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STATUS REPORT NO. 1 ON CLINCH RIVER STUDY

R. J. Morton, Editor

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HEALTH PHYSICS DIVISION

STATUS REPORT NO. 1 ON CLINCH RIVER STUDY

Clinch River Study Steering Committee

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TABLE OF CONTENTS

	Page
LIST OF FIGURES	iv
LIST OF TABLES	v
CLINCH RIVER STUDY STEERING COMMITTEE	vi
ACKNOWLEDGMENT	vii
INTRODUCTION	1
Objectives	1
Description of the Clinch and Tennessee Rivers	2
Use of the Clinch River for Radioactive Waste Disposal	9
Past and Present Water Monitoring Program	11
Participating Agencies	13
Meetings of the Steering Committee	15
SAMPLING AND ANALYSIS	18
Water	20
Bottom Sediments	24
Radionuclide Interactions with Minerals and River Sediment	28
BIOLOGICAL PHASES	43
Fish Populations	46
Tubificid Worms	52
Uptake of Co^{60} by Crayfish	57
Radiation Effects on Biota	58
Studies Concerning Aquatic Plants	65
HYDROLOGIC STUDIES	67
Stream Gaging on Clinch River and Its Tributaries	68
APPENDIX - SAMPLING SITES AND ALLOCATION OF SAMPLING AND ANALYSIS	73

LIST OF FIGURES

Figures		Page
1	Map - Lower Clinch River Basin	3
2	Map - Eastern Portion of Tennessee River	5
3	Map - Tennessee River Basin	6
4	Radionuclides Discharged from White Oak Creek, and Major Radionuclides Found in Clinch and Tennessee River Silt by Years 1954-58	26
5	Radionuclide Distribution on Sediments as a Function of the Sediment Load in the River Under Different pH Conditions (Cesium, Zirconium-Niobium, and Strontium)	35
6	Radionuclide Distribution on Sediments as a Function of the Sediment Load in the River Under Different pH Conditions (Cobalt)	36
7	Diagram of a Tubificid Worm Feeding on Bottom Sediment ...	54
8-15	Eight Photographs of Slides Showing Salivary Gland Chromosomes in Larvae of *Chironomus tentans* Fabr.	60-63

LIST OF TABLES

Table		Page
1	Community Water Systems in Tennessee Downstream from ORNL Supplied by Intakes on Clinch and Tennessee Rivers or Tributaries That May Be Affected by Main Stream Conditions	8
2	Type and Quantity of Samples from Each Station	19
3	Average Per Cent and Average K_d of Cesium Sorbed by Clays	30
4	Average Per Cent and Average K_d of Cobalt-60 Sorbed by Clays	31
5	Average Per Cent and Average K_d of Strontium-85 Sorbed by Clays	32
6	Average Per Cent and Average K_d of Zirconium-Niobium-95 Sorbed by Clays	33
7	Effect of pH of Solution on the Removal of Cobalt	39
8	Average Cobalt Removal by Several Materials at Selected pH.	40
9	Cobalt Removal by Several Organic Materials and River Sediments	41
10	Measurement Data Used in Model to Determine Downstream Transport of Sediment by Tubificid Worms	56
A.1-5	Sampling Sites and Allocation of Sampling and Analysis (APPENDIX)	73-75

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ACKNOWLEDGMENT

This Study is made possible through the work and co-operation of a number of groups within the Laboratory and of many people connected with federal, state, and public agencies represented on the Steering Committee. It is with gratitude that the Steering Committee recognizes and gives its appreciation to the investigators named below.

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INTRODUCTION

This is the first of a series of status reports on the study of the Clinch River initiated in February 1960. Although preliminary data are included, the main purpose of this report is to outline the objectives and the plans for this co-operative Study. The Study is carried out under the technical co-ordination of the Steering Committee; and, as more information becomes available, subsequent status reports will be issued by the Steering Committee.

Objectives

The purpose of the study of the Clinch River below ORNL is to obtain fundamental information on the physical, chemical, and biological dynamics of the fresh-water stream which receives large volumes of low-level radioactive wastes. This program has four general objectives, namely: (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, and (4) to evaluate the over-all usefulness of this river for radioactive waste disposal purposes.

Information from a broadly conceived fundamental and applied program of study will have important implications for two world-wide problems involving large-scale environmental contamination: First, what is the over-all diluent capacity of fresh-water environments for the continuous input of

large volumes of low-level radioactive wastes? Second, what is the long-term indirect impact of radioactive contamination on such an environment.

Description of the Clinch and Tennessee Rivers

The Clinch River, a tributary of the Tennessee River, rises near Tazewell, Virginia, and flows southwest to join the Tennessee River near Kingston, Tennessee. It is over 350 miles long and drains an area of 4413 square miles. The portion of the Clinch River from Norris Dam at Clinch River Mile (CRM) 79.8 to its confluence with the Tennessee River, CRM 0.0, is shown on the accompanying map (see Fig. 1). This map shows the relative locations of major features, such as nuclear energy installations, highways, towns, and water and power plants which are of interest in the Clinch River Study.

Below Norris Dam, the river is highly regulated by varying releases from the reservoir and by changes in water level of Watts Bar Reservoir. White Oak Creek, which drains the site of the Oak Ridge National Laboratory, flows into the north side (right bank) of the Clinch River at CRM 20.8. Backwater from Watts Bar Dam extends upstream past White Oak Creek to about CRM 28 during the nonflooding season, May to September, and to White Oak Creek, CRM 20.8, during minimum pool elevation. The 1936-1960 average flow in the river above the mouth of White Oak Creek (at Scarboro gage, CRM 39.0) is 4564 cfs with a maximum of 42,900 cfs and a minimum daily of 130 cfs since impoundment at Norris Reservoir began.

The time for a power-release wave to move from Norris Dam to CRM 20.8 is variable, depending upon conditions in the river. The velocity of the wave depends, in part, upon the depth of water in the river and upon the rate of change of discharge with respect to water level. The time of water travel

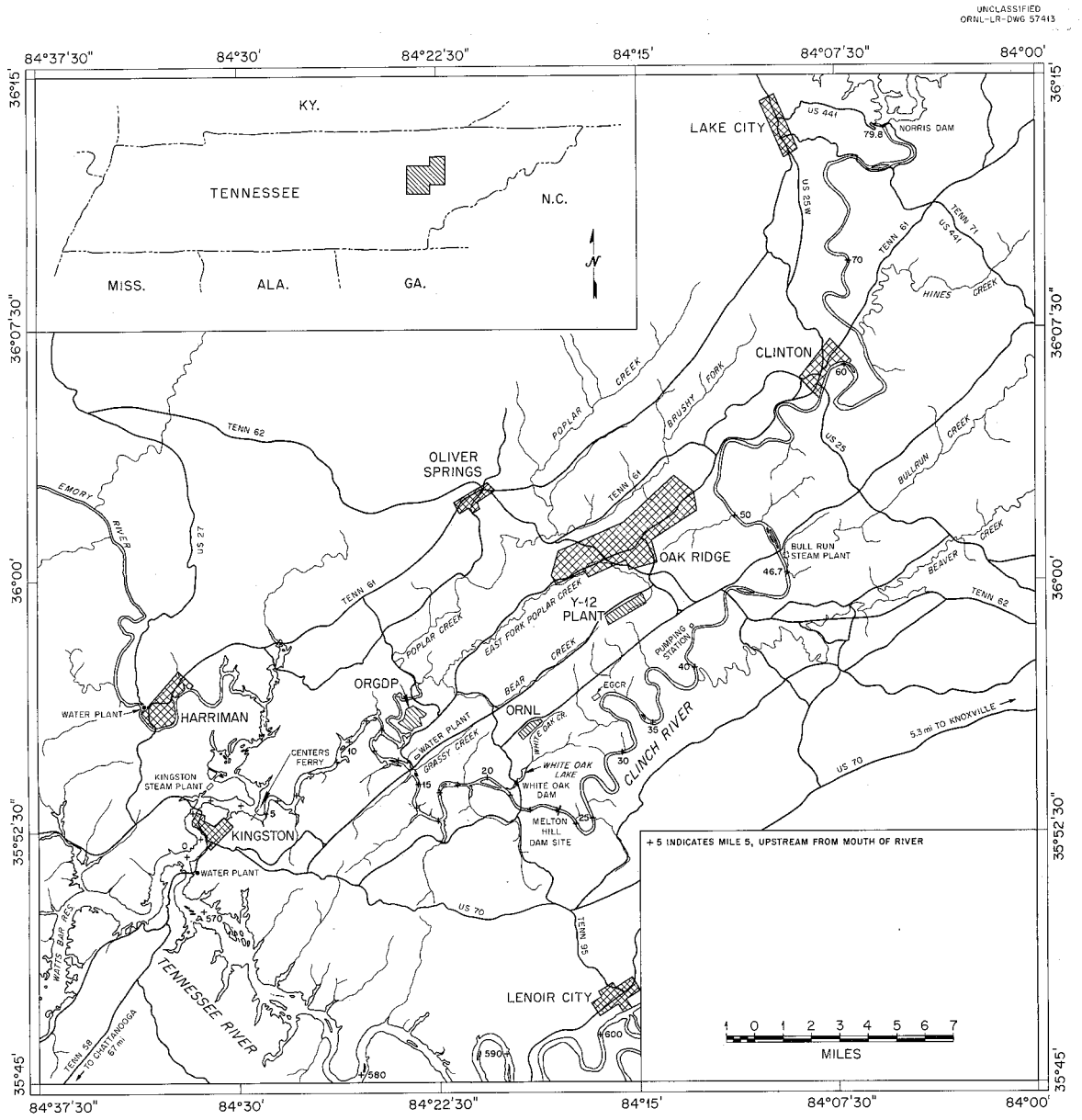

Fig. 1. Map – Lower Clinch River Basin.

from Norris Dam to CRM 20.8 is about twice the time of wave travel. This assumes unstratified flow in the river which is not always the case as discussed below.

In the summer, backwaters from Watts Bar Dam are warmer than the Clinch River water released from Norris Dam, which causes the Norris water to flow under the pooled water. The flow in Watts Bar Reservoir downstream from White Oak Creek during the period, May - September, is profoundly modified by differences in water temperature of the Clinch River and Watts Bar Reservoir. When Clinch River water is significantly cooler, stratified flow conditions due to density differences may exist. The section at which stratification begins varies, depending upon conditions in the river, but commonly occurs at about CRM 12.6. This phenomenon markedly affects the travel time of water through the reservoir and complicates the analysis of flow. In addition, during the period of stratified flow, some Clinch River water may flow up the Emory River as far as Harriman. It is evident that the Clinch River is a highly complex hydraulic system.

The Tennessee River Basin extends from the mouth at Ohio River near Paducah, Kentucky, to headwater tributaries in Virginia, North Carolina, and Georgia. The river system drains a large part of eastern and western Tennessee, a large area in northern Alabama, and areas in Kentucky, Mississippi, Georgia, Virginia, and North Carolina (see Figs. 2 and 3). The drainage area of the Tennessee River is 40,910 square miles. The mean annual discharge of the Tennessee River for the period of record, ending in 1960, at Knoxville, Tennessee, is 12,810 cfs (61 years); at Chattanooga, Tennessee, 37,030 cfs (86 years); at Florence, Alabama, 50,620 cfs (66 years); and at Paducah, Kentucky, 63,790 cfs (71 years). Many multipurpose dams are located on the

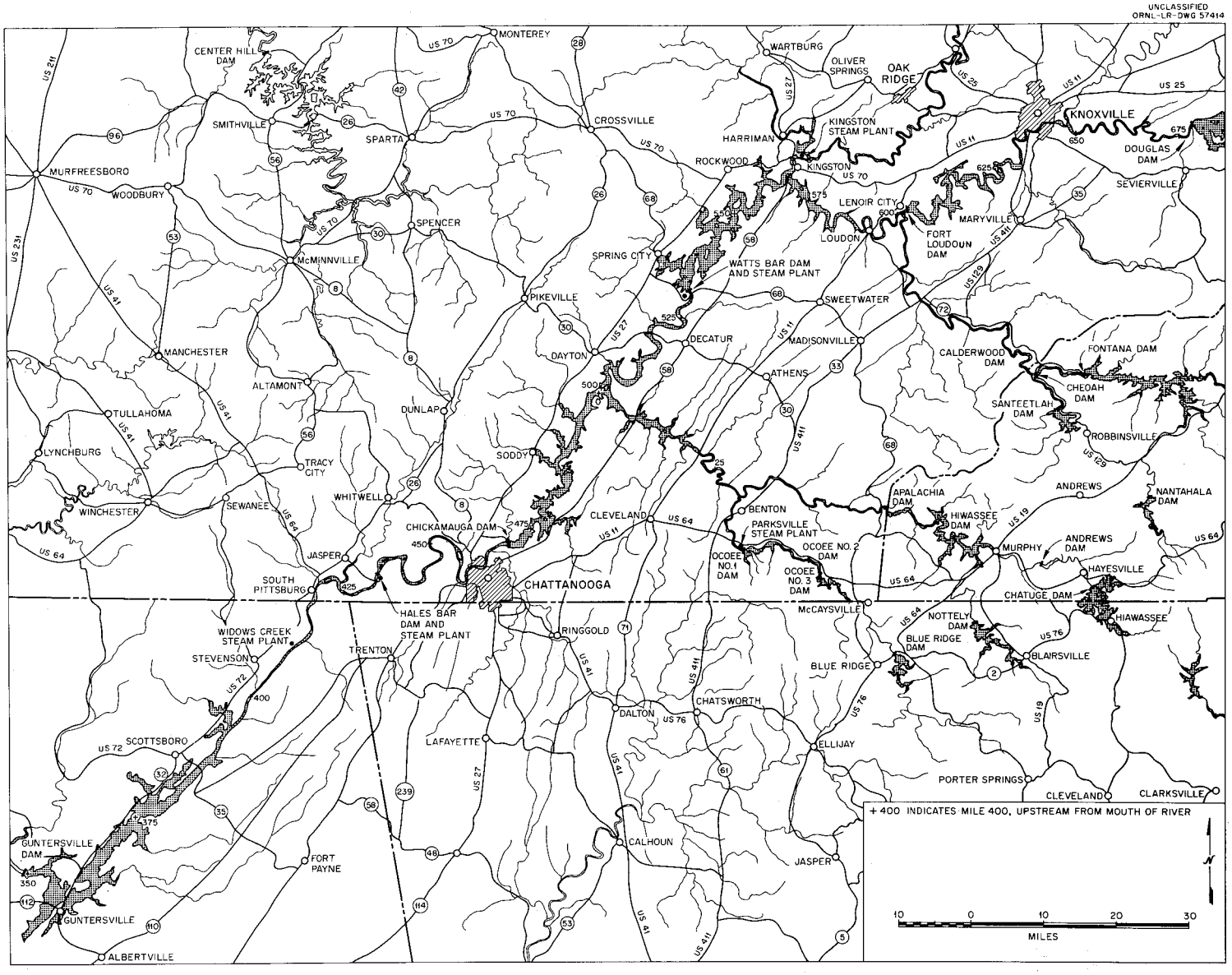

Fig. 2. Map – Eastern Portion of Tennessee River.

