTIAL BOUNDARY BETWEEN SAND & GRAVEL AND HARD BOTTOM. AVERAGE WATER DEPTH IS 75 FEET.

RIVER BOTTOM

POTENTIAL BOTTOM OF SAND AND GRAVEL DEPOSITS

DOWNSTREAM 500 YDS. FROM STATION 4-16: SHOWN
 HERE IS A MAJOR BUILD-UP OF SEDIMENT ALONG
 THE WASHINGTON SHORE LINE. THE PARTICULAR
 SECTION SHOWN IS LOCATED IN A SEMI-BAY AREA
 WHERE STREAM DEPOSITS ENTER THE COLUMBIA
 RIVER. SOIL SAMPLING IN THIS AREA WOULD PRO-
 VIDE CONTROL DATA ON TYPICAL SEDIMENT TYPES
 PRESENT ALONG THE WASHINGTON SHORE LINE. AV-
 ERAGE WATER DEPTH IS 24 FEET.

SURVEY #4

RIVER BOTTOM

SAND POCKETS

MULTIPLE REFLECTION
OF BOTTOM

SURVEY #1-A

DOWNSTREAM 200 YDS. FROM TWO SISTERS BEFORE
START OF SURVEY 1-A: SHOWN HERE ARE SAND
DEPOSITS TYPICAL OF AREA UPSTREAM FROM PORT
KELLEY. AVERAGE WATER DEPTH IS 65 FEET.

RIVER BOTTOM

POTENTIAL SILT
BUILD-UP

MULTIPLE REFLECTION
OF BOTTOM

SAND BUILD-UP

SURVEY #2-A

NEAR BUOY #22 ON SURVEY LINE 2-A: SHOWN HERE
ARE SAND DEPOSITS WHICH ARE FILLING IN A
CHANNEL IN THE RIVER BOTTOM. WEAK REFLEC-
TION IN THE RIGHT SIDE SHOW THE POSSIBILITY OF
FINE GRAIN (SILT) SEDIMENT BUILD-UP. AVERAGE
WATER DEPTH IS 65 FEET.

RIVER BOTTOM

MULTIPLE REFLECTION
OF BOTTOM

SURVEY #4-A

NEAR RANGE MARKER 23 ON SURVEY LINE 4-A: SHOWN
HERE ARE TYPICAL SAND DEPOSITS WITH RIPPLE
MARKS CAUSED BY WAVE ACTION. DEPOSITS IN THIS
AREA MAY BE UP TO 6 FEET THICK. AVERAGE WATER
DEPTH IS 48 FEET.

APPENDIX B

TABULATED RADIONUCLIDE CONCENTRATIONS

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 3, 1976

SAMPLE LOCATION: PRIEST RAPIDS (PR-A)

SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-2.5	32.2	<0.04	<0.04	<0.2	2.57	<0.06	1.05	7.14	0.00179 ± 17	0.0324	0.00434 ± 17
2.5-5.1		<0.06	0.135	<0.2	2.70	<0.09					
5.1-7.6		<0.04	0.053	<0.2	3.27	<0.06			0.00242 ± 11	0.0362	
7.6-10.2		<0.07	0.123	<0.2	3.88	<0.10					
10.2-12.7		<0.06	0.071	<0.2	4.24	<0.06			0.00242 ± 13	0.0492	
12.7-15.2		<0.08	<0.06	<0.2	4.96	<0.09					
15.2-17.8	32.2	<0.04	<0.03	<0.2	5.26	<0.17	0.929	7.37	0.00205 ± 14	0.0583	
17.8-20.3		<0.04	<0.04	<0.2	6.35	<0.06					
20.3-22.9		<0.04	<0.04	<0.2	7.63	<0.06			0.00248 ± 12	0.0872	
22.9-25.4		<0.06	<0.06	<0.2	8.87	<0.10					
25.4-27.9		<0.06	<0.03	<0.2	9.77	<0.06			0.00310 ± 10	0.108	0.0138 ± 9
27.9-30.5		<0.05	<0.05	<0.2	1.39	<0.08					
30.5-33.0		<0.04	0.040	<0.2	0.073	<0.05			0.00019 ± 88	0.00088 ± 21	
33.0-38.1	28.1	<0.14	0.032	<0.2	0.024	<0.07	0.829	4.01	0.00022 ± 59	0.00084 ± 21	0.00064 ± 77

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 4, 1976

SAMPLE LOCATION: HANFORD FERRY, FAR SHORE (H-4)

SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-5.1	46.6	0.196	1.93	<0.5	2.06	1.34	1.43	7.54	0.00067 ± 27	0.0104 ± 6	0.0016 ± 35
5.1-10.2		0.241	1.41	<0.5	1.55	0.791			0.00055 ± 29	0.00560 ± 7	
10.2-12.7		0.244	1.48	<0.5	1.37	0.780			0.00048 ± 39	0.00385 ± 9	
12.7-17.8		0.364	1.71	<0.5	2.32	0.750			0.00027 ± 53	0.00446 ± 9	0.0 ± 0.0010
17.8-22.9	43.4	0.419	2.17	<0.5	2.82	1.31	1.11	5.95			
GRAB SAMPLE HANFORD SLOUGH	35.9	0.087	0.944	<0.5	1.75	0.666	0.628	3.98			

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 5, 1976

SAMPLE LOCATION: SHORTY'S RANCH, WALLULA, MIDSTREAM IN ~25' OF WATER (M-A)

SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-2.5	36.0	<0.03	1.36	<0.50	<0.5	1.35	1.16	2.92			
2.5-5.1	36.0	<0.01	1.77	<0.24	2.22	1.82	1.16	3.06			
5.1-7.6	34.4	<0.05	1.84	<0.30	2.34	2.09	1.13	3.02			
7.6-10.2	34.8	<0.07	0.635	<0.50	2.13	1.22	1.09	2.60			
10.2-12.7	36.3	<0.10	0.207	<0.50	1.28	0.198	1.12	2.41			
12.7-15.2	36.6	<0.10	0.026	<0.50	0.901	<0.1	1.18	2.33			
15.2-17.8	36.2	<0.10	0.013	<0.50	0.910	<0.1	1.20	2.48			
17.8-20.3	34.3	<0.10	0.024	<0.50	0.963	<0.1	1.28	2.47			
20.3-22.9	34.1	<0.10	0.029	<0.50	1.35	<0.03	1.15	2.35			
22.9-25.4	35.1	<0.10	0.020	<0.50	0.994	<0.1	1.13	2.33			
25.4-27.9	36.4	<0.10	0.025	<0.50	0.972	<0.1	1.22	2.55			
27.9-30.5	37.3	<0.10	0.016	<0.50	0.949	<0.1	1.34	2.67			
30.5-33.0	36.4	<0.10	0.018	<0.50	1.07	<0.1	1.27	2.62			
33.0-35.6	37.3	<0.25	0.021	<0.17	1.40	<0.06	1.33	2.64			
35.6-40.6	36.6	<0.19	0.024	<0.13	1.59	<0.1	1.29	2.58			

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 5, 1976
SAMPLE LOCATION: PORT KELLY, BETWEEN PARK AND TWIN ROCKS, IN ~39' OF WATER (M-B)
SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm							238Pu	239-240Pu	241Am
	40K	54Mn	60Co	65Zn	137Cs	152-154Eu	228Th			
0-2.5	34.1	0.248	0.599	<0.269	1.92	0.491	1.16	2.49		
2.5-5.1	33.6	0.226	0.668	<0.303	2.05	0.616	1.12	2.43		
5.1-7.6	33.1	0.203	0.808	<0.340	2.10	0.688	1.11	2.48		
7.6-10.2	34.9	0.161	0.827	<0.398	2.11	0.591	1.20	2.40		
10.2-12.7	33.7	0.171	1.08	<0.408	2.08	0.798	1.11	2.61		
12.7-15.2	34.5	0.217	2.48	<0.707	2.59	1.35	1.12	3.25		
15.2-17.8	32.4	0.308	1.31	<1.04	2.50	1.17	0.990	2.47		
17.8-20.3	34.7	0.197	2.17	<0.918	2.96	1.96	1.10	2.98		
20.3-22.9	35.4	0.237	3.94	<1.36	3.57	4.05	1.09	3.45		
22.9-25.4	35.4	0.289	4.63	<1.68	3.83	4.97	1.12	3.76		
25.4-27.9	37.2	0.379	8.38	<2.91	3.75	9.95	1.14	5.15		
27.9-30.5	37.8	0.432	12.9	<4.12	6.66	14.2	1.10	6.70		
30.5-33.0	37.9	0.402	12.0	<3.38	4.35	16.8	1.08	6.65		
33.0-35.6	39.2	0.500	11.7	<3.70	6.54	19.7	1.10	6.40		
35.6-38.1	39.8	0.482	10.8	<3.12	3.23	17.7	1.11	6.23		
38.1-40.6	36.0	0.445	9.13	<2.76	4.79	18.7	1.08	5.80		
40.6-43.2	34.9	0.347	6.56	<1.96	8.27	15.2	1.06	4.80		
43.2-47.0	34.8	0.277	4.17	<1.24	4.33	10.3	1.04	3.77		
47.0-52.1	33.5	0.216	1.70	<0.486	3.42	3.94	0.989	2.65		

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: SEPTEMBER 9, 1976

SAMPLE LOCATION: PORT KELLY (M-B)

