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RADIOACTIVE MATERIALS IN BOTTOM SEDIMENT OF CLINCH RIVER: PART A, INVESTIGATIONS OF RADIONUCLIDES IN UPPER PORTION OF SEDIMENT

P. H. Carrigan, Jr.
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HEALTH PHYSICS DIVISION

RADIOACTIVE MATERIALS IN BOTTOM SEDIMENT OF CLINCH RIVER: PART A, INVESTIGATIONS OF RADIONUCLIDES IN UPPER PORTION OF SEDIMENT

Supplement No. 2A to Status Report No. 5 on Clinch River Study

By

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Final Progress Report, Part A, of Subcommittee on Bottom Sediment Sampling and Analysis

MARCH 1967

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ACKNOWLEDGMENT

The Subcommittee on Bottom Sediment Sampling and Analysis arranged for canvass of information pertaining to the association of radionuclides with bed deposits of the Clinch and Tennessee Rivers. From this compilation, a summary of available data pertinent to the area of study of the subcommittee[1] was prepared.

The Subcommittee on Bottom Sediment Sampling and Analysis was appointed in May 1961 to help coordinate and implement the investigations of the Clinch River Study[2].

Membership of the subcommittee has been as follows: P. H. Carrigan, Jr., (USGS), Chairman (1961-3, 1965); R. M. Richardson (USGS), Chairman (1964); H. H. Abee (ORNL); T. Tamura (ORNL); J. Smallshaw (TVA, 1961-3, ret.); J. W. Beverage (TVA, 1963); and R. W. Andrew (USPHS). Staff to the subcommittee has been as follows: W. P. Bonner (ORNL); R. Forbes (TVA); R. J. Pickering (USGS); and S. L. Cummings (USPHS).

Personal acknowledgments are made to W. D. Cottrell, Applied Health Physics Section, ORNL, for his many special efforts in consultation on aspects of the programs of monitoring radioactivity in water and sediments at ORNL, to E. J. Witkowski, Operations Division, ORNL, J. O. Blomeke, F. N. Browder, and H. E. Goeller, Chemical Technology Division, ORNL, for their valuable descriptions of the historical development of processes and facilities at ORNL, and to R. W. Andrew, USPHS, for providing heretofore unpublished results of his studies of radioactivity in bottom sediments.

Parts of the text of this report have appeared as short progress reports of investigations in Status Reports Nos. 2-5 on Clinch River Study[1-4], and a summary of this report is in Status Report No. 5 on Clinch River Study[4].

INTRODUCTION

Radionuclides in the bottom sediment of the Clinch and Tennessee Rivers originate from three sources: naturally occurring radioactive materials in the earth, fallout from weapons testing, and the release of low-level radioactive waste from various industrial and research facilities to streams in eastern Tennessee. The principal source is the Oak Ridge National Laboratory (ORNL). Operations began at the Oak Ridge National Laboratory in 1943.

Radioactive waste effluents from facilities at ORNL pass through a waste processing system. The processed liquid wastes, containing low-level radioactivity, enter the Clinch River via White Oak Creek (Fig. 1).

Health physicists at ORNL noted radioactive materials associated with bottom sediments in the creek embayment (0.6 mile long) downstream from White Oak Dam. Later (1951) their investigations indicated radioactivity in bottom sediment of the Clinch and Tennessee Rivers.

Origin of Fission Product Wastes

Fission products are discharged into White Oak Creek basin from the process waste water treatment system, waste seepage pits, and several minor sources not included in the main waste systems at ORNL[9]. Intermediate-level radioactive liquid wastes (more than 1.0 microcurie per gallon) flow in special drains to storage tanks centrally located in the ORNL plant area. The wastes are transferred by pipeline to waste seepage pits. Low-level radioactive waters seep from these pits into White Oak Creek. Low-level radioactive liquid wastes (less than 1.0 microcurie per gallon) flow in another sewage system to the process waste water treatment area. After treatment these waste waters are released into White Oak Creek.

Some facilities at ORNL are not connected into either the intermediate-level or low-level radioactive liquid waste sewage networks. Drainage of low-level radioactive materials from these facilities into White Oak Creek or tributaries is monitored to insure against discharge of waters containing radioactivity above prescribed limits.

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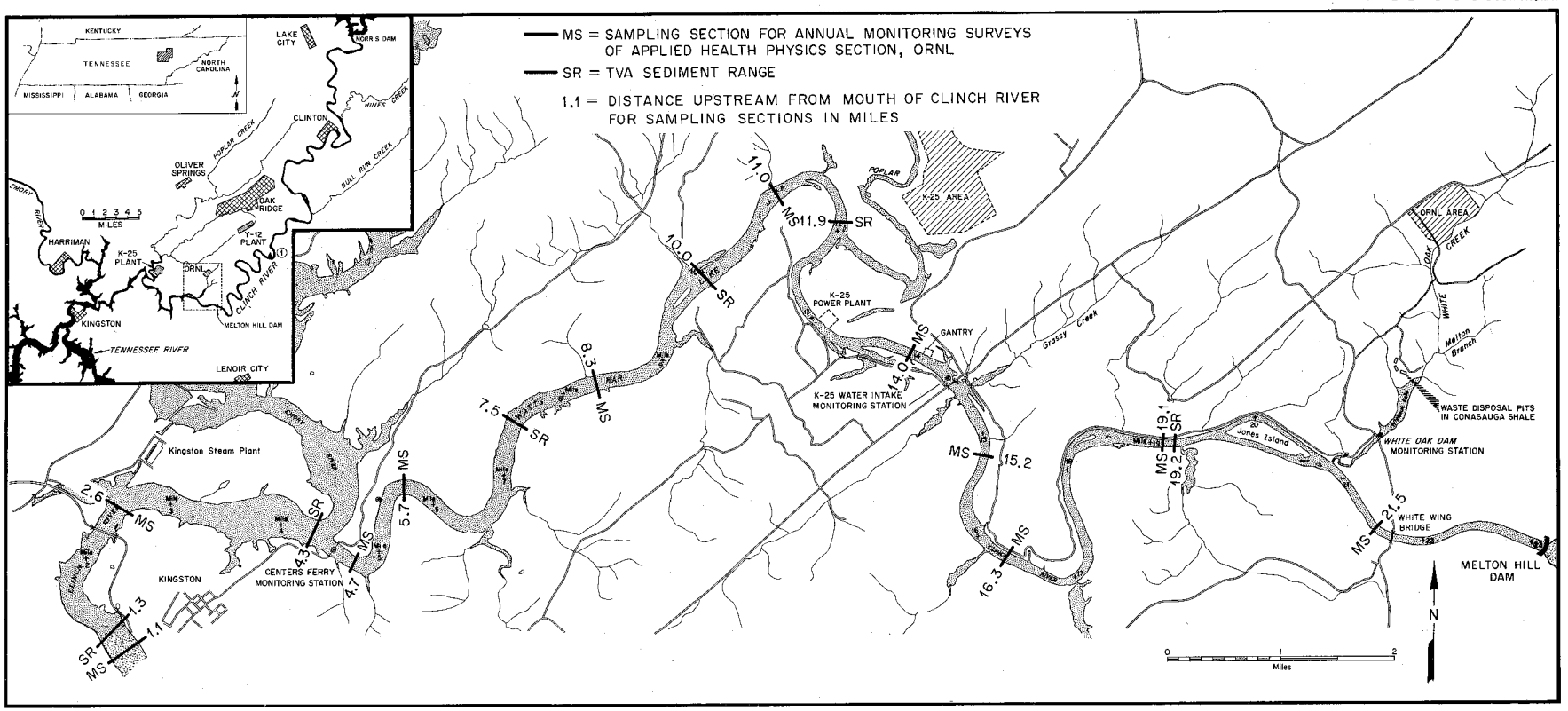


Fig. 1. Map of Clinch River Showing Bottom Sediment Observation Sections.

Objective of Report

Sources of information pertaining to the various investigations concerned with radioactivity in the bed sediments are diverse; some information is in the open literature, some in reports issued by ORNL, and much is in the files of the investigators and of the various agencies involved in the Clinch River Study. In this report information about radionuclides in bottom sediment of the Clinch and Tennessee Rivers, pertinent to objectives of the Clinch River Study is summarized and interpreted.

The objectives of the Study, as set forth by the Clinch River Study Steering Committee[10], are

(1) To determine the fate of radioactive materials currently being discharged to the Clinch River,

(2) To determine and understand the mechanisms of dispersion of radionuclides released to the river,

(3) To evaluate the direct and indirect hazards of current disposal practices in the river,

(4) To evaluate the over-all usefulness of this river for radioactive waste disposal purposes, and

(5) To provide appropriate conclusions regarding long-term monitoring procedures.

Two factors tend to define the scope of information in this report. First, most information is from investigations in progress or completed at the time of canvass of available information, June 1962. Second, a substantial change in flow conditions has occurred in the Clinch River downstream from Melton Hill Dam since this structure was completed (Fig. 1). Because these changes in flow conditions may affect the movement of radionuclides in the river, only investigations conducted prior to the time operations began at Melton Hill Dam are included in the report.

Two important studies pertaining to the Study have not been fully treated in this report. These studies are: (1) a firm estimate of the quantity of fission products in the bed of the Clinch River and (2) a description of the vertical distribution of radioactivity in bottom

sediments of the Clinch and of geochemical factors which influence this distribution. These studies are the subject of Supplement 2B.[4]

Available Data

At five-year intervals, beginning in 1946, personnel of the Hydraulic Data Branch, TVA, measured the elevation of the surface of the bottom sediments of the Clinch River at selected sections. The purpose of these measurements was (1) to estimate the number of years that sedimentation will occur (a) before sedimentation interferes with water-control operations in Watts Bar Lake and (b) before the useful life of the reservoir is ended, and (2) to determine the current capacity of the reservoir[11]. These sections, called sediment ranges, are located at Clinch River Miles (CRM) 1.3 (1.3 miles upstream from mouth of river), 4.3, 7.5, 10.0, 11.9, and 19.2 (Fig. 1). Similar work has been done in other reservoirs on the Tennessee River.

Each year, beginning in 1951, personnel of the Applied Health Physics Section, ORNL, made surveys of the radioactivity in the bottom sediments of the Clinch and Tennessee Rivers. From these surveys, they evaluated potential, present, and future hazards resulting from radioactivity in these sediments, predicted the capacity of the sediments for storing radioactive materials, recommended rates of release of radioactive wastes to the Clinch River, and determined the effect of increased radioactivity in sediments in the river system on industry[6]. The surveys extended from Norris Lake on Clinch River anf from Fort Loudoun Lake on Tennessee River into Guntersville Lake on Tennessee River (in 1952 and 1961 Kentucky Lake included; see Figs. 1 and 2)[5-8].

In 1960, personnel of the Waste Disposal Research Section, ORNL, collected core samples of bottom sediments in 19 sections of the Clinch River, from CRM 4.7 to 22.5. L. Hemphill and W. B. Nix of ORNL and P. H. Carrigan, Jr., of USGS used the cores for study of the distribution of radionuclides in the upper horizon of Clinch River bottom sediments. T. Tamura, ORNL, determined physicochemical characteristics and sorption capacity of the composites of the cores.

Composites of cores which were collected in 1961 at five sections in the Clinch River, from CRM 4.7 to 19.2, were sent to USGS

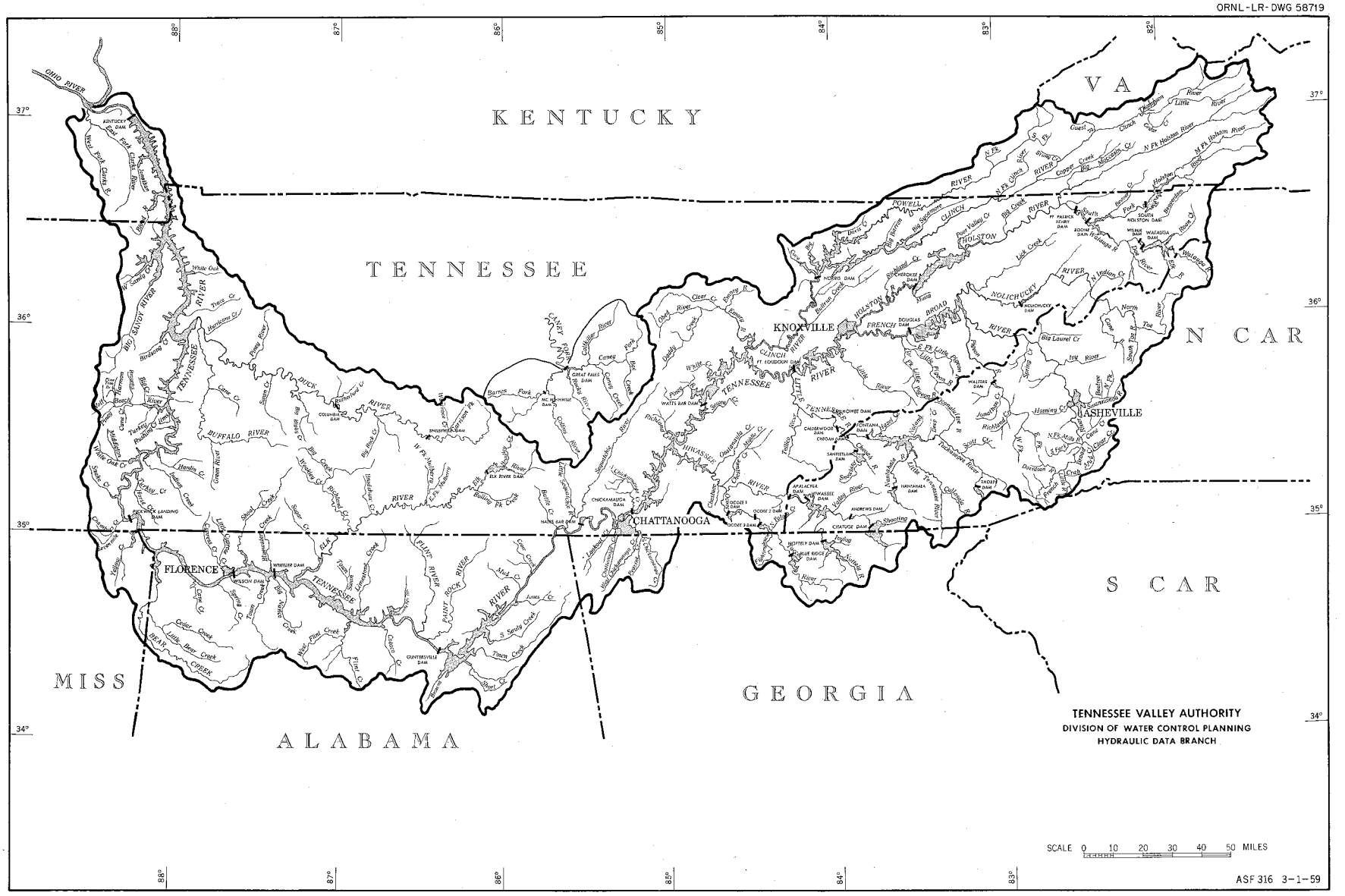


Fig. 2. Tennessee River Basin

laboratories (Denver, Colorado, and Releigh, North Carolina) for mineralogical, cation exchange, and size-distribution analyses. Study of these analyses was the first step in describing the physicochemical properties of the cores.

Scientists of the Division of Radiologic Health, USPHS, Cincinnati, Ohio, undertook investigations of bottom sediments of the Clinch and Tennessee Rivers as well. They studied the variation of radionuclide concentration with particle size and with location in the study reaches, particularly for bottom sediment of the Tennessee River.

Information on flows in the Clinch and Tennessee Rivers used in this report has been obtained from USGS and TVA reports.

DESCRIPTION OF STUDY REACH

Studies of radionuclides in river-bottom sediments have extended from Norris Lake on the Clinch River and Fort Loudoun Lake on the Tennessee River as far downstream as Kentucky Lake. A map showing the portion of the Tennessee River System included in these studies appears in Fig. 2.

The Clinch River enters the Tennessee River in the backwater pool of Watts Bar Lake, and contributes the minor portion of the inflow to the lake. Drainage area of the Clinch River at Norris Dam is 2,912 square miles, and at the mouth it is 4,413 square miles. Drainage area of the Tennessee River at Fort Loudoun Dam is 9,550 square miles, which is increased by the Little Tennessee River and minor drainage to 12,470 square miles just upstream from the mouth of the Clinch River.

The Clinch River portion of the Tennessee River basin lies principally in the Valley and Ridge Province. Sediment flowing into the study reaches is largely that contributed by minor tributaries of the Valley and Ridge Province, because the major storage reservoirs--Norris on the Clinch River, Cherokee on the Holston River, Douglas on the French Broad River, and Fontana and three downstream power pools on the Little Tennessee River--trap most of the sediment from the upper 12,850 square miles (76 percent) of the drainage area above the mouth of the Clinch River. As the sediment load passes downstream, a succession of reservoirs (Table 1) acts to retard the flow and accumulate bottom sediment from the suspended material.

For study reaches in the Clinch and Tennessee River, water levels are affected by reservoir impoundments, and flow is affected by water-control operations. In the Clinch River, backwater of Watts Bar Lake extended as far upstream as CRM 25 in the winter and CRM 28 in the summer prior to the closure of Melton Hill Dam.