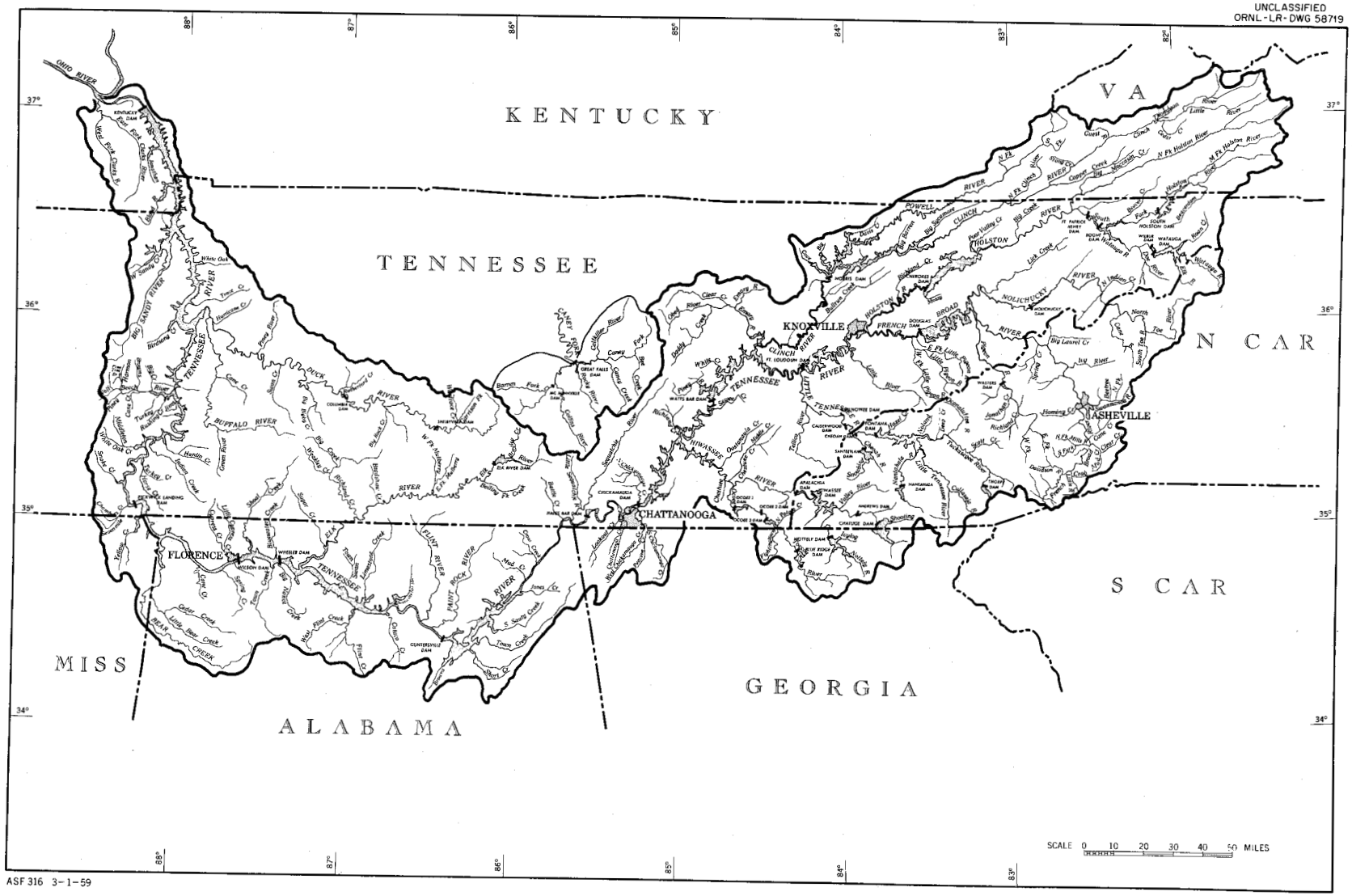

Fig. 3. Map – Tennessee River Basin.

main stem of the Tennessee River and several principal tributaries; the Tennessee River, alone, is affected by nine main-stream reservoirs from Knoxville, Tennessee, to the mouth.

The Clinch and Tennessee Rivers downstream below ORNL are used for drinking water, irrigation, industrial cooling, and recreational activities, such as fishing, swimming, boating, and water skiing. Two large existing steam plants on the Clinch River are the TVA Kingston Steam Plant at CRM 3 and the steam plant of the Oak Ridge Gaseous Diffusion Plant (K-25) at CRM 13. Another TVA steam plant is authorized for construction near Oak Ridge at approximately CRM 50. The Clinch River is also used for navigation, primarily coal barges, up to the K-25 Steam Plant. The use of the river will be materially increased when Melton Hill Dam, which includes navigation locks, is constructed at CRM 23.1, possibly including navigation as far upstream as Clinton at CRM 60. If completed as tentatively planned, this project will entail important channel changes and increased velocities and lower temperatures in the river for some distance below the Melton Hill Dam.

Contamination of community drinking-water supplies is the most serious potential hazard that may result from discharges of radioactive materials to the Clinch River system. The seriousness of the hazard depends on the population potentially exposed, as well as on the intensity and duration of contamination in the water-supply systems. Information regarding community water systems on or near the Clinch and Tennessee Rivers downstream from ORNL to South Pittsburgh, Tennessee, is given in Table 1.

The estimated total population of communities downstream from ORNL and served by surface-water sources on or adjacent to the Clinch and Tennessee Rivers is about 200,000 (Table 1). More than 80% of this population is in

Table 1. Community Water Systems in Tennessee Downstream from ORNL Supplied by Intakes on Clinch and Tennessee Rivers or Tributaries That May Be Affected by Main Stream Conditions

Community	Estimated Population*	Intake Source		
		Stream	Approx. Location	
ORGDP - K-25 Area	5,000	Clinch R.	CRMi. 14	Industrial plant water system
Harriman	6,000	Emory R.	ERMi. 12	Mouth of Emory R. is at CRMi. 4.5
Kingston Steam Plant (TVA)	< 500	Clinch R.	CRMi. 3	
Kingston	2,000	Tenn. R.	TRMi. 570	River used for supplementary supply
Watts Bar Dam (Resort Village and TVA Steam Plant)	1,000	Tenn. R.	TRMi. 530	
Dayton	3,000	Richland Cr.	RCMi. 3	Opposite TRMi. 505
Cleveland	15,000	Hiwassee R.	HRMi. 15	Mouth of Hiwassee R. is at TRMi. 500
Soddy	2,000	Tenn. R.	TRMi. 488	
Chattanooga	155,000	Tenn. R.	TRMi. 465	Metropolitan area served by City Water Company
South Pittsburg	3,000	Tenn. R.	TRMi. 435	
Total	192,000			

*Based on published 1957 estimates.

the municipality and suburbs of Chattanooga, 125 miles downstream from ORNL, which must use the Tennessee River water to supply the large requirements for domestic and industrial uses. In addition to potential health hazards, the possibility must be considered that radioactive contamination in the water supply might make it unsuitable for use in certain industrial processes.

The pumping and use of water from the Watts Bar and Chickamauga Reservoirs for irrigation of agricultural crops is increasing very rapidly. One estimate in 1955 indicated that there were then more than 1000 such irrigation installations in Tennessee, that they had increased in number more than tenfold in a 7-year period, and that raw river waters were used for supplementary spray irrigation on various cultivated crops and pastures for cattle. Radioactive contamination in water used for irrigation of human or animal food crops is a potential hazard of human exposure through food or milk.

Use of the Clinch River for Radioactive Waste Disposal

The Oak Ridge National Laboratory releases some radioactive wastes to White Oak Creek from the waste water treatment plant, waste seepage pits, drainage from various reactor facilities, cooling water from the reactors, and seepage from the bed of White Oak Lake.

White Oak Lake from 1943 to 1955 was used as an impoundment for the wastes released from the Laboratory. This lake covered an area of 35 to 44 acres and had an average depth of 6 ft. Some of the wastes flowing from the Laboratory were sorbed on the muds and silts and settled in White Oak Lake. Eventually, equilibrium was reached in the lake between inflow and

outflow of radioactive materials, and the lake was drained in October 1955. Now the wastes flow into White Oak Creek and through part of the bed of White Oak Lake. The gates of White Oak Dam have been reworked and are maintained at a sufficient elevation above Watts Bar Reservoir so that a standing pool of approximately 5 acres exists back of the dam. By this means a one-way flow of water through the gates is assured even during periods of high elevation of Watts Bar Reservoir. Proportional water samples are now taken continuously at the dam-control point and provide a more accurate measure of radionuclide content in the water than was possible prior to remodeling.

During the 10 years, 1948 to 1957, approximately 3600 curies were discharged from White Oak Creek into the Clinch River. The major radioactive constituents in these wastes were the rare earths, Sr^{89}, Sr^{90}, Cs^{137}, and Ru^{106}. In addition, White Oak Creek discharged substantial quantities of nonradioactive chemicals, particularly nitrates. This chemical discharge and the slowing down and warming up of Clinch River waters below White Oak Creek result in periodic dense growths of algae in the nutrient-rich waters.

The Oak Ridge Gaseous Diffusion Plant (K-25) and the Y-12 Plant also discharge wastes to the Clinch River. These wastes consist of uranium and uranium-derived elements and are a by-product of uranium processing at these plants. Although of low activity, these effluents do increase the contaminant load of the river. The wastes from the K-25 and Y-12 plants flow into the river through Poplar Creek downstream from the K-25 potable water-supply intake.

The Clinch river below ORNL is not used as a source for community drinking-water supplies. However, due to the fact that cold Clinch River

water flows upstream in the Emory River during the summer months, Clinch River water is at times drawn into the Harriman municipal water intake. During the summer months, Clinch River water is used for the domestic supply by personnel of the TVA Kingston Steam Plant. In addition, the water intake in the Tennessee River used by Kingston, along with springs, for the municipal supply is so located that during the summer months some Clinch River water could possibly be drawn into the municipal system, but the probability is slight and the expected frequency rare (see Fig. 1).

The continuous discharge of radioactive material, by definition, will allow the physical, chemical, and biological environments to approach steady-state conditions. The absorption and adsorption of the radioactive materials by the suspended solids and biota will tend to decrease the concentration of dissolved radioactive material in the water. The physical processes of diffusion apply principally at the beginning and end of waste flows. The rest of the time simple dilution is the primary physical factor, provided the contaminant is uniformly mixed with the water by the time it reaches the cross sections of interest. The monitoring of continuous discharges of radioactive materials must include measurements of concentrations in the biota, mud, and water to ensure that the exposure from water used for drinking, irrigation, and recreation does not exceed acceptable dosages to downstream users (see page 43).

Past and Present Water Monitoring Program

The primary emphasis of normal ORNL monitoring of releases to the Clinch River is to ensure that the concentrations of radioactive materials in the river are below the maximum permissible concentrations (MPC_w) for drinking

water recommended by the NCRP*. To ensure this, the liquid wastes from ORNL are continuously sampled in White Oak Creek at White Oak Dam and are sampled daily in the Clinch River at the Oak Ridge Gaseous Diffusion Plant (K-25). The U. S. Geological Survey (USGS) measures the amount of flow in White Oak Creek and in the Clinch River so that the concentration of wastes in the river, assuming complete dilution, can be determined. The daily samples at White Oak Dam are composited and counted for gross beta and gamma activity. A portion of the flow is brought past a beta monitor, consisting of a detector head employing a five-G-M-tube cluster, a count-rate meter, and a continuous sampling system. The count rate is telemetered back to the area-control laboratory. If the count should exceed a certain limit, an alarm will sound, and White Oak Dam can be closed manually until such time as the activity has decayed or some remedial action has been taken.

Weekly composite samples are analyzed radiochemically for plutonium and Sr^{90}. Monthly composite samples are analyzed radiochemically for the radioisotopes of strontium, cerium, praseodynium, ruthenium, rhodium, iodine, zirconium, trivalent rare earths, niobium, barium, and cobalt. Once the radioactive materials pass out of White Oak Creek they then flow into the Clinch River and eventually into the Tennessee River.

Each year since 1951 the Laboratory has conducted a survey of the amount of radioactive materials in the Clinch and Tennessee River sediments. The gamma radiation of the bottom sediments in place is measured by twelve battery-operated G-M tubes connected in parallel. Bottom sediments are also collected and analyzed for their radiochemical constituents (see page 25).

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*National Committee on Radiation Protection and Measurements.

Water samples are collected daily from the Clinch River at Centers Ferry near Kingston, Tennessee, by the Applied Health Physics Section, ORNL, and composited for 3-month periods. The composite is filtered and concentrated by evaporation. The residue of suspended solids and the concentrate are analyzed for fission products to determine the level and composition of the radionuclides existing in the Clinch River waters at this point.

The highest concentration of radioactivity in the river bottom sediments, except near the mouth of White Oak Creek, is about eighteen times background and is located about 12 miles below the outfall of White Oak Creek. The concentration of radioactive materials in the river sediments falls off very quickly after the first 20 miles and is only about twice background at 100 miles and approaches background beyond Chattanooga at 150 miles downstream, though fission products are still detected by sediment analysis. At this level it is difficult, if not impossible, to distinguish between fall-out and waste-disposal contaminants. The level of radioactive contamination in the bottom sediments drops off rapidly below each dam in the Tennessee River and increases again as the next dam is approached. This occurs because the water velocity and turbulence decrease as the water approaches the dam and are increased in the channel immediately below the dam.

Participating Agencies

At the invitation of the U. S. Atomic Energy Commission, representatives of two Tennessee State agencies and three other Federal agencies met with representatives of the AEC-Washington, AEC-ORO, and ORNL in Oak Ridge on December 18, 1959. The purpose of this meeting was exploratory, to

consider the need for and scope of a proposed river study and to determine the extent to which these agencies would be willing to participate in the investigations indicated in the proposal. The agencies represented at this meeting were: Tennessee State Game and Fish Commission (SGFC), Tennessee State Department of Public Health and Stream Pollution Control Board (SDPH), U. S. Public Health Service (PHS), U. S. Geological Survey (USGS), Tennessee Valley Authority (TVA), U. S. Atomic Energy Commission (AEC), and Oak Ridge National Laboratory (ORNL).

Detailed reports of waste releases to the river and of the Applied Health Physics Section's monitoring program in the river were presented by representatives of the ORNL Health Physics Division. The scope of the proposed study and its objectives were also considered, and general agreement was reached that the study should be undertaken. It was impossible for the representatives of the outside agencies to state at that time what their respective roles in this co-operative study would be.

At the meeting, it was decided to organize a Technical Steering Committee made up of representatives of each agency. E. G. Struxness, ORNL Health Physics Division, was asked to serve as Chairman of the Steering Committee, and the membership was made up as follows: F. V. Durand (SGFC), A. G. Friend (PHS), F. E. Gartrell (TVA), R. G. Godfrey (USGS), S. Leary Jones (SDPH), J. A. Lieberman (AEC-WASH, ex officio), I. E. Wallen (AEC-WASH, ex officio), and A. A. Schoen (AEC-ORO, ex officio).*

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*Based on minutes of the exploratory meeting, December 18, 1959. Distributed to the Steering Committee and members of the staff of the Study.

Meetings of the Steering Committee*

On December 18, 1959, immediately following the exploratory meeting, the newly-organized Steering Committee held a brief meeting. General procedures for the work of the committee were considered; and the dates for the next meeting, viz., January 21-22, 1960, were selected.

The second Steering Committee meeting was held at Oak Ridge on January 21, 1960. The decisions of the committee made at this meeting were as follows:

(1) That the exploratory phase of this Study, requiring a period of approximately 6 to 9 months, would deal with the sampling and analysis of river water, suspended solids, bottom sediments, bottom fauna, and fish populations at mutually agreed upon collecting stations.

(2) That the ORNL Ecology Section would assume primary responsibility for the bottom fauna.

(3) That the ORNL Waste Research Section would assume primary responsibility for river water, suspended solids, and bottom sediments.

(4) That the PHS group at the Sanitary Engineering Center in Cincinnati would assume primary responsibility for a study of fish populations.

It was later pointed out that the activities to be carried out by PHS would require justification from the viewpoint of public health interest. The PHS group at Cincinnati was oriented toward and equipped to handle work of public health interest, and this philosophy governed the types of samples to be taken and analyses to be made. They were at that time conducting

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*Summarized from minutes of all meetings of the Steering Committee which were distributed to members of the Steering Committee and the staff of the Study.

stream-pollution surveys in the Mohawk River and in the Savannah River, and it was their feeling that they should conduct a similar survey in connection with the Clinch River Study; that is, they preferred to take samples of everything and to take them back to Cincinnati for preparation and analysis. While there were some conflicting viewpoints on sampling techniques and in respect to responsibilities, there seemed to be general agreement between the ORNL and PHS groups as to the over-all objectives. At this meeting, Dr. I. E. Wallen, AEC-WASH, requested that Dr. Vincent Schultz serve as an ex-officio member of the Steering Committee in his stead.