SAMPLING METHOD: PISTON CORING

CORE DEPTH (cm)	40K	54Mn	60Co	65Zn	d/m/gm					228Th	226Ra	238Pu	239 - 240Pu	241Am
					137Cs	152 - 154Eu								
0-10.2	38.9	0.11	2.17	<0.09	2.12	0.552				1.13	6.36	0.0044 ± 42	0.271	0.0121 ± 9
10.2-20.3		<0.07	3.61	<0.083	2.81	0.667								
20.3-30.5		0.113	6.28	<0.140	4.07	2.17								
30.5-40.6		<0.14	16.8	<0.519	6.03	9.10								
40.6-50.8		0.154	14.2	<0.370	7.58	9.98						0.00028 ± 50	0.0311	0.0125 ± 16
50.8-61.0		0.161	14.5	<0.539	10.9	10.9								
61.0-71.1	36.2	<0.05	5.04	<0.208	6.77	5.16			0.999	6.63				
71.1-81.3		<0.07	3.75	<0.170	4.65	3.50								
81.3-91.4		<0.07	9.19	<0.301	9.39	6.05						0.00431 ± 10	0.0993	
91.4-101.6		0.190	10.1	<0.504	7.88	10.0								
101.6-111.8		0.080	6.63	<0.224	4.12	5.69								
111.8-121.9		0.117	6.28	<0.471	6.19	8.12								
121.9-132.1	38.7	0.036	3.32	<0.391	9.40	5.43			1.17	6.92				
132.1-142.2		0.095	1.75	<0.116	6.33	4.04								
142.2-152.4		0.098	0.899	<0.288	5.53	3.00								
152.4-162.6		<0.06	0.449	<0.103	2.33	1.13								
162.6-172.7		<0.08	0.182	<0.148	1.30	0.535								
172.7-182.9		<0.04	0.500	<0.150	3.95	2.16								
182.9-193.0	41.5	<0.07	0.137	<0.041	1.61	0.241			1.32	7.35		0.00389 ± 12	0.0586	
193.0-203.2		<0.07	0.129	<0.046	1.12	0.143								
203.2-213.4		<0.04	0.033	<0.038	1.12	0.206								
213.4-223.5		<0.07	0.142	<0.045	1.25	0.239								
223.5-233.7	39.7	<0.07	0.210	<0.02	1.12	0.271			1.38	7.63	0.00159 ± 19	0.0263		0.0053 ± 25

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 5, 1976

SAMPLE LOCATION: REFUGE ISLAND, OREGON SIDE 1/2 MILE DOWNSTREAM, IN ~40' OF WATER (M-C)

SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵² Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-5.1 (SAVED)											
5.1-7.6	26.2	0.256	0.993	<0.179	2.20	1.23	0.803	2.38			
7.6-10.2	33.2	2.06	1.58	<3.22	4.57	4.95	0.751	3.88			
10.2-12.7	25.8	0.211	1.71	<0.175	2.57	1.96	0.756	2.21			
12.7-15.2	17.4	<0.10	1.82	<0.50	1.39	2.41	0.665	2.13			
15.2-17.8	24.3	0.353	5.03	<0.556	2.36	2.06	0.723	2.86			
17.8-20.3	26.1	0.180	1.76	<0.178	2.29	1.73	0.767	2.43			
20.3-22.9	24.3	0.196	2.21	<0.267	2.37	2.28	0.775	2.27			
22.9-25.4	23.9	0.284	2.78	<0.379	2.55	2.52	0.702	2.53			
25.4-27.9	24.2	<0.10	3.65	<0.50	2.97	4.43	0.732	2.34			
27.9-30.5	25.1	0.246	4.37	<0.379	3.50	4.58	0.728	2.39			
30.5-33.0	22.3	0.269	3.90	<0.602	3.35	4.01	0.737	2.69			
33.0-35.6	39.7	0.349	4.04	<0.675	4.47	4.76	1.02	3.32			
35.6-38.1	25.3	0.168	2.83	<0.312	2.88	3.56	0.742	2.25			
38.1-40.6	25.6	0.183	3.39	<0.319	3.16	3.39	0.704	2.26			
40.6-43.2	23.9	<0.10	3.09	<0.50	3.00	3.64	0.738	2.45			
43.2-45.7	24.7	0.128	3.74	<0.285	3.29	4.51	0.721	2.22			
45.7-48.3	23.9	0.151	8.59	<0.559	4.89	8.57	0.762	2.83			
48.3-50.8	19.5	0.210	8.88	<1.21	5.41	9.51	0.734	3.21			
50.8-53.5	21.5	0.150	9.48	<0.910	4.04	8.14	0.787	3.13			
53.5-55.9	23.8	0.197	7.97	<0.814	4.08	7.79	0.776	2.59			
55.9-58.4	21.5	0.279	8.95	<1.24	4.19	7.53	0.721	3.02			
58.4-63.5	14.9	<0.10	14.7	<0.50	5.01	18.1	0.749	2.36			