Thermal stratification affects flow through these reservoirs[12,13]. During summer months, cold water from Norris Lake begins to underflow the warm, stilled water of the lower Clinch River embayment in the vicinity of CRM 12. Practical use has been made of this condition by construction of a submerged dam at CRM 3.8, just below the Emory

Table 1. Location of Clinch River Tributaries and Tennessee River Dams[a]

Identification	Distance Above Mouth (miles)	Distance Downstream from White Oak Creek (miles)
Clinch River		
Mouth of White Oak Creek	CRM 20.8	0.0
Mouth of Poplar Creek	12.0	8.8
Mouth of Emory River	4.4	16.4
Submerged dam for underflow diversion	3.8	17.0
Tennessee River		
Mouth of Clinch River	TRM 567.7	20.8
Watts Bar Dam	529.9	58.6
Chickamauga Dam	471.0	117.5
Hales Bar Dam	431.1	157.4
Guntersville Dam	349.0	239.5
Wheeler Dam	274.9	313.6
Wilson Dam	259.4	329.1
Pickwick Landing Dam	206.7	381.8
Kentucky Dam	22.4	566.1

[a]Dams on the Clinch River upstream from White Oak Creek are Norris at CRM 79.8 and Melton Hill at CRM 23.1. The mean annual flow of the Clinch River near Scarboro, Tennessee, was 4,564 cubic feet per second (cfs) for the 24-year period 1936–60. Following are the long-term mean annual flows at principal stations on the Tennessee River for the periods indicated:

Station	Period of Record (years)	Mean Annual Flow (cfs)
Knoxville, Tennessee	61	12,810
Chattanooga, Tennessee	86	37,030
Florence, Alabama	66	50,620
Paducah, Kentucky	71	63,790

River mouth, to divert this cold water up the Emory River to the condenser intakes of the Kingston Power Plant. The condenser effluent returns to the lower Clinch River.

In the future, thermal differences, resulting from operation of Bull Run Power Plant (under construction at CRM 47.6), will stratify flow to an appreciable degree in Melton Hill Lake. The first unit of the plant will have a capacity of 900 megawatts. The cooling water will be pumped through the unit at 928 cubic feet per second and will be heated about 18 degrees Fahrenheit.

SEDIMENT DEPOSITION

Whether retention of fission products in bottom sediments of the Tennessee River basin is a major factor in determining the fate of the releases or constitutes a potential hazard, depends on the concentrations of the fission products in the bottom sediment, mass of sediment accumulated on the stream beds, and movement of the deposits subsequent to deposition. In later sections of the report, concentrations of the fission products in the sediments will be considered. In this section, the location and extent of the sediment deposits will be presented.

Sediment deposition is considered only in Watts Bar and Chickamauga Lakes (see Fig. 2). Consideration of sediment deposition elsewhere is not included because radionuclide concentrations in the sediment are extremely low.

Description of variations in sediment volume for the period of record comes from TVA sediment range surveys. See Figs. 1, 3, and 4 for locations of sediment ranges, and Fig. 5 and Tables 2 and 3 for variations in volume of bottom sediment in study reaches.

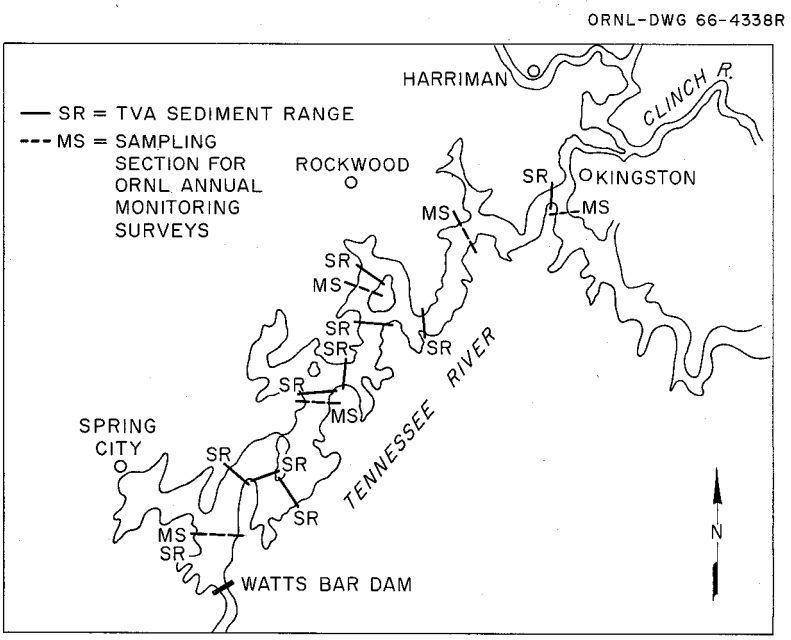


Fig. 3. Map of Watts Bar Lake Showing Bottom Sediment Observation Sections

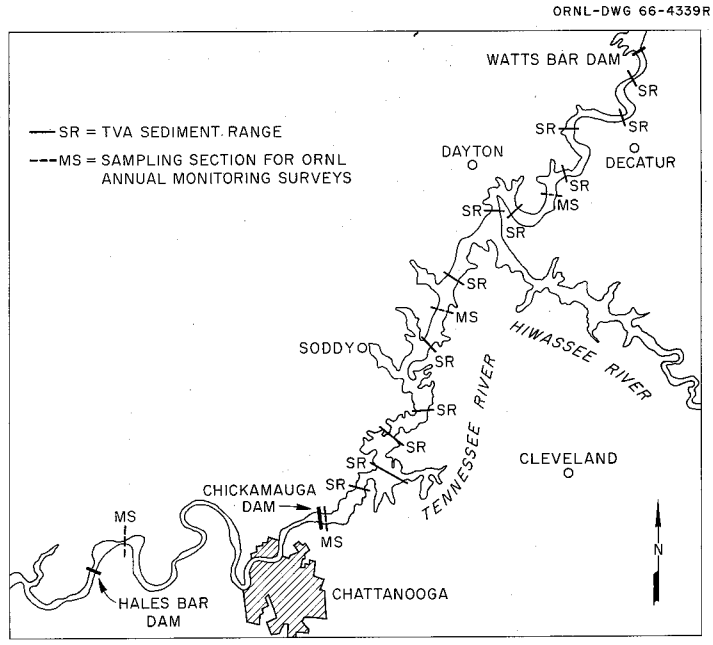


Fig. 4. Map of Chickamauga Lake Showing Bottom Sediment Observation Sections

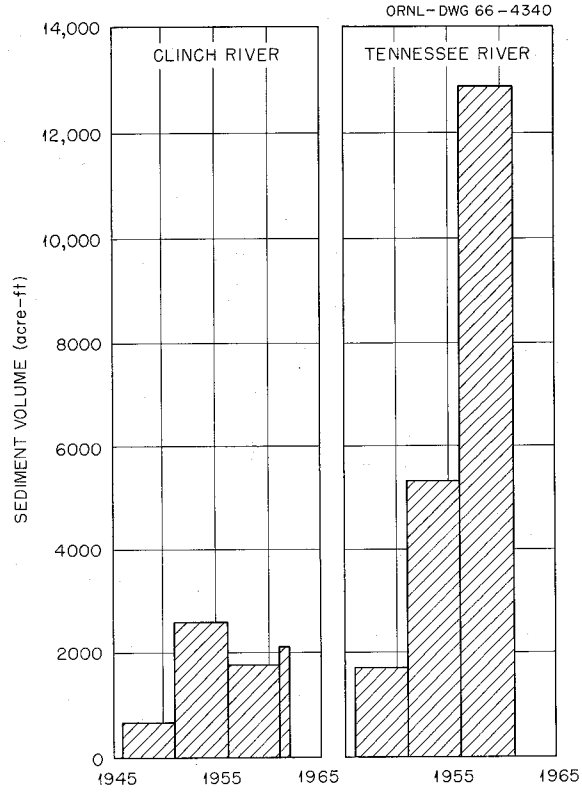


Fig. 5. Total Accumulation of Bottom Sediments in Clinch and Tennessee River Embayments of Watts Bar Lake, 1946 to 1962, and to 1961, Respectively.

Table 2. Change in Volume of Bottom Sediment in Tennessee River Embayment of Watts Bar Lake for Indicated Periods

Reach (TRM)		Change in Volume (acre-feet per mile)		
Begin	End	1946–51	1951–56	1956–61
529.9	532.1	98	−55	278
532.1	534.7	85	36	327
534.7	537.8	47	179	226
537.8	538.8	134	347	346
538.8	543.7	40	158	142
543.7	546.2	14.7	77	200
546.2	549.9	11.0	−30	210
549.9	552.7	44	25	241
552.7	557.1	44	147	181
557.1	562.2	34	102	174
562.2	567.7	22	90	96

Table 3. Change in Volume of Bottom Sediment in Tennessee River Embayment of Chickamauga Lake for Indicated Periods

Reach (TRM)		Change in Volume (acre-feet per mile)			
Begin	End	1940–47	1947–54	1954–56	1956–61
471.0	475.1	211	−89.3	89.3	−2.46
475.1	478.2	180	3.00	−90.7	73.6
478.2	480.8	534	−338	−153	237
480.8	484.8	243	−209	−62.1	157
484.8	490.4	271	−190	55.2	80.0
490.4	496.4	290	−274	166	149
496.4	501.7	236	−230	184	112
501.7	506.6	156	−119	97.0	−32.4
506.6	514.3	142	−176	94.7	−34.4
514.3	517.9	82.5	−104	6.41	6.28
517.9	523.2	88.7	−89.4	−30.1	2.62
523.2	527.3	89.3	−108	19.8	−32.5
527.3	529.9	29.3	−45.5	12.9	0.29

In the Clinch River downstream from the Emory River, the rate of accumulation of bottom sediments averaged a nearly steady 931 acre-feet per year (1946-62). Upstream from the Emory River, alternate periods of gains and losses in volume occurred, with gains and losses being nearly equal over the period of record from CRM 4.3 to 7.5 and from CRM 11.9 to 19.2. The continuous and uniform accumulation of bed material downstream from Emory River, in contrast to the alternate periods of gains and losses upstream from this section, appears to result from extremely low velocities, and deposition of sediments contributed from the Emory River basin. Larger changes in volume of bottom sediments observed in the reach between CRM 7.5 and 11.9 than in the reaches immediately upstream or downstream, seem to result from loads discharged from Poplar Creek (at CRM 12.0).

In the Tennessee River Embayment of Watts Bar Lake (downstream from the Clinch River), the volume of bottom sediments increased in each reach for the period of record of sediment range surveys, except in reaches near Watts Bar Dam (TRM 529.9 to 532.1) and about midway between Watts Bar Dam and the mouth of Clinch River (TRM 546.2-549.9). In the two cited reaches, sediment volume decreased between 1951 and 1956; the losses in the two reaches were more than offset by gains occurring in other reaches. At most sediment ranges in the Tennessee River Embayment of Watts Bar Lake, shifts in sediment volume (gains or losses) occurred in the deeper parts of the section.

High rates of increase in volume of bottom sediments in the Tennessee River Embayment of Watts Bar Lake occurred generally in the downstream portions of the reservoir, downstream from TRM 543.7 (Table 2). Moderate rates of increase have occurred in the reaches between TRM 549.9 and 557.1. In other reaches, the rate of increase in volume of bottom sediments has been relatively low.

In Chickamauga Lake sediment volume increased in all reaches between 1940 and 1947. In the next period between sediment range surveys, 1947-54, volume decreased in all reaches but one (4.1 to 7.2 miles upstream from Chickamauga Dam); the magnitude of losses was nearly the same or greater than the gains in the preceding period,

especially in the upstream two-thirds of the reservoir (upstream from TRM 490.4). After 1954, the volume increased slightly in about three-fourths of the reaches in the reservoir. In the upstream half of the reservoir, changes in volume, either losses or gains, were appreciably less than changes in the downstream part throughout the period of record.

Channel alignment seems to influence the transverse distribution of bottom sediments in a section. Zones of greatest deposition in a section occur in that portion affected by eddies in the flow. Eddies are created as the 'live' flow separates from a curving channel boundary. The size of the eddy depends on the degree of curvature in the boundary and on the length of the curve. Bends, islands, and constrictions in a channel create eddy zones. Water in the eddy zone is in slow rotation with less velocity and turbulence than in the main stream of the flow. With the decrease in dynamic forces acting to suspend the sediment particles, more deposition takes place in the eddy zones than in the live stream of the river.

In the Clinch River, the influence of bends on the distribution of sediment deposits in a section has been observed in the TVA sediment ranges located at CRM 1.3, 4.7, 7.5, and 16.9. Islands in the channel also have affected deposition patterns in the Clinch River. The influence of the flow pattern on sediment deposition through one bend in the Clinch River is shown in Fig. 6. The bend is located between CRM 5.4 and 6.3, and is one of the sharpest bends in the study reach.

Deposition patterns in the Tennessee River Embayment of Watts Bar Lake are influenced by channel alignment, also. Eddy zones created by islands and constrictions in the channel affect transverse distribution of sediment at more than half the sediment ranges.

The influence of channel alignment on deposition patterns in Chickamauga Lake is not so apparent as in Watts Bar Lake. Apparently the curvature of the bends is so large that pronounced eddy zones are not created. The transverse slope of the channel bed seems to have more influence. Little or no gain in volume of bed material occurs in the steepest sloping portions of the bed.

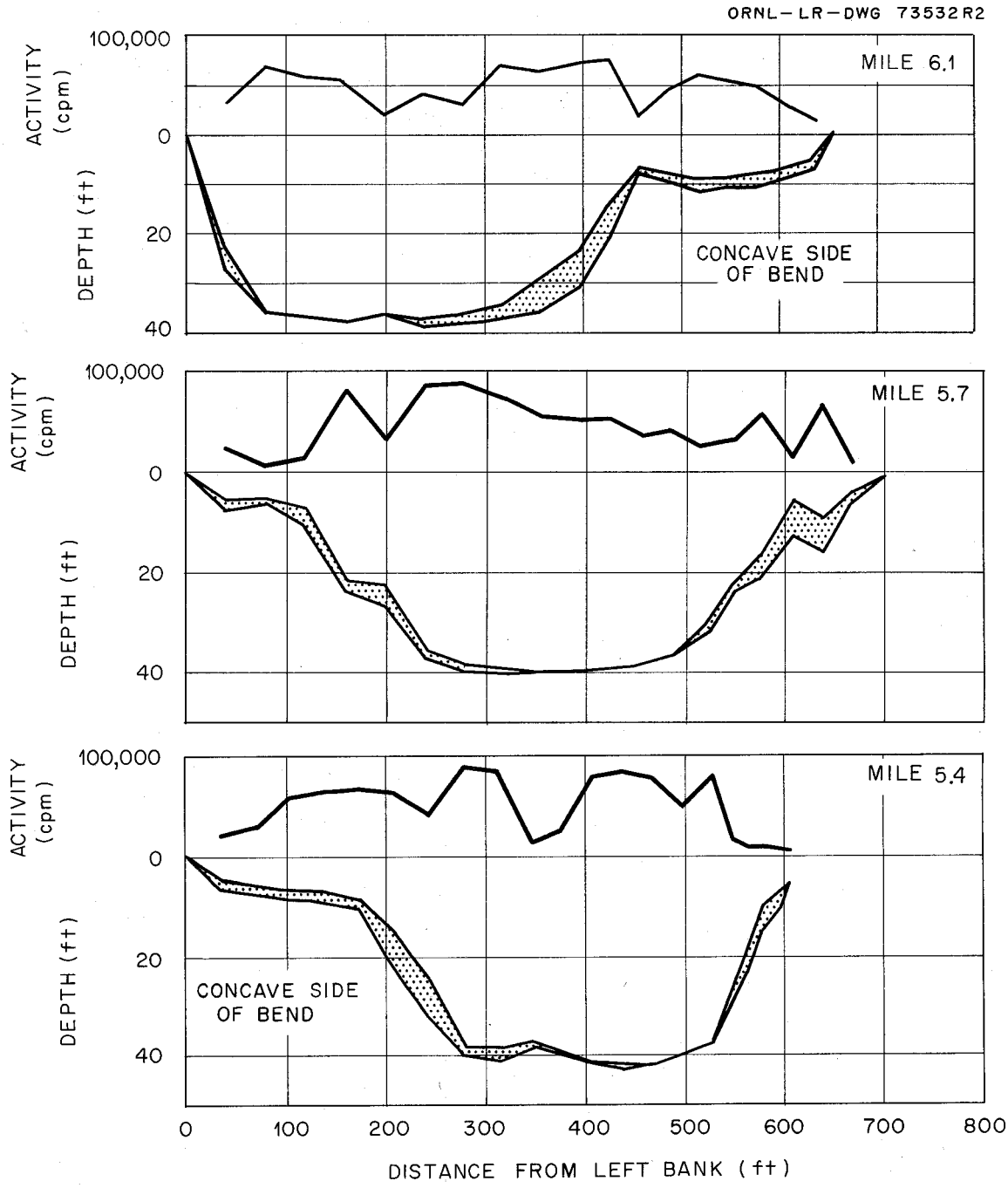


Fig. 6. Variation of Water Depth, Probed Depth of Bottom Sediment, and Gross Gamma Radioactivity Detected at Surface of Bottom Sediment in Cross Sections at CRM 5.4, 5.7, and 6.1

RELEASE OF RADIONUCLIDES FROM OAK RIDGE NATIONAL LABORATORY

Much of the liquid waste products at ORNL originate from various chemical processes used to extract a specific radionuclide, or group of radionuclides, from nuclear fuels removed from a reactor. In 1943 and 1944, the primary efforts were directed toward extracting plutonium from fuel irradiated in the graphite reactor. These extractions were made in the Chemical-separations Pilot Plant. In 1945 the RALA program for extraction of ^{140}Ba and ^{140}La began in the Hot Laboratory and Fission Products Separation Building. In 1947 a number of fission-product extraction processes, at pilot-plant scale, were initiated at ORNL. Many of these processes were in the Chemical-separations Pilot Plant. Later activities at the Laboratory diversified and other specialized facilities were constructed to house experiments using radioactive materials. A listing of major facilities producing radioactive waste at ORNL is given in Table 4.

The effect of changes in methods of disposing of liquid wastes released from facilities processing radionuclides may be discerned in the records of the release of radioactive waste waters from White Oak Lake (see Table 5). For instance, a decrease in the loads of all radionuclides between 1949 and 1950 resulted when treatment of waste waters in the Evaporator (Fig. 7) began. The loads of ^{137}Cs, ^{60}Co, and ^{144}Ce in 1955 and 1956 suddenly increased due to draining White Oak Lake in October 1955. The release of ^{144}Ce from the lake bed occurred in 1955 because either this particular radionuclide was not strongly sorbed in the sediments on the lake bed or because sediments containing this radionuclide were at the surface of the lake bed. The cesium and cobalt releases accompanied heavy runoff in the early part of 1956.