The third meeting of the Steering Committee was held in Oak Ridge on April 21, 1960. By this time the ORNL groups and the PHS group had begun their respective investigations in the river, and detailed progress reports were distributed and discussed at the meeting. Preliminary discussions indicated that there were some differences of understanding by workers in the several agencies and insufficient or ineffective liaison regarding specific work assignments and procedures. The purpose of this meeting was to eliminate these misunderstandings, and discussions covered the following points: (1) specific clarification of the immediate objectives, (2) more exact definition of work to be done by each agency, (3) discussion of each major phase of the program by those directly in charge of the work, (4) review of the relationships of the different types of data to various parts of the work program, (5) agreement as to what should be done by the several working groups during the next 3 to 6 months, and (6) information to the Steering Committee regarding procedures agreed upon and progress in the field program. It was finally agreed that each agency would use its own analytical procedures with enough cross checks of duplicate samples to be sure that the

results were comparable. It was also agreed that, operationally, the two groups (ORNL and PHS) could move independently toward the common objective.

The fourth meeting of the Steering Committee was held in Oak Ridge on September 22 and 23, 1960. Two changes in committee membership were made at this meeting; namely, J. S. Cragwall to replace R. G Godfrey of the Surface Water Branch (USGS) and Glenn Gentry to replace F. V. Durand of the SGFC. A Subcommittee on Water Sampling and Analysis was appointed to plan and implement all water sampling and analysis for the Clinch River Study.

SAMPLING AND ANALYSIS

Quantitative information necessary to define and gain an understanding of physical, chemical, and biological conditions in the river must be obtained primarily by collection and analysis of various types of samples. In an effort to make the analytical results most meaningful in relation to radioactivity in the river and also to minimize the work load and cost of collecting and analyzing samples, a great deal of time in the early stages of the Study has been devoted to the selection of sampling points and in deciding on the frequency of sampling, types of samples, and analytical procedures. As mentioned earlier the Steering Committee considered these problems in detail during its meetings and set up a special committee to design and implement a suitable program and distribution of effort by the various agencies in sample collection and analysis.

In quarterly environmental surveys the Public Health Service has included collection of samples of water, bottom muds, fish, miscellaneous aquatic fauna, plankton, and filter sand from a water plant which uses the Tennessee River as a source of raw water for a municipal supply. The locations of the sampling stations and the number and types of samples collected in the quarterly survey by the Public Health Service, February 9-15, 1960, are summarized in Table 1 and described in more detail in Appendix A.

On the Clinch River more intensive sampling is being done by ORNL, and the results, as they become available, are correlated with hydraulic data and with information about the releases of radioactivity through White Oak

Table 2. Type and Quantity of Samples from Each Station (1)

Sample Type	Station Number (see footnotes)								Type Totals
	1	2	3	4	5	6	7	X	
Algae bags		5						10	15
Clam (shells)	1					1			2
Crayfish	1								1
Filamentous algae	1								1
Filter sand							2		2
Fish	18	6	40	38	9		16		127
Mud	1	4	4	2	1	1	2	4	19
Plankton tow	1		1	1	1				4
Rock								1	1
Sand Wash H_2O							3		3
Sludge							1		1
Spinach bags		5						6	11
Snails	1								1
Tea bags		11						13	24
Turtle			1						1
Water	1	6	5	1	1	1	2		17

1 - Clinch River at Norris Dam (CRM 79.8)
2 - Clinch River at White Oak Creek (CRM 20.8)
3 - Clinch River at Gallaher Bridge (CRM 14.5)
4 - Clinch River at Centers Ferry (CRM 4.6)
5 - Tennessee River at Fort Loudoun Dam (TRM 602.4)
6 - Tennessee River at Watts Bar Dam (TRM 529.9)
7 - Tennessee River at Chattanooga, Tenn. (TRM 465)
X - Three different locations on Bear Creek

Creek to the Clinch River. Of primary interest in this Study are data from the sampling of water, bottom sediments, and biological organisms in the water or sediments.

A composite tabulation of information concerning sampling sites, types of analyses, and agencies responsible for collection and analysis for all phases of the Study is given in Appendix A.

Water

A budget of radioactive materials in the Clinch River is an essential prerequisite to the achievement of the objectives of the Study outlined on page 1. The establishment of such a budget requires a determination of what is already in the river. If the budget is to be dynamic rather than static, then, data are needed on dispersal and dilution of radioactive contaminants, the proportions of radioactivity associated with the liquid phase and with suspended matter in the water, the accumulation of particular radionuclides through settling and deposition of bottom sediments, and resuspension or redissolution of radioactive materials from bottom sediments back into the water phase. Water samples are taken to determine the radioactive and chemical constituents both in the water phase and in the suspended matter. The cross-sectional distribution of radioactive materials in the water phase is determined to indicate the pattern of dispersal and dilution under various conditions of temperature, stream flow, and reservoir elevation.

During the first 7 months of 1960, routine water sampling stations were established at the Oak Ridge Water Treatment Plant, CRM 41.5; at the Oak Ridge Gaseous Diffusion Plant's water treatment plant, CRM 14.5; and at the Kingston Steam Plant, CRM 3.8. During this period, the ORNL Applied Health

Physics Section's monitoring data indicated that at the mouth of the Clinch River over 40% of the total activity carried downstream was Sr^{90}; and that the percentages of Ru^{106}, Ce^{144}, Cs^{137}, Co^{60}, and Zr-Nb^{95} were 23, 13, 13, 7, and 3% respectively. Also, these data indicated that approximately 70% of the cesium was associated with the suspended sediments, while only 5, 14, 22, 25, and 29% of Sr^{90}, Ru^{106}, Ce^{144}, Co^{60}, and Zr-Nb^{95}, respectively, were associated with sediments. Based on the average suspended sediment load of 27 ppm at the Oak Ridge Water Plant, CRM 41.5 (upstream from White Oak Creek), the percentage of each isotope associated with suspended silt agreed quite well with the values predicted from laboratory studies of sorption by suspended and deposited sediments.

From the recently-established continuous-sampling stations at the Oak Ridge water plant, the Gaseous Diffusion Plant water plant, and the Kingston Steam Plant, samples are composited for weekly analyses. The sampling station at the Steam Plant (CRM 4.5) was discontinued on October 31, 1960, and a replacement station was established at CRM 5.5, one mile upstream from Centers Ferry, November 1, 1960. A fourth continuous sampling station is to be established at CRM 19.1, which is 1.7 miles downstream from the mouth of White Oak Creek (2)(3). At each of these stations samples are composited for weekly analyses. For practical reasons it has been necessary to limit the number of water samples taken routinely and to take the samples at a fixed point or in a small area within the cross section of the stream.

In order to evaluate the relationship of these point-integrated samples to the water in the entire cross section, data from a special series of samples representing various river conditions are being studied by at least two methods. The homogeneity of water masses in the river cross sections

selected for water-quality sampling is being tested statistically by response-surface analysis of a central composite sampling design. The depth-integration method is being used to determine the mean concentrations of chemical constituents and sediments flowing through the cross sections. A depth-integrated sample is obtained at several verticals in the section, each representing an equal portion of the flow. Concentrations in samples collected by point-integrated methods are then compared to the mean values.

The Subcommittee on Water Sampling and Analysis prepared a long-term plan for collection of water samples during the Study (4). Their proposal specified the location of stations and frequency of sample collection and analysis, and suggested methods for obtaining samples which would be proportional to the volume of flow in the river. Under this plan water sampling stations will be at (1) the Clinch River at the Oak Ridge water plant; (2) the Clinch River near Centers Ferry above the mouth of the Emory River; (3) the Tennessee River at Loudon, Tennessee; (4) the Tennessee River at Watts Bar Dam; and (5) the Tennessee River at Chickamauga Dam. Subsamples will be collected daily and composited into weekly samples (Sunday through Saturday) for analysis. The daily subsamples collected from each of the two Clinch River stations and from the two Tennessee River stations at Watts Bar Dam and Chickamauga Dam will be proportioned at each station so that the weekly composite sample will represent proportionally the river flow during that week. Water samples from the station at Loudon, Tennessee, which is upstream from the mouth of the Clinch River, will not be made proportional to river flow. The Subcommittee also proposed that the weekly composite from each station be split into two portions; namely, a 5-gal portion for radioactivity determinations and a 1-gal portion for chemical analysis. In

addition to the basic sampling scheme outlined above, the Committee recommended that the collection of special water samples from selected locations, particularly from White Oak Creek, be established if necessary for better interpretation of the water analyses.

From time to time active participants in the survey have discussed the handling and analysis of water samples, and a co-ordinated system has been developed. In the quarterly-survey sampling and analysis by the Public Health Service, all water samples were stored and shipped in 2-gal polyethylene bottles. These were composited into 10-gal samples for each station, reduced by evaporation to 3.5 liters, and counted on the gamma spectrometers in the standard 3.5-liter milk beakers. After gamma scanning the samples were analyzed for Sr^{90} by radiochemical methods (1). At a meeting in May 1960, PHS and ORNL agreed that water samples should be treated comparably. Sediments have been separated from the dissolved matter, and both have been counted. Duplicate samples have been counted at both Cincinnati and Oak Ridge.

The Steering Committee agreed that the analyses of water samples would include a Sr^{90} determination and gamma scan. A more complete radionuclide analysis will be made on samples from stations in the basic sampling scheme proposed by the Subcommittee on Sampling and Analysis (see above). In addition, chemical analyses will be provided by the State of Tennessee. The extent and frequency of analyses for various minerals will depend upon the concentration and importance of the particular mineral and the frequency of change in concentration.

As to results, analytical data from ORNL groups have not yet been tabulated and made available. Tentative data on the gamma spectra of water

collected by the Public Health Service from White Oak Creek and from the Clinch River at Kingston, Tennessee, have been made available in graphic and tabular form in a preliminary report which is in process of completion (1). This preliminary report has been made available for use by the Steering Committee and staff of the Clinch River Study, but requires further checking and revision before it can be released generally.

Bottom Sediments

In its preliminary quarterly surveys, the Public Health Service collected mud samples with either an Eckman or Petersen dredge, depending on the composition of the bottom. In general, the Petersen dredge was used only where the bottom deposits contained pebbles or hard clayey materials. Mud samples were put into pint-sized plastic containers for storage, transportation, and subsequent gamma counting. No preservatives were used for mud samples, and no special preparation was given to them before analysis. They were weighed in the container and placed directly onto the crystal for gamma scanning. Some samples with high radioactivity were counted on a stainless steel planchet after air drying and weighing out approximately 5 g more or less, depending upon the activity of the sample. For all mud samples corrections were made for self-absorption. As to results in the quarterly surveys, gamma spectra of mud samples from White Oak Creek and the Clinch River at Kingston and the Sr^{90} content in certain samples, determined by radiochemical analysis, are shown in the preliminary report (1).

Beginning on August 16, 1960, core sampling of the bottom sediments of the Clinch River was begun by the ORNL groups. These samples were collected at previously established and monumented cross sections. The sections are

approximately 1 to 1 1/2 miles apart, beginning at CRM 22.5 and ending at CRM 4.7 (Centers Ferry). A core was obtained at every 50-ft interval in the cross section. The collection of samples was completed on September 2, 1960. The radionuclide content, activity levels, sediment-size distribution and composition of the cores are to be determined. No date has been set for completion of these determinations, and no results are available as yet (3).

Annual surveys of radioactivity in bottom sediments of the Clinch and Tennessee Rivers have been made by the ORNL Applied Health Physics Section since 1954. The surveys for the first 3 years (1951-1953) were made by the Radioactive Waste Disposal Research Section and were reported by Garner and Kochtitzky in a paper published August 1956 (5). The results of surveys covering the period 1954 to 1958, inclusive, are available in a report by W. D. Cottrell, issued November 18, 1959 (6).

In the survey during the 5-year period (1954-1958) reported by Cottrell, measurements were made at cross sections 2 miles apart in the Clinch River and approximately 10 miles apart in the Tennessee River and TVA Reservoirs. In the Clinch River measurements were made at 50-ft intervals across the river at each cross section, and in the Tennessee River ten measurements were made at each cross section. Measurements consisted of gamma counts obtained with a multiple-G-M-tube detector ("Flounder"), lowered to the surface of the bottom sediments, and analysis of mud samples taken at each measurement point. The results of radiochemical assays of the samples of sediment analyzed were averaged, and the radionuclide content averages for the Clinch River and for the Tennessee River are presented graphically in Fig. 4, which is taken from Cottrell's report. The radionuclides, Cs^{137}-Ba^{137},

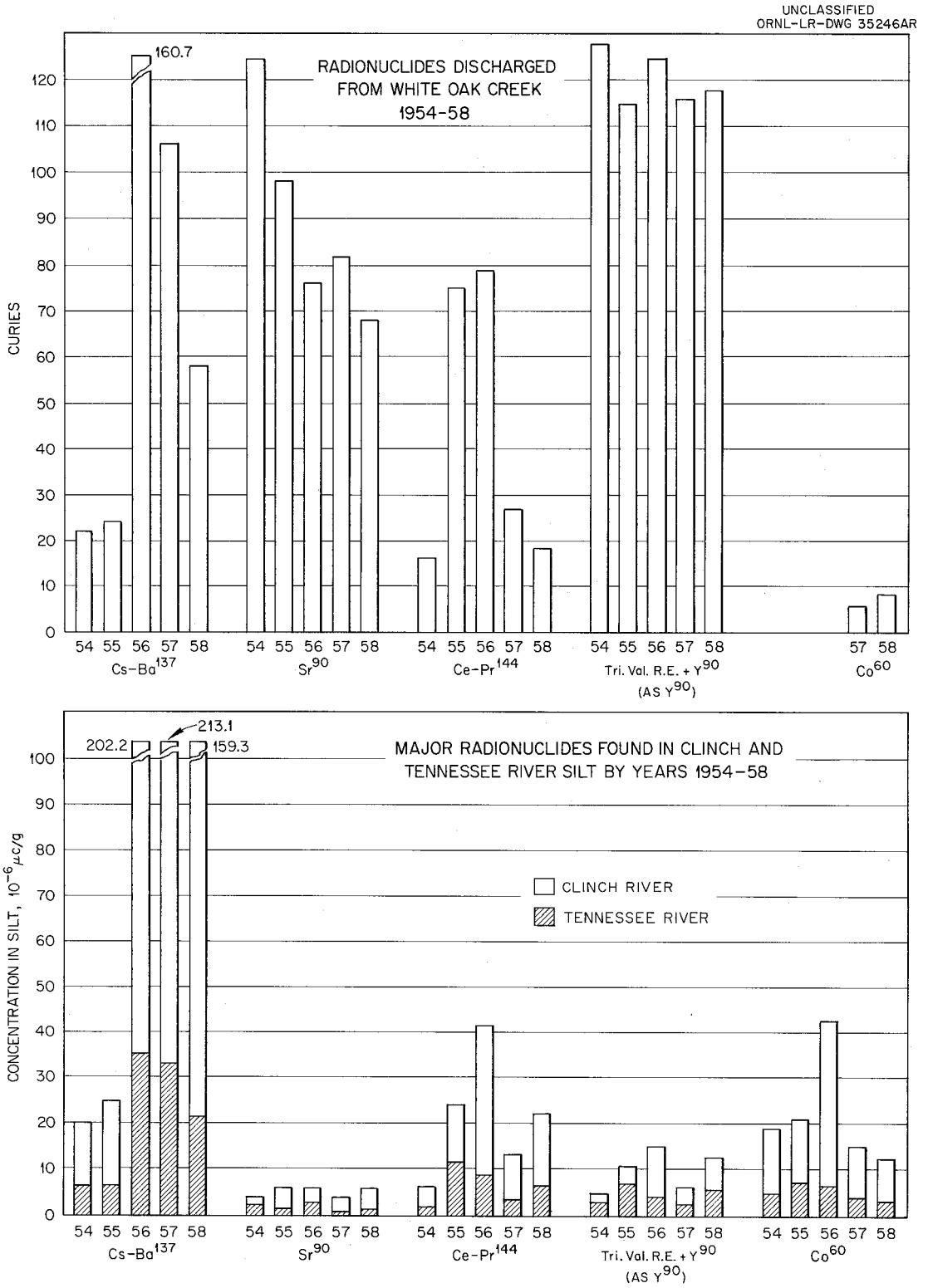

Fig. 4. Radionuclides Discharged from White Oak Creek, and Major Radionuclides Found in Clinch and Tennessee River Silt by Years 1954–58.