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 5, 1976

SAMPLE LOCATION: REFUGE ISLAND, WASHINGTON SIDE, UPSTREAM END IN ~30' OF WATER (M-D)

SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵² Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-2.5	22.3	0.47	3.91	<0.50	5.39	5.55	0.777	3.93			
2.5-5.1	20.8	0.47	6.78	<0.25	13.3	8.95	0.769	4.53			
5.1-7.6	20.7	1.1	8.39	2.9	6.49	8.03	0.708	5.12			
7.6-10.2	18.9	<0.28	10.3	<0.92	7.89	13.6	0.731	5.59			
10.2-12.7	11.5	<0.25	14.8	<1.5	9.70	25.0	0.656	6.97			
12.7	13.4	<0.1	10.8	<0.64	10.5	23.3	0.678	5.95			
15.2	16.5	<0.1	7.85	<1.3	9.26	20.7	0.686	4.96			
17.8	17.4	<0.1	7.88	<0.50	8.36	20.1	0.667	4.76			
20.3	12.7	<0.1	13.6	<0.50	12.9	36.0	0.678	6.16			
22.9	14.9	<0.1	12.0	<0.50	11.8	34.7	0.695	6.39			
25.4	20.0	<0.1	6.23	<0.50	9.39	19.8	0.700	4.58			
27.9	23.3	<0.1	1.51	<0.50	7.35	8.57	0.670	3.23			
30.5-34.3	23.6	<0.1	1.03	<0.50	7.27	6.22	0.679	3.08			
34.3-39.4	24.4	<0.11	0.999	<0.50	6.76	5.68	0.670	3.16			
39.4-44.5	21.3	<0.29	0.347	<0.50	2.74	1.32	0.594	2.14			

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 18, 1976

SAMPLE LOCATION: HAT ROCK IN ~51' OF WATER (M - E)

SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-5.1	38.9	0.719	1.83	<0.33	2.11	1.44	1.30	6.40			
5.1-12.7		0.218	2.61	<0.34	2.56	2.67					
12.7-15.2		0.248	3.54	<0.19	2.42	2.73					
15.2-17.8		0.124	3.36	<0.18	2.44	2.71					
17.8-20.3		0.222	5.09	<0.22	3.04	4.34					
20.3-22.9		0.156	5.02	<0.24	3.18	4.84					
22.9-25.4	39.4	<0.17	4.25	<0.42	3.04	4.34	1.13	6.73			
25.4-27.9		0.121	3.46	<0.18	2.89	3.72					
27.9-30.5		0.146	4.43	<0.60	3.21	3.98					
30.5-33.0		0.149	4.32	<0.30	2.81	4.02					
33.0-35.6		<0.13	8.13	<0.30	4.35	7.94					
35.6-38.1		0.458	12.2	<0.65	4.91	10.6					
38.1-40.6	39.0	0.214	13.3	<0.38	5.11	10.4	1.14	6.36			
40.6-43.2		<0.29	17.6	<0.82	6.15	15.7					
43.2-45.7		0.298	12.0	<0.41	4.00	16.4					
45.7-48.3		<0.37	26.7	<1.15	8.74	33.5					
48.3-50.8		<0.21	25.9	<0.65	8.00	33.3					
50.8-53.5		<0.36	25.7	<1.15	8.12	35.5					
53.5-55.9	39.5	0.247	23.9	<0.68	8.04	35.4	1.16	7.43			
55.9-58.4		0.259	24.5	<0.73	9.26	38.8					
58.4-60.0		0.309	25.2	<0.72	10.3	42.3					
60.0-63.5		<0.21	22.3	<0.68	9.63	36.8					
63.5-66.0		<0.34	16.3	<1.13	9.11	31.7					
66.0-71.1	37.7	<0.15	11.7	<0.62	7.76	23.0	1.02	6.25			