Until 1949, the waste-disposal treatment procedure at ORNL could be described as a triple settling process[14]: (1) storage in underground tanks permitting precipitation and decay of short-lived radionuclides, (2) deposition of precipitates in the Settling Basin, and (3) settling of solids in the Intermediate Pond and White Oak Lake

Table 4. Facilities Producing and Processing Significant Quantities of Radioactive Waste Materials at ORNL

Facility	Year Operation Began
Graphite Reactor	1943
Chemical-Separation Pilot Plant	1943
Chemical Laboratory	1943
Tank Farms	1943
Retention Pond (Equalization Basin locale)	1943
White Oak Lake	1943
Hot Laboratory and Fission Products Separation Building	1944
Settling Basin	1944
High Radiation Level Chemistry Laboratory	1948
Evaporator	1949
Metal Recovery Plant	1951
Radioisotopes Production Area	1951
Sewage Treatment Plant	1951
Seepage Pits	1952
Decontamination Laundry	1955
High Radiation Level Analytical Facility	1956
Process Waste Water Treatment Plant	1957
Equalization Basin (Process Waste System Basin)	1957
Fission Products Development Laboratory	1957

Table 5. Yearly Discharges of Radionuclides to Clinch River (curies)[16,a]

Year	Gross Beta	^{137}Cs	^{106}Ru	^{90}Sr	TRE(−Ce)	^{144}Ce	^{95}Zr	^{95}Nb	^{131}I	^{60}Co
1949	718	77	110	150	77	18	180	22	77	
1950	191	19	23	38	30		15	42	19	
1951	101	20	18	29	11		4.5	2.2	18	
1952	214	9.9	15	72	26	23	19	18	20	
1953	304	6.4	26	130	110	6.7	7.6	3.6	2.1	
1954	384	22	11	140	160	24	14	9.2	3.5	
1955	437	63	31	93	150	85	5.2	5.7	7.0	6.6
1956	582	170	29	100	140	59	12	15	3.5	46
1957	397	89	60	83	110	13	23	7.1	1.2	4.8
1958	544	55	42	150	240	30	6.0	6.0	8.2	8.7
1959	937	76	520	60	94	48	27	30	0.5	77
1960	2190	31	1900	28	48	27	38	45	5.3	72
1961	2230	15	2000	22	24	4.2	20	70	3.7	31
1962	1440	5.6	1400	9.4	11	1.2	2.2	7.7	0.36	14
1963	470	3.5	430	7.8	9.4	1.5	0.34	0.71	0.44	14

[a]Values calculated from data supplied by Applied Health Physics Section, ORNL.

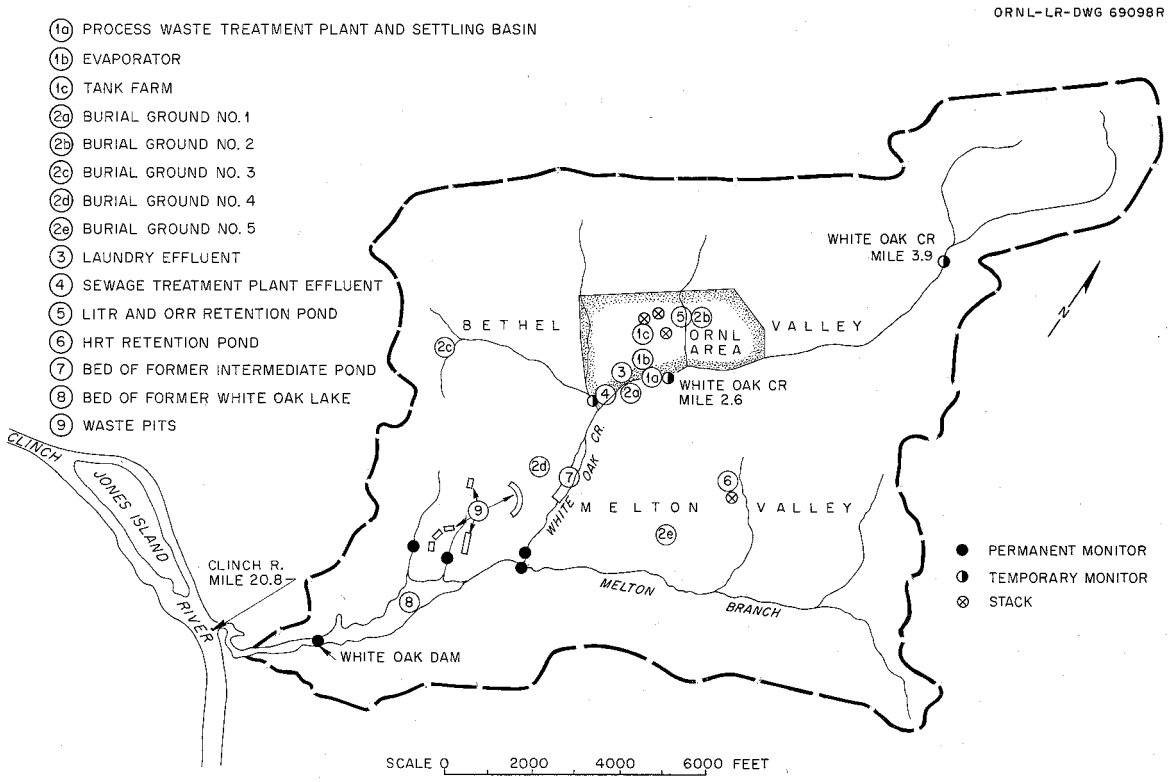


Fig. 7. Map of White Oak Creek Basin Showing Sources of Radioactive Contamination and Location of Stream Monitoring Stations

(flood destroyed Pond in 1944). In addition to triple settling supernatant from the tanks mixed with process-waste waters for dilution within the plant area at ORNL and effluents from the Settling Basin mixed with waters of White Oak Creek and the Clinch River for dilution outside the plant area. "This method..of waste disposal..was entirely satisfactory because the dilution afforded by the Clinch River lowers the (radioactive) liquid waste concentration to acceptable levels"[15].

In 1949, the Evaporator, the first major modification to waste treatment, was placed in operation. Supernatant from the storage tanks fed into the Evaporator and its condensates flowed into White Oak Creek. The Evaporator was an interim process in waste treatment, being decommissioned in 1954. In 1952, a pit dug in Conasauga Shale residuum demonstrated that radionuclides could be removed from waters seeping through the banks and walls of the pit by filtration and sorption in the soil. These seepage pits (trenches) constituted the method of waste disposal which soon supplanted the Evaporator. Seven pits have been put in operation since 1952.

In 1955, the accumulation of radionuclides in White Oak Lake presented problems because: (1) the lake had become a habitat for migratory birds and fish, and (2) radionuclides in lake waters had come to equilibrium with radionuclides deposited or sorbed on lake bed[15]. For these reasons the lake was drained in October 1955. The drained lake provided a facility for emergency storage in the event of an unusually high-level release of radioactivity.

Growth and diversification of activities at ORNL created many sources of release of low-levels of radioactivity to the waste water system. To control this problem the Process Waste-Water Treatment Plant was constructed in 1957.

The release of ^{106}Ru from White Oak Lake had been almost negligible prior to 1959. As a result of leakage from the seepage pits subsequent to the transfer of a large quantity of this radionuclide to the pits, the release increased very substantially in 1959, 1960, and 1961.

There are many other fluctuations in the loads of

radionuclides released from White Oak Creek that cannot be easily documented. The inability to document the fluctuations is due to the complexity of operations at ORNL.

ANNUAL MONITORING SURVEYS OF RADIOACTIVITY IN BOTTOM SEDIMENTS

Annual monitoring surveys have been made since 1951 at selected cross sections between Clinch River Miles 1.1 and 27.5 and between Tennessee River Miles 354.5 and 570.8 (note locations of tributaries and dams in figures 1 and 2 and in table 1 and locations of the observation sections in figures 1, 3, 4, and 8). In 1952 and 1961 the surveys extended downstream on the Tennessee River to TRM 24.6; in 1961 the survey was extended upstream on the Clinch River to CRM 39.1. In each survey the flounder, a Geiger-Mueller tube detector, was used to measure radiation levels at the surface of the sediment at about ten equally-spaced points in each section. Beginning in 1954 the survey included sampling of the upper portion of the sediment at flounder observation points with an Ekman dredge. Sampling at every point was not always possible because of encountering bedrock or large-sized particles (gravel or cobbles). The point samples for each section were composited and radiochemical analyses were made (see Tables 8-19 for results of radiochemical analyses, Appendix).

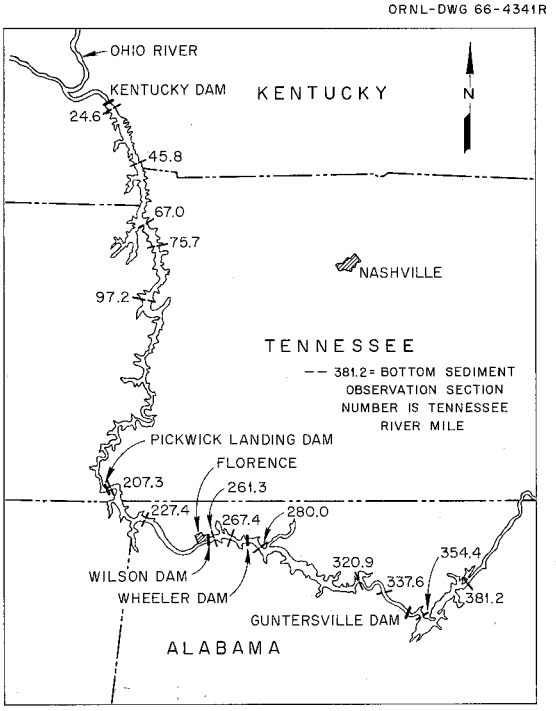


Fig. 8. Map of Tennessee River Showing Bottom Sediment Observation Sections in Kentucky, Pickwick Landing, Wilson, Wheeler, and Guntersville Lakes

Before each survey the flounder was calibrated for attenuation of cosmic radiation by water shielding, and dredge samples from Fort Loudoun Lake provided sediment for an estimate of background concentrations of specific radionuclides.

Descriptions of instrumentation and of methods of conducting surveys and of analyses of results of the surveys are given in greater detail in reports by Garner and Kochtitzky[5] and by Cottrell[6].

Longitudinal Distribution

Flounder data from the 1958 and 1961 surveys illustrate general patterns of distribution of radioactivity in bottom sediment of the Clinch and Tennessee Rivers (Figs. 9 and 10). Flounder count rates observed in 1958 were generally higher than rates for preceding or subsequent surveys; data from the 1961 survey are the most recent available.

Highest average count rates in the Clinch River have been confined to the reach extending from CRM 5 to 15. The annual maximum

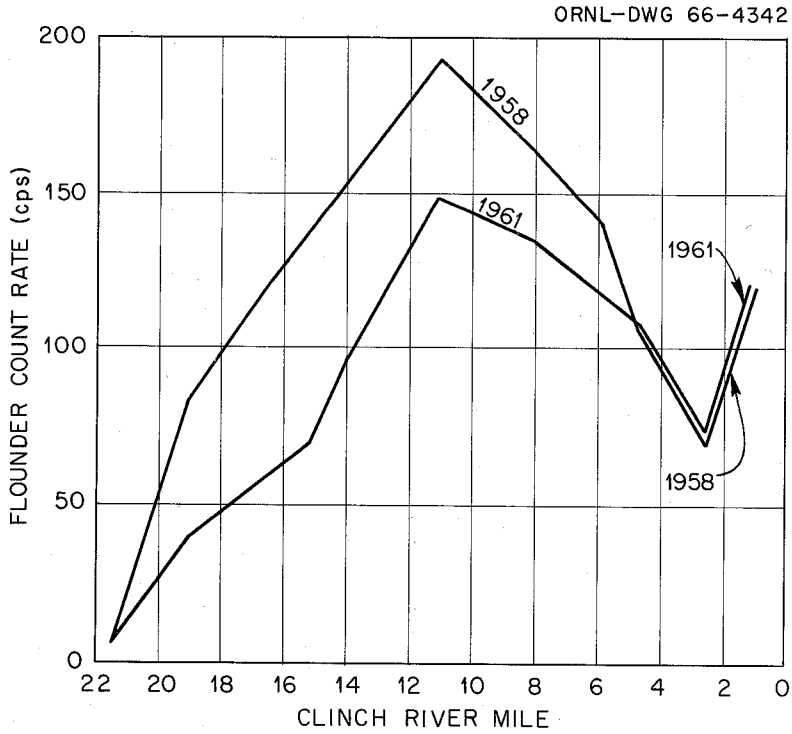


Fig. 9. Variation of Average Flounder Count Rate in Clinch River, Surveys of 1958 and 1961.

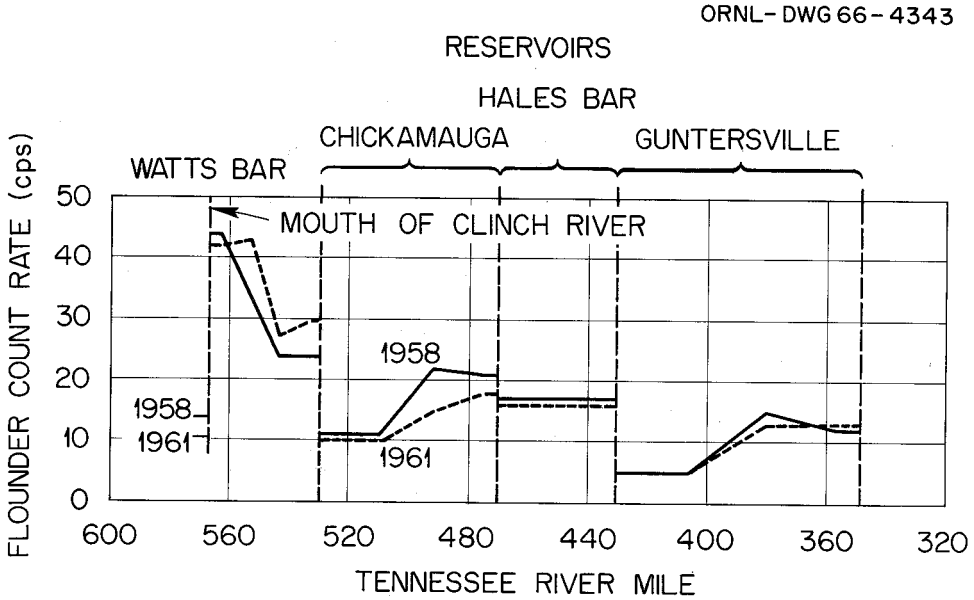


Fig. 10. Variation of Average Flounder Count Rate in Tennessee River, Surveys of 1958 and 1961.

average count rate shifted somewhat from year to year, generally occurring at either CRM 8.0 or 10.0. The centroid of the longitudinal distribution of radioactivity between CRM 5 and 15 does not appear to shift appreciably as the radionuclide loads released from White Oak Lake change from year to year.

In most years average flounder count rates upstream from CRM 14 or 15 were lower than those in reaches downstream. Accumulation of sediment deposits in this portion of the river has been less than in the portion of the study reach downstream from CRM 14 or 15. Lack of accumulation of sediment deposits, especially finely divided particles, upstream from these sections is the probable reason for observing lower levels of radioactivity (see section on Physicochemical Characteristics).

Low count rates have been observed at CRM 2.6, relative to those for sections at CRM 1.1 and 4.7, in each annual flounder survey. The decrease in average count rate between CRM 4.7 and 2.6 is greater than that to be expected from volumetric dilution due to inflow from

the Emory River (24 percent of flow in Clinch River). Count-rate measurements made at CRM 2.6 may not be representative of the general longitudinal distribution of radioactive sediments in this region of the river. The measuring section is immediately downstream from the cooling-water outlet from Kingston Power Plant, and is also immediately downstream from a small tributary entering from the right bank. At a section located immediately upstream from the cooling-water outlet, radiation levels are higher than at the 'standard' measuring section for CRM 2.6 and are about 16 percent less than those observed at CRM 4.7.

Hemphill and others compared various methods of determining longitudinal distribution of radioactivity in the Clinch River (Fig. 11)[2]. Data used in comparison included average flounder count rate at the surface of the sediment, average gross gamma count of one-inch segments of cores, and radionuclide content of composites of the cores. Later, R. W. Andrew[17] superposed results of radiochemical analyses of total identified radioactivity in dredge samples (collected by USPHS

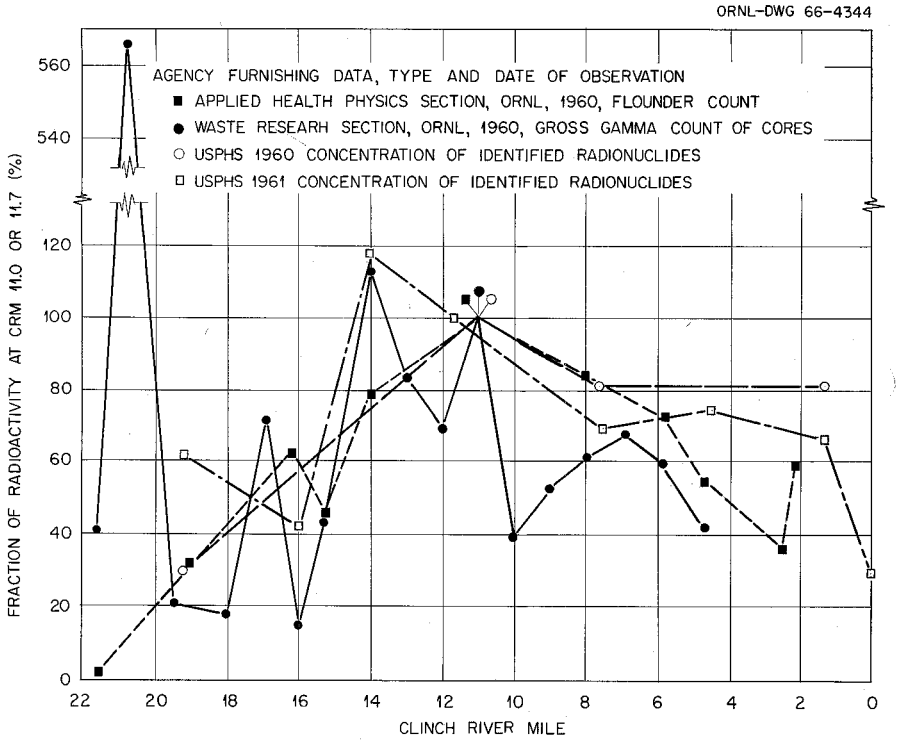


Fig. 11. Comparison of Methods for Determining Longitudinal Distribution of Radioactivity

personnel) on the comparative plot, Fig. 11. The patterns in Fig. 11 are much alike for all methods. Differences in patterns result primarily from differences in location of sampling sections. Only one survey in 1960 included observations at CRM 20.8.