Sr^{90}, Ce^{144}-Pr^{144}, Tri.Val.R.E.+Y^{90}, and Co^{60}, for each of the 5 years, are shown individually in Fig. 4 (Ref. No. 6, Fig. 9, page 22). The most striking result of these surveys is the demonstration of a significant increase in bottom radioactivity between 1955 and 1956. Cottrell attributes this increase to the draining of White Oak Lake (in October 1955) with the attendant scouring of contaminated silt from the lake bottom.

A preliminary analysis of the results of sampling and analysis of sediments in the Clinch River and the lower part of Watts Bar Reservoir in May 1960 has been made by the staff of the Tennessee Valley Authority. From the survey data and information regarding the volume of sediment in acre feet, the approximate area covered by sediment in acres, the rate of accumulation per year in acre feet, and the estimated dry weight in pounds per cubic foot, a very rough approximation of the total activity in these parts of the river system has been made. Estimates of the number of curies of six individual radionuclides indicated that in the Clinch River arm from the mouth of the river to mile 20.8 at the mouth of White Oak Creek the total of curies deposited between mid-1943 and mid-1960 was approximately 1670. Of the principal radionuclides of interest (Ce^{144}-Pr^{144}, Ru^{106}-Rh^{106}, Cs^{137}-Ba^{137}, Zr^{95}-Nb^{95}, Co^{60}, and Sr^{90}), ruthenium-rhodium contributed 58% and cesium-barium 36% of the total radioactivity deposited in the Clinch River sediment. In Watts Bar Reservoir from the mouth of Clinch River downstream to Watts Bar Dam, it was estimated that approximately 50 curies were deposited during the same 17-year period of which 38% was contributed by Ru^{106}-Rh^{106} and 52% by Cs^{137}-Ba^{137}. When additional data are available, these rough estimates will be rechecked and broken down to represent smaller sections of the two rivers (7).

In order to make calculations of the estimated curies of activity mentioned above, it was assumed:

(1) The activity found in the top several inches of sediment represents the activity in all sediment deposited since Oak Ridge began releasing radionuclides to the Clinch River in 1943.

(2) The average annual rate of sediment accumulation determined for the period of October 1946 to May 1956 holds true for the 17-year period, mid-1943 to mid-1960.

(3) The averages of the three activity levels found at the three sampled ranges in the Clinch River arm, and the average of the two levels found at the two ranges in the main section of Watts Bar Reservoir, represent activity levels for all sediment deposited since mid-1943 in the Clinch River, and in the Tennessee River segments of Watts Bar Reservoir respectively.

(4) Sediment densities (wet weights and volumes) are as estimated from the analyses of sediment samples by the Public Health Service.

Radionuclide Interactions with Minerals and River Sediment

Previous geochemical studies in the Waste Disposal Research Section have provided information regarding the sorption of radionuclides by clay minerals. During 1960 a laboratory study of the affinity for radionuclides of typical Clinch River sediments and four standard clays was made and reported (8). Uncontaminated sediment from the bottom of the Clinch River, about 2 miles upstream from the mouth of White Oak Creek, was obtained; and sorption studies were made to compare the affinity of the sediment and of four standard clays; namely, illite, kaolinite, montmorillonite (bentonite), and vermiculite. The standard clays were selected for comparison after

x-ray diffractometer tests of the Clinch River sediment sample had shown that it consisted of approximately 60% illite, 15% kaolinite, 10-15% vermiculite, and 10-15% quartz. The radioisotopes used were Cs^{137}, Co^{60}, Sr^{85}, and Zr^{95}-Nb^{95}. Master solutions for the tests were prepared by mixing each of these isotopes with distilled water separately in such amounts that the activity in each master solution was between 15,000 and 30,000 counts min^{-1} ml^{-1}.

The test procedure was to mix the standard clays and the river sediments with the radioisotope solution and to count the activity removed by the suspended matter after various periods of contact and clarification by centrifugation. Tests were made at pH 6 and pH 9, and the sorption of activity by suspended matter was determined after 1 hour, 3 days, and 7 days of contact. The affinity of the clays and the river sediment to sorb the radioactivity was expressed for comparison in terms of K_d, the distribution coefficient value. The distribution coefficient, K_d, was defined as:

$$K_d = \frac{f_c/M}{f_s/V} , \qquad (1)$$

where

f_c = fraction of activity sorbed by clay,

f_s = fraction of activity left in solution,

M = weight of sorbent expressed in grams,

V = volume of solution expressed in milliliters.

Tables 3, 4, 5, and 6 show the average percentages of cesium, cobalt, strontium, and zirconium-niobium sorbed by the various standard clays and by the river bottom sediment.

Table 3. Average Per Cent and Average K_d of Cesium Sorbed by Clays

Material	Contact Time	Average % Activity Sorbed		Average K_d		Ratio of Clay to Master Solution
		pH 6	pH 9	pH 6	pH 9	
Illite	1 hr	89.99 ± 0.25*	90.48 ± 0.25	27,000	28,500	0.1 g/300 ml
	3 days	97.92 ± 0.23	98.60 ± 0.23	140,000	220,000	
	7 days	98.39 ± 0.23	98.56 ± 0.23	180,000	200,000	
Kaolinite	1 hr	74.23 ± 0.28	93.19 ± 0.28	2,900	13,700	0.1 g/100 ml
	3 days	73.96 ± 0.25	62.35 ± 0.27	2,800	1,600	
	7 days	68.47 ± 0.25	51.20 ± 0.44	2,200	1,000	
Montmorillonite	1 hr	61.20 ± 0.34	58.26 ± 0.35	1,600	1,400	0.1 g/100 ml
	3 days	55.14 ± 0.34	56.16 ± 0.35	1,200	1,300	
	7 days	49.95 ± 0.45	50.54 ± 0.45	1,000	1,000	
Vermiculite	1 hr	96.63 ± 0.25	95.77 ± 0.42	1,400	1,100	1 g/50 ml
	2 days	99.41 ± 0.24	99.64 ± 0.24	8,400	14,000	
	8 days	99.60 ± 0.24	99.76 ± 0.24	12,000	21,000	
River Sediment	1 hr	53.75 ± 0.42	61.31 ± 0.37	2,300	3,200	0.1 g/200 ml
	3 days	96.17 ± 0.25	96.16 ± 0.25	50,000	50,000	
	7 days	97.78 ± 0.24	97.64 ± 0.24	88,000	83,000	

*± = 1 standard error.

Table 4. Average Per Cent and Average K_d of Cobalt-60 Sorbed by Clays*

Material	Contact Time	Average % Activity Sorbed		Average K_d		Ratio of Clay to Master Solution
		pH 6	pH 9	pH 6	pH 9	
Illite	1 hr	28.98 ± 0.52**	78.04 ± 0.19	410	3,600	0.1 g/100 ml
	3 days	85.49 ± 0.37	94.65 ± 0.35	5,900	18,000	
	7 days	86.43 ± 0.37	95.94 ± 0.35	6,400	24,000	
Kaolinite	1 hr	63.91 ± 0.24	69.17 ± 0.22	3,500	4,500	0.1 g/200 ml
	3 days	71.54 ± 0.21	51.51 ± 0.29	5,000	2,100	
	7 days	60.92 ± 0.25	46.58 ± 0.32	3,100	1,700	
Montmorillonite	1 hr	69.70 ± 0.21	56.38 ± 0.26	2,300	1,300	0.1 g/100 ml
	3 days	63.91 ± 0.46	45.68 ± 0.60	1,800	800	
	7 days	62.36 ± 0.46	45.37 ± 0.60	1,600	800	
Vermiculite	1 hr	70.63 ± 0.21	72.87 ± 0.21	120	130	1 g/50 ml
	2 days	98.63 ± 0.16	84.62 ± 0.18	3,600	280	
	8 days	98.96 ± 0.16	89.80 ± 0.18	4,700	440	
River Sediment	1 hr	46.44 ± 0.33	71.91 ± 0.22	1,700	5,100	0.1 g/200 ml
	3 days	93.34 ± 0.17	82.38 ± 0.19	28,000	9,400	
	7 days	97.28 ± 0.17	85.12 ± 0.18	72,000	11,000	

*Above results were calculated from centrifuged master solution.
**± = 1 standard error.

Table 5. Average Per Cent and Average K_d of Strontium-85 Sorbed by Clays

Material	Contact Time	Average % Activity Sorbed		Average K_d		Ratio of Clay to Master Solution
		pH 6	pH 9	pH 6	pH 9	
Illite	1 hr	23.42 ± 0.62*	31.67 ± 0.45	310	320	0.1 g/100 ml
	3 days	26.69 ± 0.54	41.05 ± 0.34	360	700	
	7 days	26.88 ± 0.54	43.17 ± 0.33	370	760	
Kaolinite	1 hr	62.77 ± 0.25	71.24 ± 0.22	3400	5000	0.1 g/200 ml
	3 days	67.49 ± 0.23	68.55 ± 0.23	4200	4400	
	7 days	66.44 ± 0.24	66.28 ± 0.24	4000	3900	
Montmorillonite	1 hr	70.85 ± 0.20	71.88 ± 0.20	2400	2600	0.1 g/100 ml
	3 days	66.88 ± 0.21	68.65 ± 0.21	2000	2200	
	7 days	67.21 ± 0.21	68.67 ± 0.21	2100	2200	
Vermiculite	1 hr	77.45 ± 0.22	67.14 ± 0.26	170	100	1 g/50 ml
	2 days	96.95 ± 0.19	96.46 ± 0.19	1600	1400	
	8 days	97.33 ± 0.19	98.73 ± 0.19	1800	3900	
River Sediment	1 hr	21.42 ± 0.78	24.79 ± 0.67	540	660	0.1 g/200 ml
	3 days	45.79 ± 0.36	63.87 ± 0.26	1700	3500	
	7 days	41.83 ± 0.39	66.80 ± 0.25	1400	4000	

*± = 1 standard error.

Table 6. Average Per Cent and Average K_d of Zirconium-Niobium-95 Sorbed by Clays*

Material	Contact Time	Average % Activity Sorbed		Average K_d		Ratio of Clay to Master Solution
		pH 6	pH 9	pH 6	pH 9	
Illite	1 hr	83.62 ± 0.25**	75.99 ± 0.27	15,500	9,500	0.1 g/300 ml
	3 days	90.39 ± 0.23	83.92 ± 0.30	28,000	15,500	
	7 days	94.05 ± 0.22	89.08 ± 0.23	47,500	24,500	
Kaolinite	1 hr	89.18 ± 0.23	81.73 ± 0.25	24,500	13,500	0.1 g/300 ml
	3 days	94.00 ± 0.22	87.03 ± 0.24	47,000	20,000	
	7 days	94.93 ± 0.22	85.82 ± 0.24	56,000	18,000	
Montmorillonite	1 hr	14.45 ± 1.16	26.28 ± 0.63	170	360	0.1 g/100 ml
	3 days	28.74 ± 0.57	37.90 ± 0.43	400	610	
	7 days	35.24 ± 0.46	42.07 ± 0.39	540	730	
River Sediment	1 hr	62.83 ± 0.32	54.37 ± 0.37	3,400	2,400	0.1 g/200 ml
	3 days	82.69 ± 0.25	75.55 ± 0.27	9,600	6,200	
	7 days	86.56 ± 0.24	79.94 ± 0.25	12,900	8,000	

*The above results were calculated from counts/ml of zirconium-niobium.
Master Solution - well mixed and stirred but not centrifuged.
**± = 1 standard error.

The selectivity (or affinity) of illite, kaolinite, and montmorillonite for the test radionuclides is discussed in the conclusions of the report. With regard to the river sediments, it was found that the sediments from the Clinch River at CRM 22.6 sorbed cesium, cobalt, and strontium and that the per cent sorbed increased with time. The high cesium uptake was attributed to the high percentage of illite present in the bottom sediments, since illite has a high selectivity for cesium due to its favorable structural properties. The higher-than-expected sorption of cobalt and strontium by sediment on the basis of mineralogic composition suggests that sediment organic matter with ion-exchange properties may be influential. This observation suggested that studies of this type be made to help differentiate sorption by minerals and by organic compounds in sediments and soils. The influence of organic matter in the sediments upon the cobalt and strontium uptakes should be considered in determining the mechanisms of accumulation and transport of radionuclides in the Clinch River.

In the report it was pointed out that the affinity, or K_d value, is influenced by the sediment concentration and by variations in pH (Ref. No. 8, page 22). From the K_d values for the river sediment, the distribution of radionuclides between the sediment and the liquid phase can be calculated over a range of sediment concentrations. It is to be remembered that the K_d value changes with different ionic strengths, since the amount sorbed is dependent on the concentration of the dissolved constituents. At tracer-level concentrations pH would be one of the more significant parameters.

In Figs 5 and 6 the percentage of the radionuclide on the sediment as a function of the sediment concentration (ppm) and pH is shown. The curves are derived from the definition of K_d and by assuming unit density of water

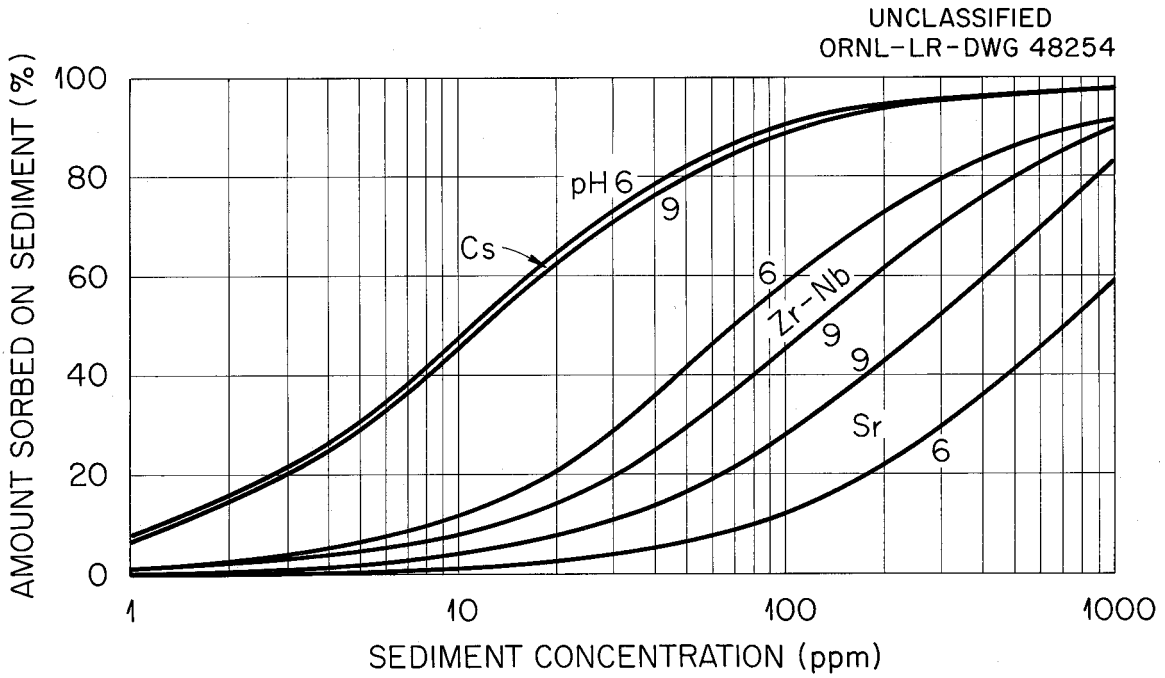

Fig. 5. Radionuclide Distribution on Sediments as a Function of the Sediment Load in the River Under Different pH Conditions (Cesium, Zirconium-Niobium, and Strontium).

