MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0050873 3

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION

ORNL-3202
UC-70–Waste Disposal and Processing
TID-4500 (17th ed.)

STATUS REPORT NO. 2 ON CLINCH RIVER STUDY

R. J. Morton, Editor

OAK RIDGE NATIONAL LABORATORY
CENTRAL RESEARCH LIBRARY
CIRCULATION SECTION
4500N ROOM 175
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this report, send in name with report and the library will arrange a loan.
UCN-7969 (3 9-77)

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

Printed in USA. Price $2.25 Available from the

Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

ORNL-3202

Contract No. W-7405-eng-26

HEALTH PHYSICS DIVISION

STATUS REPORT NO. 2 ON CLINCH RIVER STUDY

Clinch River Study Steering Committee

EDITOR

R. J. Morton

CONTRIBUTING AUTHORS

H. H. Abee
S. I. Auerbach
P. H. Carrigan
M. A. Churchill
L. Hemphill
E. P. Mathews
D. J. Nelson
W. B. Nix
E. G. Struxness

DATE ISSUED

MAR 30 1962

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
Operated by
UNION CARBIDE CORPORATION
for the
U. S. ATOMIC ENERGY COMMISSION

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES

3 4456 0050873 3

TABLE OF CONTENTS

	Page
LIST OF FIGURES	iv
LIST OF TABLES	v
ACKNOWLEDGMENT	vii
CLINCH RIVER STUDY STEERING COMMITTEE	viii
INTRODUCTION	1
STEERING COMMITTEE ACTIONS	2
WATER SAMPLING AND ANALYSIS	6
Sampling Stations	7
Sampling Procedures at the Selected Sampling Stations	8
Analyses of Water Samples	15
SEDIMENT SAMPLING AND ANALYSIS	39
Applied Health Physics Annual River Survey	39
Distribution of Radioactivity in the Upper Horizon of Clinch River Bottom Sediment	45
BIOLOGICAL PHASES	61
Biogeochemistry of Strontium and Calcium in Clams	61
Radiation Effects on Biota - Estimated Radiation Dose Received by Diptera with Life Stages in Bottom Sediments	71
HYDROLOGIC ACTIVITIES	80
APPENDIX - DESCRIPTION OF GAGING STATIONS	88
REFERENCES	91

LIST OF FIGURES

Figure		Page
1	Map - Lower Clinch River Basin	9
2	Map - Eastern Portion of Tennessee River	10
3	Gamma Count at Surface of Clinch River Silt	41
4	Gamma Count at Surface of Tennessee River Silt	42
5	Average Gamma Count at Surface of Silt in Clinch and Tennessee Rivers, 1951-60	43
6	Major Radionuclides Discharged and Concentrations Found in Clinch and Tennessee River Silt	44
7	Comparison of Core Data (Gross Gamma) and "Flounder" Data	52
8	Longitudinal Distribution of Specific Activity - 1960 Samples	55
9	Variation in Unit Radioactivity in Clinch River, CRM 4.7 to CRM 22.5 - 1960 Samples	59
10	Velocity and Temperature Distribution in Clinch River, Section at CRM 5.5, October 13, 1960	82
11	Velocity and Temperature Distribution in Clinch River, Section at CRM 14.0, October 13, 1960	83
12	Velocity and Temperature Distribution in Clinch River, Section at CRM 19.1, October 12, 1960	84
13	Velocity and Temperature Distribution in Clinch River, Section at CRM 22.5, October 12, 1960	85

LIST OF TABLES

Table		Page
1	Concentrations of Ru^{106} in Water Samples	18
2	Concentrations of Co^{60} in Water Samples	19
3	Concentrations of Sr^{90} and Sr^{89} in Water Samples	21
4	Total Loads of Ru^{106} and Co^{60} at Sampling Stations on Clinch and Tennessee Rivers	23
5	Concentrations of Ru^{106}, Cs^{137}, and Sr^{89+90} in Suspended Sediment	27
6	Results of Stable-Chemical Analyses, Clinch River at Oak Ridge Water Plant - CRM 41.5	29
7	Results of Stable-Chemical Analyses, Clinch River Above Centers Ferry - CRM 5.5	30
8	Results of Stable-Chemical Analyses, Tennessee River at Loudon - TRM 591.8	31
9	Results of Stable-Chemical Analyses, Tennessee River at Watts Bar Dam - TRM 529.9	32
10	Results of Stable-Chemical Analyses, Tennessee River at Chickamauga Dam - TRM 471.0	33
11	Suspended Solids, Total Solids, and Loss on Ignition in Clinch River Samples from Three Stations, June 7 to November 20, 1960	35
12	Results of Stable-Chemical Analyses, Clinch River at Water Plant of ORGDP, CRM 14.5, November 28, 1960, to February 5, 1961	37
13	Results of Stable-Chemical Analyses, Clinch River at Water Plant of ORGDP, CRM 14.5, February 6 to April 9, 1961	38
14	Clinch River Cross Sections and Mass Specific Weight of Sediment	49

LIST OF TABLES (contd)

Table		Page
15	Distribution of Gross Gamma Activity in Clinch River Bottom Sediment from Mile 21.6 to Mile 4.7	51
16	Analyses of Clinch River Silt for Specific Radionuclides	54
17	Comparison of Analyses of Clinch River Silt by Oak Ridge National Laboratory and U. S. Public Health Service ...	56
18	Unit Activity for Each Radionuclide in Upper Horizon of Sediment Deposits - Clinch River, CRM 4.7 to CRM 22.5 .	58
19	Stable Strontium and Sr^{90} Concentrations in River Clams with Calculated Strontium-Calcium Atom Ratios and Sr^{90}-Stable Strontium Atom Ratios	63
20	Observed and Expected Sr^{90}-Stable Strontium Atom Ratios in Clams as a Function of the Dilution of Clinch River Water	69
21	Summary of Natural Background Radiation to Bottom Organisms in the Clinch River	75
22	Dose Rates Calculated on the Basis of Radionuclide Content of the Clinch River Bottom Sediments	77

ACKNOWLEDGMENT

This study has continued as a cooperative project in which essential parts of the work are performed by a number of groups in the Laboratory and other agencies represented on the Steering Committee. The Committee recognizes and appreciates the participation of the investigators named below.

STAFF INVESTIGATORS PARTICIPATING IN THE CLINCH RIVER STUDY

For the OAK RIDGE NATIONAL LABORATORY, Health Physics Division:
Applied Health Physics Section

H. H. Abee
W. D. Cottrell

Ecology Section

S. I. Auerbach
D. J. Nelson

Radioactive Waste Disposal Section

L. Hemphill
W. B. Nix
W. E. Parker
J. A. Payne

For the U. S. GEOLOGICAL SURVEY, Water Resources Division:

R. M. Richardson
P. H. Carrigan
E. P. Mathews
J. P. Monis

For the TENNESSEE VALLEY AUTHORITY, Health and Safety Division:
Stream Sanitation Section

M. A. Churchill
W. T. Lammers

Forestry Relations Division, Fish and Game Branch

Paul Bryan
C. J. Chance

For the U. S. PUBLIC HEALTH SERVICE, Division of Radiological Health:
Robert A. Taft Sanitary Engineering Center

A. G. Friend
A. H. Story

For the TENNESSEE DEPARTMENT OF PUBLIC HEALTH
Stream Pollution Control Board

S. Leary Jones

For the TENNESSEE GAME AND FISH COMMISSION

John Conder
L. P. Wilkins

Current Membership

CLINCH RIVER STUDY STEERING COMMITTEE

E. G. Struxness, Chairman, Health Physics Division, Oak Ridge National Laboratory, P. O. Box X, Oak Ridge, Tennessee

J. S. Cragwall, Surface Water Branch, Water Resources Division, U. S. Geological Survey, 823 Edney Building, Chattanooga, Tennessee

A. G. Friend, Division of Radiological Health, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio

F. E. Gartrell, Health and Safety Division, Tennessee Valley Authority, Edney Building, Chattanooga, Tennessee

Glenn Gentry, Tennessee State Game and Fish Commission, Cordell Hull Building, Nashville, Tennessee

S. Leary Jones, Tennessee State Department of Public Health and Tennessee Stream Pollution Control Board, Cordell Hull Building, Nashville, Tennessee

W. G. Belter (ex officio), Division of Reactor Development, U. S. Atomic Energy Commission, Washington 25, D. C.

C. S. Shoup (ex officio), Research and Development Division, U. S. Atomic Energy Commission, Oak Ridge Operations, P. O. Box E, Oak Ridge, Tennessee

Vincent Schultz (ex officio), Division of Biology and Medicine, U. S. Atomic Energy Commission, Washington 25, D. C.

INTRODUCTION

This is the second of the series of status reports on the study of the Clinch River which was initiated in February 1960 and described in Status Report No. 1.[1] The present report covers the major aspects of work on the Clinch River Study from September 1960 through April 1961. It is based mainly on reports of activities and information presented at the meeting of the Steering Committee on May 4, 1961.

During this period the project has continued as a cooperative effort in which essential parts of the work are done by various individuals from agencies represented on the Clinch River Study Steering Committee (See page vii.). The necessary specific information and basic data are obtained primarily by field measurements of stream flow and other hydraulic parameters, and by sampling and analysis of water, sediments, and biological materials in the river. The sampling sites and the allocation of sampling and analysis work by the several agencies were given in the Appendix of the previous status report.[1]

STEERING COMMITTEE ACTIONS

The Clinch River Study Steering Committee meets regularly about twice a year and has additional special meetings if necessary. An open meeting and an executive session of the committee were held on May 4, 1961. Agency representation and individual membership on the committee at that time were the same as listed in Status Report No. 1.[1]

The open session consisted mainly of the presentation and discussion of seven progress reports; namely: "Applied Health Physics Annual River Survey" by H. H. Abee, Applied Health Physics Section, ORNL*; "Summary of USGS Activities for the Clinch River Study" by E. P. Mathews, Surface Water Branch, USGS; "Progress Report No. 1, Subcommittee on Water Sampling and Analysis" by M. A. Churchill, Subcommittee Chairman, Stream Sanitation Section, TVA; "Chemical-Physical Studies of Clinch River Water and Sediment" by P. H. Carrigan, Surface Water Branch, USGS; "Preliminary Estimate of Radioactivity in Clinch River Bottom Sediment" by L. Hemphill, Radioactive Waste Disposal Section, ORNL; "Biogeochemistry of Strontium and Calcium in Tennessee-River-System Clams" by D. J. Nelson, Ecology Section, ORNL; and "Estimated Radiation Dose Received by Diptera with Life Stages in Bottom Sediments" by D. J. Nelson, Ecology Section, ORNL. These reports were supplemented by explanatory comments from the chairman and members of the committee, and informal discussion of plans for additional ecological studies in the Clinch River by S. I. Auerbach of the Ecology Section, ORNL.