Radionuclide concentration in bottom sediment of the Tennessee River appears to decrease exponentially for standardized concentration of ^{137}Cs (Fig. 12). Standardized concentrations are estimates of the concentration for sections located 3 miles upstream from the dams.

Garner and Kochtitzky[5] concluded that in the 1952 survey the flounder was detecting only variations in the radioactivity of naturally occurring radionuclides in bottom sediment downstream from Hales Bar Dam (TRM 431.1). Therefore, variation in concentration of ^{137}Cs rather than that of flounder count rate is used to study longitudinal distribution of radioactivity in the Tennessee River (Fig. 13).

There is a tendency in the Tennessee River for radioactivity to increase in concentration in the downstream direction within a reservoir (see Fig. 13). Cottrell[6] reasoned that the increase was the result of scouring action in the first 20 miles of reach downstream from the dam and deposition farther downstream into the reservoir.

The general pattern of longitudinal distribution of radioactivity in the Tennessee River, shown in Fig. 13, has remained about the same from 1954 through 1961 in each reservoir upstream from TRM 354.5.

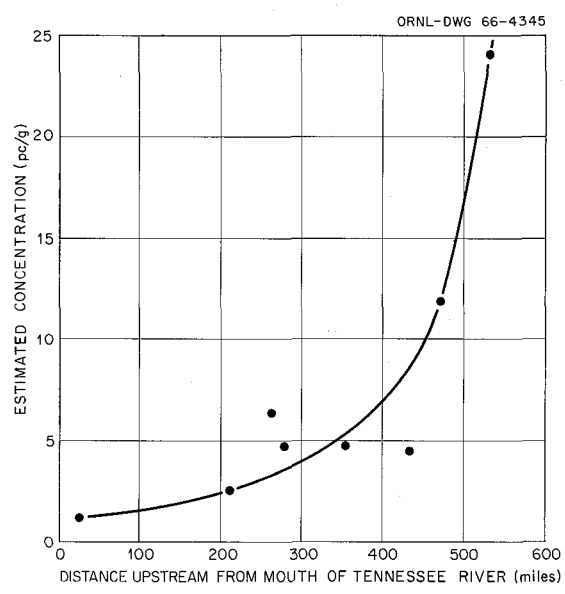


Fig. 12. Variation in ^{137}Cs Content, Tennessee River Bottom Sediment in 1961

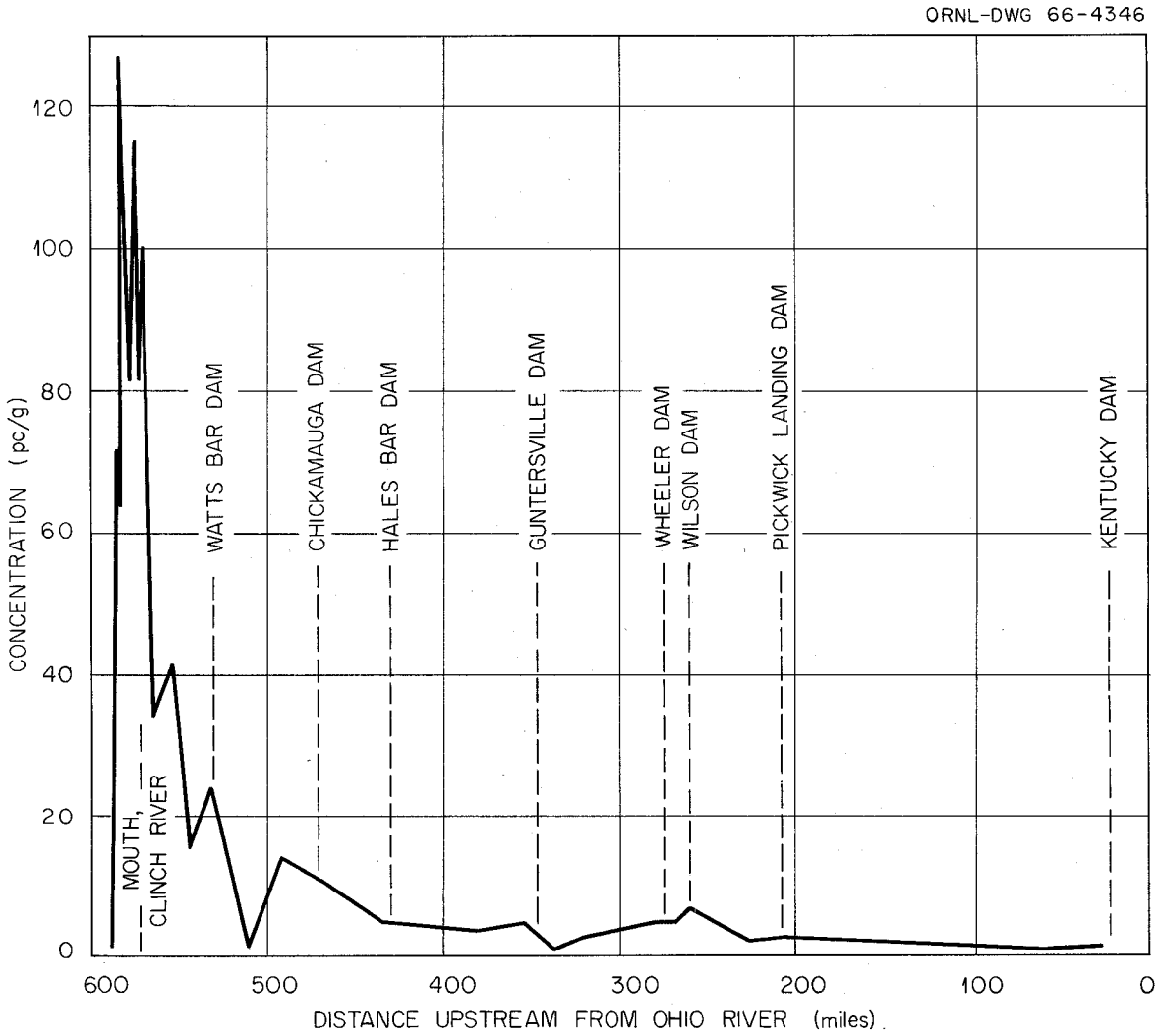


Fig. 13. Longitudinal Distribution of ^{137}Cs in Clinch and Tennessee Rivers in 1961

Influence of Dispersion and Flow Pattern

Releases from White Oak Creek remain close to the right bank of the Clinch River for more than a mile downstream. Lateral mixing of waters from White Oak Creek is complete at distances somewhere between 4 and 6 miles downstream from the mouth of the creek[1, 3, 18]. Parker investigated factors influencing development of complete lateral mixing, particularly temperature differences between waters of the creek and river, in 1957 and in 1959[18, 19]. Through a series of tracer tests he found that waters from White Oak Creek generally passed through the right channel of the river at Jones Island (Fig. 1) and remained in the right portion of the channel for a considerable distance downstream from the island.

Incomplete lateral mixing of waters from White Oak Creek has an effect on the dispersion of radioactive materials in bottom sediment in the uppermost reaches of the study area. At CRM 19.4 and 20.7 the highest flounder count rates occur in the right third of the channel bed (see Fig. 10, Ref. 6).

Farther downstream in the Clinch River distribution of radioactivity across the section seems to be influenced by the local flow pattern. In particular eddy zones in and about bends, islands, and submerged ridges affect the distribution. Count rates are higher in the part of the stream bed which is in or near the convex side bends (CRM 4.7, 5.8, 6.9, 9.4, 12.5, 14.0, and 15.2, Fig. 1). Concentration of radioactivity in the sediment is fairly uniform across the sections, or is slightly higher at mid-section, at CRM 8.0, 11.0, and 16.3. There are small slightly exposed islands or slightly submerged ridges in the vicinity of these sections.

In the Tennessee River distribution of radioactivity in bottom sediments across sections is more uniform than for sections in the Clinch River. Nevertheless channel alignment has an effect on the distribution pattern, but the effect is less marked than in the Clinch River (see Figs. 3, and 10-14, Ref. 6).

Limits of Detection

Presumably bottom sediments in the Clinch River upstream from the mouth of White Oak Creek should not be contaminated by fission-product releases from White Oak Lake. Sediments at CRM 27.5 do seem to be free of contamination by these releases. At CRM 21.5, 0.7 mile upstream from the mouth of White Oak Creek, unusually high flounder count rates were obtained in surveys of 1957, -58, and -59. Contamination of bottom sediments with fission-product releases apparently occurred in the river upstream from the creek, at least as far as CRM 21.5. During short periods of essentially no flow, contaminated material could have been carried in waters of the Clinch River upstream from White Oak Creek either by adverse velocity gradients or by wind action. In 1961, radioactive contamination of the river bed sediment due to releases from White Oak Creek did not extend upstream to CRM 24.1, nor was there pronounced contamination at CRM 21.5.

From study of available data it is concluded that the bottom sediments of the Tennessee River upstream from the mouth of the Clinch River at TRM 570.8 (Fig. 3) have not been contaminated by fission-product releases during the period 1954-61.

Samples of bottom sediments collected in the Clinch River at CRM 21.5, in the Tennessee River at TRM 570.8, and in Fort Loudoun Lake in 1961 are assumed to be uncontaminated by releases from White Oak Lake. The average concentration of each radionuclide in samples from these sections is considered to represent the background concentration for the radionuclide. Concentrations of ^{106}Ru in composite samples obtained in the annual monitoring survey of 1961 (Tables 16, 17, Appendix) were greater than background (2.4 pc/g) in the reach extending from the mouth of White Oak Creek on the Clinch River to near the mouth of the Tennessee River, near Paducah, Kentucky.

Concentrations of ^{137}Cs, ^{90}Sr, ^{144}Ce, and ^{60}Co were found to be greater than background (respectively 1.3, 0.18, 0.73, and 0.34 pc/g) in Pickwick Landing Lake. Concentrations of ^{95}Zr and ^{95}Nb,

trivalent rare earths, and ^{90}Y were higher than background upstream from Guntersville Dam (backgrounds, respectively, were 0.73, 1.0, and 1.0 pc/g).

As Garner and Kochtitzky[5] have pointed out, the concentrations of fission products in the bottom sediments are not enough greater than concentrations of naturally occurring radionuclides in sediments to cause a significant response in the detector of the flounder. Very low-level contamination detected by the founder is almost exclusively that due to gamma emissions of ^{137}Cs. The concentration of ^{137}Cs must be greater than 4 pc/g in order to cause a significant response in flounder count rate. Concentrations of ^{137}Cs have been generally less than 4 pc/g in bottom sediments downstream from Guntersville Dam (see Table 9, Appendix).

RADIONUCLIDE CONTENT OF UPPER PORTION OF BOTTOM SEDIMENTS

Relationship of Concentration in Sediment to Annual Load Released from White Oak Lake

Annual variations in concentrations of radionuclides in the upper portion of bottom sediments appear to follow the same patterns of variations as annual releases of these radionuclides from White Oak Lake. For example, the concentration of ^{137}Cs in composite samples of bottom sediment from CRM 1.1 (from annual monitoring surveys) varies almost directly with the total quantity of this radionuclide released from White Oak Lake during the preceding year (July 1 to June 30) for the period 1954-61 (see Fig. 14)[4]. The correlation index is 0.80. Correlation indices for other principal radionuclides, found in bottom sediment at this section of the Clinch River, are listed in Table 6. Annual changes in the concentration of most radio-

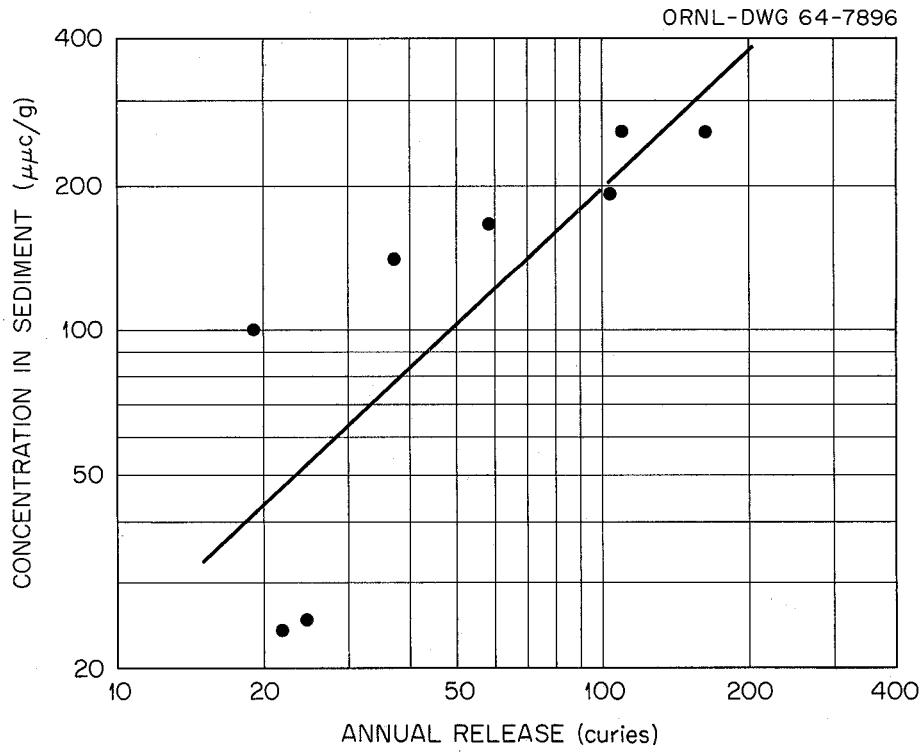


Fig. 14. Relationship of Annual Changes in ^{137}Cs Concentration in Bottom Sediments at CRM 1.1 to Changes in Annual Load of ^{137}Cs Released from White Oak Lake in Year Beginning July 1 and ending June 30

Table 6. Correlation Indices for Comparison of Annual Determinations of Radionuclide Concentrations in Bottom Sediment at Selected Sections in the Clinch and Tennessee Rivers to Annual Loads Released[a]

Location (CRM)	Correlation Index					
	Radionuclide					
	^{137}Cs	^{106}Ru	^{144}Ce	^{90}Sr	^{60}Co	Rare Earths[b]
19.1	0.87	0.76[c]	0.41[d]	0.62[c,d]	0.51[c,d]	0.69
16.3	0.96	0.97	0.40[d]	0.81	0.62[c]	0.89
15.2	0.90	0.94[c]	0.75[c]	0.92[c]	0.79	0.90
14.0	0.90	0.95	0.57[d]	0.79	0.48[d]	0.92
11.0	0.93	0.98	0.80	0.90	0.84	0.92
1.1	0.80	0.89	0.66	0.72	e	0.48[d]
(TRM)						
562.7	0.96	0.99	0.97	0.27[d]	0.70	0.89
432.0	0.92[c]	0.93	0.91	0.22[d]	0.78	0.47[d]
491.9	0.91	0.97[c]	0.73[c]	−0.11[c,d]	0.85[c]	0.66[c]

[a]Correlation of logarithms of radionuclide concentrations which were determined for annual monitoring surveys in period 1954–61. From records furnished by ORNL Applied Health Physics Section.

[b]Radiochemical analyses included ^{90}Y but exculded ^{144}Ce.

[c]No data for 1955 survey.

[d]Correlation index not significantly different from zero.

[e]Insufficient data for analysis.

nuclides in the upper portion of bottom sediments appear related to load of the radionuclides released annually through White Oak Dam throughout the study reaches in the Clinch and Tennessee Rivers (Table 6).

Two models describe possible means of incorporation of radionuclides in the bottom sediment in response to annual releases through White Oak Dam: (1) deposition during preceding 12 months of suspended sediments which sorbed radionuclides prior to their release through White Oak Dam (2) Or, sorption <u>in situ</u> by bottom sediments in the river of radionuclides released as dissolved ions[4].

Both models require either regular, continuous deposition of sediment over much of the sampled section, or release of fairly constant quantities of the radionuclides during the preceding 12 months. Model (2) requires rapid establishment of chemical equilibrium between water and sediment followed by each incremental layer of sediment being covered and sealed by other sediment. Quantities of radionuclides released from White Oak Lake have not been constant. Furthermore,

deposition of sediment at sampling sections is not continuous across the entire width of the section (see Tables 2 and 3, Fig. 5). However, data for TVA sediment ranges show wide zones of continuous, net accumulation of sediment on the sides of the stream channel, and only areas along the thalweg of the stream channel are subject to scour, particularly in periods of high streamflow[4].

For releases of ^{137}Cs, more than 80 percent of the radionuclide passing through White Oak Dam is associated with suspended sediment[20]. The reaction by which cesium is sorbed on the sediment is not readily reversible[4]. Hence, incorporation of ^{137}Cs into bottom sediments can be assumed to conform to model (1).

Relationships in the Longitudinal Distribution of Radionuclides

Similarities in longitudinal distribution of certain radionuclides in the bottom sediments in 1961 annual monitoring survey appear to persist from the mouth of White Oak Creek on the Clinch River to the mouth of the Tennessee River (see Tables 8-19, Appendix). Correlation analyses have been used to study the relationships in longitudinal distribution of these radionuclides. In the correlation analyses the index of correlation, standard error of the estimate, and regression coefficient were computed for the comparison of logarithms of concentrations for all possible pairings of ^{137}Cs, ^{106}Ru, ^{60}Co, ^{144}Ce, ^{95}Zr, ^{95}Nb, ^{90}Sr, and trivalent rare earths (including ^{90}Y but excluding ^{144}Ce)[4]. In Fig. 15 the regression curves for the comparison of concentration of the indicated radionuclide to the concentration of ^{137}Cs are plotted, and the indices of correlation and standard errors of the estimate are listed.