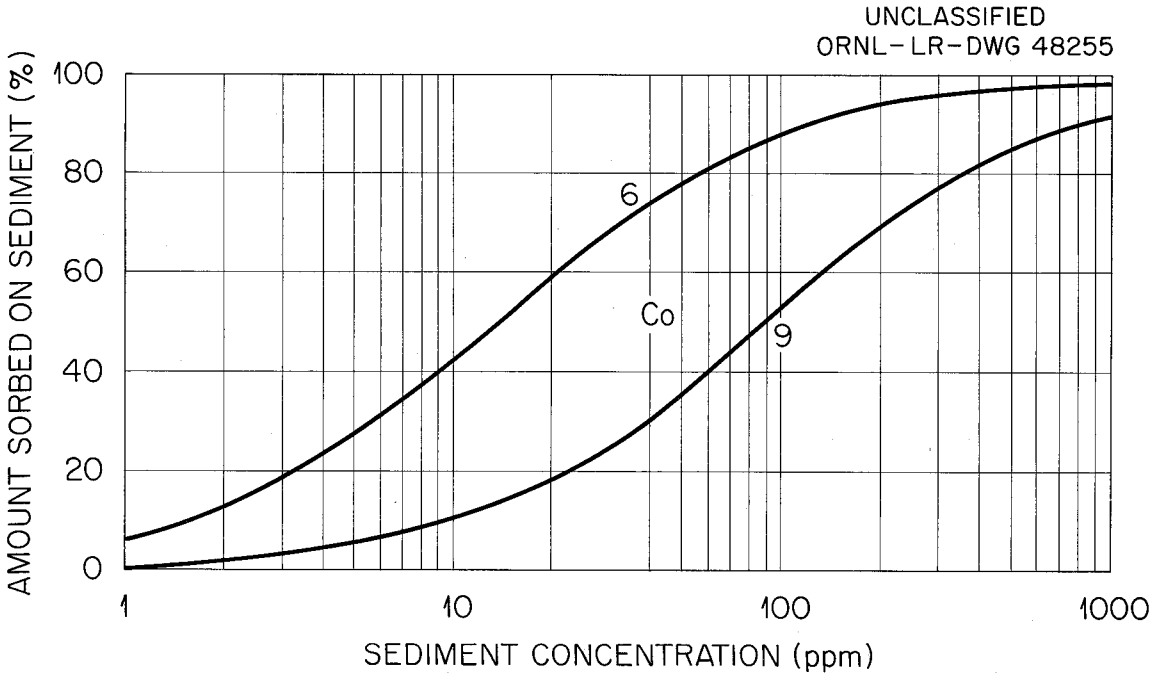

Fig. 6. Radionuclide Distribution on Sediments as a Function of the Sediment Load in the River Under Different pH Conditions (Cobalt).

and a constant K_d. Thus from Equation 1:

$$K_d = \frac{f_c/M}{f_s/V} \text{ , and} \tag{1}$$

$$f_s = 1-f_c. \tag{2}$$

By rearrangement and substitution,

$$\frac{f_c}{1-f_c} = K_d(\frac{M}{V}) \text{ ,} \tag{3}$$

and, therefore, for any concentration of sediment $(\frac{M}{V})$ expressed in parts per million the fraction which will be sorbed (f_c) can be calculated. For cesium, the sediment curve is calculated from the data in Table 3, using M/V of 0.1 g/200 ml (500 ppm) and K_d of 88,000.

Cesium removal is insensitive to changes in pH; strontium sorption is favorably influenced by increasing pH. As discussed earlier, the lower removal of cobalt and zirconium-niobium at higher pH suggests that the principal mechanism of removal is filtration or scavenging of the hydrolysis product and not ion exchange. Thus, if the Clinch River contains 30 ppm of sediment of the type used here, over 70% of the cesium would be associated with the sediment, but only about 5% of the strontium. Comparing these data with other data now available for the Clinch River sediment, these percentages appear to be in line with the earlier findings. These preliminary results for the sediment justify further research on K_d determinations of sediments collected at different localities along the Clinch and Tennessee Rivers.

Tamura has reported on sediment studies with cobalt, which are continued further in order to understand the behavior of cobalt in solution and to

evaluate the use of this nuclide in possibly establishing the role of organic matter in radionuclide uptake (9). Tamura's report and discussion included data concerning the influence of pH on the hydrolysis of cobalt, the uptake of cobalt by certain minerals, and tests of cobalt removal by certain organic materials and by river sediments (see Tables 7, 8, and 9).

In Table 7 the influence of pH on the hydrolysis of cobalt is shown. The increasing removal of cobalt with increasing pH is to be expected; the reduction observed at pH 10.0 - 9.5 is considered to be due to the dispersion of colloids at these pH levels. Several pH measurements of water from the Clinch River gave values about 8.5. Tennessee Valley Authority reports indicate that pH values as high as this have been found for water in the Clinch River.

Tests of cobalt removal by biotite, illite, Arizona Bentonite, and vermiculite are summarized in Table 8. Arizona Bentonite shows a much higher affinity for cobalt than Wyoming Bentonite which was reported earlier (see page 28). The much higher K_d reported for vermiculite in this test than in the earlier experiments is attributable to the much finer particle size of the material shown in Table 8. Structural and steric characteristics of vermiculite favor removal of ions such as cobalt.

In Table 9 cobalt removals by several organic materials are shown. It may be noted that with increasing contact time organic matter taken from a river sediment removes appreciable quantities of cobalt. It was mentioned that the final pH of the organic matter increased to 6.8 for the 250-micron material and to 6.1 for the 840-micron material. Considering the impurities in the sample the removal was excellent. In other tests using lignite, which has a much lower ion-exchange capacity than peat, it was found that cobalt was efficiently removed.

Table 7. Effect of pH of Solution on the Removal of Cobalt*

pH		% Removal After		
Initial	Final	2 hr	20 hr	120 hr
4.0	4.3	0.1	0.0	0.1
6.0	6.9	6.6	7.2	17.7
8.0	8.0	22.4	19.6	19.5
10.0	9.5	9.9	12.7	9.4

*The results are averages of duplicate analyses.

Table 8. Average Cobalt Removal by Several Materials at Selected pH*

Material	Contact Time	% Removal**		K_d	
		pH 6	pH 8	pH 6	pH 8
Biotite	1 hr	8.96	39.10	200	1,300
	1 day	10.80	72.31	240	5,200
	5 days	11.93	86.81	270	13,000
Illite	1 hr	20.82	35.71	530	1,100
	1 day	32.10	66.51	950	4,000
	5 days	42.38	84.17	1,600	10,500
Arizona Bentonite	1 hr	74.08	78.86	5,700	7,600
	1 day	92.40	87.40	24,000	14,000
	5 days	98.70	90.05	152,000	18,000
Vermiculite	1 hr	66.29	74.73	3,900	5,900
	1 day	79.80	92.03	7,900	23,000
	5 days	92.86	97.66	26,000	83,000

*0.05 g material in 100 ml Co^{60} solution.

**Standard error not calculated; experimental conditions were similar to those reported in Table 4; and errors should be of similar magnitude.

Table 9. Cobalt Removal by Several Organic Materials and River Sediments

Material	Particle Size	pH	% Removal After***			K_d After		
			1 hr	20 hr	120 hr	1 hr	20 hr	120 hr
Peat Moss	> 20 mesh	5.5	95.95	96.92		24,000	31,500	
Peat Moss	< 30 mesh	5.3	97.76	97.94		44,000	48,000	
River Sediment 6.0* - 150**		8.2	96.94	94.80		31,500	18,000	
River Sediment 7.0* - 450**		8.2	94.48	96.08		17,000	24,500	
Organic Matter	250 μ	5.5	13.23	40.89	70.17	300	1,400	4,700
Organic Matter	500 μ	5.4	11.88	46.86	84.03	270	1,800	10,500
Organic Matter	840 μ	5.3	10.48	38.73	82.61	230	1,300	9,500

*Clinch River Mile - distance above mouth.
**Distance in feet from left bank of river.
***Standard error not calculated.

The report concluded: "These studies, though preliminary in nature, are useful in formulating procedures for ascertaining the radionuclide budget in the Clinch River. In addition to determining the mineral content of the sediments, studies will be made on the organic portions of the sediment. Selected samples which have been assayed for radionuclides will be analyzed for their particle-size distribution, ion-exchange capacity, and radionuclide content after hydrogen peroxide decomposition of organic matter"(9).

In discussing this report Tamura has pointed out that the pH of the samples containing river sediments fall in the optimum range for cobalt removal, resulting in excellent removals. He recommended that after all analytical work is completed, a particle-size separation and mineralogic analysis of the sediment fractions should be performed. Also, peroxide digestion of the sample should be performed if and when the effect of the digestion process on the inorganic phase of the sediment is known.

BIOLOGICAL PHASES

Prior to the initiation of the Clinch River Study, investigations of radioactivity in the Clinch River have been mainly to ensure that the concentrations in the water are below the maximum permissible concentrations for drinking water. Biological factors have been studied only occasionally or through special investigations of fish and other specific organisms. The Committee realized that the most important elements of the environment to be monitored are those that are directly involved in human food chains; namely, water, fish, and irrigated agricultural crops. They also recognized that the entire food web should be studied in order to determine concentrations and rates of transfer and turnover of radioactivity. Such data would help to deduce the relationships between these components of the food web and the human environment in order to evaluate ecological effects in the environment as a whole (10).

In the "Plan for Clinch River Study" (10), proposed in 1959, the purpose and scope of the biological phases of the Study were summarized. It was stated: "The general objective of the ecological research on the Clinch River is to obtain an understanding of the steady-state chemical and biological composition of the Clinch River ecosystem which includes:

"(1) The population densities, distributions, biomass, and radionuclide concentrations in the major bottom dwelling organisms, such as shellfish (clams), crustacea, and insects, will be determined.

"(2) The seasonal and annual composition and variation of the Clinch River above and below the White Oak Creek outfall will be characterized.

This objective will involve selecting suitable segments of the river for detailed study and analyses. Measurements will include the chemical and radiochemical composition of both organic and inorganic phases of the river water. For example, nitrogen, phosphorus, carbonates, stable isotopes (strontium, iodine, potassium, calcium, etc.), radioactive isotopes, temperature, and turbidity will be measured. Changes in dissolved oxygen and carbon dioxide will be measured to determine the gross primary productivity which is the total rate of photosynthesis in the flowing water mass.

"(3) The movements and rates of biological and chemical cycling of Sr^{90}, Cs^{137}, and other isotopes in the Clinch River, will be measured. This work will include field and laboratory studies on rates of uptake and turnover of isotopes by characteristic river organisms under steady- and nonsteady-state conditions and varying substrate conditions."

A proposed work plan for the biological phases was discussed by members of the ORNL Ecology Group at a Steering Committee Meeting, January 21, 1960. The minutes of the meeting indicate that this plan was designed to give some information on the river as quickly as possible with particular regard to the kinds of organisms present. It was proposed to measure only gross gamma activity at that stage of the Study, although in a definitive survey radioactivity due to specific isotopes would be determined and exact radiochemical work would be done. The radioisotopes of strontium, cesium, ruthenium, and transuranics were listed as those of primary importance. It was anticipated that exploratory work on the detection of transuranics would be necessary, since these must be measured by alpha analysis which would present problems. Gross gamma measurements were emphasized as the method of locating the radioactive organisms most quickly and easily.

Sampling stations proposed included one above the mouth of White Oak Creek, two or three stations in the Clinch River downstream, and one station in the Tennessee River between the Clinch River and Watts Bar Dam. It was agreed that the bulk of the collection of biological samples must be done by the ORNL groups with occasional assistance from others; for example, assignment of summer personnel by the TVA, or temporary assistance in the collection and analysis of fish samples by the Game and Fish Commission, Public Health Service, and other agencies.

On May 19, 1960, representatives of the Public Health Service and the ORNL Ecology Group met and developed a more specific outline on the biological phases of the Study. This outline which was accepted by the Steering Committee was as follows (11):

"1. The Oak Ridge National Laboratory and the U. S. Public Health Service are approaching the problem in accordance with their respective missions. The studies of the bottom fauna and fish by the ORNL group are specific investigations, while the PHS approach is more in the nature of a general survey.

"2. Major support for the biological phases by the PHS will be provided by making as many fish analyses as possible in the PHS laboratories.

"3. The PHS program of sampling and analyses should continue for at least 6 months and preferably 1 year before an attempt is made to interpret and use the data.

"4. Operationally, the two groups (ORNL and PHS) can move independently toward the common objective.

"5. Preliminary analytical data should be assembled before the next meeting of the Steering Committee. A meeting of the Committee on August 18 and 19, as scheduled, would be too early; it would be better for the Committee

to meet late in September or as soon thereafter as the data can be made available.

"6. Laboratory studies by the PHS in Cincinnati are of interest to other groups. In particular, data on water analyses covering both the Clinch and Tennessee Rivers will be useful and should be made available.

"7. It was agreed that each agency will use its own analytical procedures with enough cross checks of duplicate samples to be sure that the results are comparable (see page 23).

"8. It was agreed that each agency will use the units it customarily employs in reporting its results. In tabulations these units can be translated, and if necessary the different units can be shown in separate columns to make comparison easier."

Fish Populations

Collection and analyses of samples from fish populations in the Clinch River and to a lesser extent in the Tennessee River have been done primarily by the U. S. Public Health Service and by the ORNL Ecology Group with co-operation from the TVA Fish and Game Branch. Preliminary data on these studies have been reported to the Steering Committee and staff of the Study, but the results have not been published.

The Public Health Service has included fish specimens in samples collected during quarterly surveys in the Clinch River and in the Tennessee River from Norris Dam downstream to Chattanooga. Preliminary data have been reported by PHS (1). Analysis and tabulation of data covering later quarterly survey samples have not yet been completed.

Fish samples, consisting usually of both large and small fish, were collected by the PHS from Norris Reservoir on the Clinch River above Norris Dam (CRM 79.8), near the mouth of White Oak Creek (CRM 20.8), near Gallaher Bridge (CRM 14.5), and at two points above the mouth of Clinch River (CRM 2.2 and 4.6). From the Tennessee River fish were collected at Station 5 near Fort Loudoun Dam (TRM 602.4) and at Station 7 which was 7 miles upstream from Chickamauga Dam (TRM 477). Small fish were collected by seining with 1/4-in. mesh nets in shallow water areas. Large fish were collected by bottom sets with 1-in., 2-in., and 3-in. nylon gill nets or were obtained from commercial fishermen in the area. Fish samples were preserved in 10% formalin for transport to the Laboratory. The fish were separated into species, and a total of 20 species, which are listed in the report, were identified from the PHS collection.

After being separated into species, the fish were divided into component parts which were placed in the standard plastic counting and storage containers, preserved with formalin and counted on the gamma spectrometer. For Sr^{90} analyses the samples were ashed at 600° C in a muffle furnace. In general, the large fish were divided into component parts consisting of flesh, bone, scales, liver, small organs (gill, heart, and thyroid), intestinal tract and contents, and the remaining viscera. Small fish were divided into two component parts; namely, the internal organs obtained by gutting, and the remainder of the fish.