---

*For names of agencies designated by initials, see page vii.

Status Report No. 1 was prepared and issued under the auspices of the Steering Committee. Individual members of the committee reviewed a preliminary draft of the report and submitted comments and suggestions for revision. At the meeting on May 4, 1961, the committee discussed the report and submitted further suggestions, after which it was completed and released. It was decided that status reports would be issued after each regular meeting of the Steering Committee in order that the information prepared for these meetings could be made available for distribution more promptly.

At the executive session on May 4, 1961, the Subcommittee on Water Sampling and Analysis, appointed earlier, was continued with the following membership: M. A. Churchill (TVA), chairman, J. S. Cragwall (USGS), A. G. Friend (USPHS), and S. L. Jones (TDPH). The functions of this subcommittee as previously assigned are to establish and maintain a system of water sampling and analysis, including the selection of water sampling locations; the determination of procedures for collection, preparation, and shipment of samples; arrangements for radiological determinations and stable chemical analyses; and coordination of assembly and presentation of the results. This system has been developed and put into effect. The establishment of a similar system for sampling and analysis of suspended river sediments was added to the subcommittee's functions. This subcommittee was requested to continue its consideration of the sampling and analysis requirements, review the results of the analytical programs as they become available, and study and modify the sampling and analytical systems.

A Subcommittee on Bottom Sediment Sampling and Analysis was appointed, consisting of P. H. Carrigan (USGS), chairman, T. Tamura (ORNL), James

Smallshaw (TVA), and a USPHS representative (not designated). The functions of this subcommittee, with respect to sampling and analysis of bottom sediments, are similar to the functions of the Subcommittee on Water Sampling and Analysis.

A Subcommittee on Aquatic Biology was appointed with the following members: S. I. Auerbach (ORNL), chairman, C. J. Chance (TVA), Donald B. Porcella (USPHS), and L. P. Wilkins (TGFC). This subcommittee was requested to study the fish sampling programs and other biological phases of the Clinch River Study, and to establish or recommend to the Steering Committee measures considered necessary for coordination of the biological investigations in connection with the Clinch River Study.

The Steering Committee reviewed and redefined its policy regarding the release for publication of analytical data and other information resulting from work on the Clinch River Study. It was agreed that all data supplied for and used in a status report on the study is free to be published elsewhere after the status report is issued. Until such information is published in a status report, it is considered preliminary and not for release, except with permission granted by a vote of members of the Steering Committee. Types of information that are usually published periodically, such as "base data" on stream flow and stable chemistry, are not covered by this policy unless they include radiochemical analyses or other information of such a nature that improper release might cause misunderstanding and adverse public reaction. With regard to oral presentations as in talks and lectures, it was agreed that prior approval must be obtained from the chairman of the Steering Committee.

From time to time the Steering Committee has reviewed the level of effort and the scope of studies included in the Clinch River program. For the fiscal year 1962 (July 1, 1961, to June 30, 1962) continued work on water sampling and analysis, bottom sediment sampling, stream gaging, and ecological studies at about the same levels as in fiscal year 1961 was approved.

WATER SAMPLING AND ANALYSIS

The primary purpose of the water sampling and analysis program is to determine what fractions of the total loads of selected radionuclides discharged to the Clinch River from White Oak Creek remain in the flowing waters of the Clinch and Tennessee Rivers at various locations downstream from Oak Ridge. A secondary purpose is to determine the mineral (stable chemical) quality of river waters at and downstream from Oak Ridge, with special attention to phosphates and nitrates.

Furthermore, water sampling and analysis is an essential part of more detailed studies of the Clinch River downstream from White Oak Creek. The primary purpose of these studies is research to determine more definitively the mechanisms of dispersion of radionuclides and other contaminants; the distribution and transfer of radionuclides among the different phases of the river system - water, suspended sediments, bottom sediments, and biota; the fate of the contaminants that are retained within these reaches of the Clinch River; and any discernible effects of biological exposures from the radioactivity in the river system.[1]

The general plan of the water sampling and analysis program involves compositing, into weekly samples for analysis, daily subsamples of water. The individual volumes of the subsamples composited are proportional to the volumes of daily stream flow passing particular sampling stations which comprise a basic network of selected sampling locations. By this procedure the weekly mean concentration of each radionuclide or stable-chemical

constituent is determined, and the total load of each nuclide or stable chemical passing a particular station may be computed. As outlined in the Appendix of Status Report No. 1, portions of the periodic water samples from the basic network of sampling stations are sent to the USPHS laboratory in Cincinnati, Ohio, for radiological determinations, and to the TDPH laboratory in Nashville for stable-chemical determinations.[1] Supplementary samples from stations on the Clinch River are obtained by the staff of the study for analysis at ORNL.

Sampling Stations

Basic Sampling Network

A basic network of sampling stations was worked out by the Subcommittee on Water Sampling and Analysis (See page 3.), and regular sampling at these stations was begun November 1, 1960. Considerations of costs and obligations to other programs forced the subcommittee to limit both the number of stations and the frequency of sampling to the very minimum. Six sampling stations were included in the minimum basic network as follow:

1. Clinch River at Oak Ridge Water Plant - Clinch River Mile (CRM) 41.5, presumably upstream from all radioactive wastes discharged from Oak Ridge.

2. White Oak Creek at White Oak Dam - the stream carrying most of the total load of water-borne radionuclides discharged at Oak Ridge.

3. Clinch River Above Centers Ferry* - CRM 5.5, presumably downstream from all radioactive wastes discharged at Oak Ridge.

---

*Prior to November 1, 1960, samples representing the lower portion of Clinch River were collected in the Kingston Steam Plant, equivalent to CRM 4.5, for analysis at ORNL.

4. Tennessee River at Loudon, Tennessee - Tennessee River Mile (TRM) 591.8, to determine whether a significant load of radionuclides is flowing down the Tennessee River from above the mouth of the Clinch River; that is, from a source or sources other than ORNL.

5. Tennessee River at Watts Bar Dam - TRM 529.9.

6. Tennessee River at Chickamauga Dam - TRM 471.0, approximately 5 miles upstream from Chattanooga, Tennessee.

Supplementary Sampling on the Clinch River

For more detailed or special analyses at ORNL, supplementary samples are taken at No. 1 and No. 3 above. Also, one additional sampling station has been established, namely:

7. Clinch River at Water Plant of the Oak Ridge Gaseous Diffusion Plant (ORGDP) - CRM 14.5, downstream from White Oak Creek but upstream from the mouth of Poplar Creek; also the first water-supply system using river water downstream from ORNL.

The maps in Fig. 1 and Fig. 2 indicate the portions of the Clinch and Tennessee Rivers represented by water sampling and the locations of the stations listed above.

Sampling Procedures at the Selected Sampling Stations

Clinch River at Oak Ridge Water Plant (Station 1)

Weekly composites of continuous nonproportional samples at the Oak Ridge water plant were obtained from June 7 through October 1960. Proportional sampling was started by the Radioactive Waste Disposal Section of ORNL at this station on November 1, 1960. A 2-gal grab subsample is

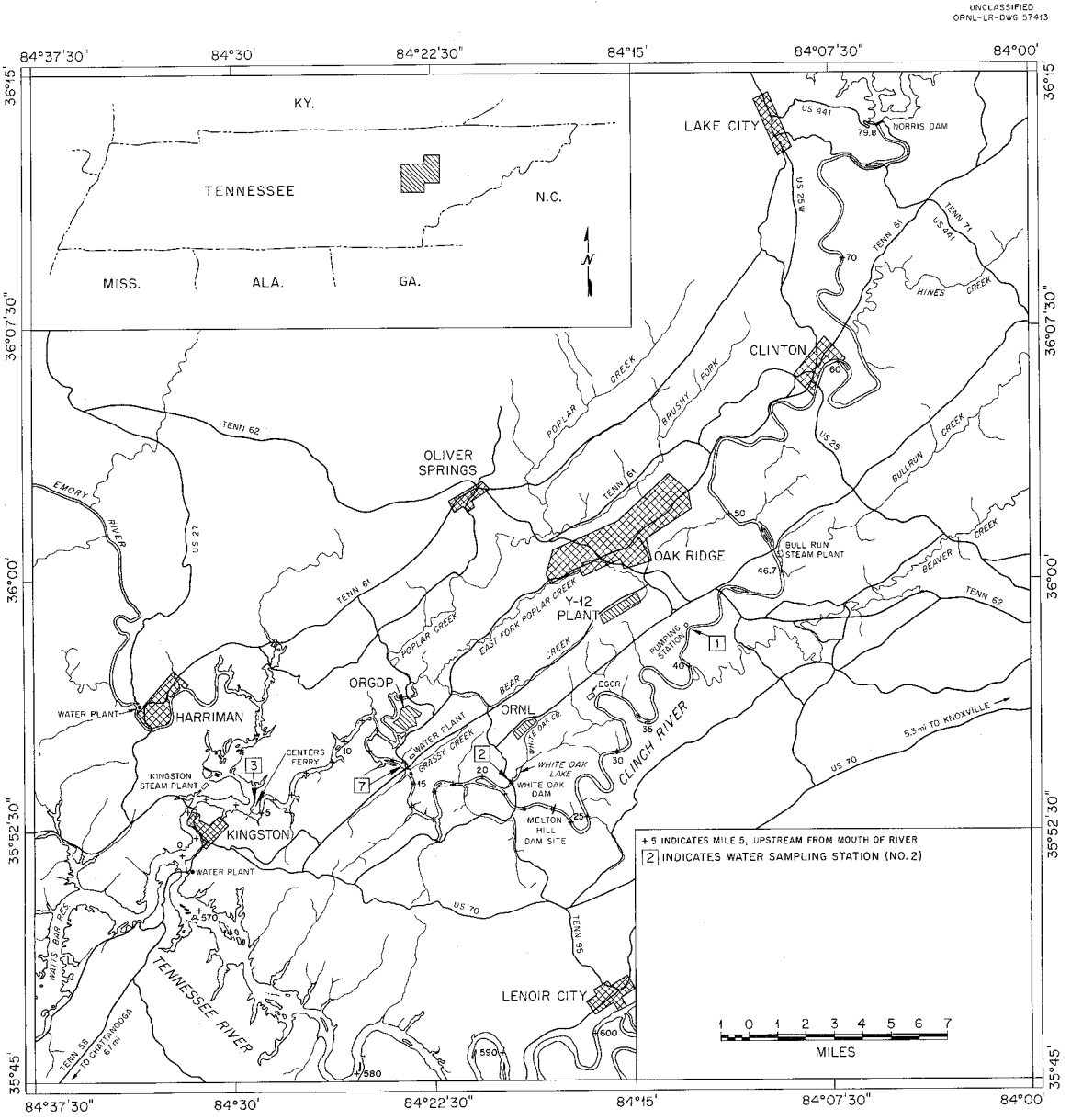

Fig. 1. Map — Lower Clinch River Basin.