The similarity in slopes for the regression curves in Fig. 15 between concentrations of ^{106}Ru, ^{60}Co, rare earths, and ^{137}Cs suggests that similar mechanisms control the longitudinal distribution of these particular radionuclides.

The concentrations of radionuclides in bottom sediments

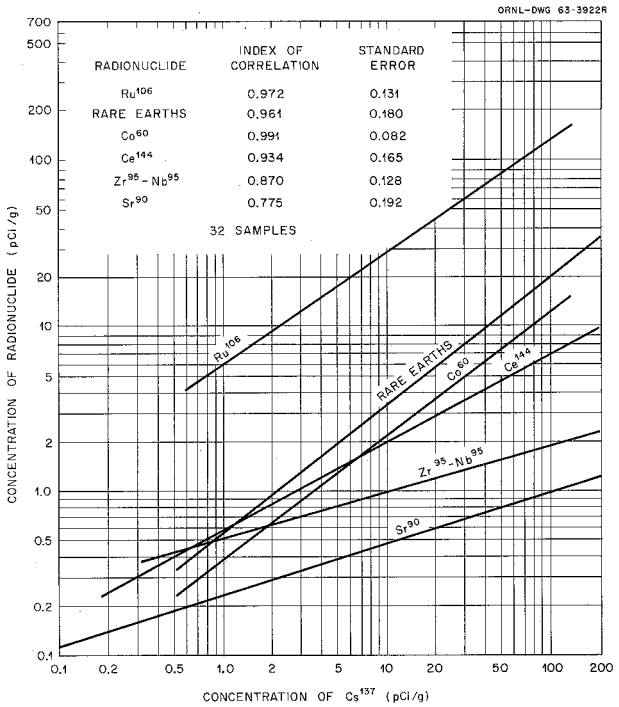


Fig. 15. Correlations Showing Similarity in the Longitudinal Distribution of Radionuclides in the Bottom Sediments of the Clinch and Tennessee Rivers

decrease in the downstream direction in the Tennessee River (see Fig. 16). The possibility exists that flow dilution is the cause for the decrease in concentration. In Fig. 16, the decrease in concentration to be expected due to flow dilution (discharge records for the period 1960-60 furnished by TVA and USGS) with distance downstream from Watts Bar Dam is shown by the line labelled "discharge". Other curves in the figure depict the relative change in concentration of a radionuclide with distance downstream from Watts Bar Dam (referred to its concentration for the first section upstream from Watts Bar Dam). Another possibility exists — that the decrease in radionuclide concentrations in the downstream direction results from dilution of contaminated sediments by uncontaminated sediments (lowermost curve in Fig. 16). The expected dilution of contaminated sediments by uncontaminated sediments was computed from data on the fraction of the sediment in a reservoir that originated from the next upstream reservoir[5].

Based on curves in Fig. 16, the reduction in concentration of each radionuclide, except for ^{90}Sr, appears to be greater than

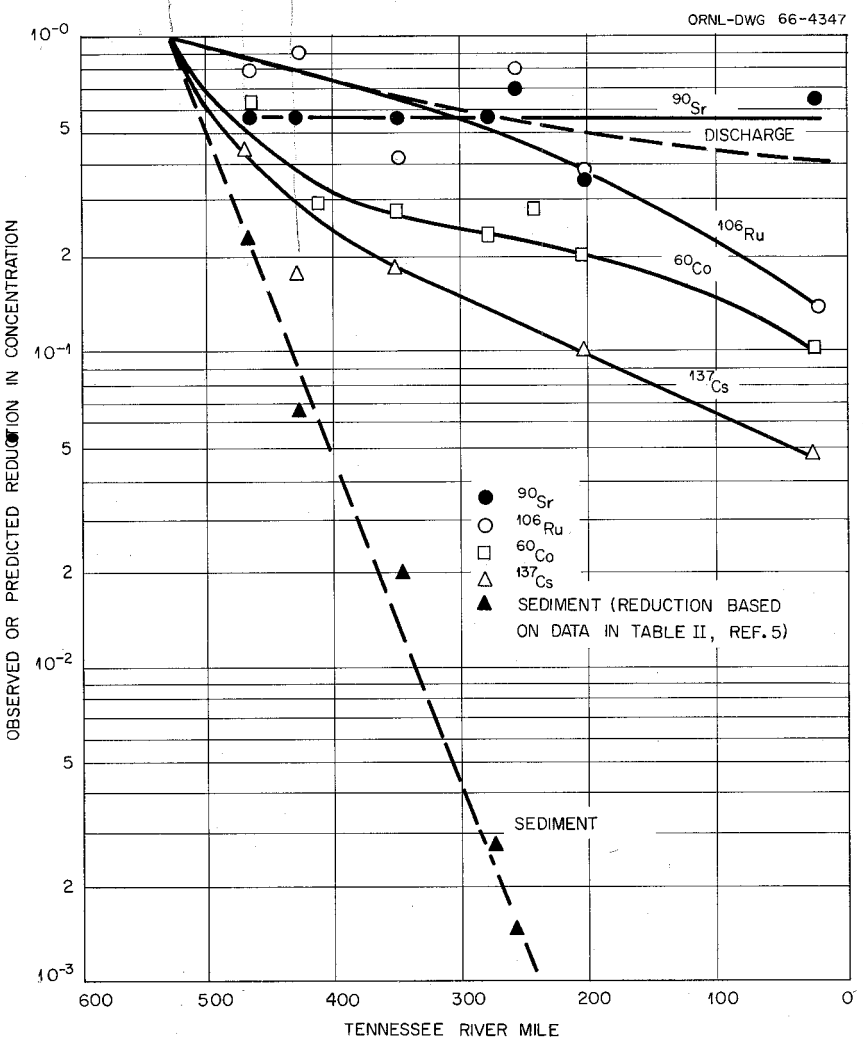


Fig. 16. Observed Reduction in Concentration of Radionuclides and Reduction Predicted by Flow or Uncontaminated Sediment Dilution

simple volumetric dilution but not as great as dilution by uncontaminated sediment.

Results of analysis in Figures 15 and 16 further suggest that the mechanism controlling the distribution pattern for several radionuclides is sedimentation rather than the chemical process of equilibration (reversible sorption) between radionuclide concentrations in the sediments and in the water. Furthermore, once these radionuclides are incorporated into bottom sediments the potential for their release through desorption is almost negligible[4].

Slopes of the curves for ^{95}Zr and ^{95}Nb and for ^{90}Sr are different from those for other radionuclides in Fig. 15. The differences in slopes of the curves imply that different mechanisms may be controlling the distribution of these three radionuclides in the bottom sediments. Longitudinal distribution of ^{90}Sr in the bottom sediments is quite similar to the distribution that would have resulted from the effects of flow dilution (Fig. 16). It is quite probable that the most important mechanism controlling the longitudinal distribution of ^{90}Sr is flow dilution (see section on Physicochemical Characteristics and Ref. 4).

Seasonal Changes in Distribution of Radioactivity

In general, levels of radiation in bottom sediments of the Clinch River tend to increase as the distance downstream from White Oak Creek increases (see Fig. 17). This tendency has been ascribed to hydraulic factors that may influence sediment deposition: larger flow areas, lower velocities, and greater surface area. However, the change in radiation levels with distance is not regular. In particular relatively high levels of radiation have been observed, in summer surveys, at several sections downstream from CRM 12[4].

Possibly the higher zones of radiation levels downstream from CRM 12 result from seasonal variations in these and other hydraulic factors; in the winter season greater discharges and increased velocities of flow occur; in the summer thermal stratification occurs when flows are less than 10,000 cfs (see Fig. 13, Ref. 4).

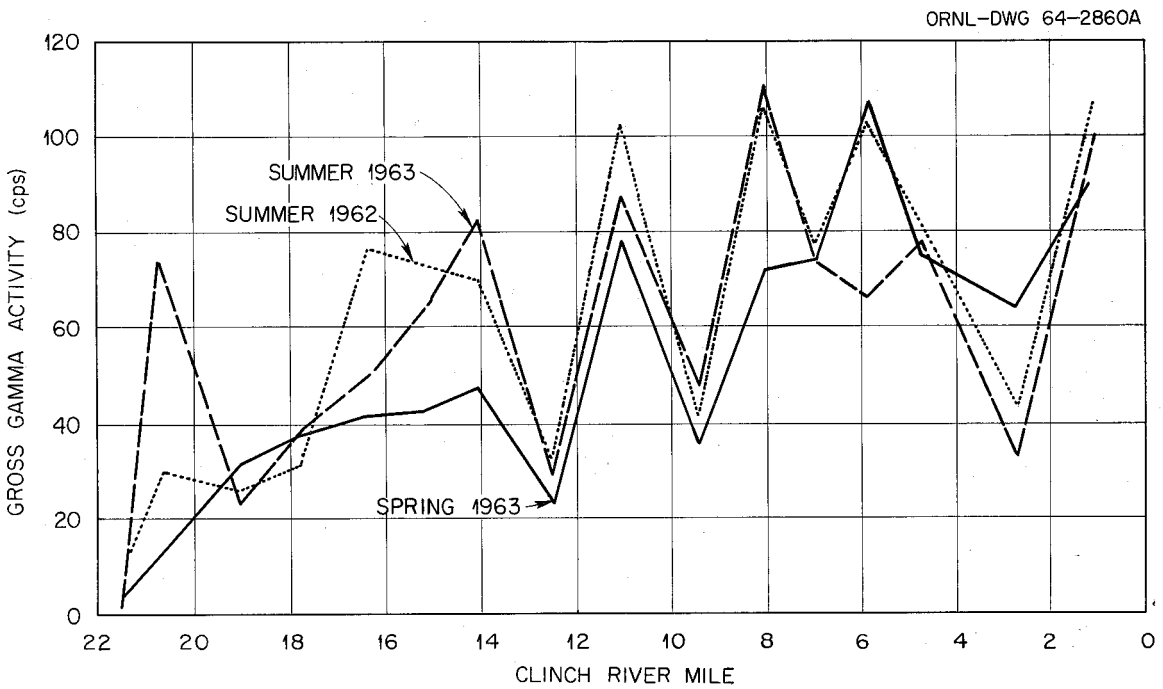


Fig. 17. Longitudinal Variation in Average Sectional Gamma Count Rate at the Surface of Bottom Sediments in Clinch River

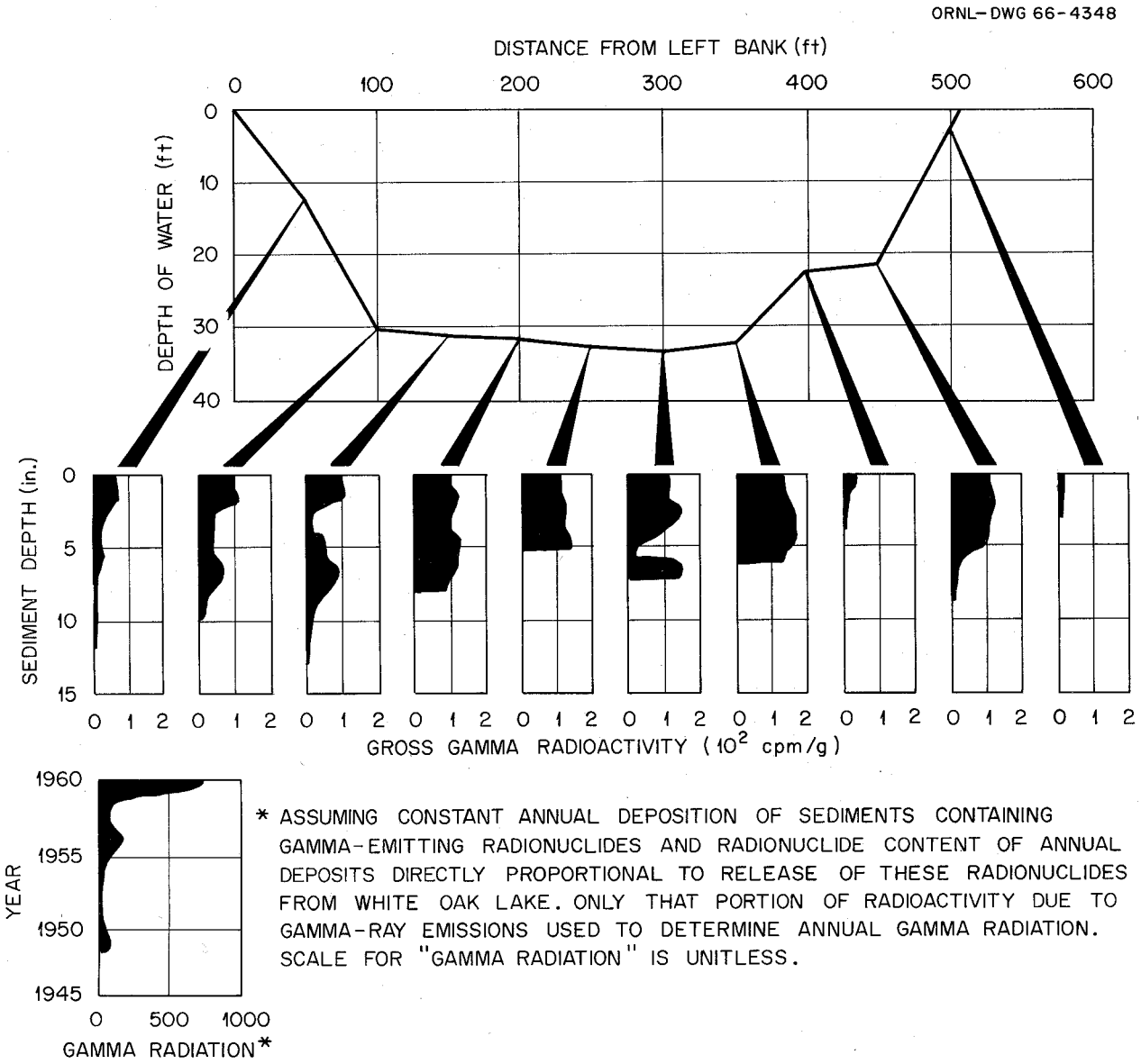
A survey of gamma radiation at the surface of bottom sediment, by ORNL Waste Disposal Research Section and USGS, in the spring of 1963 (April 30 to May 8) explored the possible influence of the seasonal changes in the various hydraulic factors on distribution of radioactive sediments. This spring survey (1963) was made as soon after the winter high flows as practicable using the method reported by Cottrell[6].

The results of three gamma radiation surveys shown in Fig. 17, summer surveys of 1962 and 1963 and spring survey of 1963, seem to indicate that the decrease in effective flow area due to thermal stratification in the summer period does not cause any major change in the longitudinal variation of radioactivity in the bottom sediments[4].

Vertical Distribution of Radioactivity in Upper Strata of Bottom Sediments

Limited information is available on the vertical distribution of radioactivity in bottom sediments of the Clinch River from gross gamma counting of cores, collected in the summer of 1960 (see Description of Available Data). Maximum depth of penetration of the coring tool used for the sampling was 14 inches. In addition to the short depth of penetration available, plugging of the core barrel frequently occurred. Hence, information on the vertical distribution of radioactivity was restricted to a relatively thin layer of the uppermost strate of bottom sediments (average length of sample 7-1/2 inches).

Some variation in radioactivity with depth was noted in practically all of the 107 cores collected from the nineteen sections, CRM 4.7 to 22.5, sampled in 1960. The distribution of radioactivity in some cores seemed to be related to increases and decreases in the annual loads of radionuclides released through White Oak Dam. For example, similar patterns of vertical distribution in gross gamma count occurred in three cores collected at CRM 9.0 (Fig. 18). These patterns were similar to the pattern of gross gamma radioactivity released annually through White Oak Dam (inset, lower left corner,



* ASSUMING CONSTANT ANNUAL DEPOSITION OF SEDIMENTS CONTAINING GAMMA-EMITTING RADIONUCLIDES AND RADIONUCLIDE CONTENT OF ANNUAL DEPOSITS DIRECTLY PROPORTIONAL TO RELEASE OF THESE RADIONUCLIDES FROM WHITE OAK LAKE. ONLY THAT PORTION OF RADIOACTIVITY DUE TO GAMMA-RAY EMISSIONS USED TO DETERMINE ANNUAL GAMMA RADIATION. SCALE FOR "GAMMA RADIATION" IS UNITLESS.

Fig. 18. Vertical Distribution of Radioactivity at Indicated Verticals and Cross-Sectional Shape at CRM 9.0, and Simulated Vertical Distribution of Radioactivity for Constant Deposition of of Releases from White Oak Lake

Fig. 18).

A study of all plots of vertical distribution of radioactivity in cores, showed that radioactivity levels neared background levels where the water depth over the coring hole, at the time of coring, was less than five feet, in sections downstream from CRM 16.9. From November to April in each year water levels in the river are nominally five to six feet lower than the levels at the time of coring (summer 1960). Low radioactivity levels in shallow-water portions of the sampling section may result from shorter duration of contact with radioactive waters of the Clinch ('summer' period) River and, also, may result from subaerial erosion of exposed sediments in the 'winter' period.