The results of radioactivity measurements in fish samples are given in detail in the tables and charts contained in the report. A summary of the results of the quarterly-survey program must await completion of later analyses and tabulations, since this report covers only one series of samples

collected February 9-15, 1960. Even these preliminary results are informative, however, wherever the nature of the data permits comparisons. For example, the levels of Sr^{90} found in three specimens of carp, collected at Fort Loudoun Dam, Gallaher Bridge on Clinch River, and Clinch River Mile 2.2, in μμc/kg were: in scales, 47, 1080, and 691, respectively; in flesh, 3, 340, and 285, respectively; and in bone, 37, 1715, and 808, respectively. No data for carp at Station 7, TRM 477, were obtained, but in catfish the Sr^{90} concentrations found in flesh were 49.7 μμc/kg, and in bone, 66.5 μμc/kg.

A preliminary hazard evaluation of the Sr^{90} in fish was made by D. J. Nelson of the ORNL Ecology Section. His evaluation was based upon the analyses of the fish samples taken from the Clinch River in February 1960 by the Public Health Service and reported in their quarterly survey. From these data the expected human body burden of Sr^{90}, which would result from the continuous consumption of these food and game species, was estimated. The Sr^{90} content of the flesh of the eight individual fish used in this estimation was as follows:

Species	Location of Catch (CRM)	Sr^{90} μμc/kg (wet wt.)
White bass (*Roccus chrysops* (Rafinesque))	14.5	298
Sauger (*Stizostedion canadense* (Smith))	14.5	115
Carp (*Cyprinus carpio* Linnaeus)	14.5	340
Sauger (*Stizostedion canadense* (Smith))	2.2	69
Smallmouth bass (*Micropterus dolomicui* Lacepede)	2.2	500
Smallmouth buffalo (*Ictiobus bubalus* (Rafinesque))	2.2	134
Carp (*Cyprinus carpio* Linnaeus)	2.2	285
River carpsucker (*Carpiodes carpio* (Rafinesque))	2.2	1030
Average Concentration		346

These were all of the food and game fish analyzed. Gizzard shad (*Dorosoma cepedianum* (LeSueur) had a higher Sr^{90} content but was omitted from this

calculation, because this species is not generally used for food. The Public Health Service cooked these fish before analysis so that the Sr^{90} concentrations in flesh were those which could be expected in food.

Criteria in the report of the International Commission on Radiological Protection were used to calculate the expected body burden of Sr^{90}. Nelson assumed that one-half pound of fish constitutes a serving and that this quantity of fish would be eaten once a week by a human individual for a period of 50 years. Since the body burden from continuous intake of Sr^{90} reaches 86% of its equilibrium value in 50 years, a human who ate one-half pound of fish every week for this period would have a body burden of 8.013×10^{-3} μc of Sr^{90}. The maximum permissible body burden in bone for occupational exposure is 2 μc and for the population at large one-thirtieth of this or 6.67×10^{-2} μc. Thus, a member of the population at large eating these Clinch River fish in the manner stated would accumulate 12% of his maximum permissible body burden in a period of 50 years. Stated in another way, the individual would have to increase his consumption of fish by a factor of 8.3 over a 50-year period to attain his maximum permissible body burden.

These estimates are based on limited data - small number of specimens from only one collection of fish - and the suggestion was made that when analyses of later collections become available, the potential body burdens that may result from the consumption of the fish in Clinch River should be calculated again with consideration being given to sampling errors. Also it was noted that the average Sr^{90} concentrations in 1960 were larger by a factor of 38 times than those reported by Knobf (12), obtained from collection and analyses of 79 fish representing six species collected from the

Clinch River in October 1948. Based on these preliminary data, the estimated concentration factor for Sr^{90} by fish was approximately 35, which is similar to concentration factors of 15 to 30 for Sr^{90} obtained in controlled laboratory and field experiments elsewhere in 1958 (13).

Under the work plans for the Clinch River Study, the ORNL group has concentrated its efforts on more intensive investigations of fish populations in the Clinch River. In a report to the Steering Committee, April 12, 1960, co-operative fish studies by ORNL and the TVA Fish and Game Branch were described, and the ORNL investigations up to that time were summarized. The studies were made to determine the feasibility of more intensive fisheries investigations on the Clinch River. The specific objectives were (1) to compare relative fish catching ability of hoop nets and fish baskets, (2) to determine the species of fish which may be caught by these types of fishing gear, and (3) to obtain an estimate of gross gamma activity of fish caught from Clinch River Mile 21.7 to 24.4.

One hundred and fifteen fish, representing sixteen species, were caught. The species caught in nets were comparable to those collected after rotenone poisoning in 1943 for Knobf's analyses (12) and are probably the most common species in this reach of the Clinch River. The hoop nets were more effective than the baskets in the numbers of fish and numbers of species caught. Gross gamma activity was determined by placing the whole fish in a gamma scintillation detector with a 3-in. crystal. The background for this counter varied from 250 to 270 counts per minute. Fish were obtained from Douglas Reservoir (uncontaminated) as an aid in evaluating the gross gamma activity of fish that are slightly above background in radioactivity. It was stated that a study of fish movements in the Clinch River would be

conducted during the summer of 1960. From such studies it was hoped to estimate the fish populations of those species for which migratory movement is not great, and from length and weight data to make age and growth studies of each species.

A summary report of further fish studies by the ORNL group was submitted to the Steering Committee, September 22, 1960 (14). With regard to fish movements in the Clinch River in the vicinity of White Oak Creek, ten hoop nets with a 1-in. mesh were set close to shore at intervals from Clinch River Mile 21.7 to Clinch River Mile 16.5. The nets were lifted 6 days each week from July 5, 1960, until September 9, 1960, and an additional catch made on September 14. The fish were measured as to length and weight and tagged with a red plastic dangler tag marked for return to TVA at Norris, Tennessee. The return of tags to that date from seven species totaled 30 tags from a total of 1,362 individual fish of these seven species which were tagged and released. An additional 807 fish of 15 species were also tagged, but no returns for these species have been obtained. The mean of the days free after tagging for the different species ranged from 4 to 40 days, and the mean movement of different species upstream or downstream ranged from 3.3 to 17.0 miles. The tags returned were too few to justify positive statements, but tentative suggestions were made. The White crappies (*Pomoxis annularis* (Rafinesque)) tended to remain in the vicinity of netting and showed a very slight upstream movement. Returns and recoveries from all other species were always downstream from the site of tagging. The greatest distance at which a fish was recovered was a White bass (*Roccus chrysops* (Rafinesque)), tagged at Clinch River Mile 18.5 and recovered at Caney Creek (TRM 562), a distance of 24.5 river miles.

To obtain information on the uptake of radioactivity by fish in water, carp (Cyprinus carpio Linnaeus) obtained from the Fish Management Division of the Tennessee Game and Fish Commission were placed in the White Oak Creek Embayment of the Clinch River from July 26 to September 6 (unless the individual fish died or were lost earlier). Two fish were placed in each of six boxes, 3 ft square and 1 ft deep, which were covered with 1-in. mesh chicken netting. Three sets of two boxes each were made by tying one box on top of another so that one-half of the fish were able to feed on the bottom, while the other half were exposed to activity in the water only. The fish were counted for gross gamma activity weekly from July 26 to September 6. The data were variable, but it was apparent that fish excluded from free access to the bottom of the river became more radioactive than those which had access to the bottom food. The more radioactive fish had algae in their digestive tracts, and it is possible that a great deal of the activity in the fish was due to algae. When the experiment was terminated, only 25% of the original number of fish remained. These survivors were considerably emaciated, which suggests that the cages were not large enough to support the fish. In future work with this experimental technique, larger cages and a more satisfactory method for transporting fish to and from the laboratory for counting of radioactivity will be needed. Radiochemical analyses of the fish from the boxes would serve no useful purpose; therefore, they will not be requested.

Tubificid Worms

In the initial plan for the Clinch River Study, specific studies of the population densities, distributions, biomass, and radionuclide concentrations in the major bottom-dwelling organisms, such as shellfish (clams),

crustacea, and insects, were proposed. At the Steering Committee Meeting, April 21, 1960, Nelson described a planned study to determine movement of radionuclides by bottom organisms. The question was raised whether transport by biological organisms was important as compared with direct transport by the water in solution. However, there was no answer to this question at that time, and it appeared that more definite information was needed. In a report distributed to the Steering Committee members at a meeting, September 22, 1960, the role of Tubifex sp. in the turnover and downstream transport of radioactive bottom sediments was discussed. This discussion was as follows:

"Tubificid worms are the most abundant organisms living in the radioactive bottom sediments of the Clinch River. They feed with their anterior ends in the mud and with their posterior ends extending into the overlying water. There are weak bottom currents, created by differences in water density in Watts Bar Reservoir. Feeding activity of the worms and density currents might contribute to the downstream transport of radioactive bottom sediments. Consequently, the following mathematical model* was used to evaluate the movement of bottom mud by the worms (Fig. 7):

Height variable, $y = a - rt$

where

a = the height of the worm tail above the sediment surface,

r = the rate of fall of fecal pellets,

t = time.

Distance variable, $x = vt$

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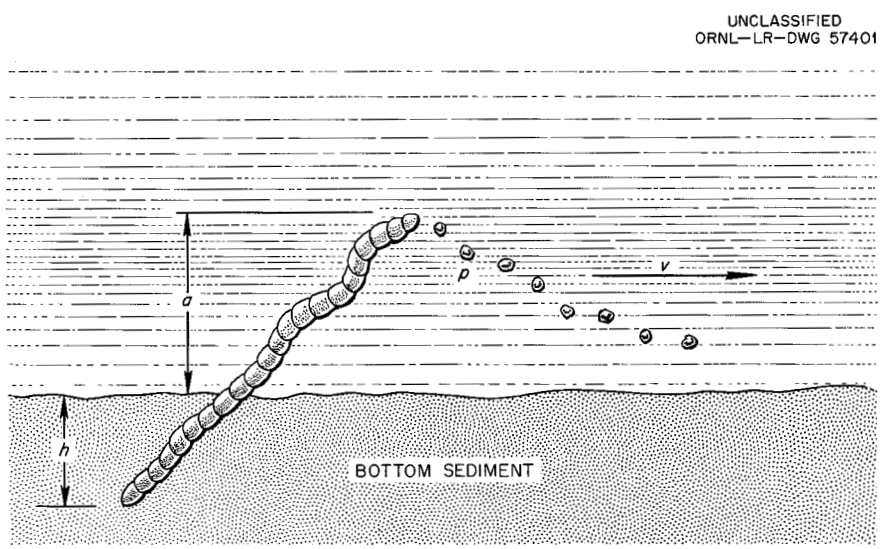
*M. A. Kastenbaun, ORNL Mathematics Panel, assisted.



v = CURRENT VELOCITY
a = TAIL ELEVATION
h = DEPTH OF HEAD
p = FECAL PELLETS

Fig. 7. Diagram of a Tubificid Worm Feeding on Bottom Sediment.

where

v = current velocity.

Then

$$y = a - \frac{rx}{v} .$$

a, r, and v are determined experimentally; therefore $y = 0$.

$x = \frac{av}{r}$ or distance downstream.

$t = \frac{a}{r}$, time to travel distance x.

"For purposes of simplicity, the worm is considered to be feeding in an area of 1 cm^2 of bottom surface with its head at a depth of h cm in the mud. In order for a worm to ingest a pellet on the surface of the mud, we assume it must eat the entire volume of mud. Therefore, the volume the worm needs to displace is h cm^3.

"When w is the rate of feeding in g/hr and s is the specific weight of the sediment, mg/cm^3, it will take $\frac{hs}{w}$ hours to move the volume of the h cm^3.

"Data obtained experimentally (Table 10) were used in the model.

x = distance downstream = $\frac{av}{r}$

= 9.18 cm downstream

t = time to travel distance $x = \frac{a}{r}$

= 4.19×10^{-4} hours

Time to move sediment from 1 cm^2 to depth h for 1 worm = $\frac{hs}{w}$

= 2.92×10^3 hours

= 0.333 years.

"On the basis of feeding activity of 1 worm/cm^2, it would take 0.333 years to move the sediment from this area 9.18 cm downstream. Worm populations in

Table 10. Measurement Data Used in Model to Determine Downstream Transport of Sediment by Tubificid Worms

	Symbol	Number of Observations	Mean Value ± S.D.**
Rate of fecal pellet fall	r	14	26.43 ± 8.56 cm/min
Rate of feeding	w	15	$7.47 \pm 4.36 \times 10^{-4}$ g/hr
Height of worm tail	a	88	0.665 ± 0.309 cm
Depth of burrowing	h	15	0.827 ± 0.317 cm
Diameter of feeding worms		21	$17.6 \pm 4.96 \times 10^{-3}$ cm
Mud density	s	1	2.64 g/cm^3
Current velocity	v	*	2.19×10^4 cm/hr

*Value estimated from: A. S. Fry, M. A. Churchill, and Rex Elder, 1953, "Significant Effects of Density Currents in TVA's Integrated Reservoir and River System," Proc. Minnesota International Hydraulics Convention, pp 335-354.

**S.D. = one sample standard deviation.

the river average 1/10 cm^2; therefore, the effect of these populations on the movement of sediment is insignificant. Since tubificid populations may reach 100 individuals/cm^2 under conditions of high organic pollution, one might consider that high populations could have a significant effect for two reasons. First, their head ends burrowing into the sediment would displace a sufficient volume to decrease the amount of silt present per h cm^3; and, secondly, more worms would move more silt. The average volume of the worm head end buried in the sediment is 2.01×10^{-6} cm^3. Population increases of three orders of magnitude would not result in the displacement of sufficient silt to change the original conclusion. An increase to 100 worms/cm^2 would cause the sediment to be moved 27.5 meters/year downstream. Cesium-137 could be moved downstream by the worms 800 meters during one half life, which is insignificant when compared with the sediment movement by water currents.

Uptake of Co^{60} by Crayfish

The rate at which crayfish, an important link in aquatic food chains, accumulate Co^{60} from solution is given by: $Co_{acc}(t)-Co_{eq}(1-c^{kt})$, where Co_{acc} is the accumulated cobalt at time, t, Co_{eq} is the equilibrium level, and k is a positive constant. The values for k, obtained in an experimental system in which a solution containing 2.52×10^3 dpm/ml Co^{60} was pumped over crayfish (*Cambarus longulus longerostris*, Ort.) continuously, were 0.238 and 0.252 per day for groups of crayfish with average weights of 0.9 and 6.4 g respectively.

Excretion rates were determined by placing tagged crayfish in clean spring water and counting them at daily intervals. The k values (negative for excretion) were 0.019/day and 0.010/day for groups of crayfish with

average weights of 0.87 and 5.02 g respectively. Experiments including dead crayfish showed that about 50% of the uptake was due to adsorption on the exoskeleton. Adsorption occurs rapidly accounting for the higher k value for uptake by the large as compared with the small crayfish. The higher k value for excretion by small crayfish is due to the greater metabolic rate of these individuals and elimination of metabolically available cobalt. Cobalt-60 was found in low and equal levels in the blood, muscle, and gonads, while greater concentrations were found in the gut, hepatopancreas, and exoskeleton. The exoskeleton contained 95% of the body burden of Co^{60} (15).

Radiation Effects on Biota

Larvae of *Chironomus tentans*, a bloodworm common to bottoms of many ponds and streams, live in the radioactive bottom sediments of White Oak Creek and the Clinch River. These larvae are subject to a continuous dose of ionizing radiation which is a minimum of ten times background. The population has been subject to radiation higher than background since the first releases of radioactive waste effluents from the ORNL area in 1943.

Chironomus tentans Fabr. has large, easily identifiable salivary-gland chromosomes in which the typical pattern of bonds and the commonly-occurring chromosomal aberrations have been studied by Beerman in Germany and Acton in Canada and England. This population near the Laboratory is living under natural conditions in an area polluted by radioactive wastes released to the environment.

A preliminary investigation to determine whether the chironomus population was suitable for salivary gland chromosome analysis was conducted in

1960. This Study is the first attempt to describe the effects of chronic low-level radiation resulting from radioactive wastes on a natural population by sensitive cytogenetic methods.