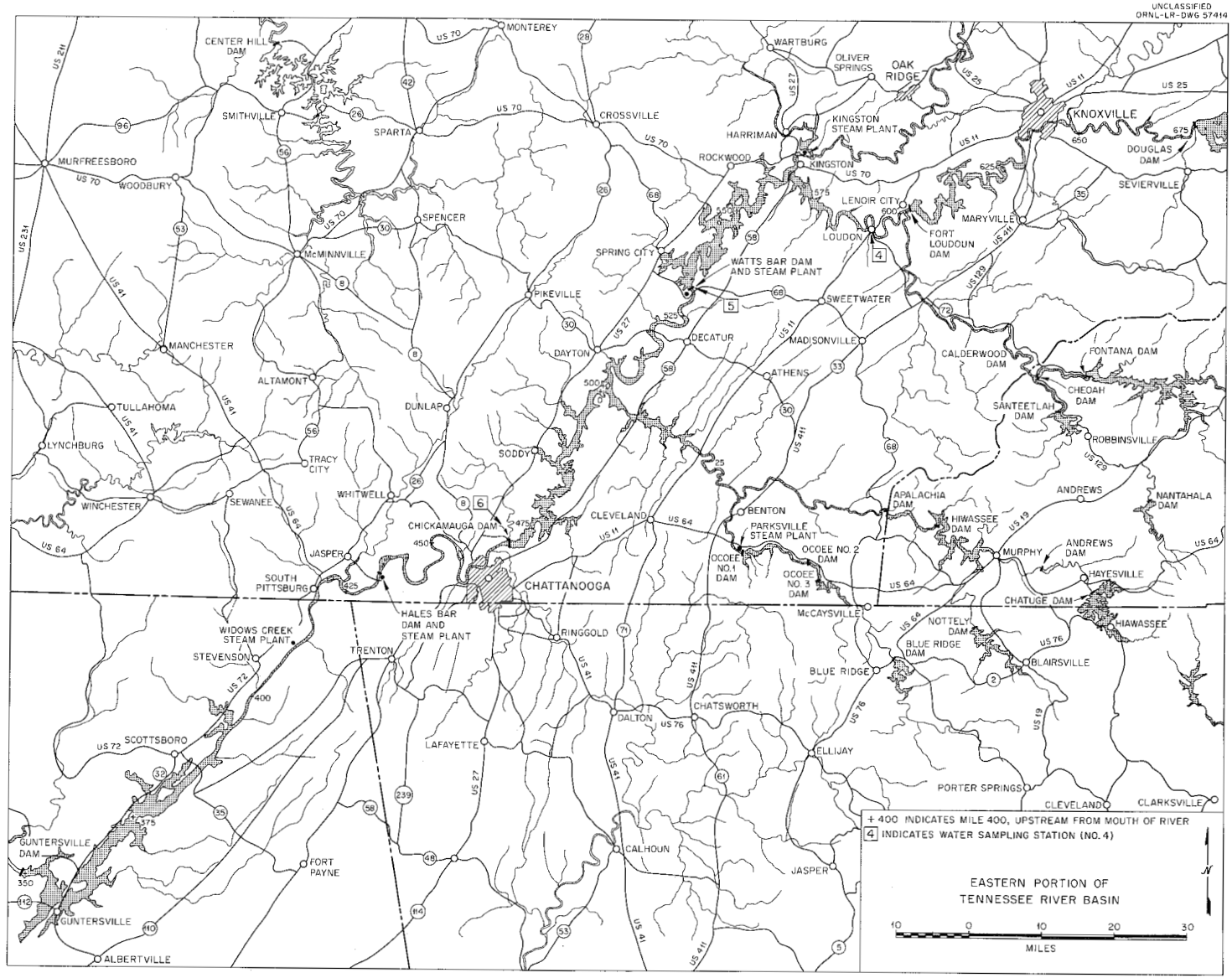

Fig. 2. Map — Eastern Portion of Tennessee River.

collected daily from the raw-water influent. The 2-gal bottle is filled automatically from the raw-water line in about 20 sec by means of sequence timer-actuated solenoid valves. The time of sampling (9 a.m. each day) was chosen on the basis of an estimate of the time at which stream flow at the Scarboro gage on Clinch River would be about equal to the mean daily discharge (See pages 82 and 87.). The duration of sampling (~ 20 sec) was set so that the maximum size of suspended particles withdrawn would be equal to the maximum size of particle that might be transported in the raw-water line, about 600 μ (microns).

In compositing at the end of the week, the daily subsamples are agitated to resuspend the sediment before the proper volume of each (proportional to the daily river flow at Scarboro gaging station) is poured into a 13-gal carboy. The composite is well mixed. A 5-gal sample from the carboy is sent to the U. S. Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, for radiological determinations. A 1-gal sample is sent to the laboratory of the Tennessee Department of Public Health in Nashville, Tennessee, for stable-chemical determinations. A 0.5- to 1.0-liter portion is withdrawn for supplementary stable-chemical analyses at ORNL.

White Oak Creek at White Oak Dam (Station 2)

The Applied Health Physics Section of ORNL had been collecting proportional samples of the flow of White Oak Creek at White Oak Dam for some time before the Subcommittee on Water Sampling and Analysis was organized. The continuous proportional sample is collected from the nappe of flow over the weir. Through cooperation of the Applied Health Physics Section,

a 1-liter proportional sample is obtained weekly and sent to the USPHS for radiological determinations. This 1-liter sample is made up of daily subsamples, the volume of each of which is proportional to the creek flow on the corresponding day.

No stable-chemical determinations are made on the water samples from White Oak Creek as yet. Plans are being put into effect for making these determinations at ORNL in the future.

Clinch River Above Centers Ferry (Station 3)

Sampling of the Clinch River, at CRM 5.5 (0.8 mile upstream from Centers Ferry), was started by the Radioactive Waste Disposal Section of ORNL on November 1, 1960. The sample is pumped through a pipe, the intake of which is located in the river 5 ft off the bottom and approximately 200 ft from the right bank, which is the point of maximum depth in this cross section. A 2-gal grab subsample is drawn each day. The size of the pump (35 gpm) and intake line (2-in. dia) were chosen to insure that a 1000-μ particle would be transported to the 0.5-in. discharge line and that the suction head would not exceed 25 ft. The actual sampling time to fill the 2-gal bottle is 23 sec. The subsample volumes are composited at the end of each week in proportion to the daily river discharge. Both a radiological and a stable-chemical sample are taken from the well-mixed weekly composite for analyses in Cincinnati and Nashville, respectively.

The staff of the study and the members of the subcommittee realize that improvements in the sampling technique at this station are needed (See pages 22 and 24.). Methods and equipment for obtaining samples that would be more nearly proportional to Clinch River flows are discussed on pages 14 and 15.

Tennessee River at Loudon (Station 4)

Through arrangements made by the Tennessee Department of Public Health, the Visking Company at Loudon, Tennessee, had been collecting fixed-volume daily grab samples from the Tennessee River, at the location of the water intake for the plant, for some time prior to the organization of the subcommittee. The daily samples are composited monthly for analysis in the Nashville laboratory of the Tennessee Department of Public Health.

Inasmuch as the radionuclide load in the Tennessee River at Loudon was thought to be very low, the subcommittee has been glad to accept a 5-gal portion of this nonproportional monthly composite for radiological determinations in Cincinnati and a 1-gal portion for stable-chemical determinations in Nashville.

Tennessee River at Watts Bar Dam (Station 5)

Beginning on November 20, 1960, daily grab subsamples have been collected from the tailrace by operating personnel at the dam and composited into weekly samples. The daily portions of the subsamples composited are proportional to the mean daily stream flow. At the end of each calendar week, the total composite is well-agitated to resuspend the sediment, and a 5-gal sample is withdrawn for radiological determinations by the USPHS in Cincinnati. A 1-gal sample is withdrawn for stable-chemical determinations in Nashville.

Tennessee River at Chickamauga Dam (Station 6)

Sampling at Chickamauga Dam also began on November 20, 1960. Sampling procedures are identical to those given above for Watts Bar Dam.

Clinch River at Water Plant of ORGDP (Station 7)

From the intake in Clinch River the raw water is pumped to a storage basin from which it flows to the water plant. Personnel of the water plant collect grab samples from the plant influent at 2-hr intervals, and a weekly composite of equal daily volumes is prepared. The radiological and stable-chemical analyses are done by personnel at ORNL.

Sampling procedures are to be changed so that the weekly composite samples will be more nearly representative of the river water passing this station. The sampling point is to be relocated at the pumping station ahead of the storage tank so as to obtain water directly from the river. The samples will be composited weekly of daily subsamples that are proportional to the daily volumes of river flow.

Possible Revision of Sampling Procedures at Clinch River Stations

Some question about the validity of procedures used in collecting and preparing the proportional weekly composite samples for the Clinch River stations has arisen. Once-daily "instantaneous" samples may not be adequate for preparation of "proportional-to-flow" composites.

A possible revision in collection would be to collect separate daily continuous samples. The daily samples would not be proportional to the flow, but they would be proportioned into a composite on the basis of mean daily discharge in the river observed at the Scarboro gage (CRM 39.0). A difficulty is that in order to collect a continuous daily sample, the sampling flow rate would be extremely low. With the low flow rate, based on experience at the Oak Ridge water plant, the valving would clog; and also the size of sediment transported into the sample would be considerably

reduced. Experimental studies of fluvial sediments indicate that considerable radioactivity is sorbed on sand-size particles. At the Oak Ridge water plant neglect of large particle sizes in the suspended sediment would not be significant, but at the other Clinch River stations such neglect probably would be significant.

An approximate method of continuous sampling would be to collect hourly samples "instantaneously." This system would guarantee collection of the larger-size particles of suspended sediment. The collection of several separate "instantaneous" samples each day for preparing proportioned daily samples is feasible. However, a collection of more than four samples per day does not appear to be practicable without especially designed automatic instrumentation.

Based upon a preliminary exploration by the staff of availability and conceptual designs of equipment systems, several possibilities of automatically collecting samples which would be more nearly proportional to the river flow were suggested to the Steering Committee. It was apparent that such sampling systems would be quite complex and rather costly. Four specific suggestions of alternative types of equipment for sampling systems with estimated equipment costs ranging from $1000 to more than $3500 per station were presented to the Subcommittee on Water Sampling and Analysis for its further consideration.

Analyses of Water Samples

Because of the sequence of steps in the development of the Clinch River Study and of the water sampling program, the analyses of water samples are divided into two time periods as follow:

(1) June 7 through October, 1960.-- This was an exploratory period of work to improve the basis for selection of sampling locations, develop and test sampling procedures, select and evaluate analytical techniques, and arrange for coordinated use of the analytical services provided by the USPHS, TDPH, and ORNL.