Effects of Flow Area and Channel Curvature on Distribution of Radionuclides

R. W. Andrew[21] was first to define a relation between flow area and the concentration of radionuclides in bottom sediments for the Clinch and Tennessee Rivers (Fig. 19). Andrew described the

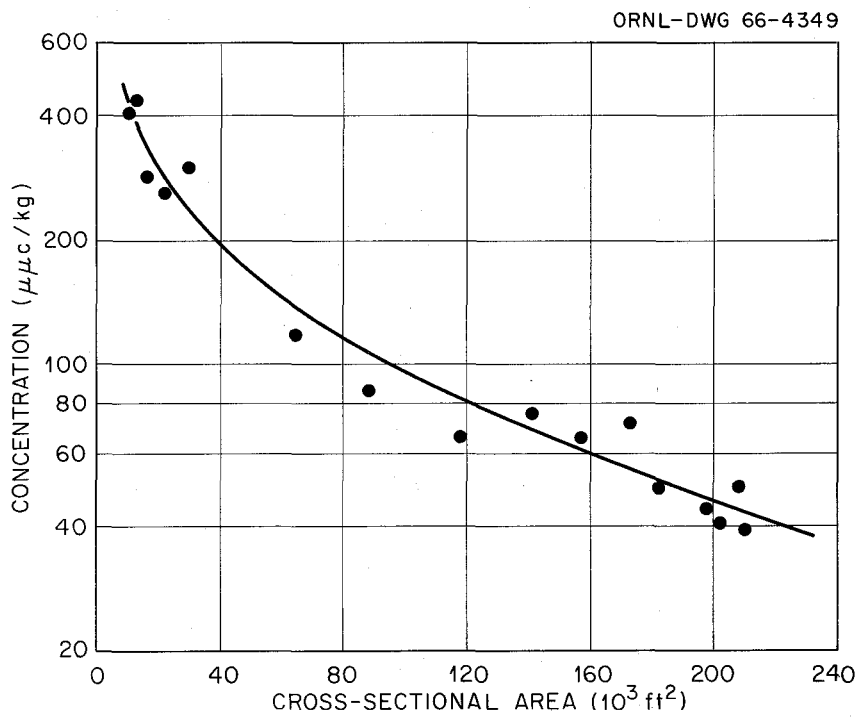


Fig. 19. Variation of Total Identified Radionuclide Concentration with Flow Area

relation in Fig. 19 as defining a dilution effect. He, as Cottrell[6], believed that if the radioactivity is dispersed over a larger area (surface area of the bottom sediments) the concentration of the radioactivity must be less.

The flow area, used to develop the relationship in Fig. 19, is normal to the channel-bed surface area. Hence, the flow area is not a direct expression of either 'dilution' or surface area. However, geometrical properties of sections in the Clinch and Tennessee Rivers are such that the length of perimeter for the sections generally increases as the flow area of these sections increases. The product of perimeter length and longitudinal distance is the surface area of the channel bed. Thus, flow area for the study reaches in the two rivers is an indirect measure of surface area.

In previous sections of this report the influence of channel geometry, particularly curvature, on the deposition of sediment and on the distribution of radioactivity in these sediments has been discussed. R. W. Andrew[21] delineated a possible relationship between radionuclide content of the bottom sediments and channel curvature. He found that the concentration of radionuclides in the upper portion of bottom sediments increased as the radius of curvature increased. A definitive relationship between concentration and curvature was not established because information was lacking on effects of other factors (particle size, position of the sampling section relative to beginning of bend).

INVENTORY OF RADIONUCLIDES IN SEDIMENTS

Complete inventory of radioactivity in the bottom sediments of the Clinch and Tennessee Rivers has not been made prior to work reported in Part B of this report. The quantity of radioactive materials associated with these sediments might be ascertained by utilizing data on radionuclide concentrations obtained in annual monitoring surveys and on sediment deposition or by radiochemical analyses of cores collected in these river sediments[4].

Inventory of Radionuclides in Upper Portion of Clinch River Bottom Sediments

Based on estimates of radioactivity in the bottom sediments of the Clinch River, from results of core sampling program in 1960, the total quantity of radioactive material accumulated is small relative to the quantity of radioactivity released through White Oak Dam.

The following quantities of radionuclides, in curies, were found to be associated with the upper 6-10 inches of sediments: 43.2 for ^{137}Cs, 14.7 for rare earths, 13.2 for ^{106}Ru, 4.7 for ^{60}Co, and 0.7 for ^{90}Sr; the total is 76.5 curies. This inventory was made for the reach extending from CRM 4.7 to 21.5 (essentially between the mouths of Emory River and White Oak Creek). Computational methods of obtaining this inventory and more detailed results of the work were reported by Morton[2].

Through review of sediment range data furnished by TVA the average sediment thickness is estimated to be three to four times greater than that sampled by the coring tool used in the 1960 inventory work. For this reason it might be assumed that the total quantity of radioactivity in the bottom sediments is a few times greater than the 76.5 curies determined as a result of the coring done in the summer of 1960.

The inventory could be on the order of 200 curies. A comparison with the quantities of radionuclides released through White Oak Dam, listed in Table 5, will show that the relative retention of these radionuclides in the bottom sediments is small.

PHYSICOCHEMICAL CHARACTERISTICS OF BOTTOM SEDIMENTS

Particle-Size Distribution in Bottom Sediments

Two separate determinations were made by the U. S. Geological Survey of the particle-size distribution in cross-sectional samples composited from bottom sediment cores collected during 1961 at five sections in the Clinch River. The averages of the results of those determinations (Table 20, Appendix) indicate the bottom sediment in the Clinch River to be a well graded silty loam with a rather constant content of clay-size material. The minimum median particle size occurred at CRM 11.9.

The quantity of radionuclides sorbed on river sediment should increase with decreasing particle size of the sediment for two reasons: (1) because the relative content of clay minerals, the mineral group with the highest sorption capacities for many cations, usually increases as the median particle size of the sediment decreases; (2) because in many minerals, including the clay minerals, the exchange capacity varies directly with the surface area, which increases as particle size decreases.

Relationship between particle-size distribution and radionuclide concentrations (ORNL radiochemical analysis) in the sediment with distance for the five river cross sections sampled is shown in Fig. 20. Radionuclide concentrations vary more widely from section to section than does particle-size distribution and do not appear to bear the direct relationship to particle-size distribution that might be expected on the basis of the statement made in the preceding paragraph.

Comparison plots of particle-size distribution and ^{137}Cs content of bottom sediment samples collected in a single survey of the Clinch and Tennessee Rivers by the USPHS have been made by R. W. Andrew and are shown in Fig. 21 [22]. A possible correlation exists between the percent clay-size particles in the bottom sediments and the cesium content of the samples studied by Andrew.

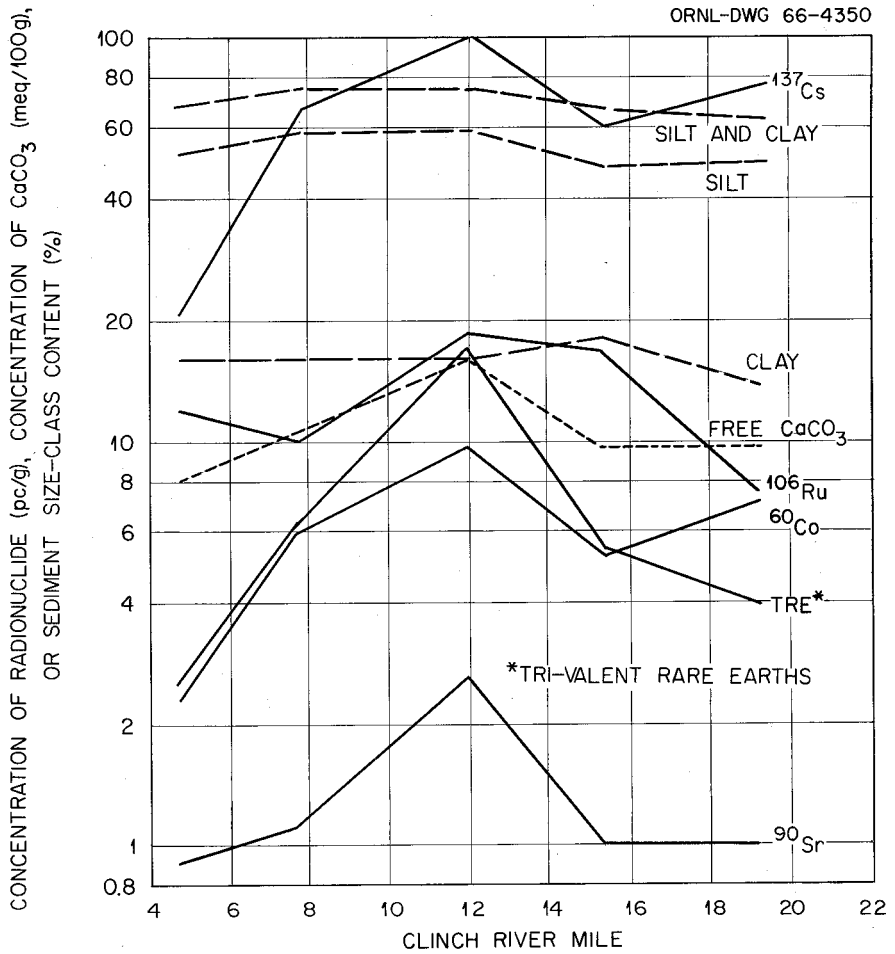


Fig. 20. Longitudinal Variation in Radionuclide Content, in Free Calcium Carbonate Content, and in Particle-Size Distribution of Clinch River Bottom Sediment

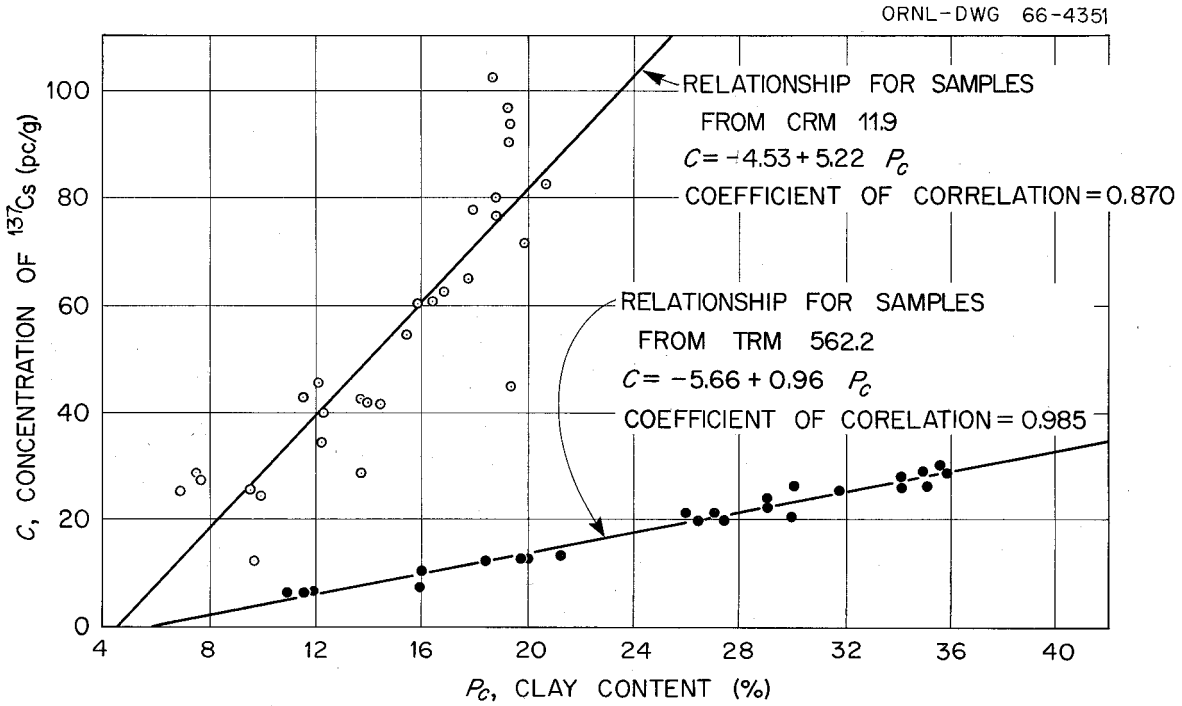


Fig. 21. Relation of Content of Clay-Size Fraction (<2μ diameter) in Bottom Sediment to Radionuclide Concentration in Sample.

Sorption and Cation Exchange Properties of Bottom Sediments

The principal means of uptake of radionuclides by Clinch River bottom sediments has been postulated to be cation exchange, a type of sorption. For this reason, the total cation exchange capacity and the exchangeable cation content of bottom sediment cores collected at the five sections sampled during 1961 were determined by the U. S. Geological Survey.

The total cation exchange capacity, determined by an ammonium chloride leaching method, was much the same for all samples (11.3 ± 0.2 meq/100 grams). The total "exchangeable" cation contents varied, however, and in all samples exceeded the determined total cation exchange capacity. Because exchangeable sodium and potassium were not present, and the content of exchangeable magnesium was almost the same in all samples (6.0 ± 0.2 meq/100 grams), the variation in total "exchangeable" cation content is obviously the result of variation in the "exchangeable" calcium content of the five samples. The anomalously high "exchangeable" calcium content, higher in all samples than the determined total cation exchange capacity, together with the moderately high pH's of the samples, indicates that calcium carbonate in the sediment was dissolved when the sediment was leached with ammonium chloride. This implication concerning the mineralogy of the bottom sediments will be discussed in a later paragraph.

In order to further define the cation exchange properties of Clinch River bottom sediments, eleven sediment samples of the composited cores collected from the Clinch River in 1960 were evaluated for their ability to sorb strontium. In demineralized water containing ^{85}Sr as a radioactive tracer (5.0×10^{-5} meq of strontium in 200 ml), a mean value of 49.3 ± 1.7 percent of the strontium was removed by 0.1 gram of the sediments. The data on exchangeable cation content of the composite samples indicate that the saturating cations on the clays are calcium and magnesium. If in a system of this sort approximately 50% of the strontium can be sorbed, leaving 50% of the strontium still in solution, then one would suspect that the calcium plus magnesium on the exchange sites equals that in solution, i.e., it equals 50% of the

total calcium plus magnesium (ion exchange plus dissolved) in the system. This suspicion is based on the assumption that the ratio for Sr/Mg selectivity by clays is the same as the observed ratio for Sr/Ca selectivity by clays, i.e., 1.0.

The source of the dissolved calcium in the sediment-distilled water mixtures used in the sorption studies can be assumed to have been calcium carbonate contained in the sediment. The solubility of calcium carbonate has been reported to be 0.014 grams/liter[23]. This value would correspond to 0.056 meq Ca in 200 ml of saturated solution, which is greater than the 0.022 meq Ca that would be 50% of the total calcium plus magnesium in the system (0.022 meq Ca + Mg on exchange sites per 0.1 gram sediment and 0.022 meq Ca + Mg in solution based on total exchangeable cation content of sediment). Hence, it can be assumed that when strontium sorption was measured using demineralized water, dissolution of calcium carbonate in the sediment had not yet reached equilibrium.

When Oak Ridge tap water was substituted for demineralized water, the calcium concentration in the solution was increased to 26 ppm, and the magnesium concentration to 8 ppm, which resulted in a solution containing 0.39 meq of Ca and Mg in 200 ml. The sorption of strontium in this system was reduced to 5.07 ± 0.27 percent of that in the demineralized water system. This effect can be explained if it is assumed that the sorption of strontium by the sediment in the tap water system should be reduced in proportion to the reduction in the Sr/(Ca + Mg) ratio in the tap water system as compared to the same ratio in the distilled water system. Thus,

$$\frac{\text{Sr in distilled water system}}{\text{Ca + Mg in distilled water system}} = \frac{5 \times 10^{-5}\,\text{meq}}{0.022\ \text{meq}} = 0.00114,$$

and

$$\frac{\text{Sr in tap water system}}{\text{Ca + Mg in tap water system}} = \frac{5 \times 10^{-5}\,\text{meq}}{0.39\ \text{meq}} = 0.00013,$$

so reduced sorption should be $\left(\frac{0.00013}{0.00114}\right)(49.3\%) = 5.6\%$.

Thus, the high concentration of dissolved calcium in the river water, the apparently calcium-saturated status of the sediment, and the low exchange capacity of the sediment all contribute to the

very low strontium content of Clinch River bottom sediment.

Sorption of cesium by sediment samples collected during 1960 has been studied by the same methods used in the strontium sorption studies described above[24]. Sorption capacities were high in both tap and demineralized water (93.1 ± 0.25 and 97.6 ± 0.25 percent respectively), and thus provide an explanation for the high ^{137}Cs content of Clinch River bottom sediment.

Sediment samples taken at CRM 22.6, above the mouth of White Oak Creek, were composited to provide material for sorption studies made by Sorathesn, et al[25]. The mineralogical composition of the clay fraction of the sediment, determined by X-ray diffraction methods, is 60% illite, 15% kaolinite, 10-15% vermiculite, and 10-15 % quartz. The 140 mesh size fraction of the crushed sediment was used in determining its sorption capacities for the radionuclides ^{137}Cs, ^{60}Co, ^{85}Sr, and ^{95}Zr-Nb. The results of these determinations are shown in Table 7.

The high uptake of ^{137}Cs by the sediment has been ascribed

Table 7. Sorption of Radionuclides by Bottom Sediment from CRM 22.6[25,a]

Radionuclide	Contact Time	Activity Sorbed (%)		K_d[b]	
		pH 6	pH 9	pH 6	pH 9
^{137}Cs	1 hour	53.75 ± 0.42	61.31 ± 0.37	2,326	3,169
	3 days	96.17 ± 0.25	96.16 ± 0.25	50,152	50,152
	7 days	97.78 ± 0.24	97.64 ± 0.24	88,048	82,769
^{60}Co	1 hour	46.44 ± 0.33	71.91 ± 0.22	1,734	5,120
	3 days	93.34 ± 0.17	82.38 ± 0.19	28,017	9,354
	7 days	97.28 ± 0.17	85.12 ± 0.18	71,567	11,445
^{85}Sr	1 hour	21.42 ± 0.78	24.79 ± 0.67	545	659
	3 days	45.79 ± 0.36	63.87 ± 0.26	1,690	3,537
	7 days	41.83 ± 0.39	66.80 ± 0.25	1,438	4,024
^{95}Zr-^{95}Nb	1 hour	62.83 ± 0.32	54.37 ± 0.37	3,380	2,383
	3 days	82.69 ± 0.25	75.55 ± 0.27	9,554	6,181
	7 days	86.56 ± 0.24	79.94 ± 0.25	12,886	7,970

[a] 0.1 gram of sediment contacted with 200 ml of master solution.

[b] K_d, the distribution coefficient, is the ratio of the fraction of ions sorbed per unit weight of clay to the fraction of ions remaining in solution per unit volume of solution.

to its high illite content. Sorption of ^{85}Sr and ^{60}Co by sediment was higher than had been expected on the basis of the sediment's mineralogy, and may have been due in part to the presence of organic material with ion exchange properties in the sediment. More recent work has shown that peat moss, plant remains extracted from river sediment, and raw river sediment all possess a strong affinity for ^{60}Co.