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: SEPTEMBER 9, 1976
 SAMPLE LOCATION: HAT ROCK (M-E)
 SAMPLING METHOD: PISTON CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-10.2	38.7	0.039	3.86	<0.176	2.35	0.851	1.23	6.88	0.00404 ± 9	0.102	0.0249 ± 6
10.2-20.3		0.054	7.86	<0.360	3.43	2.43					
20.3-30.5		0.066	3.71	<0.150	3.44	1.54					
30.5-40.6		0.193	7.57	<0.213	5.72	1.19					
40.6-50.8		0.195	13.9	<0.248	5.50	4.17			0.00664 ± 7	0.162	
50.8-61.0		0.582	23.5	<0.575	7.89	7.18					
61.0-71.1	40.1	0.237	27.0	<0.266	8.75	11.8	1.64	8.86	0.00439 ± 10	0.129	0.0292
71.1-81.3		0.205	24.8	<0.488	9.14	16.8					
81.3-91.4		0.182	25.6	<0.762	10.9	18.4					
91.4-101.6		0.185	15.6	<0.637	9.25	12.1					
101.6-111.8		0.262	9.87	<0.532	7.56	7.63					
111.8-121.9		0.116	14.0	<0.305	8.56	10.1					
121.9-132.1	39.8	0.213	23.3	<0.730	13.1	15.7	1.30	10.4	0.00425 ± 11	0.164	0.0397
132.1-142.2		0.266	17.5	<0.889	16.8	19.0					
142.2-152.4		<0.093	11.9	<0.394	11.2	10.9					
152.4-162.6		<0.070	7.40	<0.270	8.68	6.69					
162.6-172.7		<0.15	12.3	<0.726	11.5	12.9			0.00601 ± 9	0.189	
172.7-182.9		<0.07	10.7	<0.348	10.0	10.7					
182.9-193.0	41.9	0.240	18.8	<0.962	16.2	22.4	1.33	10.4	0.00452 ± 8	0.116	0.0259 ± 8
193.0-203.2		<0.06	18.5	<0.579	15.0	22.7					
203.2-213.4		0.344	17.0	<0.843	11.4	18.1					
213.4-223.5		0.111	12.9	<0.414	9.34	13.2					
223.5-233.7		0.104	9.93	<0.414	8.76	12.9			0.00899 ± 7	0.0962	
233.7-243.8		0.154	12.5	<0.368	8.43	12.8					
243.8-254.0	39.7	<0.08	11.9	<0.375	8.17	12.5	1.27	10.8			
254.0-264.2		<0.14	11.4	<0.616	8.33	9.82			0.00910 ± 7	0.0977	
264.2-274.3		<0.13	10.8	<0.565	6.94	11.0					
274.0-284.5		<0.13	11.1	<0.560	6.58	10.8					
284.5-294.6	39.4	<0.08	10.2	<0.336	6.59	11.6	1.06	9.9	0.00082 ± 27	0.0286	0.00738 ± 11

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 18, 1976

SAMPLE LOCATION: 1-1/2 MILES UPSTREAM FROM McNARY DAM, OREGON SIDE (M-F)

SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-5.1	37.2	0.246	2.13	<0.16	2.69	1.74	1.12	6.21			
5.1-7.6		0.229	2.60	<0.23	2.87	2.08					
7.6-10.2		0.320	3.72	<0.22	2.97	3.17					
10.2-12.7		0.329	8.21	<0.27	3.53	5.04					
12.7-15.2		0.385	9.72	<0.54	4.54	7.92					
15.2-17.9		<0.19	14.8	<0.46	5.79	14.1					
17.8-20.3	37.1	0.332	24.5	<1.1	8.83	31.3	1.11	7.90			
20.3-22.9		0.354	20.6	<0.65	10.0	34.1					
22.9-25.4		0.401	12.7	<0.80	7.56	23.2					
25.4-27.9		<0.22	24.3	<0.70	12.7	38.3					
27.9-30.5		<0.36	20.2	<1.17	14.2	36.8					
30.5-33.0		<0.25	15.3	<0.63	12.5	31.7					
33.0-35.6	37.0	<0.12	13.3	<0.66	12.5	31.7	1.02	7.50			
35.6-38.1		<0.16	14.0	<0.67	11.6	35.5					
38.1-40.6		<0.15	17.0	<0.79	12.6	44.4					
40.6-43.2		<0.31	12.0	<1.07	7.52	28.1					
43.2-45.7		<0.12	10.7	<0.64	9.96	28.9					
45.7-48.3		<0.26	5.64	<0.96	13.1	21.5					
48.3-50.8	38.2	<0.09	4.38	<0.52	11.8	18.9	1.03	8.20			
50.8-53.5		<0.09	3.88	<0.52	11.2	19.1					
53.5-55.9		<0.20	3.22	<0.50	10.5	17.6					
55.9-58.4		<0.15	3.73	<0.86	9.34	14.7					
58.4-60.0	37.7	<0.12	1.08	<0.57	4.78	7.42	1.08	7.10			