(2) November 1, 1960, to Present Time.-- An over-all water sampling system was established. This system includes: (a) a basic sampling network of six stations on the Clinch and Tennessee Rivers and (b) one supplementary sampling station on the Clinch River.

Prior to November 1, 1960, analyses of Clinch River water samples were done by ORNL personnel. Since that time radiological and stable-chemical analyses of samples from the six stations in the basic sampling network have been made, respectively, by personnel of the U. S. Public Health Service and of the Tennessee Department of Public Health; and ORNL personnel have made additional analyses of Clinch River samples to determine stable trace elements and to provide supplementary radiological and stable-chemical data on the Clinch River (See page 7.).

All available results from sampling after November 1, 1960, are summarized below. The results from samples collected during the summer of 1960 were of a preliminary nature and limited scope, but summaries of the useful analytical data are included.

Radiological Determinations

Basic Sampling Network

Nuclides of Importance.-- It was decided that the radionuclides of primary importance in the Clinch River Study, in the order named, are Sr^{90},

Cs^{137}, Co^{60}, and Ru^{106}. As compared with other materials released at the Laboratory, they are relatively high in abundance, of long radioactive half lives, and low in maximum permissible concentrations (MPC_w) for drinking water. Consequently, determinations are being made of concentrations and total loads of these radionuclides.

Sample Preparation.-- The 5-gal samples are evaporated to dryness, and the solids (including the silt) are transferred to 2-in. stainless steel planchettes for gamma determinations of Ru^{106}, Cs^{137}, and Co^{60}. Radiochemical methods are used for Sr^{89} and Sr^{90}.

Procedure.-- The data from the gamma analyzer for Ru^{106}, Cs^{137}, and Co^{60} are plotted on semilog paper. The pertinent peaks are each rounded off to approximate a normal distribution curve. A sloping line is drawn parallel to the background curve at the base of these peaks, and the net counts, found between this sloping line and the normal curve, are estimated.

From these net counts per minute, and after applying the necessary conversion factors, the concentration of each radionuclide in micromicrocuries per liter of water is computed.

About the time this summary was prepared, the U. S. Public Health Service at Cincinnati was having a program written for the solution of the gamma spectrum on an electronic computer. After the data reported herein are recomputed, more accurate results should be available. In the meantime, the following should be considered as good approximations.

Results.-- Radionuclide concentrations are reported here in tabular form. Concentrations of Ru^{106} and of Co^{60} at the several sampling stations are shown in Table 1 and Table 2, respectively.

Table 1. Concentrations of Ru^{106} in Water Samples
($\mu\mu c$/liter)

Date	Clinch River at Oak Ridge Water Plant	White Oak Creek at Dam	Clinch River above Centers Ferry	Tennessee River at Watts Bar Dam	Tennessee River at Chickamauga Dam
1960					
Nov. 1-12	*		150		
Nov. 13-19	--**	131,000	24		
Nov. 20-26	50	274,000	320	8	290
Nov. 27 - Dec. 3	--	197,000	625	73	35
Dec. 4-10	210	135,000	165	52	75
Dec. 11-17	25	186,000	570	79	140
Dec. 18-24	10	197,000	580	89	58
Dec. 25-31	200	209,000	800	98	48
1961					
Jan. 1-7	35	116,000	1500	53	--
Jan. 8-14	Tr***	125,000	130	90	74
Jan. 15-21	--	232,000	--	139	166
Jan. 22-28	--	144,000	315	100	130
Jan. 29 - Feb. 4			150	100	85
Feb. 5-11			--		80
Feb. 12-18				50	60

*A blank in this table indicates sample not available, or not analyzed.
**A dash indicates concentration too low for detection.
***Tr indicates a trace concentration but too low for measurement.

Note: For the Tennessee River at Loudon, only the December 1960 sample had been analyzed. The concentration of Ru^{106} was too low for detection.

Table 2. Concentrations of Co^{60} in Water Samples
($\mu\mu c$/liter)

Date	Clinch River at Oak Ridge Water Plant	White Oak Creek at Dam	Clinch River above Centers Ferry	Tennessee River at Watts Bar Dam	Tennessee River at Chickamauga Dam
1960					
Nov. 1-12	*		3		
Nov. 13-19	--**	7700	12		
Nov. 20-26	--	6200	7.5	--	--
Nov. 27 - Dec. 3	--	3900	15	--	--
Dec. 4-10	--	2500	4	--	--
Dec. 11-17	--	3900	10	--	--
Dec. 18-24	--	4800	19	--	--
Dec. 25-31	--	5200	20	--	--
1961					
Jan. 1-7	--	2500	33	--	--
Jan. 8-14	--	2500	5	--	--
Jan. 15-21	--	4100	--	--	--
Jan. 22-28	--	3300	6	--	--
Jan. 29 - Feb. 4			4	--	--
Feb. 5-11			--		--
Feb. 12-18				--	--

*A blank in this table indicates sample not available, or not analyzed.
**A dash indicates concentration too low for detection.

Note: For the Tennessee River at Loudon, only the December 1960 sample had been analyzed. The concentration of Co^{60} was too low for detection.

Cesium-137 was determined by counting the same samples as for Ru^{106} and Co^{60}, but in all samples concentrations were too low for detection, except (1) a trace was found in each of two samples from the Clinch River at the Oak Ridge water plant (November 27 to December 3, 1960, and January 15-21, 1961), and (2) the December sample at Loudon showed 10 micromicrocuries per liter.

For Sr^{90} and Sr^{89} only five samples were analyzed before this summary was prepared. The results are shown in Table 3.

Total Loads in Period of 11 Weeks.-- Data on concentrations of Ru^{106} and Co^{60} are shown in Tables 1 and 2, respectively. Weekly mean stream discharges at each sampling station were supplied by the U. S. Geological Survey and by TVA. By combining data on nuclide concentrations and stream discharges, it was possible to compute the load of nuclides passing each sampling station, on what can be considered a continuous basis. In this way the mean loads in curies per day were estimated and tabulated. Mass curves of these data were also prepared for information of the staff of the study.

In comparing the loads at successive downstream stations, it was recognized that the time required for the water to flow from one station to the next is far from constant. For very general guidance, however, the estimated flow time from Oak Ridge to Watts Bar Dam is normally in the range of 1 to 3 weeks, and from Watts Bar to Chickamauga Dam, about 1 week. It must also be recognized that the process of weekly compositing may result in some apparent inconsistencies from one station to another. For example, apparently higher concentrations may be found downstream than were observed upstream.

Table 3. Concentrations of Sr^{90} and Sr^{89} in Water Samples
($\mu\mu c$/liter)

Source	Date	Sr^{90}	Sr^{89}
White Oak Creek at Dam	Nov. 13-19, 1960	17,450 ± 450	422 ± 8.0
Clinch River above Centers Ferry	Nov. 13-19, 1960	21.6 ± 0.57	6.6 ± 1.8
Tennessee River at Watts Bar Dam	Dec. 25-31, 1960	16.4 ± 1.3	
Tennessee River at Watts Bar Dam	Jan. 1-7, 1961	1.98 ± 0.009	
Tennessee River at Chickamauga Dam	Nov. 20-26, 1960	2.7 ± 1.4	

Running totals, or mass curves, of the station loads should give a good measure of the proportion of the total load leaving White Oak Creek that arrives at each of the downstream stations. Time-of-flow must, of course, be taken into account. Such total-load data as are available for Ru^{106} and Co^{60} are shown in Table 4.

The total load of ruthenium discharged from White Oak Creek during the period, November 13, 1960, through January 28, 1961, was accounted for almost exactly at Centers Ferry, and apparently only about 10% of the load was lost down to Watts Bar Dam. At Chickamauga Dam the results indicate an increase of 24% over that found at Watts Bar, and about 10% over that discharged by White Oak Creek. In view of the many factors involved, it is surprising that such good agreement was found, station to station. These data lend support to earlier observations that most of the Ru^{106} is not retained in the bottom sediments in the river, but passes downstream in the water.*

The computed load of Co^{60} discharged from White Oak Creek showed an apparent 10% gain down to Centers Ferry. Cobalt-60 could not be detected at Watts Bar or Chickamauga.

Improved Sampling Technique Needed at Centers Ferry.-- It is probable that short-term variations in nuclide concentrations would be smoothed out during the time of flow from Oak Ridge to Watts Bar Dam, and to Chickamauga Dam. Consequently, daily grab samples, proportioned according to daily discharge in the weekly composites, should be satisfactory at Watts Bar and Chickamauga. Such may not be the case at Centers Ferry. Variations

---

*For concentrations of Ru^{106} in suspended sediments and in Clinch River silt, see Table 5 and Table 16, respectively.

Table 4. Total Loads of Ru^{106} and Co^{60} at Sampling Stations on Clinch and Tennessee Rivers

Stations	Period Included	Total Curies
	Ruthenium-106	
White Oak Dam	Nov. 13, 1960 - Jan. 28, 1961	381
Centers Ferry	Nov. 13, 1960 - Jan. 28, 1961	377
Watts Bar	Nov. 20, 1960 - Feb. 4, 1961	341
Chickamauga	Nov. 27, 1960 - Feb. 11, 1961	423
	Cobalt-60	
White Oak Dam	Nov. 13, 1960 - Jan. 28, 1961	8.7
Centers Ferry	Nov. 13, 1960 - Jan. 28, 1961	9.8

in rates of release of water throughout the day from Norris reservoir, coupled with variations in the rates of discharge of radionuclides from White Oak Creek, may produce variations with time in the concentrations of radionuclides in the Clinch River downstream. Although the peaks of concentration below White Oak Creek will be reduced farther downstream, they may persist to an undetermined extent at Centers Ferry. Consequently, a sampling technique is needed at Centers Ferry that will permit the automatic collection of a sample throughout the 24 hr of a day with the rate of collection being always proportional to the instantaneous rate of river discharge. Under the backwater and resulting low-velocity conditions existing at Centers Ferry, it is very difficult to even approximate the instantaneous rate of discharge in cubic feet per second at this location. Therefore, truly proportional sampling at this station has been impossible. The subcommittee and the study staff will give this problem further study.

The Steering Committee and study staff have recognized that when Melton Hill Dam begins operating, releases will be made primarily to carry peak power loads. This will normally result in relatively high rates of discharge for short periods of the day. Consequently, radioactive materials discharged continuously from White Oak Creek will collect in a relatively short reach of Clinch River when the dam is shut off, and then will be flushed downstream when the power units begin operating. Operation of this dam is expected to bring about variations in concentrations of radionuclides below White Oak Creek and to increase the difficulty of obtaining representative water samples at Centers Ferry.