The effect of pH on sorption of the various radionuclides by the sediment (Table 7) is in part a reflection of the ability of the radionuclides to displace sorbed hydrogen ions. Cesium exchanges with hydrogen ions to a much greater extent than strontium, so the sorption of cesium is less adversely affected by an increase in abundance of hydrogen ions competing for ion exchange positions than is the sorption of strontium. The nuclides ^{60}Co and ^{95}Zr-Nb were present as colloidal particles in the solution, and thus were flocculated and could be centrifuged out more effectively at pH 6 than at pH 9 where the hydroxyl ions apparently helped stabilize the negatively charged colloidal particles.

Mineralogy of Bottom Sediments

A knowledge of bottom-sediment mineralogy is requisite to an understanding of radionuclide distribution in the sediment because of differences between minerals in both total sorption capacities and capacities for sorbing specific nuclides. Most clay minerals and certain oxides are known to have high total cation adsorption capacities; vermiculite with a particular lattice spacing perferentially sorbs cesium[27].

Cross-sectional composites of bottom sediment cores collected in 1961 (CRM 4.7, 7.6, 11.9, 15.3, and 19.2) were examined by the U. S. Geological Survey for variations in mineralogy of the sand-, silt-, and clay-size fractions. The sand-size fraction of the sediment is composed almost entirely of quartz grains with traces of feldspar and dolomite. The silt-size fraction also consists almost entirely of quartz grains, with traces of feldspar, dolomite, and possibly

diaspore. Quartz is the predominant mineral in the clay-size fraction, but appreciable quantities of clay minerals are also present; proportions of minerals in clay-size fraction are: 30-40% quartz, 20% vermiculite, 20% mica, 10-20% kaolinite, and 10% randomly interstratified vermiculite-mica.

Any comparison of radionuclide content in the 1961 core samples with their mineralogy must be very general because of the semi-quantitative nature of the mineral determinations. Of the three relative mineral content variations mentioned, the variation in mica content of the samples might be expected to have the most pronounced effect on radionuclide sorption. Without more precise mineralogic data, however, little more can be said than that differences in the mica contents of the composites might be in part responsible for differences in their radionuclide contents. In general, the composite sediment samples for all five cross sections sampled have much the same mineralogy. This fact may explain the lack of variation in the total cation exchange capacities of the five samples.

The calcium carbonate content of each composite sample was estimated from the exchangeable cation content and total cation exchange capacity of the sediment as follows:

$$(CaCO_3) = Ca_X^{++} - R_T^{++} + Mg_X^{++}$$

in which

$(CaCO_3)$ = calcium carbonate in sediment in meq/100g,

Ca_X^{++} = exchangeable calcium in sediment in meq/100g,

R_T^{++} = total cation exchange capacity of sediment in meq/100g, and

Mg_X^{++} = exchangeable magnesium in sediments in meq/100g; or

$CaCO_3$ = exchangeable Ca minus total cation exchange capacity plus exchangeable Mg.

This calculation was made on the assumption that the amount of calcium held on mineral exchange sites is equal to the difference between the total cation exchange capacity and exchangeable magnesium.

Because exchangeable sodium and potassium were shown to be absent, it was assumed that no other exchangeable cations were present. The amount of "exchanged" calcium (from analysis) in excess of the estimated calcium on exchange sites is thus assumed to have been contributed by free calcium carbonate in the sample. Variations in the calcium carbonate content with distance are very similar to variations in ^{90}Sr concentrations, as is demonstrated in Fig. 20, and may indicate a direct association of ^{90}Sr in bottom sediments with free calcium carbonate.

The nearly identical variations with distance of cesium and cobalt concentrations in the composite samples suggest that those two nuclides are incorporated into the bottom sediment by the same, or similar, processes.

Discussion.-- Several shortcomings must be recognized in connection with the determinations to date of the physical properties and mineralogy of Clinch River bottom sediments. Mineral determinations were made by X-ray diffraction only, a method which cannot be expected to detect amorphous substances such as organic fragments. Coal has been observed to be fairly abundant in the sand-size fraction of sediments collected near the mouth of Poplar Creek and in certain downstream locations, but its relative abundance is not known because petrographic examinations of the bottom sediment samples were not made. An analysis by the USPHS of a leaf fragment collected at the mouth of the Emory River showed that the organic leaf material contained forty times as much radioactivity per gram as did clayey silt from the same location[28], yet little data are available on plant and animal detritus in the sediment. Also, care must be taken to avoid dissolution of highly soluble chemical constituents during the processing of sediment samples.

RADIATION DOSAGE FROM BOTTOM SEDIMENT

Main Channels of Clinch and Tennessee Rivers

Re-examination of Figs. 9 and 10 is useful in gaining an impression of reaches in which high gamma radiation dosage may occur. As mentioned in the section on annual monitoring surveys the highest radiation levels occur in the Clinch River; and the highest levels in the Clinch River occur between CRM 5 and 15. Data for curves in these two figures are average count rates in the sections. As pointed out in the section "Influence of Dispersion and Flow Pattern" count rates vary across the sections, with a likelihood of the maximum count rate being considerably different from the average in the Clinch River. The pattern of longitudinal distribution of maximum count rate is generally similar to the pattern for average count rate. Hence, the aforementioned curves for average count rates delineate reaches that would be of major interest in a safety analysis.

The maximum count rate for the period of record (1954-61) was observed in 1959 at CRM 15.2 on the Clinch River: 394 cps (average, 176 cps); maximum count rate observed in 1961 was at CRM 5.8: 219 cps (average, 137 cps). As pointed out by Cottrell[6] and by Cowser and Snyder[16] these maxima were well below maximum permissible dose rates even if the exposure to radiation from the sediments were continuous.

Estimates of gamma radiation dosages, using flounder count rates, are meaningful only upstream from Chattanooga, Tenn. Garner and Kocktitzky[5] have shown that the radiation due to fission products in bottom sediments cannot be distinguished from radiation due to naturally occurring radionuclides downstream from this city. Cowser and Snyder[16] have investigated the relation between gamma radiation dose and flounder count rate and have concluded that such relationships are particularly meaningful only in the Clinch River.

Water shields radiation emitted from the sediments; 0.7 foot of water attenuates the dose by a factor of about two. Hence, the most critical situation, in general, for external exposure to this radiation will occur if the person is in direct contact with

the contaminated sediment, sitting or lying on the sediment. This type of exposure can occur under at least two conditions: (1) the unusual circumstance of divers working on the riverbed, and (2) people sitting or lying on the river banks during 'winter-flow' conditions (fishermen). During the winter, water levels in Watts Bar Lake are about six feet lower than during the summer. As a result sediments in contact with radioactive waters during the summer are exposed. The enveloping curve in Fig. 22 gives evidence that the maximum flounder count rate on the exposed riverbank in the winter of 1961 would have been 105 cps, about one-half of the maximum count rate observed in the 1961 annual monitoring survey.

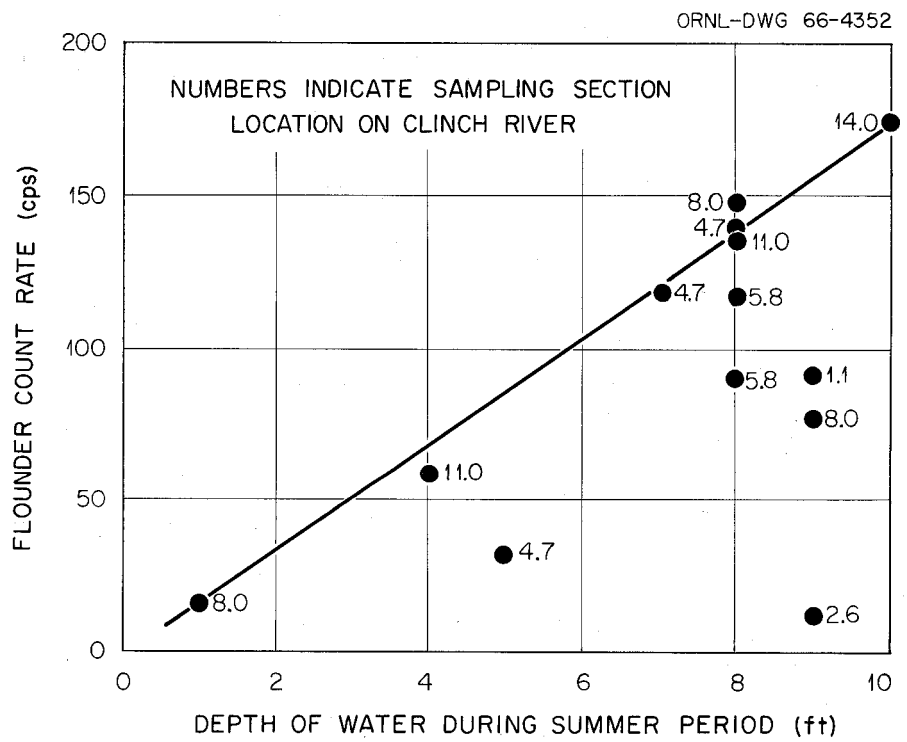


Fig. 22. Estimate of Maximum Flounder Count Rate on Exposed Banks of Clinch River when Lake is Drawn Down

Clinch River Sloughs

In 1963, a survey of radioactivity in bottom sediment of six large sloughs of the Clinch River and one slough of the Emory River was made. The purpose of the survey was to determine the level of surface radioactivity in fine sediment of the sloughs. Radioactivity readings were made with the Flounder instrument.

The results of the survey indicate that, though the radioactivity of sediment in the sloughs is within the range of radioactivity in the main river channel, the maximum radioactivity value was not as high as the maximum radioactivity in adjacent portions of the main channel[4].

In several of the deeper sloughs, a direct relationship between bottom sediment radioactivity and depth of water was found. Causes of this relationship are not definitely known. Two erosional processes may be largely responsible: (1) subaerial erosion of exposed sediments during winter low water in Watts Bar Lake, and (2) movement of sediment from shallower to deeper portions of the sloughs by sheet erosion[4].

CONCLUSIONS

Contents of this report illustrate the wealth of information available which is related to association of radioactivity with bottom sediments of the Clinch and Tennessee Rivers. Action by the Clinch River Study Steering Committee which catalyzed study of this information was well taken. Through compilation and interpretation of pertinent data, perspective has been gained as to how well investigations have met objectives of the Study (p. 4) and to suggest direction of other investigations, such as those reported in Part B of this report.

The first objective of the Clinch River Study is "to determine the fate of radioactive materials currently being discharged to the Clinch River".

The predominant radionuclide retained in bottom sediments, determined in the inventory of radioactivity of the uppermost strata of bottom sediments of the Clinch River, is ^{137}Cs. By application of an appropriate scaling factor to this inventory of the ^{137}Cs content in the sediments, probable retention of releases of this radionuclide to the study reach of the Clinch River is estimated to be 20 percent. Continued application of the same scaling factor to this incomplete inventory suggests that the fraction of retention for other radionuclides released to the Clinch River is much less than for ^{137}Cs, especially for ^{90}Sr (almost negligible).

Results of this partial inventory suggest only a small fraction of the fission-product load released from White Oak Lake has been retained in bottom sediments. Work was specifically undertaken to accurately determine fission-product activity retained in the bottom sediments, and results of this work are described in Part B of this report.

Several factors may influence deposition and retention of radioactive materials in bottom sediments of the Clinch and Tennessee Rivers. Among these factors are variations in radionuclide loads released from White Oak Lake, diffusion, sedimentation, some aspects of flow pattern, particle size, sorption, mineralogy, and states of

calcium equilibrium in water and sediment. Other factors that appear to be important, but which are not reported in this paper, are plant and animal detritus contents of sediment, coal content, potential for desorption of radionuclides (see Morton[4]), and the physico-chemical state of radionuclides in water and in suspended and deposited sediments (see Part B, this report).

Study of these factors has a direct bearing on satisfying the aims of the second objective of the study: "to determine and understand mechanisms of dispersion...".

Evidence has been obtained that changes in the concentration of radionuclides at the surface of bottom sediments are directly related to variations in radionuclide loads released through White Oak Dam. Evidence has also been obtained that suggests that most radionuclides that are associated with bottom sediment are sorbed on the sediments, or are in the form of particulate matter, prior to their release to the river (as suspended sediment) and that sedimentation is the primary mechanism for incorporation of radionuclides in bed deposits.

Effects of thermal stratification on depositional patterns of sediments in the Clinch River do not seem to be of primary importance. Other hydraulic characteristics, however, do affect depositional patterns: diffusion of sediment-bearing water from White Oak Creek into the Clinch River, surface area of the channel bed, and flow pattern.

In at least the first three miles downstream from the mouth of White Oak Creek lateral distribution of contaminated sediments is constrained, being related to the diffusion of White Oak Creek waters in the river. Between 4 and 6 miles downstream from the creek mouth these waters become fully mixed in the river[1, 3, 18] and lateral distribution of contaminated sediments should be independent of this particular aspect of diffusion.

As radioactive material is dispersed over a larger and larger area, concentration of radionuclides in bottom sediments is decreased.

Deposition of sediments and lateral distribution of radioactivity in these sediments are influenced by flow patterns around bends and about islands. Greater deposition and higher concentrations occur in eddy zones. Attempts to quantitatively relate concentration to curvature of bends, although not brought to complete fruition, are encouraging.

Sorption of radionuclides in river sediments may be expected to vary with changes in particle size, because the relative mineral composition usually varies with particle size and the chemically reactive surface of the particle increases, per unit weight, as its size decreases. Such concepts have been tentatively confirmed for sediments in the Tennessee River System by directly relating concentration of radionuclides to clay content of the sample. In the Clinch River the variation in radionuclide contents of five samples, collected at widely spaced (longitudinally) sections, was found to be greater than variations in particle size; essentially this contradicts findings for the samples from the Tennessee River and must for the moment remain an unexplained anomaly.

Only sorption of strontium and cesium by bottom sediments of the Clinch River has been measured extensively. Sorption of both radionuclides was found to be practically constant with longitudinal location. In tracer studies, using bottom sediments, sorption of strontium was found to be 49.3 ± 1.7 percent and for sorption cesium it was 97.6 ± 0.25 percent in demineralized-water solutions.

High sorption of ^{137}Cs has been ascribed to high illitic-type mineral content of the sediments. An appreciable content of illitic-type minerals, particularly in the clay-size fraction, is in the riverbed. Mineralogic composition of these samples is fairly constant. Sand and silt sizes have consisted mostly of quartz. Mineral composition of clay-size particles is more varied than for large sizes; variations in content of one mineralogic group in this size fraction, the mica-related minerals, may be the most important control on cesium sorption in the sediments.

Similar variations in ^{90}Sr content of the riverbed sediments

and in free calcium content have been noted in the Clinch River. This relationship may indicate that calcium in the water and sediment has a considerable influence on association of ^{90}Sr with bottom sediment.

Studies of physico-chemical properties of bottom sediments in the Clinch River have not shown any property which may singularly affect variations in radionuclide content of these sediments. Incorporation of radionuclides in sediments is due to complex interaction of a number of properties: size distribution, mineralogy, sorption capacities, and cation exchange capacities.

Desorption of radionuclides from riverbed sediments is being studied. Progress on investigations by Bonner and Tamura has been reported by Morton[4].

Geochemical studies, needed to delineate the processes which lead to incorporation of radionuclides in bottom sediment, strongly suggest that radioactivity has become associated with suspended sediments in White Oak Lake and that incorporation of some radioactivity in sediments on beds of the Clinch and Tennessee Rivers is the result of a hydraulic process, sedimentation. The possibility exists that some of the radioactivity is not associated with lithologic or biotic sediments; this radioactivity may have become associated with bed deposits through formation of chemical precipitates and subsequent agglomeration of these precipitates into particles of settleable size. Another possibility exists that these precipitates are occluded with other settleable-sized sediments and are thereby included into bed material.

Parts of material presented in this report are germane to safety analysis and will serve as an aid to achieving the third objective of the Study: "to evaluate direct and indirect hazards of current disposal practices...".

Highest levels of radiation and highest concentration of radionuclides are found to occur in bottom sediments of the Clinch River rather in reaches of the Tennessee River. Higher concentrations of radionuclides are found to occur in the reach between CRM 5 and 15 than elsewhere in the Clinch River.

The dominant radionuclide in these sediments is ^{137}Cs; very little ^{90}Sr is present.

Although there have been exceptions, contamination of the bottom sediments, due to release of radioactivity from White Oak Lake, is negligible upstream from the mouth of White Oak Creek in the Clinch River and upstream from the mouth of the Clinch River in the Tennessee River. Contamination of bed deposits in the Tennessee River has been found as far downstream as the Ohio River (Kentucky Dam). From information obtained in 1961, contamination to the mouth of the Tennessee River was limited to ^{106}Ru. However, releases of ^{137}Cs, ^{90}Sr, ^{60}Co, and ^{144}Ce were considerably less in 1961 than in previous years. Considering that concentration of radionuclides in bottom sediment is related to load of radionuclides released through White Oak Da, it appears possible that higher releases in years prior to 1961 could have produced contamination of sediments in reaches much farther downstream than those observed in 1961, possibly to the mouth of the Tennessee River for radionuclides other than ^{106}Ru.

Radiation levels of bottom sediments in sloughs of the Clinch River are not as high as those for sediments on the bed of the main stream. In addition, radiation levels of sediments deposited on parts of the slough or riverbed that are above 'winter' water levels are considerably less than levels measured at other locations which are continuously inundated.

Most radiation detecting devices used to measure distribution of radioactivity in bottom sediments <u>in situ</u> have performed well in the Clinch River. Farther downstream in the Tennessee River the higher levels of natural radiation and radiation from fallout relative to radiation from fission-product contamination originating from ORNL tend to limit the usefulness of these detectors. One limitation of detectors used is that the instruments do not have the capability to discriminate radiation emitted from one radionuclide from that emitted by another.

An attempt at this time to evaluate the usefulness of this

river system for the disposal of radioactive materials, the fourth objective of the Study, would seem to be premature insofar as bottom sediments are concerned. Lack of an inventory, an incomplete picture of the relative importance of various physical and chemical factors which lead to the association of fission products with sediments in channel beds, and only the beginnings of work on desorption mechanisms have led to this conclusion of prematurity.