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 5, 1976
SAMPLE LOCATION: McNARY BOUY #3 (M-G)
SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm DRY SEDIMENT										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-5.1	34.6	0.317	2.69	<0.14	2.65	2.23	1.21	5.82	0.00237 ± 12	0.0324	0.0052 ± 23
5.1-10.2		0.288	3.70	<0.17	5.81	3.10					
10.2-12.7		0.262	3.48	<0.14	2.35	2.37					
12.7-15.2		0.288	4.63	<0.16	2.36	3.01					
15.2-17.8		0.193	6.46	<0.20	3.18	4.82			0.00185 ± 16	0.0365	
17.8-20.3		0.259	7.41	<0.25	3.88	6.52					
20.3-22.9	37.1	0.203	6.18	<0.23	3.72	5.95	1.10	5.85	0.00296 ± 14	0.0426	
22.9-25.4		0.092	5.69	<0.22	3.92	5.13					
25.4-27.9		0.187	6.54	<0.23	4.14	4.80					
27.9-30.5		0.188	8.92	<0.24	4.10	6.67					
30.5-33.0		0.248	16.6	<0.35	6.74	14.0			0.00438 ± 11	0.0685	
33.0-35.6		0.237	18.0	<0.39	7.43	15.4					
35.6-38.1	37.5	0.247	18.6	<0.39	6.63	14.9	1.07	8.07	0.00426 ± 10	0.0586	
38.1-40.6		0.267	25.1	<0.48	7.72	22.9					
40.6-43.2		0.501	36.8	<1.2	9.96	37.6			0.00733 ± 7	0.0941	0.020 ± 9
43.2-45.7		0.348	36.2	<0.66	10.1	41.7					
45.7-48.3		0.439	32.2	<0.68	10.0	45.9			0.00894 ± 7	0.117	
48.3-50.8		0.223	28.5	<0.65	9.48	44.0					
50.8-53.5	37.7	0.388	27.6	<0.68	10.9	48.2	1.06	8.76			
53.5-55.9		<0.18	29.6	<0.75	12.4	51.0					
55.9-58.4		<0.26	28.2	<0.72	11.7	51.3			0.00806 ± 7	0.156	
58.4-61.0		<0.14	22.6	<0.65	11.3	42.5					
61.0-63.5		<0.16	19.1	<0.65	10.1	35.0			0.00705 ± 8	0.195	
63.5-68.6	37.9	<0.14	27.2	<0.65	12.1	43.2	1.19	7.84	0.00762 ± 9	0.220	0.0409 ± 6

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: SEPTEMBER 9, 1976
SAMPLE LOCATION: McNARY, BOUY #3 (M-G)
SAMPLING METHOD: PISTON CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-10.2	36.1	0.277	3.04	<0.095	2.89	1.08	1.10	6.18	0.00039 ± 41	0.00840 ± 7	0.0015 ± 38
10.2-20.3		0.269	5.01	<0.105	2.83	1.31					
20.3-30.5		0.134	5.94	<0.136	3.71	1.89					
30.5-40.6		0.285	12.5	<0.306	5.80	4.09					
40.6-50.8		0.345	22.7	<0.096	8.62	7.84					
50.8-61.0		0.430	31.2	<0.742	9.93	17.0			0.00079 ± 28	0.0427	0.0172 ± 11
61.0-71.1	38.7	0.194	27.6	<0.464	12.6	20.0	1.19	9.83			
71.1-81.3		0.145	18.6	<0.610	10.4	13.8			0.00415 ± 13	0.0992	
81.3-91.4		0.201	25.7	<0.437	12.4	18.0					
91.4-101.6		0.171	15.5	<0.637	12.7	14.2					
101.6-111.8		<0.07	9.37	<0.330	9.93	11.7					
111.8-121.9		<0.16	17.5	<0.773	14.6	20.5					
121.9-132.1	39.3	<0.10	19.5	<0.433	14.4	21.0	1.12	9.00	0.00478 ± 9	0.137	0.0281 ± 7
132.1-142.2		<0.08	11.3	<0.337	7.30	12.9					
142.2-152.4		<0.08	12.6	<0.362	8.41	14.6					
152.4-162.6		<0.13	6.49	<0.535	11.4	10.9					
162.6-172.7		<0.06	4.19	<0.286	9.69	8.32					
172.7-182.9		<0.14	2.46	<0.422	8.86	6.51					
182.9-193.0	37.8	<0.14	1.57	<0.191	5.48	3.69	1.04	7.56	0.00796 ± 7	0.208	0.0469
193.0-203.2		<0.04	0.755	<0.167	3.61	2.67					
203.2-213.4		<0.08	1.24	<0.216	4.33	1.58			0.00743 ± 7	0.110	
213.4-223.5		<0.03	0.561	<0.070	2.20	0.583					
223.5-233.7		<0.04	0.524	<0.086	2.50	0.777			0.00450 ± 10	0.0589	
233.7-243.8		<0.12	1.40	<0.197	7.59	3.70	1.13	8.92			
243.8-254.0	40.5	<0.15	0.874	<0.293	7.46	2.28					
254.0-264.2		<0.06	0.874	<0.063	1.49	0.389			0.00202 ± 14	0.0319	0.0070 ± 16
264.2-274.3		<0.09	0.175	<0.06	0.123	0.042					

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: SEPTEMBER 9, 1976

SAMPLE LOCATION: McNARY, BOUY #3 (M-G)