Analyses of Clinch River Samples at ORNL

During the 5-month period, June to October 1960, sampling stations on Clinch River were located at the Oak Ridge water plant, the water plant at the Oak Ridge Gaseous Diffusion Plant (ORGDP), and the Kingston Steam Plant. Concentrations of radioactive and stable-chemical constituents were determined in these analyses for most of the weekly periods through October 1960.

In radiological determinations, filtered water and suspended sediment fractions for radiochemical analysis were prepared by passing 1 liter of the river-water sample through a membrane filter with 0.5-μ openings. The results from the weekly samples that were collected and analyzed from these three stations are summarized below.

From earlier analyses the radionuclides of importance, found to be present in the water samples collected at the water plant of ORGDP, were Co^{60}, Sr^{90}, Cs^{137}, and Ru^{106}. Activity levels of these radionuclides were determined by gamma spectrometry and radiochemical separations of both filtered water and filter residue.

The filtered water was evaporated at 102° C to dryness. The evaporating dish was policed with a dilute acid solution, and the sample was transferred to suitable containers for use in a deep-well scintillation detector. The filter residue was left on the membrane filter for determination of radioactivity in the suspended sediment.

In the analyses of ten weekly samples from the Oak Ridge water plant, only a possible trace of Ru^{106} and of radiostrontium was detected in one filtered water sample (week of July 11 to 17). No Cs^{137} or Co^{60} was found in any of the filtered water samples. In the suspended sediments of eleven

weekly samples from the Oak Ridge water plant, a trace of Ru^{106}, Cs^{137}, and Co^{60} was found for the week of July 25 to 31; and a trace of Ru^{106}, 21 μμc per g of Cs^{137}, and a trace of Co^{60} was found for the week of September 6 to 11. All other sediment samples from the Oak Ridge water plant during this period were reported as negative.

Reports on filtered water of eight weekly samples from the water plant of ORGDP indicated 500 μμc per liter of Ru^{106} and 9 μμc per liter of Sr^{89+90} for the week of July 11 to 17, and a trace of Ru^{106} for the week of August 8 to 14. There was no indication of Cs^{137} or Co^{60} in the filtered water samples from this station. Reports on filtered water of twelve weekly samples from Clinch River at the Kingston Steam Plant showed 500 μμc per liter of Ru^{106} and 9 μμc per liter of Sr^{89+90} for the week of July 11 to 17, a trace of Ru^{106} for the week of August 15 to 21, and a trace of Ru^{106} for the week of August 22 to 28. All other determinations were reported as negative.

The suspended sediments in weekly samples from the Clinch River at the water plant of ORGDP and at the Kingston Steam Plant during the period of July 11 to November 1 showed measurable or trace amounts of Ru^{106}, Cs^{137}, and Sr^{89+90} in a majority of the samples. These results are summarized in Table 5. In none of the samples from these two stations was Co^{60} detected in the suspended sediments.

Stable-Chemical Analyses

Basic Sampling Network

Stable-chemical analyses have been made in Nashville in the laboratory of the Tennessee Department of Public Health on all weekly composite

Table 5. Concentrations of Ru^{106}, Cs^{137}, and Sr^{89+90} in Suspended Sediment[a] ($\mu\mu c/g$)

Period	Clinch River at ORGDP			Clinch River at Kingston Steam Plant[b]		
	Ru^{106}	Cs^{137}	Sr^{89+90}	Ru^{106}	Cs^{137}	Sr^{89+90}
1960						
July 11 - 17	1960	954	*	3680	1190	
July 18 - 24	Tr**	904		Tr	464	
July 25 - 31	Tr	Tr		Tr	466	
Aug. 1 - 7	Tr	Tr		867	674	
Aug. 8 - 14	--***	--		859	409	
Aug. 15 - 21	--	--		1380	597	
Aug. 22 - 28	1420	773		488	521	
Aug. 29 - Sept. 4	Tr	312		577	635	
Sept. 5 - 11	805	313		370	555	
Sept. 12 - 18	Tr	320	54	Tr	Tr	40
Sept. 19 - 25	Tr	410	110	445	148	21
Sept. 26 - Oct. 2	Tr	Tr	165	Tr	385	15
Oct. 3 - 9	2630	344	41	Tr	415	31
Oct. 10 - 16	Tr	Tr	49	Tr	162	5
Oct. 17 - 23	No sample analyzed			Tr	218	130
Oct. 24 - 30	Tr	Tr	41	1420	407	Tr
Oct. 31 - Nov. 1	Tr	1280	18			

[a]Residue from raw water sample filtered through membrane with 0.5-μ openings.

[b]Station equivalent to CRM 4.5.

*A blank in this table indicates concentration not determined.
**Tr indicates a trace concentration but too low for measurement.
***A dash indicates concentration too low for detection.

Note: No Co^{60} was detected in any of the above samples.

samples collected from the two stations on the Clinch River, from Watts Bar and Chickamauga Dams, and on the monthly composite sample from the Tennessee River at Loudon. As stated previously, stable-chemical analyses have not been made on the samples from White Oak Creek.

Data from these analyses are given in Tables 6, 7, 8, 9, and 10. Inasmuch as both nitrates and phosphates are being released to the river system by ORNL, four forms of nitrogen were determined in the samples collected during November, December, and January. In view of the low concentrations of ammonia and nitrites found, determinations for only Kjeldahl nitrogen and nitrates have been continued after January. Phosphorus has been reported as phosphate. The analyses show no significant increases in the various forms of nitrogen, or in phosphates, between the upper and lower Clinch River stations.

Because the data are quite voluminous, and variations from week to week during the winter months are minor, the results of only one analysis per month, at each of the five river stations, are given in the tables.

The Subcommittee on Water Sampling and Analysis recommended that the need for weekly stable-chemical analyses be re-examined critically; less frequent sampling might satisfy the need.

Analyses of Clinch River Samples at ORNL

During the exploratory period (June to October 1960), mentioned earlier, weekly samples for stable-chemical analyses at ORNL were collected from the Oak Ridge water plant, the water plant of ORGDP, and the Kingston Steam Plant. Preliminary determinations were made on a number of these samples to indicate the expected range of concentrations of calcium, magnesium, sodium, potassium, and nitrates. The data obtained were intermittent

Table 6. Results of Stable-Chemical Analyses, Clinch River at Oak Ridge Water Plant - CRM 41.5
(Daily grab subsamples composited for periods indicated.)

	Date Collected				
	1960		1961		
	Nov. 11-13	Dec. 4-10	Jan. 1-7	Feb. 5-11	Mar. 5-11
Turbidity, ppm	3	6	61	30	52
Apparent Color, ppm	50	30	423	211	307
Centrifuged Color, ppm	12		110	25	66
pH	7.7	7.7	7.6	8.0	7.7
M.O. Alk. as $CaCO_3$, ppm	101	91	77	106	88
Phth. Alk. as $CaCO_3$, ppm	0	0	0	0	0
Acidity as $CaCO_3$, ppm			2	2	2
Hardness as $CaCO_3$, ppm	110	124	79	98	84
Calcium as $CaCO_3$, ppm	64	64	57	78	56
Magnesium as $CaCO_3$, ppm	46	60	22	20	28
Chlorides as Cl, ppm	5	6	5	3	4
Sulfates as SO_4, ppm	14	17	7	16	18
Nitrites as NO_2, ppm	0.0	0.0	0.0		
Nitrates as NO_3, ppm	0.5	0.7	0.7	0.9	0.4
Ammonia as NH_3, ppm	0.2	0.0	0.1		
Kjeldahl Nitrogen as N, ppm	0.3	0.3	0.9	1.3	0.7
Iron as Fe, ppm	0.2	0.1	0.6	1.7	7.0
Phosphates as PO_4, ppm	0.0	0.0	0.9	0.3	0.3
Potassium as K, ppm	1.3	1.7	3.1	2.3	3.6
Sodium as Na, ppm	3.0	3.9	2.6	5.6	2.2
Silica as SiO_2, ppm		3.9	6.9	4.3	6.2
Manganese as Mn, ppm	0.0	0.0	0.0	0.4	0.6
Fluorides as F, ppm	0.4	0.3	0.0	0.0	0.0
Specific Resistance (ohms at 20° C)		5000	6706	4242	4991
Suspended Solids, ppm	5	0	7	269	385
Total Solids, ppm	321	197	171	356	478
Dissolved Solids, ppm	316	197	164	87	93

Table 7. Results of Stable-Chemical Analyses, Clinch River Above Centers Ferry - CRM 5.5
(Daily grab subsamples composited for periods indicated.)

	Date Collected				
	1960		1961		
	Nov. 13-19	Dec. 4-10	Jan. 1-7	Feb. 5-11	Mar. 5-11
Turbidity, ppm	6	7	36	1	52
Apparent Color, ppm	54	49	273	3	223
Centrifuged Color, ppm	10	13	100	0	49
pH	8.0	7.5	7.8	8.0	7.7
M.O. Alk. as $CaCO_3$, ppm	109	71	73	106	88
Phth. Alk. as $CaCO_3$, ppm	0	0	0	0	0
Acidity as $CaCO_3$, ppm	0		2	2	2
Hardness as $CaCO_3$, ppm	117	136	73	93	80
Calcium as $CaCO_3$, ppm	69	99	51	51	53
Magnesium as $CaCO_3$, ppm	48	37	22	42	27
Chlorides as Cl, ppm	4	4	3	3	3
Sulfates as SO_4, ppm	15	14	14	13	18
Nitrites as NO_2, ppm	0.1	0.9	0.0		
Nitrates as NO_3, ppm	0.8	0.8	0.3	0.5	0.8
Ammonia as NH_3, ppm	0.2	0.0	0.1		
Kjeldahl Nitrogen as N, ppm	0.2	0.6	1.1	0.9	0.5
Iron as Fe, ppm	0.2	0.4	1.9	0.2	4.1
Phosphates as PO_4, ppm	0.0	0.0	0.6	0.1	0.2
Potassium as K, ppm	1.5	1.9	2.5	1.9	3.1
Sodium as Na, ppm	3.8	3.0	0.5	6.0	3.0
Silica as SiO , ppm		4.6	6.9	3.0	5.3
Manganese as Mn, ppm	0.0	0.0	0.0	0.0	0.5
Fluorides as F, ppm	0.2	0.3	0.0	0.0	0.0
Specific Resistance (ohms at 20° C)			6986	4499	5439
Suspended Solids, ppm	16	13	35	7	126
Total Solids, ppm	150	283	134	156	245
Dissolved Solids, ppm	134	270	99	149	119

Table 8. Results of Stable-Chemical Analyses, Tennessee River at Loudon - TRM 591.8
(Daily grab subsamples composited for periods indicated.)