Materials and Methods.-- Chironomus larvae were collected from the Clinch River at Mile 20.8, and salivary gland slides were made using conventional cytogenetic techniques. The salivary glands were removed from 4th instar larvae in an isotonic salt solution, placed on a microscope slide, fixed in acetic acid, stained with lactic orecin and squashed with a siliconized cover slip.

Results.-- At least three hundred temporary slides were prepared, and, of these, 86 were made permanent and studied in some detail. Heterozygous inversions, which are easily recognized because of their ring formation in synapsing chromosomes (Fig. 8), were listed from one location in the Clinch River. This was at mile 20.8 where White Oak Creek empties into the Clinch River. A total of 48 slides suitable for study were obtained. Fourteen of these slides contained at least one heterozygous inversion in one of the three large chromosomes. Two of the slides contained two heterozygous inversions in three large chromosomes. Figures 8 to 15 are from eight photographs of slides showing salivary-gland chromosomes in larvae of *Chironomus tentans* Fabr.

The fourth chromosome, which is easily recognized by the puff-like structures known as Balbiani Rings (Fig. 12) and its length, was studied in more detail. However, the spreading of the chromosomes by the puffs frequently prevented exact analysis. Homozygous inversions were studied only in the fourth chromosome. The banding of the chromosomes from the Clinch River specimens differs from the published chromosome maps of Beerman. A further study of the chromosome banding is needed to make exact comparisons with the findings of Beerman (16) and Acton (17).

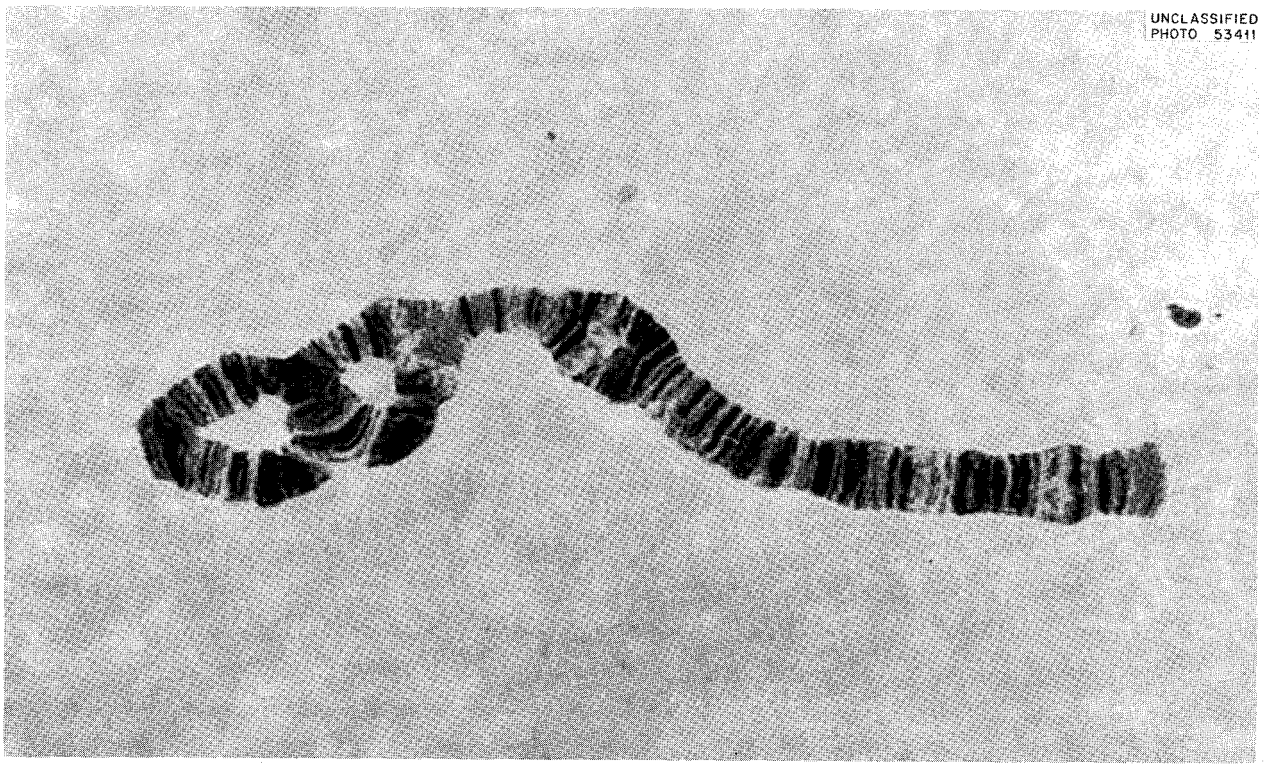


Fig. 8

Fig. 9

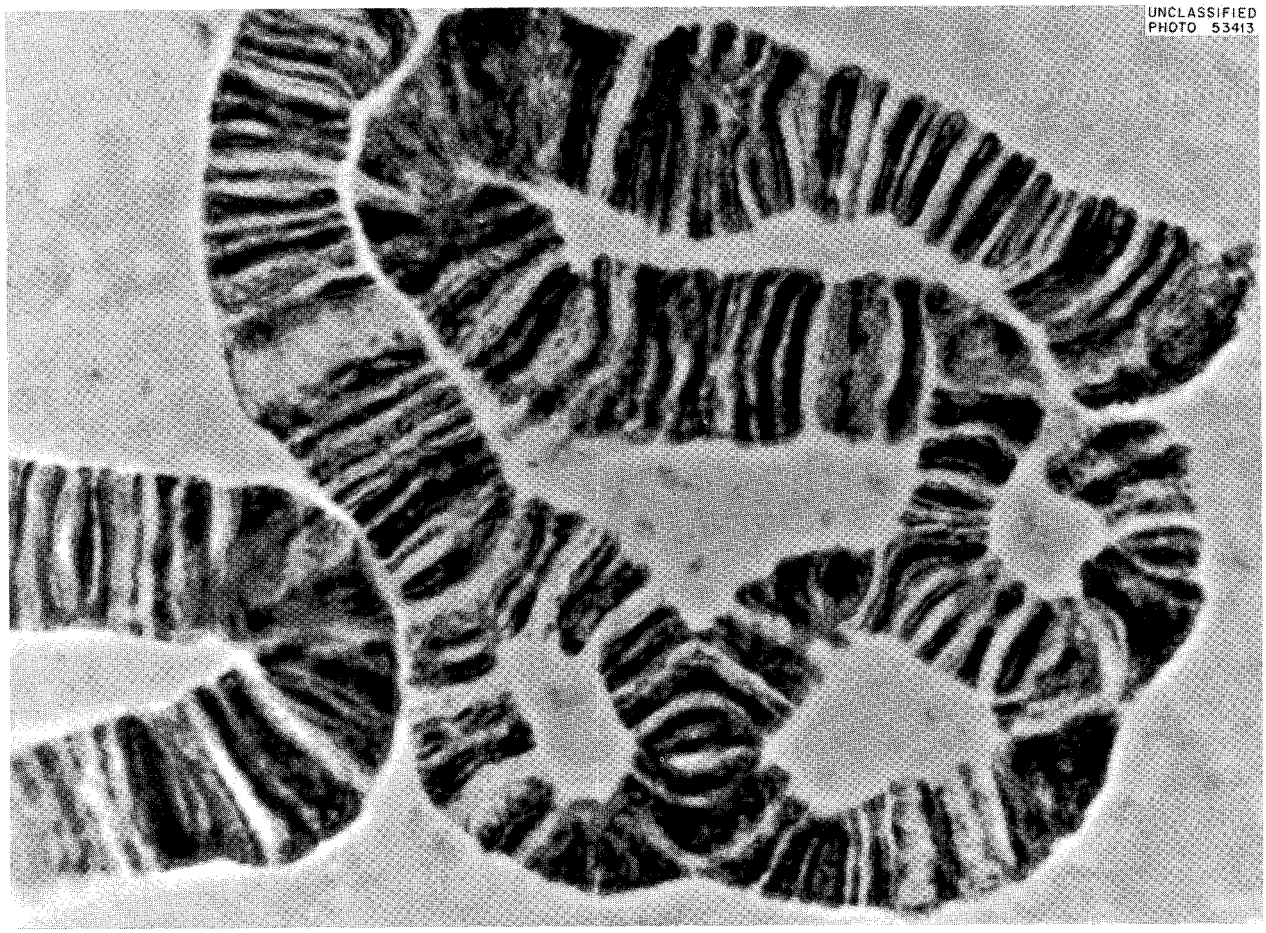


Fig. 10

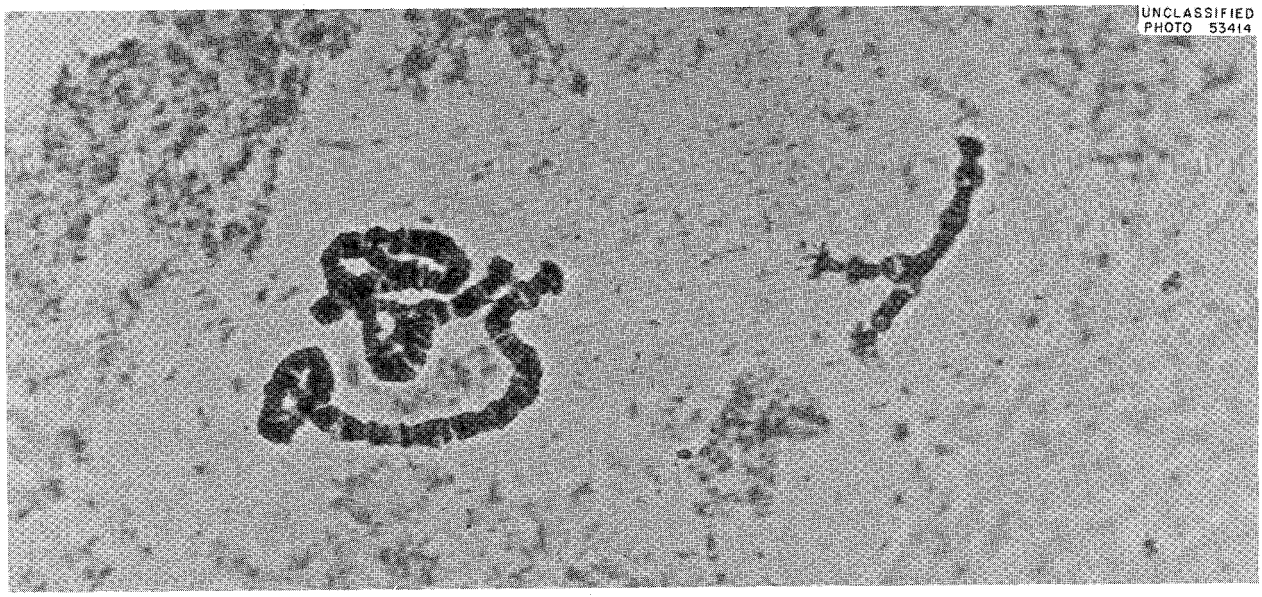


Fig. 11

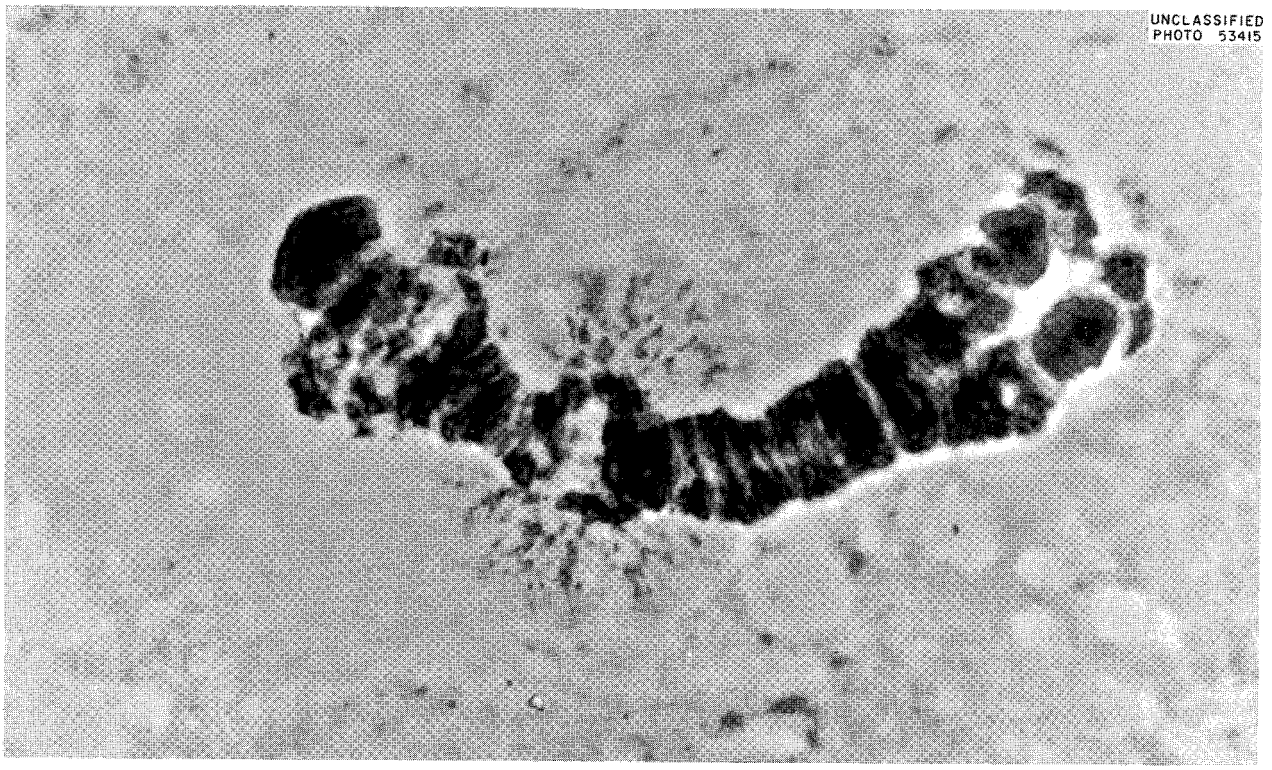


Fig. 12

Fig. 13

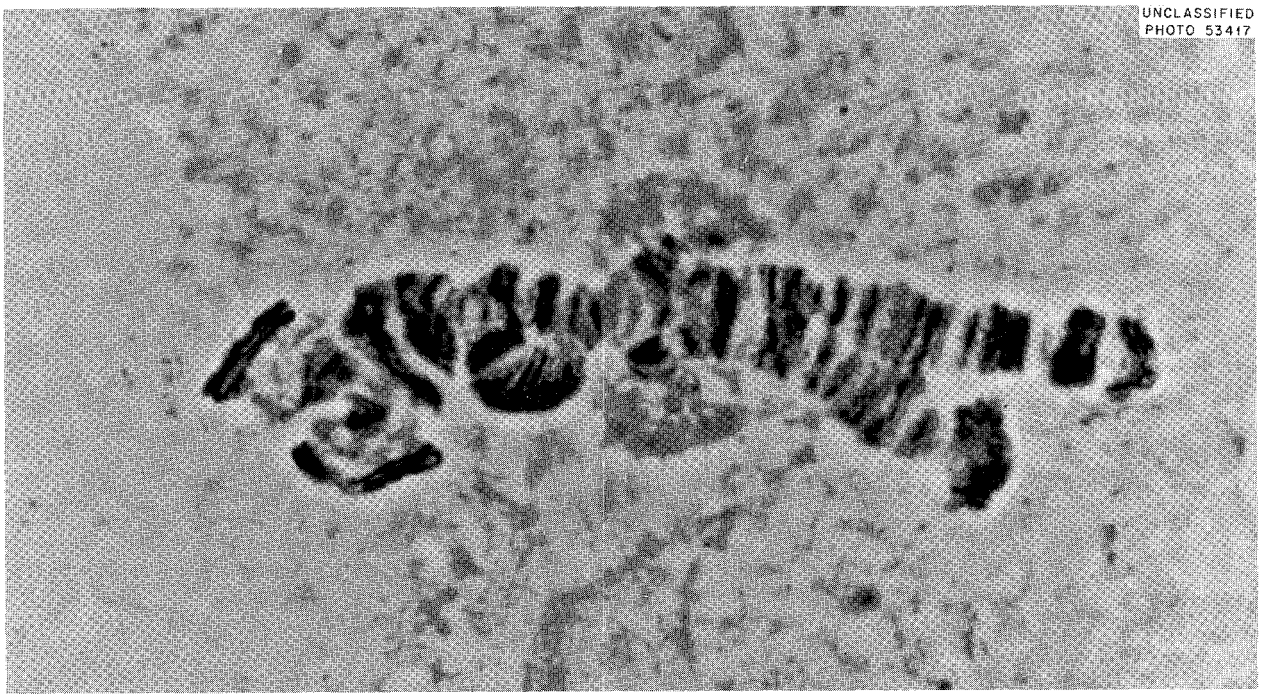


Fig. 14

Fig. 15

Approximately 29% of the 48 organisms carried some type of heterozygous inversion in one of the three large chromosomes. Since inversions are known to occur readily in Chironomus tentans Fabr., this percentage is not as astonishing as it would be in other organisms.