SAMPLING METHOD: PISTON CORING

CORE DEPTH (cm)	d/m/gm						²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu					
0-15.2	34.2	0.184	2.86	<0.086	2.48	1.09	0.957	5.14			
15.2-25.4		0.160	5.13	<0.140	2.98	1.59					
25.4-35.6		0.149	4.94	<0.223	3.47	1.64					
35.6-45.7		0.167	9.11	<0.145	4.09	2.70					
45.7-55.9		0.235	22.0	<0.279	6.70	8.30					
55.9-66.0	32.9	0.198	27.9	<0.341	8.31	14.4	0.972	7.03			
66.0-76.2		<0.17	22.7	<0.340	10.4	17.2					
76.2-86.4		<0.16	22.8	<0.684	13.3	17.9					
86.4-96.5		<0.10	15.4	<0.286	12.8	13.7					
96.5-106.7		<0.09	8.96	<0.434	8.43	9.72					
106.7-116.8		<0.09	16.6	<0.416	14.3	19.5					
116.8-127.0	34.9	<0.15	17.0	<0.329	12.3	19.6	1.07	6.98			
127.0-137.2		<0.06	11.9	<0.280	7.81	13.7					
137.2-147.3		<0.04	5.60	<0.425	11.5	9.65					
147.3-157.4		<0.07	3.71	<0.352	8.80	6.28					
157.4-167.6		<0.07	1.96	<0.142	7.69	5.10					
167.6-177.8		<0.13	0.797	<0.596	3.97	2.64					
177.8-188.0	35.3	<0.03	0.917	<0.114	4.96	1.67	1.19	5.71			
188.0-198.1		<0.09	0.318	<0.150	2.23	0.686					
198.1-208.3		<0.04	1.19	<0.142	5.83	2.57					
208.3-218.4		<0.04	1.39	<0.133	7.11	1.98					

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RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 10, 1976

SAMPLE LOCATION: JOHN DAY DAM, OREGON SIDE, DOWNSTREAM FROM JOHN DAY RIVER BRIDGE,
IN ~55' OF WATER (JD-A)

SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-2.5	37.2	0.642	4.30	<0.220	3.31	2.76	1.13	6.09			
2.5-5.1		0.557	4.51	<0.253	3.64	3.42					
5.1-7.6		0.565	5.17	<0.255	3.94	3.54					
7.6-10.2		0.286	4.00	<0.381	2.37	3.13					
10.2-12.7		0.506	5.21	<0.269	3.99	3.72					
12.7-15.2		0.234	5.03	<0.425	2.66	3.94					
15.2-17.8	36.3	0.285	10.3	<0.386	4.23	7.51	1.09	6.94			
17.8-20.3		0.282	10.8	<0.754	4.92	7.90					
20.3-22.9		0.206	10.3	<0.382	4.79	8.34					
22.9-25.4		0.193	9.00	<0.623	4.67	7.95					
25.4-27.9		0.104	7.52	<0.320	4.65	6.08					
27.9-30.5		0.326	8.98	<0.381	5.34	7.21					
30.5-33.0	34.1	0.411	9.51	<0.370	5.18	7.62	1.11	6.52			
33.0-35.6		0.295	10.7	<0.383	4.49	8.52					
35.6-38.1		0.398	22.7	<1.10	7.35	19.3					
38.1-40.6		0.367	29.7	<0.580	7.75	18.1					
40.6-43.2		0.406	24.4	<1.03	8.59	18.1					
43.2-45.7		0.443	24.2	<0.644	9.25	18.3					
45.7-48.3	28.9	0.544	22.3	<0.920	6.05	20.6	0.895	5.10			
48.3-53.5		0.373	27.7	<0.708	7.54	30.8					

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 10, 1976

SAMPLE LOCATION: THE DALLES, DOWNSTREAM FROM RABBIT ISLAND IN ~35' OF WATER (D-A)

SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-2.5	33.2	0.213	1.67	<0.2	1.31	1.66	0.910	5.50			
2.5-5.1		0.246	1.68	<0.2	1.40	1.59					
5.1-7.6		<0.07	4.27	<0.2	2.28	6.14					
7.6-10.2		0.126	6.45	<0.2	3.48	10.1					
10.2-12.7		<0.07	4.64	<0.2	3.23	7.99					
12.7-15.2	32.5	<0.10	3.36	<0.2	2.60	4.57	0.823	5.18			
15.2-17.8		<0.06	6.01	<0.2	4.16	7.46					
17.8-20.3		<0.10	8.68	<0.2	5.10	11.6					
20.3-22.9		<0.10	14.7	<0.2	9.15	22.2					
22.7-25.4		<0.12	11.7	<0.2	8.29	19.9					
25.4-30.5	30.8	<0.13	6.48	<0.2	6.25	11.8	0.891	5.54			