	Date Collected			
	1960		1961	
	November	December	January	February
Turbidity, ppm	6	3	6	17
Apparent Color, ppm	54	45	64	108
Centrifuged Color, ppm	18	12	25	25
pH	8.1	8.2	7.6	8.1
M.O. Alk. as $CaCO_3$, ppm	65	47	58	52
Phth. Alk. as $CaCO_3$, ppm	0	0	0	0
Acidity as $CaCO_3$, ppm	0	0	2	0
Hardness as $CaCO_3$, ppm	83	71	69	62
Calcium as $CaCO_3$, ppm	64	50	58	47
Magnesium as $CaCO_3$, ppm	19	21	11	15
Chlorides as Cl, ppm	30	30	33	26
Sulfates as SO_4, ppm	13	19	14	12
Nitrites as NO_2, ppm				
Nitrates as NO_3, ppm	1.4	1.4	3.0	1.9
Ammonia as NH_3, ppm				
Kjeldahl Nitrogen as N, ppm				
Iron as Fe, ppm	0.4	0.3	0.8	0.7
Phosphates as PO_4, ppm	0.0	1.1	0.1	0.2
Potassium as K, ppm	0.8	0.9	0.5	1.6
Sodium as Na, ppm	15.8	14.3	8.8	12.0
Silica as SiO_2, ppm	6.9	5.8	7.6	8.1
Manganese as Mn, ppm	0.1	0.0	0.0	0.1
Fluorides as F, ppm	0.0	0.0	0.0	0.0
Specific Resistance (ohms at 20° C)	4567	5594	4796	4667
Suspended Solids, ppm	11	0	17	31
Total Solids, ppm	144	128	187	183
Dissolved Solids, ppm	133	128	170	152

Table 9. Results of Stable-Chemical Analyses, Tennessee River at Watts Bar Dam - TRM 529.9
(Daily grab subsamples composited for periods indicated.)

	Date Collected				
	1960		1961		
	Nov. 20-26	Dec. 4-10	Jan. 1-7	Feb. 5-11	Mar. 5-11
Turbidity, ppm	1	6	1	8	35
Apparent Color, ppm	40	49	32	32	223
Centrifuged Color, ppm	15	15	18	20	123
pH	7.7	7.7	8.3	7.6	7.6
M.O. Alk. as $CaCO_3$, ppm	75	59	57	62	56
Phth. Alk. as $CaCO_3$, ppm	0	0	4	0	0
Acidity as $CaCO_3$, ppm			0	2	2
Hardness as $CaCO_3$, ppm	89	97	64	69	55
Calcium as $CaCO_3$, ppm	53	53	44	49	37
Magnesium as $CaCO_3$, ppm	36	44	20	20	18
Chlorides as Cl, ppm	26	17	19	21	9
Sulfates as SO_4, ppm	15	19	12	15	12
Nitrites as NO_2, ppm	0.0	0.0	0.0	0.0	
Nitrates as NO_3, ppm	1.1	0.9	1.4	0.4	0.8
Ammonia as NH_3, ppm	0.1	0.0	0.0	0.0	
Kjeldahl Nitrogen as N, ppm	0.6	0.4	0.3	0.4	0.5
Iron as Fe, ppm	0.2	0.6	0.2	0.2	1.9
Phosphates as PO_4, ppm	0.0	0.0	0.2	0.1	0.3
Potassium as K, ppm	1.6	1.6	0.8	1.4	4.2
Sodium as Na, ppm	12.4	8.4	11.6	10.5	4.9
Silica as SiO_2, ppm		6.2	6.2	6.4	7.3
Manganese as Mn, ppm	0.0	0.1	0.0	0.0	0.0
Fluorides as F, ppm	0.0	0.0	0.1	0.0	0.0
Specific Resistance (ohms at 20° C)	3726	5000	5278	4738	5935
Suspended Solids, ppm	0	6	5	3	38
Total Solids, ppm	149	173	124	151	150
Dissolved Solids, ppm	149	167	119	148	112

Table 10. Results of Stable-Chemical Analyses, Tennessee River at Chickamauga Dam - TRM 471.0
(Daily grab subsamples composited for periods indicated.)

	Date Collected				
	1960		1961		
	Nov. 20-26	Dec. 4-10	Jan. 1-7	Feb. 5-11	Mar. 5-11
Turbidity, ppm	3	7	1	3	29
Apparent Color, ppm	56	44	35	25	206
Centrifuged Color, ppm	15	13	18	20	123
pH	8.0	7.6	8.3	7.7	7.6
M.O. Alk. as $CaCO_3$, ppm	63	46	53	56	48
Phth. Alk. as $CaCO_3$, ppm	0	0	2	0	0
Acidity as $CaCO_3$, ppm	0		0	2	2
Hardness as $CaCO_3$, ppm	81	81	60	64	49
Calcium as $CaCO_3$, ppm	53	57	41	46	31
Magnesium as $CaCO_3$, ppm	28	24	19	18	18
Chlorides as Cl, ppm	22	21	16	14	9
Sulfates as SO_4, ppm	17	18	13	15	11
Nitrites as NO_2, ppm	0.0	0.0	0.0	0.0	
Nitrates as NO_3, ppm	2.4	1.6	1.4	1.1	0.9
Ammonia as NH_3, ppm	0.1	0.0	0.0	0.0	
Kjeldahl Nitrogen as N, ppm	0.4	0.5	1.4	0.4	0.4
Iron as Fe, ppm	0.3	0.5	0.4	0.1	2.3
Phosphates as PO_4, ppm	0.0	0.0	0.2	0.1	0.0
Potassium as K, ppm	1.4	2.4	0.9	1.1	2.2
Sodium as Na, ppm	11.0	9.6	8.5	8.6	6.4
Silica as SiO_2, ppm		6.5	6.4	6.4	7.3
Manganese as Mn, ppm	0.0	0.1	0.0	0.0	0.0
Fluorides as F, ppm	0.0	0.0	0.1	0.0	0.0
Specific Resistance (ohms at 20° C)	3846	4750	5555	4994	7285
Suspended Solids, ppm	8	14	4	2	39
Total Solids, ppm	146	162	121	149	135
Dissolved Solids, ppm	138	148	117	147	96

and not very precise; and, since later results from the basic sampling network system were more accurate and extensive, the exploratory work on these five constituents will not be tabulated in this report. The determinations of suspended solids, total solids, and loss of solids on ignition provided good comparative data for the three sampling stations. These results are summarized in Table 11.

After November 1, 1960, stable-chemical analyses of Clinch River water samples were made to supplement the results from the basic sampling network (analyses in Nashville, Tables 6 and 7, above).

One of the factors which may influence the sorption of a radionuclide on sediments is the presence of the stable form of the element or the presence of other stable ions of the same group in the periodic table. The majority of constituents that were included in the supplementary determinations are those which may influence sediment sorption. Furthermore, water released to the river contains stable chemical, as well as radioactive chemical, wastes. Determinations of the concentrations of such stable constituents were included in the analyses at ORNL.

Weekly composite samples representing a 3-week period, March 19 to April 8, 1961, were collected at the Oak Ridge water plant and at the station above Centers Ferry, CRM 5.5. The average concentration of stable strontium in the three samples at the Oak Ridge water plant was 0.07 ppm; and at the station above Centers Ferry 0.06 ppm. In all of the samples at both stations during this period, the concentrations of stable cesium, cobalt, and ruthenium were below the limits of detection; that is, less than 0.01 ppm for cesium, 0.02 ppm for cobalt, and 0.1 ppm for ruthenium.

Table 11. Suspended Solids, Total Solids, and Loss on Ignition in Clinch River Samples from Three Stations, June 7 to November 20, 1960 (ppm)

Period		Oak Ridge Water Plant, CRM 41.5			Water Plant at ORGDP, CRM 14.5			Kingston Steam Plant Equivalent to CRM 4.5[a]		
			Total Solids			Total Solids			Total Solids	
From 1960	To 1960	Suspended Solids	Dried 102° C	Loss on Ignition 500° C	Suspended Solids	Dried 102° C	Loss on Ignition 500° C	Suspended Solids	Dried 102° C	Loss on Ignition 500° C
June 7	June 12	4	133	21				4.3		
13	19	7	131	22				9.4	133	21
20	26	16	147	5.6				17	132	0.4
27	July 4	33	164		25	150	2.4	40	157	40
July 5	10				4	134	0.5	25	139	13
11	17	260	358	13	48	183	52	42	197	37
18	24				25	136	24	24	160	37
25	31	41	326	36	36.2	136	19	15	180	
Aug. 1	Aug. 7	69	131		7.0	122		12	135	
8	14	390	506	30	46.6	159	15	28	150	
15	21	7.2	138	28	5.2	135		19	142	
22	28	20	151	6.0	17.6	153	2.6	17	157	
29	Sept. 4				14.6	144		20	147	
Sept. 5	11	324	415	5.3	25.4	156		18	152	
12	18	49	185		24.9	132	10	23	131	
19	25	49	188		66.3	188	27	38	109	
26	Oct. 2	8.6	143		13.1	144		15	124	
Oct. 3	9	30	165		16.5	149		22	120	
10	16	100	233		13.9	152		49	74	
17	23	43	226					10	116	
24	30				8.2	149				
24	Nov. 1							11	95	
30	1				6.2	162				
Nov. 2	7				12.0	127				
8	13				7.4	146	41			
14	20				7.4	181	52			

[a]Sample collected in steam plant; station discontinued November 1, 1960.

Comprehensive stable-chemical analyses were made of nineteen weekly composite samples from the water plant of ORGDP, CRM 14.5, collected during the period, November 28, 1960, to April 9, 1961. The results for the period, November 28, 1960, to February 5, 1961, are shown in Table 12. Samples collected during the period, February 6 to April 9, 1961, were analyzed for the same constituents and also for eighteen additional elements and for ammonia. These results are shown in Table 13.

The results in Tables 12 and 13 agree reasonably well with the determinations at Centers Ferry (Table 7). The comprehensive stable-chemical data in Table 13 show that the principal constituents were sodium, potassium, calcium, magnesium, chlorides, nitrates, sulphates, phosphates, and bicarbonates. The pH ranged from 6.9 to 7.9. The additional elements determined include the stable forms of radionuclides; for example, rubidium, cesium, strontium, barium, titanium, zirconium, cobalt, nickel, fluorine, bromine, iodine, and ruthenium. Low concentrations, less than one part per million, of several ions were found, and trace amounts of certain elements examined for could not be detected. It is of interest that trace amounts of stable strontium were found at all water-sampling stations on the Clinch River.