Technologically, results of investigations reported in this paper may be helpful in making suggestions towards long-term monitoring procedures, the fifth and final objective of the Study. The Subcommittee on Bottom Sediment Sampling and Analyses made recommendations as outlined in the following section of this report to the Clinch River Study Steering Committee on December 11, 1964. Many of the suggestions stem from interpretation in this report of work by personnel of the Applied Health Physics Section, ORNL.

Early recognition of problems involved in monitoring radioactivity and continued responsible action by personnel of the Applied Health Physics Section provided abundant data with which to make assessments of fission-product content of bottom sediments in Tennessee River reservoirs.

1.: Monitoring of the radioactivity in the bottom sediments in the Clinch and Tennessee Rivers should be continued as long as radioactive materials are released to the Clinch River, and for a limited time thereafter. The present bottom sediment monitoring program extending from the mouth of White Oak Creek on the Clinch River to the mouth of the Tennessee River should be maintained.

Studies by the Applied Health Physics Section, ORNL indicate that radioactivity in bottom sediments above background levels has moved to sections in the Tennessee River progressively farther downstream from the mouth of White Oak Creek. Some information on radioactivity in bottom sediments should be collected as long as releases of radioactive materials to the Clinch River from White Oak Lake, or other sources at ORNL, are continued. Radioactivity stored in the seepage pits and trenches, in the burial grounds, and in the sediments and soils of White Oak Creek Basin may continue to be

released from White Oak Lake for a period of time after cessation of all controlled releases to the basin. It is suggested that the monitoring continue after such cessation until such time as the level of radioactivity in releases from White Oak Creek has dropped below a prescribed limit of concentration.

2.: The primary stations in a monitoring network should be the water sampling stations at White Oak Dam (or other control works near the mouth of White Oak Creek) and at the tailrace of Melton Hill Dam (or other upstream stations below Melton Hill Dam).

Studies by personnel of this subcommittee indicate that changes in the gamma radioactivity of the bottom sediments are directly releated to changes in the load of radionuclides released from White Oak Lake. The contribution to the total load of some radionuclides in the study reaches, especially strontium-90, upstream of the mouth of White Oak Creek is appreciable. If the radionuclide releases from White Oak Lake continue to decrease, the proportion of this upstream contribution to the total load will become more significant.

3.: Present procedures for the monitoring of radioactivity in the bottom sediments used by the Applied Health Physics Section, ORNL, are satisfactory. A general pattern of longitudinal distribution of radioactivity has been found in the past several years. After operations at Melton Hill Dam are begun, a new pattern may develop. Surveys should be made to determine when this new pattern of longitudinal distribution has been established. If power releases from Melton Hill Reservoir are affecting the distribution of radioactivity, it should be the responsibility of the Applied Health Physics Section to make appropriate modifications in the procedures to document the effects of these power releases.

At present the procedures include the determination of the level of radiation at the surface of the sediment and the determination of the concentration of radionuclides in composite samples of sediments at the surface of the deposits. These methods should not be considered standard because newer techniques in determination of radiation levels and of radionuclide concentration may indicate that

the procedures should be up-dated.

Modifications in the frequency of surveying radioactivity in bottom sediments and the selection of sections for such surveys may be suggested by information presented in this report.

The determination of bed profiles at sections which are monitored is suggested so as to provide additional information for interpretation of radiation and radionuclide concentration data.

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APPENDIX

Tables 8 through 20

Table 8. Concentration of Cesium-137 in Upper Portion of Bottom Sediments of Clinch River, 1954–61[a]

Location (CRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
21.5	3	5		5	4	4.5	1.5	1.3
19.1	12	7	116	528	44	527	64	41
16.3	27	22	208	177	223	464	175	71
15.2	22	34	268	119	146	391	374	64
14.0	24	29	115	184	298	464	257	127
11.0	22	34	144	251	236	229	240	98
8.3[b]	22	38	244	178	170	236	194	81
5.7[c]	24	29	266	299	223	207	177	115
4.7	22			236	151	169	176	112
2.6	15			173	92	171	93	82
1.1	24	25	257	192	67	259	141	100

[a]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[b]CRM 8.0 beginning in 1959.
[c]CRM 5.8 beginning in 1959.

Table 9. Concentration of Cesium-137 in Upper Portion of Bottom Sediments of Tennessee River, 1954–61[a]

Location (TRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
Fort Loudoun Reservoir								
604.1	2	2	5		2			1.2
								0.99
Watts Bar Reservoir								
570.8	3			5	2	1.8	1.5	1.1
562.7	10	7	73	55	51	41	46	34
552.7	12			57	36	41	32	42
534.8	5			47	22	23	28	15
532.0	10	11	32	39	21	26	24	25
Chickamauga Reservoir								
509.5	3			20	10	6.8		1.1
491.9	5		20	20	16	14	18	14
475.1[b]	5	2	14	16	13	11	11	11
Hales Bar Reservoir								
434.1				13	9	13	10	4.5
Guntersville Reservoir								
381.2				7	7	3.2	6.3	3.5
354.5[c]				7	4	3.6	4.0	4.6
Wheeler Reservoir								
337.6								0.45
320.9								2.5
280.0								4.6
Wilson Reservoir								
267.4								4.8
261.3								6.9
Pickwick Landing Reservoir								
227.4								2.0
207.3								2.6
Kentucky Reservoir								
97.2								1.1
75.7								0.99
67.0								0.90
45.8								0.99
24.6								1.2

[a]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[b]TRM 471.7 beginning in 1960.
[c]TRM 354.4 beginning in 1959.

Table 10. Concentration of Strontium-90 in Upper Portion of Bottom Sediments of Clinch River, 1954–61[a]

Location (CRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
21.5	1			1	1	0.5		0.26
19.1	5		4	3	2	9.5	0.7	1.0
16.3	5	4	7	5	6	9.0	2.3	2.0
15.2	5		9	5	6	7.2	4.4	0.77
14.0	5	4	4	3	11	8.6	2.7	1.1
11.0	5	4	6	5	13	5.4	3.7	1.0
8.3[b]	4	4	6	5	6	5.9	3.5	1.4
5.7[c]	4	4	6	7	1	4.5	2.6	1.0
4.7	4			5	8	4.5	1.4	1.3
2.6	3			3	5	1.4	1.0	0.90
1.1	4	3	6	3	5	2.7	1.4	0.41

[a]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[b]CRM 8.0 beginning in 1959.
[c]CRM 5.8 beginning in 1959.

Table 11. Concentration of Strontium-90 in Upper Portion of Bottom Sediments of Tennessee River, 1954–61[a]

Location (TRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
Fort Loudoun Reservoir								
604.1	2	1.4	1.3		1.1			0.14
								0.18
Watts Bar Reservoir								
570.8	2			0.9	1.0	0.5	0.2	0.14
562.7	2	0.3	3	0.8	2.0	0.9	0.5	0.49
552.7	2			0.5	1.5	1.4	0.5	0.59
534.8	2			0.9	1.7	0.9	0.5	0.27
532.0	4	0.4	3	0.6	1.7	1.4	0.7	0.63
Chickamauga Reservoir								
509.5	3			1	1.6	0.5		0.27
491.9	2		2	0.6	0.1	0.9	0.9	0.36
475.1[b]	2	0.3	2	1.3	1.3	0.9	0.4	0.36
Hales Bar Reservoir								
434.1				1.4	1.2	0.9	0.5	0.36
Guntersville Reservoir								
381.2				0.8	1.9	0.5	0.5	0.72
354.5[c]				0.7	1.5	0.5	0.5	0.36
Wheeler Reservoir								
337.6								0.32
320.9								0.09
280.0								0.36
Wilson Reservoir								
267.4								0.54
261.3								0.45
Pickwick Landing Reservoir								
227.4								0.31
207.3								0.23
Kentucky Reservoir								
97.2								0.45
75.7								0.18
67.0								0.23
45.8								0.18
24.6								0.41

[a]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[b]TRM 471.7 beginning in 1960.
[c]TRM 354.4 beginning in 1959.

Table 12. Concentration of Cerium-144 in Upper Portion of Bottom Sediments of Clinch River, 1954–61[a]

Location (CRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
21.5	2	4		5	12	6.8	0.8	0.44
19.1	5	6	24	33	7	92	9.0	2.7
16.3	8	21	37	12	20	71	23	5.6
15.2	7	32	56	9	22	54	39	4.4
14.0	8	22	20	7	43	65	25	8.2
11.0	8	31	41	10	40	27	34	9.4
8.3[b]	5	32	48	10	16	30	25	9.4
5.7[c]	8	40	56	12	24	20	22	9.9
4.7	7			13	21	18	18	9.9
2.6	4			9	17	9	11	7.0
1.1	5	30	44	13	22	20	11	8.6

[a]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[b]CRM 8.0 beginning in 1959.
[c]CRM 5.8 beginning in 1959.

Table 13. Concentration of Cerium-144 in Upper Portion of Bottom Sediments of Tennessee River, 1954–61[a]

Location (TRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
				Fort Loudoun Reservoir				
604.1	1	1.7	3		4.7			0.77
								0.99
				Watts Bar Reservoir				
570.8	1			1.3	5.7	6.8	0.9	0.72
562.7	2	13	15	5.5	8.0	92	3.1	2.9
552.7	2			4.3	9.6	71	1.8	2.9
534.8	1			3.0	7.2	54	2.3	1.1
532.0	2	15	8	2.6	4.9	65	1.8	2.3
				Chickamauga Reservoir				
509.5	1			1.9	6.2	27		0.23
491.9	2		6	1.8	4.6	30	1.8	1.8
475.1[b]	2	4	4	1.6	6.2	20	1.0	1.5
				Hales Bar Reservoir				
434.1				3.4	7.2	18	1.6	1.1
				Guntersville Reservoir				
381.2				3.4	5.4	9.0	1.3	0.76
354.5[c]				1.6	4.7	20	0.6	0.95
				Wheeler Reservoir				
337.6								0.27
320.9								0.77
280.0								1.5
				Wilson Reservoir				
267.4								1.8
261.3								2.4
				Pickwick Landing Reservoir				
227.4								0.90
207.3								0.99
				Kentucky Reservoir				
97.2								0.54
75.7								0.68
67.0								0.50
45.8								0.86
24.6								0.86

[a]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[b]TRM 471.7 beginning in 1960.
[c]TRM 354.4 beginning in 1959.

Table 14. Concentration of Trivalent Rare Earths[a] in Upper Portion of Bottom Sediments of Clinch River, 1954–61[b]

Location (CRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
21.5	1	3		2	3	5	1.4	0.7
19.1	2	3	7	10	6	251	23	7.8
16.3	4	5	11	5	13	151	74	16
15.2	4	7	15	4	17	142	144	16
14.0	4	8	7	4	21	149	132	31
11.0	6	16	19	8	18	58	177	29
8.3[c]	4	24	19	6	14	71	144	26
5.7[d]	8	12	18	7	15	57	69	28
4.7	5			6	13	33	38	20
2.6	5			5	10	19	72	23
1.1	4	9	15	5	12	41	48	35

[a]Analysis includes ^{90}Y as a constituent but excludes ^{144}Ce.
[b]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[c]CRM 8.0 beginning in 1959.
[d]CRM 5.8 beginning in 1959.

Table 15. Concentration of Trivalent Rare Earths[a] in Upper Portion of Bottom Sediments of Tennessee River, 1954–61[b]

Location (TRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
Fort Loudoun Reservoir								
604.1	2	1.7	3		4.8			0.86
								1.4
Watts Bar Reservoir								
570.8	1			1.1	5.1	1.7	0.5	1.1
562.7	3	6	6	1.9	5.5	8.3	21	8.2
552.7	1			2.7	6.1	7.0	12	5.7
534.8	2			1.3	5.5	5.4	8.6	3.1
532.0	4	7	4	1.5	5.5	6.6	5.1	4.0
Chickamauga Reservoir								
509.5	3			1.7	6.1			1.2
491.9	2		3	1.3	5.3	2.9	5.0	3.2
475.1[c]	2	6	1.8	1.0	6.4	5.5	3.1	3.4
Hales Bar Reservoir								
434.1				1.8	8.1	7.0	3.0	1.5
Guntersville Reservoir								
382.1				1.3	2.6	0.2	0.9	1.4
354.5[d]				1.4	4.7	2.5	2.0	1.9
Wheeler Reservoir								
337.6								0.54
320.9								0.86
280.0								0.68
Wilson Reservoir								
267.4								1.6
261.3								1.8
Pickwick Landing Reservoir								
227.4								0.72
207.3								1.0
Kentucky Reservoir								
97.2								0.86
75.7								0.32
67.0								1.1
45.8								0.77
24.6								0.54

[a]Analysis includes ^{90}Y as a constituent but excludes ^{144}Ce.
[b]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[c]TRM 471.7 beginning in 1960.
[d]TRM 354.4 beginning in 1959.

Table 16. Concentration of Ruthenium-106 in Upper Portion of Bottom Sediments of Clinch River, 1954–61[a]

Location (CRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
21.5	1			3	6	5.0	1.8	2.7
19.1	8		5	14	3	18	27	95
16.3	5	4	8	6	7	17	80	159
15.2	5		11	3	6	18	83	148
14.0	6	4	6	4	16	17	99	153
11.0	2	5	7	6	12	9.9	99	144
8.3[b]	5	4	10	5	7	11	85	152
5.7[c]	5	8	8	6	11	7.7	90	157
4.7	5			5	10	7.2	79	148
2.6	5			4	6	6.3	72	103
1.1	3	4	10	6	10	9.9	55	141

[a]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[b]CRM 8.0 beginning in 1959.
[c]CRM 5.8 beginning in 1959.

Table 17. Concentration of Ruthenium-106 in Upper Portion of Bottom Sediments of Tennessee River, 1954–61[a]

Location (TRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
				Fort Loudoun Reservoir				
604.1	1	0.5	3		4.6			1.9
								2.3
				Watts Bar Reservoir				
570.8	3			1.3	2.6	3.6	2.7	2.7
562.7	2	3	4	3.1	4.1	6.3	19	34
552.7	1			3.4	5.4	5.0	17	39
534.8	2			3.1	3.1	3.6	14	22
532.0	1	4	3	2.0	2.0	3.2	13	31
				Chickamauga Reservoir				
509.5	1			2.3	3.4			8.6
491.9	1		2	1.8	3.7	3.6	27	30
475.1[b]	1	1	3	1.5	3.5	5.4	10	26
				Hales Bar Reservoir				
434.1				2.9	3.5	8.6	32	28
				Guntersville Revervoir				
381.2				0.9	2.5	2.7	12	14
354.5[c]				1.7	2.3	4.1	6.9	13
				Wheeler Reservoir				
337.6								4.1
320.9								11
280.0								16
				Wilson Reservoir				
267.4								18
261.3								25
				Pickwick Landing Reservoir				
227.4								8.7
207.3								12
				Kentucky Reservoir				
97.2								7.2
75.7								6.4
67.0								5.0
45.8								5.3
24.6								4.4

[a]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[b]TRM 471.7 beginning in 1960.
[c]TRM 354.4 beginning in 1959.

Table 18. Concentration of Cobalt-60 in Upper Portion of Bottom Sediments of Clinch River, 1954–61[a]

Location (CRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
21.5	3	2			3	0.9	0.5	0.32
19.1	11		26	30	4	69	8.2	5.9
16.3	19	18	39	15	21	53	19	11
15.2	19		59	14	9	41	35	10
14.0	19	23	29	17	16	53	27	14
11.0	19	25	37	15	15	26	25	14
8.3[b]	23	29	50	15	17	28	22	11
5.7[c]	31	26	52	18	17	29	22	14
4.7	27			15	14	26	21	15
2.6	19			13	9	18	12	11
1.1	23	21	46	16	13	20	16	12

[a]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[b]CRM 8.0 beginning in 1959.
[c]CRM 5.8 beginning in 1959.

Table 19. Concentration of Cobalt-60 in Upper Portion of Bottom Sediments of Tennessee River, 1954–61[a]

Location (TRM)	Concentration (pc/g)							
	1954	1955	1956	1957	1958	1959	1960	1961
				Fort Loudoun Reservoir				
604.1	4	0	1.0		0.6			0.36
								0.32
				Watts Bar Reservoir				
570.8	4			1	0.8	0.9	0.3	0.3
562.7	8	7	11	6	5.7	6.8	6.0	4.5
552.7	6			6	6.1	8.1	5.0	5.3
534.8	7			5	3.6	5.0	4.7	2.5
532.0	7	13	7	3	2.9	3.6	4.1	3.9
				Chickamauga Reservoir				
509.5	4			2	2.1			0.6
491.9	5		4	3	3.1	3.6	3.6	3.0
475.1[b]	5	4	6	3	1.7	2.7	2.3	2.4
				Hales Bar Reservoir				
434.1				2.0	1.7	2.7	2.7	1.3
				Guntersville Reservoir				
381.2				2.0	1.7	1.4	1.4	1.0
354.5[c]				0.3	2.5	1.8	1.4	1.1
				Wheeler Reservoir				
337.6								0.23
320.9								0.41
280.0								0.90
				Wilson Reservoir				
267.4								0.90
261.3								1.2
				Pickwick Landing Reservoir				
227.4								0.72
207.3								0.81
				Kentucky Reservoir				
97.2								0.45
75.7								0.41
67.0								0.32
45.8								0.41
24.6								0.41

[a]Data from annual monitoring surveys of Applied Health Physics Section, ORNL.
[b]TRM 471.7 beginning in 1960.
[c]TRM 354.4 beginning in 1959.

Table 20. Particle-Size Distribution in Bottom Sediments from Clinch River

(percent)

Location (CRM)	Clay (<2 μ)			Silt (2–62 μ)			Sand (>62 μ)		
	Lab. A	Lab. B	Average	Lab. A	Lab. B	Average	Lab. A	Lab. B	Average
4.7	13[a]	18.1	16	55[a]	49.4	52	32[a]	31.3	32
7.6	13.5[a]	17.9	16	58[a]	59.0	58	28.5[a]	21.8	25
11.9	14	18.4	16	55	62.4	59	31	19.2	25
15.3	16	20.9	18	46	50.4	48	38	28.7	33
19.2	12	16.9	14	48	49.4	49	40	33.8	37

[a]Average of duplicate samples.

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