One inversion which occurred frequently in all populations studied was scored as 3R-12B-15B, using Acton's scoring of chromosomes. The first number represents the chromosome number, the "R" represents the right arm of the chromosome, and 12B-15B represents the inverted region. This inversion is shown in Figs. 8 and 9.

Figure 10 shows a chromosome with two heterozygous inversions which are very close together. This would suggest that the frequency of inversions is relatively high. Another indication that the frequency of inversions in the population is relatively high is shown in Fig. 11. Here only three of the four chromosomes can be seen. The upper left one has two heterozygous inversions. The lower left one has one heterozygous inversion, and the fourth chromosome, at the extreme right, has a homozygous inversion. This homozygous inversion is easily recognized by the puffed region occurring at the end of the chromosome instead of the position shown in Fig. 12. That one individual would possess this many inversions indicates a relatively high frequency of inversion.

Three inversions in the fourth chromosome, which were described by Acton (1959)(17), are believed to occur in these populations. In addition, some other aberrations were noted which have not been described in any of the literature reviewed. Figure 13 shows a one-band deletion of the fourth chromosome. Figure 14 shows a fourth chromosome with two aberrations: a deletion of the right end and one just to the left of the puffed region.

Figure 15 shows a homozygous inversion of the fourth chromosome which is recognized by the two puffs occurring at the left end. This corresponds to the common inversion, 4 - C of Beerman. Just to the right of the second puff is a heterozygous inversion as indicated by the arrow.

The preliminary study of chromosomes in the Chironomus tentans Fabr. population from Clinch River Mile 20.8 has shown there is a high frequency of chromosomal aberrations within this local insect population. Relating induction of chromosomal aberrations to environmental factors requires a detailed study of populations from several habitats (including contaminated and a variety of uncontaminated areas), as well as laboratory investigations on life cycles, reproductive capacity, and radiation-induced effects upon this species of organism. The possibility that the frequency of aberrations in the chromosomes of these bottom-dwelling insect larvae may be related to the radioactivity in the mud warrants this kind of intensive investigation. There is need for a biological indicator of radioactivity in the environment. Likewise there is a definite need for a biological parameter which can be related quantitatively to radiation dose. If frequency of chromosomal aberration can be verified experimentally as being related to the radioactivity of muds, then, there is a possibility of establishing a field biological dosimeter.

Future work planned includes a detailed comparison of local chironomus populations living in both contaminated and noncontaminated habitats.

Studies Concerning Aquatic Plants

During summer months of 1960, Dr. William T. Lammers, on assignment from TVA, initiated certain studies concerning the role played by aquatic

plants in concentrating and/or transporting radioactive materials downstream. These studies have included or will include in the summer of 1961 observations on plankton, detached benthic plants, and emergent plants rooted along the water's edge.

HYDROLOGIC STUDIES

The flow in the Clinch River and its tributaries varies both with time and with location in the drainage basin. In past years the U. S. Geological Survey has operated gaging stations to obtain continuous records of stream flow at sections on the Clinch River and White Oak Creek. Based on available stream-flow records for Clinch River near Scarboro, Tennessee (CRM 39.0), from 1936 to 1960, the average discharge is 4564 cfs (Station is upstream from the mouth of White Oak Creek.). This is equal to 18.8 in. of runoff per year on the drainage area, or about 40% of the average rainfall. From records available for the period, July 1953 to September 1955, the average discharge of White Oak Creek at White Oak Dam is 11.2 cfs with a maximum discharge of 669 cfs and a minimum daily discharge of no flow.

Through co-operation of the U. S. Geological Survey, occasional measurements have been made of stream flow and related characteristics of the Clinch River tributaries in the Oak Ridge area. Also special studies have been made in connection with the ORNL programs of area monitoring and of waste disposal research. For example, in July 1957 tracer-level tests in the Clinch River were made by Laboratory groups in which 5 curies of I^{131} was injected into White Oak Creek at its confluence with the Clinch River. Liquid samples were taken periodically during the course of the test at Clinch River Miles 19.6, 17.8, 15.5, 14.0, and 13.1, and scintillation counters were used for measuring the concentration of radioiodine flowing past these sampling stations. Through the co-operative arrangement with the USGS,

the flow in this reach of the river was measured during the test. The velocity and temperature profiles at the sampling stations were also determined by the USGS (18).

Stream Gaging on Clinch River and Its Tributaries

At continuous-record and partial-record stream gaging stations, basic data on discharge, stage, and velocities are or will be collected. These data will be used to describe variability of flow and hydraulic characteristics of the streams throughout the study area.

Description of the variability of flow in the stream network includes studies of the distribution of the flow throughout the year and of average and critical supply, studies of the duration, magnitude, and frequency of flood and low flows, and studies of areal variation in flow. The work on hydraulic characteristics includes the determination of storage potential, dispersion, stratification, flood profiles, and flow routing. Basic data from continuous-record stations will be compiled upon request at monthly intervals for immediate application in other studies. All basic data will be compiled and published annually in the Water Supply Papers issued by the USGS.

The records collected at gaging stations are needed for a variety of purposes in the Clinch River Study. Discharge records are used to determine dilution factors, material balance of radionuclides throughout the drainage network, coefficients of dispersion equations, and sediment transport and distribution. The velocity measurements are useful in studies of dispersion, time of water travel, and sediment transport. Water stages are needed to delineate flood profiles and to compute flows at ungaged points (flow routing).

A few concurrent measurements of discharge and stage during periods of critical supply will be made at selected sites, partial-record stations. These measurements, in conjunction with records from the continuous-record stations, are to be used in the description of areal characteristics of flow. Records from the continuous stations are used to describe the variation of these flow characteristics with time.

The procedures employed include continuous records of water stage (elevation of water surface) which are collected at a few key stations on the Clinch River and tributaries. At frequent intervals, velocity, discharge, and temperature measurements are made at these stations to sample the variations in these flow characteristics. Relations of measured discharge, velocity, and cross-sectional area to the water stage are established. Continuous records of discharge are computed through application of the stage-discharge relation to the record of stage. Usually velocity, area, and temperature are determined for selected periods only.

At partial-record stations, measurements of discharge and stage are made during critical periods; that is, flood, base-flow, and drought periods. The stage-discharge relation is defined for each station. The measurements for a station are correlated with records at other partial-record stations and with the continuous-record stations. From these data and relationships, together with an appraisal of geologic and physiographic effects, of the influences of land cover, and of the influences of man, the extremes of the hydrologic system are described.

At the meeting of the Steering Committee, April 21, 1960, a subcommittee was appointed to study the needs for stream gaging and submit recommendations as to what gages are needed and how the information from them is to

be made available. Based upon recommendations outlined by this subcommittee, an expanded program of stream gaging measurements by the USGS was approved by AEC-ORO, ORNL, and USGS. The effective date of this expansion was about July 1, 1960. According to a recent summary prepared by the USGS, nine continuous-record gaging stations established and in operation include: Clinch River near Scarboro, White Oak Creek below ORNL, Melton Branch near White Oak Lake, White Oak Creek at White Oak Dam, Settling Basin outlet near ORNL, Poplar Creek near Oak Ridge, East Fork of Poplar Creek near Oak Ridge, Bear Creek near Oak Ridge, Clinch River at Mile 19.1 (stage records only). The establishment and operation of partial-record stations has been proposed, and 15 sites for base-flow and crest-stage stations have been tentatively selected. Also special and miscellaneous surface water surveys and measurements at locations related to the Clinch River and White Oak Creek studies, and elsewhere on the Reservation, have been carried out as requested under this expanded gaging program.

Operation of continuous-discharge-record gaging stations on Bear Creek, East Fork Poplar Creek, and Poplar Creek was begun by the USGS in September 1960. At the same time the USGS installed an auxiliary continuous water-stage recorder at White Oak Dam to determine submergence effects. A continuous water-stage recorder operated by ORNL was installed in a gage well on September 26-27, 1960, at Clinch River Mile 19.1 (3).

Special studies have included velocity and temperature profiles at four cross sections of the Clinch River, CRM 4.7, 8.0, 19.6, and 22.5, which were measured by the USGS on July 25, 1960, and August 4, 1960. The measurements made on July 25 were during a period when no water was being released from Norris Reservoir. The data from these measurements are available but have not been fully evaluated (3).

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APPENDIX

SAMPLING SITES AND ALLOCATION OF SAMPLING AND ANALYSIS

Table A.1. Stream Flow

Site	Analysis for	Collected by	Analyzed by
Clinch River near Scarboro, Tenn., CRM 39.0	Discharge, stage	U.S. Geological Survey	U.S. Geological Survey
White Oak Creek below ORNL near Oak Ridge, Tenn.			
Melton Branch near Oak Ridge, Tenn.			
White Oak Creek at White Oak Dam near Oak Ridge, Tenn.			
Clinch River near Oak Ridge, Tenn. CRM 19.1	Velocity, area, stage, temperature*		
East Fork Poplar Creek near Oak Ridge, Tenn.	Discharge, stage		
Bear Creek near Oak Ridge, Tenn.			
Poplar Creek near Oak Ridge, Tenn.			

*Continuous record of stage only.

Table A.2. Quality of Water

Site	Analysis for	Collected by	Analyzed by
Clinch River at Oak Ridge, Tenn., water plant, CRM 41.5	Stable and radioactive chemicals, suspended sediment	ORNL	Tenn. Health Dept. and U.S. Public Health Service
White Oak Creek at White Oak Dam	Radioactive chemicals		U.S. Public Health Service
Clinch River at ORGDP water plant, CRM 14.5	Stable and radioactive chemicals, suspended sediment		ORNL
Clinch River near Centers Ferry, near Kingston, Tenn., CRM 5.5*			Tenn. Health Dept. and U.S. Public Health Service
Clinch River at Kingston Steam Plant, CRM 4.5**		TVA and ORNL	ORNL
Tenn. River at Loudon, Tenn., TRM 591.8		Visking Co. and Tenn. Health Dept.	Tenn. Health Dept. and U.S. Public Health Service
Tenn. River at Watts Bar Dam, Tenn., TRM 529.9		TVA	
Tenn. River at Chickamauga Dam, Tenn., TRM 471.0			

*Station established Nov. 1, 1960.
**Station discontinued Oct. 31. 1960.

Table A.3. Bottom Sediment

Site	Analysis for	Collected by	Analyzed by
Clinch River Miles 4.7, 5.8, 6.9, 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 14.6, 15.3, 16.0, 16.9, 18.1, 19.5, 20.8, 21.6, 22.5	Core samples: particle size, specific weight, radioactive chemicals	ORNL	ORNL and U.S. Geological Survey
Clinch River Miles 1.1, 2.6, 4.7, 5.7, 8.3, 11.0, 14.0, 15.2, 16.3, 19.1, 21.5, and Tenn. River Miles 354.5, 381.2, 434.1, 475.1, 491.9, 509.5, 532.0, 543.8, 552.7, 562.7, 570.8, 604.1	*In situ* radiation count, dredge samples, radioactive chemicals		ORNL

Table A.4. Aquatic Biology
Samples collected and analyzed by ORNL

Site	Type of Sample
Clinch River Miles 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.5, 16.0, 17.0, 18.0, 19.0, 20.0, 20.3, 21.3, 21.5, 21.7, 22.4	Bottom organism, collected by Ekman dredge
Clinch River Miles 4.7, 5.8, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.3, 16.2, 16.9, 18.1, 19.5, 20.8, 21.6, 22.4	Organic fraction of bottom sediments, collected by Ekman dredge
Clinch River near Oak Ridge, Tenn., CRM 47	Clams, analyzed for total calcium and strontium and for Sr^{90}
Clinch River near Oak Ridge, Tenn., CRM 17	
Grassy Creek near Wheat, Tenn.	
Clinch River near Wheat, Tenn., CRM 14.5	
Clinch River near Oak Ridge, Tenn., CRM 11.0	
Clinch River near Kingston, Tenn., CRM 9.9	
Clinch River near Kingston, Tenn., CRM 6.9	
Clinch River above Centers Ferry, near Kingston, Tenn., CRM 4.7	
Tenn. River downstream from Watts Bar Dam, TRM 521	
Tenn. River downstream from Hales Bar Dam, near Shellmound, Tenn., TRM 425	
Tenn. River near New Johnsonville, Tenn., TRM 100	
Clinch River Miles 16.5, 16.8, 16.9, 17.5, 18.1, 18.4, 18.5, 19.1, 19.4, 19.5, 20.1, 20.4, 20.6, 20.8, 21.1, 21.8	Fish tagging
Clinch River near Oak Ridge, Tenn., at Miles 19.5, 20.8	Diptera larva, *Chironomus tentans*, collected for cytogenetic studies

Table A.5. Quarterly Environmental Surveys, Feb. 9–15, 1960
Samples collected and analyzed by U.S. Public Health Service

Site	Type of Sample
Clinch River in Norris Reservoir, ¼ mile upstream from dam, CRM 80.0	Water and fish
Clinch River at Oak Ridge, Tenn., CRM ~50	Algae and clam
White Oak Creek at White Oak Dam near Oak Ridge, Tenn.	Bottom sediment
White Oak Creek at mouth, near Oak Ridge, Tenn.	Water, fish, and bottom sediment
Clinch River, 150 ft downstream from White Oak Creek, near Oak Ridge, Tenn., CRM 20.8	Fish and bottom sediment
Clinch River at Gallaher Bridge, near Wheat, Tenn., CRM 14.5	Water, fish, and bottom sediment
Bear Creek at White Wing Road, near Oak Ridge, Tenn.	Bottom sediment
Clinch River:	
200 ft downstream from Poplar Creek, near Oak Ridge, Tenn., CRM 12.0	Bottom sediment
Near Oak Ridge, Tenn., CRM 10.9	Bottom sediment
¼ mile upstream from Centers Ferry, near Kingston, Tenn., CRM 4.8	Fish and bottom sediment
At Centers Ferry, near Kingston, Tenn., CRM 4.5	Water and bottom sediment
½ mile downstream from U.S. Hwy 70, at Kingston, Tenn., CRM 1.8	Fish
Tennessee River:	
In Ft. Loudoun Reservoir, 8 miles upstream from dam, TRM 610	Fish and bottom sediment
In Ft. Loudoun Reservoir, at dam, TRM 602.3	Water
At Watts Bar Dam, TRM 529.9	Water
½ mile downstream from Watts Bar Dam, TRM 529.4	Bottom sediment and clam
At Chattanooga, Tenn., water plant, TRM 472.8	Raw water and treated water
In Chickamauga Reservoir, near Hixson, Tenn., TRM ~472	Fish
In Chickamauga Reservoir at dam, TRM 471.0	Bottom sediment
At Chickamauga Dam, TRM 471.0	Fish
South Chickamauga Creek, ¼ mile upstream from mouth, near Chattanooga, Tenn.	Bottom sediment
Tennessee River at Hales Bar Dam, TRM 431.1	Fish

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