Table 12. Results of Stable-Chemical Analyses, Clinch River at Water Plant of ORGDP, CRM 14.5
November 28, 1960, to February 5, 1961

Sample No.	Period From	Period To	Ca ppm	Mg ppm	Na ppm	K ppm	Cl ppm	NO_3 ppm	SO_4 ppm	PO_4 ppm	HCO_3 ppm	pH	Conductivity μmhos/cm (25°C)	Suspended Solids ppm	Total Solids 100°C ppm	Total Solids Loss on Ignition 500°C ppm
	1960															
23	Nov. 28	Dec. 4	25	8	3.2	1.3	2	1.3	15	<1	95	–	–	13.4	231	95
24	Dec. 5	11	23.9	5.0	3.12	1.62	2.3	3.85	16.6	0.75	110	7.0	226	10.7	170	26
25	12	18	26.0	<2.0	3.04	1.45	2.3	1.73	20.0	0.25	100	7.6	225	11.5	148	17
26	19	26	26.0	<2.0	2.9	1.4	2.3	1.7	0.8	0.05	98	7.3	224	6.1	134	16
27	27	Jan. 2	22	7.0	4.7	1.8	1.7	–	1.4	0.2	90	7.7	206	39.2	148	16
	1961															
28	Jan. 3	Jan. 8	22	5.6	1.8	2.3	1.9	3.9	27	0.6	87	7.6	232	46.5	167	16
29	9	15	25	9.8	2.95	1.40	4.51	1.9	8.99	0.12	103	7.5	220	7.78	141	21
30	16	22	25.7	8.4	3.0	1.4	1.2	1.7	14	<0.25	107	7.8	282	9.45	138	29
31	23	29	23.0	8.5	3.0	1.4	1.6	2.4	17	<0.5	105	–	222	3.48	142	25
32	30	Feb. 5	48.0	8.5	3.1	1.5	1.2	2.2	2.0	<0.003	110	7.9	225	0.75	139	28

Table 13. Results of Stable-Chemical Analyses, Clinch River at Water Plant of ORGDP, CRM 14.5

February 6 to April 9, 1961

Sample No.	Period From 1961	Period To 1961	Na ppm	K ppm	Cu ppm	Rb ppm	Cs ppm	NH_4 ppm	Ca ppm	Mg ppm	Zn ppm	Sr ppm	Ba ppm	Al ppm	Fe ppm	Mn ppm	Si ppm	Ti ppm	Zr ppm	Co ppm	Ni ppm	F ppm	Cl ppm	Br ppm	I ppm	Ru ppm	NO_3 ppm	SO_4 ppm	PO_4 ppm	HCO_3 ppm	pH	Specific Conductivity μmhos/cm (25°C)	Suspended Solids ppm	Total Solids 100°C ppm	Total Solids Loss on Ignition 500°C ppm
33	Feb. 6	Feb. 12	2.8	1.4			<.01		22	6.8		.06	<.3		.37	<.01			.03	<.02			1.5			<.1	1.6	13	.15	130	7.5	230	25.2	153	24
34	13	19	2.6	1.2		<.005	<.01	<.6	22	6.5	.11	.06		.09				.02		<.02	<.01		1.8			<.1	1.9	12	.21	134	7.3	222	27.1	157	
35	20	26	2.2	1.8	<.01		<.01		17	4.5		.04					1.8			<.02		.26	1.4	<1	<2	<.1	1.8	12	.23	98	7.5	204	79.9	204	54
36	27	Mar. 5	2.4	1.3			<.01		21	7.7	.13	.06	<.1	.34	.13	<.01		.03		<.02			1.9			<.1	2.0	11.8	.21	117	7.4	210	43.8	197	14
37	Mar. 6	12	2.0	1.4		<.005	<.01	<.4	18	6.7	.11	.06		.30				.02		<.02	<.01		1.5			<.10	2.4	10.0	.10	110	6.5	208	104	214	12
38	13	19	2.4	1.3			<.01		20	7.3		.07	<.3		.02	<.01			.05	<.01			1.5			<.1	2.3	8.6	.17	118	7.6	210	30.6	160	19
39	20	26	2.2	1.2	.10		<.01		20	8.2		.06					1.8			<.02		.22	1.5	<1	<2	<.1	2.6	10.9	.11	121	7.7	217	17.4	150	12
40	27	Apr. 2	2.6	1.1		<.005	<.01	<.2	19	8.5	.32	.06		.25				.03		<.02	<.01		1.4			<.1	1.8	13.1	.22	121	7.6	225	23.1		
41	Apr. 3	9	2.2	1.3			<.01		18	7.0		.06	<.3		.01	<.01		.08		<.02			1.4			<.1	1.1	14	.27	120	6.9		39.1		

SEDIMENT SAMPLING AND ANALYSIS

As shown in the Appendix of Status Report No. 1[1], determinations of radioactivity in the river-bottom sediments are made at ORNL. In these determinations three general methods are used by two sections of the ORNL Health Physics Division. The Applied Health Physics Section conducts an annual survey of the Clinch and Tennessee Rivers in which the gamma radiation of the sediments are measured directly *in situ* at selected river cross sections by means of the "flounder" bottom-scanning instrument; and sediment samples for laboratory analysis are obtained at the same cross sections with an Eckman dredge.[2] To define more exactly the vertical, as well as the horizontal distribution of radionuclides in the Clinch River sediments, the Radioactive Waste Disposal Section has collected numerous core samples of bottom sediments and has analyzed these cores in the laboratory.

Applied Health Physics Annual River Survey

The Applied Health Physics Section conducted the annual river survey in the summer of 1960, using the procedures and techniques described in the report on earlier surveys.[2] To assist the Clinch River Study program, seven additional cross sections were run in the Clinch and Emory Rivers. These additional cross sections were at points between the locations of the cross sections regularly used in the annual river survey. Gamma measurements on the bottom sediment were made, and sediment samples

were collected at these cross sections in the same manner as in the annual survey. The data collected were given to the staff of the Clinch River Study to be integrated into that study. The sediment samples have not been analyzed but are being held pending a decision regarding their analysis and disposition.

The gamma monitoring data for 1960 have been summarized and plotted in a manner similar to that reported in ORNL-2847, as shown in Figs. 3, 4, and 5. The gamma count rates in the Clinch River are essentially the same as in 1959 with the point of maximum count shifting downstream from CRM 16.3 in 1959 to CRM 11.0 in 1960. The point of maximum count had shifted upstream in 1959 from that of previous years when the maximum had been near CRM 8.0. The 1960 gamma count rate in the Tennessee River silt showed an increase in all reservoirs except Hales Bar. This reservoir is short and narrow and almost always has considerable current, thus making it more susceptible to scouring than the other reservoirs. The contaminated silt in the Tennessee River system seems to be working its way downstream from one reservoir to the next with time. This effect can best be evaluated by again extending the survey to the mouth of the Tennessee River which has not been done since 1952.

The silt samples collected during the 1960 survey are in the process of analysis and will be reported later. A graph of the major radionuclides found in the Clinch and Tennessee River silts from 1954 through 1959 is shown in Fig. 6. The 1959 data have not been reported previously. The graph presents a comparison of the curies of each major radionuclide discharged to the Clinch River with the average microcuries per gram of radionuclide detected in the Clinch and Tennessee River silt.

UNCLASSIFIED
ORNL-LR-DWG. 52795R

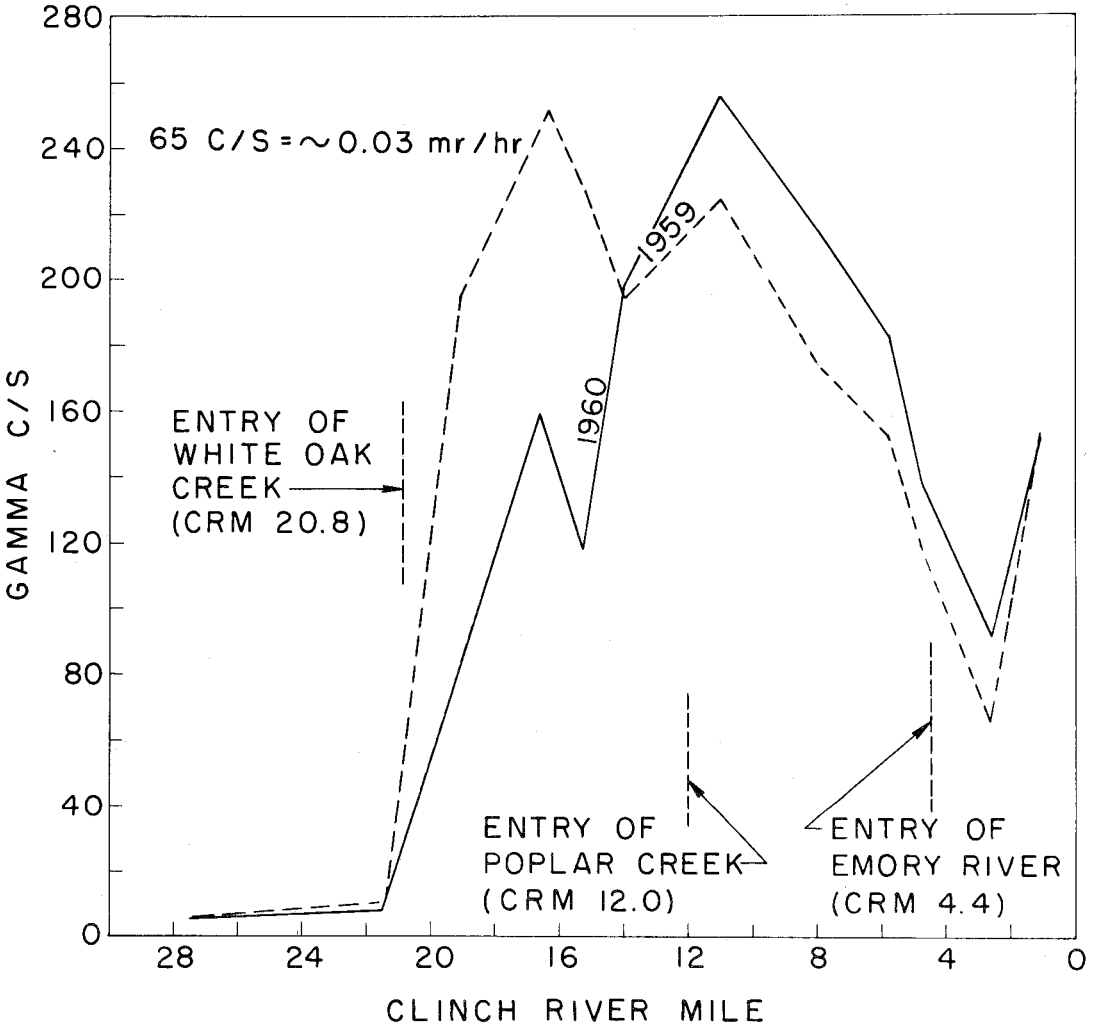

Fig. 3. Gamma Count at Surface of Clinch River Silt.