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 10, 1976
SAMPLE LOCATION: THE DALLES DAM, OREGON SIDE, OFF THE GUARD STATION, IN ~35' OF WATER (D-B)
SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	d/m/gm										
	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-2.5	31.6	0.23	1.80	<0.129	1.59	1.94	0.881	5.50			
2.5-5.1		0.15	1.91	<0.138	1.65	2.14					
5.1-7.6		0.16	2.88	<0.209	1.98	3.60					
7.6-10.2		<0.06	2.37	<0.188	1.44	3.20					
10.2-12.7		0.094	2.61	<0.129	1.44	2.91					
12.7-15.2	30.7	0.18	5.62	<0.254	2.65	7.15	0.766	4.84			
15.2-17.8		0.14	7.77	<0.322	4.19	12.6					
17.8-20.3		0.14	7.84	<0.614	5.22	15.1					
20.3-22.9		0.14	5.76	<0.396	4.38	10.6					
22.9-25.4		<0.09	6.93	<0.398	4.46	11.0					
25.4-27.9	32.6	0.12	8.50	<0.383	4.85	11.6	0.849	5.69			
27.9-30.5		0.21	13.96	<0.528	7.12	20.6					
30.5-33.0		0.21	12.53	<0.797	7.06	17.8					
33.0-35.6		0.36	13.61	<1.06	10.0	23.7					
35.6-38.1		<0.10	11.57	<0.517	8.81	19.2					
38.1-43.2	23.9	<0.12	7.23	<0.663	6.51	13.8	0.660	5.17			

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 10, 1976

SAMPLE LOCATION: THE DALLES DAM, WASHINGTON SIDE BOAT BASIN IN ~25' OF WATER (D-C)

SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹³⁷ Cs	d/m/gm	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
						¹⁵²⁻¹⁵⁴ Eu					
0-2.5	32.6	0.207	2.78	<0.2	2.17	3.19	0.897	5.47	0.00091 ± 24	0.0241	0.0054 ± 16
2.5-5.1		0.167	3.03	<0.2	2.28	4.14					
5.1-7.6		0.119	2.54	<0.2	2.00	4.10					
7.6-10.2		0.062	0.769	<0.2	1.20	1.05					
10.2-12.7		<0.04	0.289	<0.2	0.807	0.379					
12.7-15.2	34.5	0.065	0.250	<0.2	0.719	0.105	0.818	3.67	0.00203 ± 15	0.0540	
15.2-17.8		0.139	4.00	<0.2	3.65	8.14					
17.8-20.3		<0.09	10.4	<0.2	7.38	19.9					
20.3-22.9		<0.08	10.1	<0.2	7.25	21.1					
22.9-27.9		35.0	<0.07	7.90	<0.2	5.59					
							0.922	6.94	0.00326 ± 12	0.0870	0.0199 ± 7

RADIONUCLIDE CONCENTRATIONS IN COLUMBIA RIVER SEDIMENT

SAMPLE DATE: AUGUST 11, 1976

SAMPLE LOCATION: STEVENSON, WASHINGTON, OFF CEMETERY IN ~20' OF WATER (B-A)

SAMPLING METHOD: GRAVITY CORING

CORE DEPTH (cm)	⁴⁰ K	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	d/m/gm		¹³⁷ Cs	¹⁵²⁻¹⁵⁴ Eu	²²⁸ Th	²²⁶ Ra	²³⁸ Pu	²³⁹⁻²⁴⁰ Pu	²⁴¹ Am
0-2.5	31.4	<0.20	1.98	<0.2	1.51	1.55	0.993	5.56	0.00092 ± 24	0.0184	0.00078 ± 61		
2.5-5.1		<0.21	1.60	<0.2	1.54	1.65							
5.1-7.6		<0.12	1.61	<0.2	1.30	1.81							
7.6-10.2		<0.10	1.92	<0.2	1.39	1.97							
10.2-12.7		<0.10	2.62	<0.2	1.58	2.92					0.00102 ± 22	0.0210	
12.7-15.2		<0.09	3.45	<0.2	1.87	4.10							
15.2-17.8	35.7	<0.07	3.74	<0.2	2.78	6.21	0.926	5.94					
17.8-20.3		<0.03	3.25	<0.2	2.25	5.98							
20.3-22.9		<0.10	0.159	<0.2	0.212	0.270					0.0 ± 0.00004	0.00184 ± 17	
22.9-25.4		<0.10	0.048	<0.2	0.047	0.067							
25.4-27.9		<0.10	<0.04	<0.2	0.032	<0.05							
27.9-30.5		<0.10	<0.04	<0.2	0.042	0.103							
30.5-34.3	38.3	<0.10	<0.03	<0.2	0.042	0.061	0.731	4.15	0.00020 ± 71	0.00034 ± 47	0.0062 ± 21		
34.3-39.4		<0.10	<0.03	<0.2	<0.02	<0.04							

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