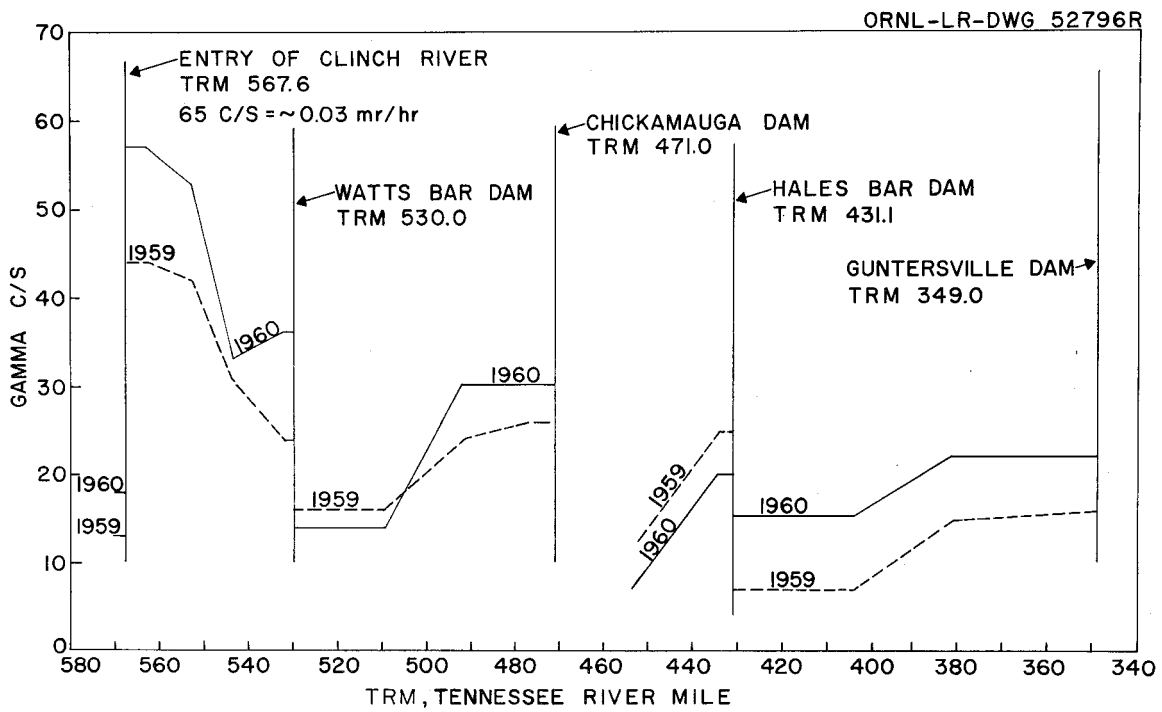

Fig. 4. Gamma Count at Surface of Tennessee River Silt.

UNCLASSIFIED
ORNL-LR-DWG. 52794R

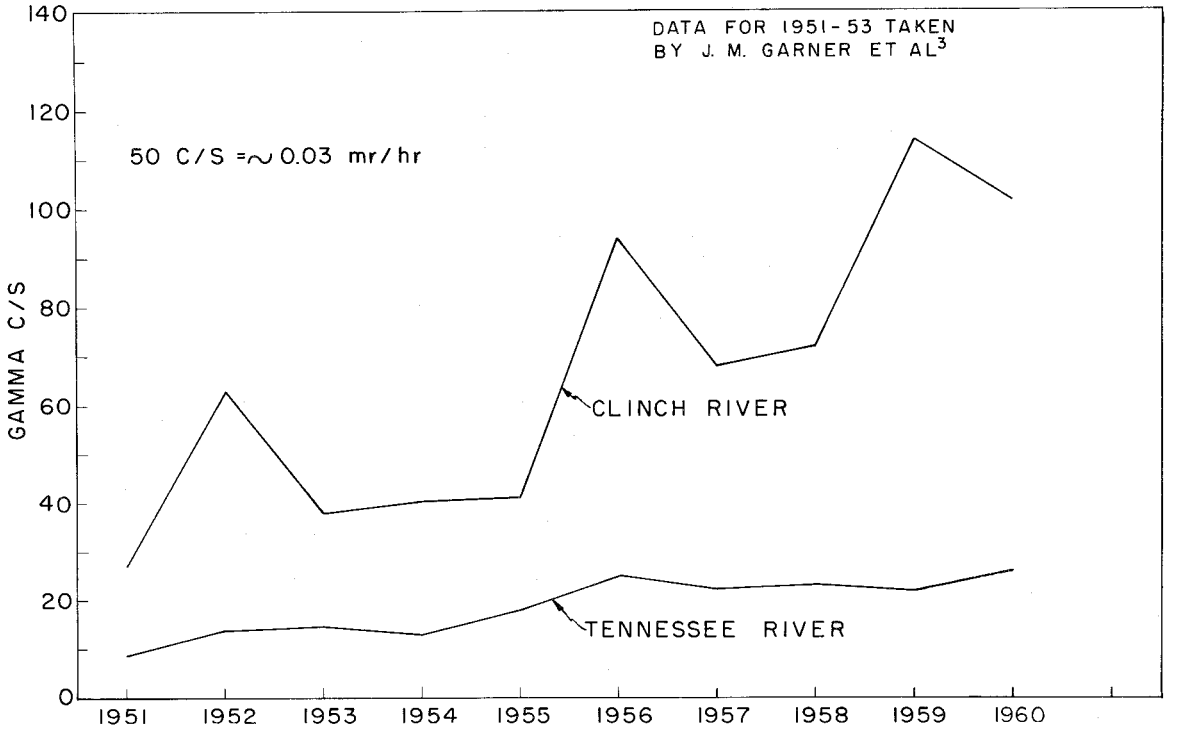

Fig. 5. Average Gamma Count at Surface of Silt in Clinch and Tennessee Rivers, 1951-60.

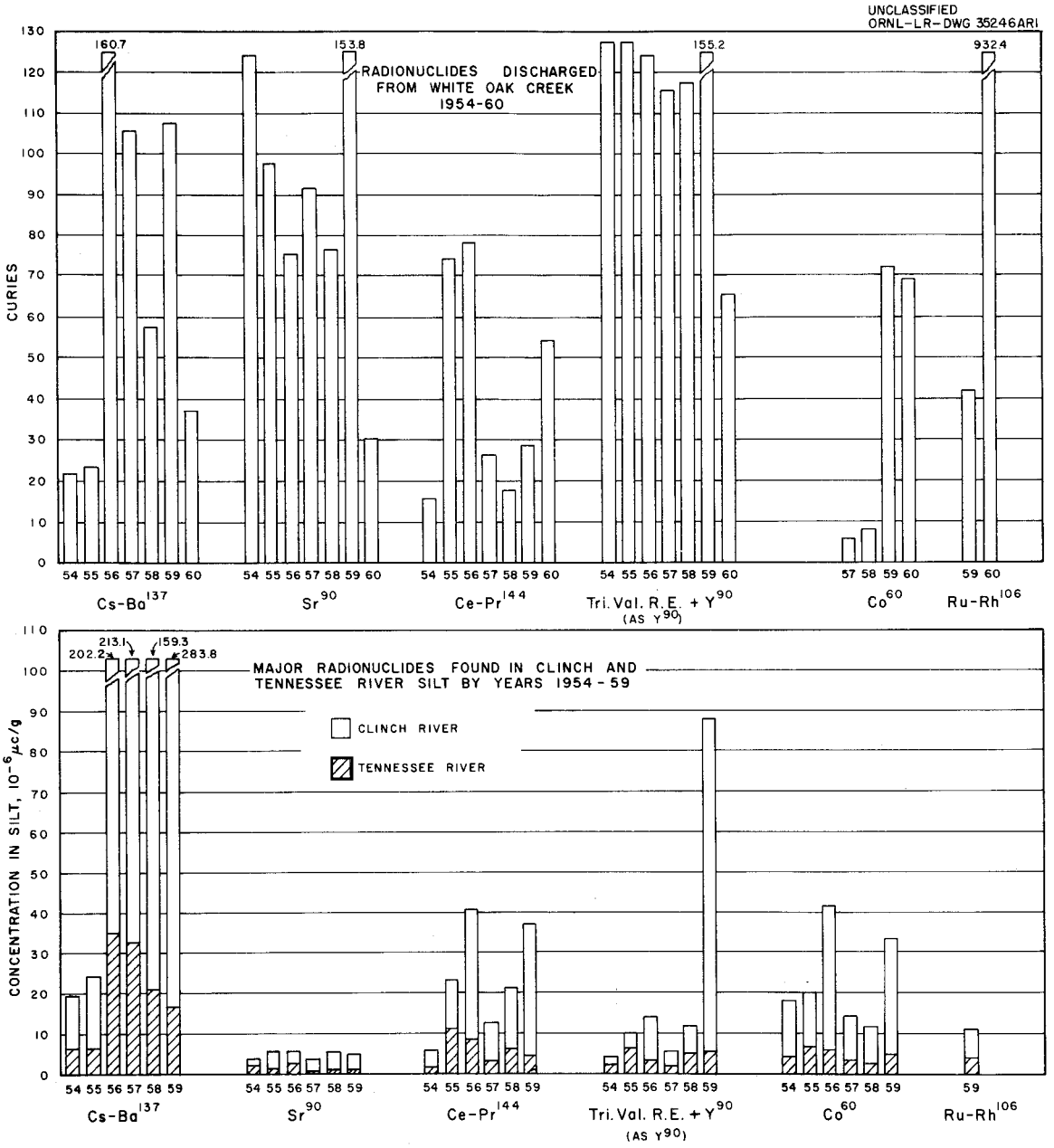

Fig. 6. Major Radionuclides Discharged and Concentrations Found in Clinch and Tennessee River Silt.

Distribution of Radioactivity in the Upper Horizon of Clinch River Bottom Sediment

A basic aim of the Clinch River Study is to determine the fate of radioactive materials released to the river channel. Results of annual bottom-sediment surveys by the Health Physics Division, conducted since 1951,[1,2,3] indicate that a portion of the radioactivity released by ORNL is deposited in the river bed.

During the summer of 1960, a special field-sampling survey of the Clinch River bottom sediments was conducted along with the Applied Health Physics survey (See pages 39-40.). In general, the two survey groups sampled at the same cross sections; however, additional intermediate sections were included for sample collection by the Radioactive Waste Disposal Section. The additional cross sections were included in order to provide better definition of the longitudinal distribution of radioactivity in the river; also, core samples, rather than Eckman dredge samples, of the sediment were obtained in order to define the distribution of radioactivity in the cross sections.

Methods

Core samples were collected at approximately eight to ten equal intervals (subsections) within each cross section. Core collection consisted of plunging a 3/4-in. ID x 14-in.-long plastic tube, contained in a weighted stainless steel tube, into the sediment. After withdrawal, the sediment sample was immediately sealed in the plastic tube with rubber stoppers. At the time of sampling, the depth of water and the widths of sampling intervals and of the cross section were measured.

The samples were prepared for radiochemical analyses according to the following procedure:

Each core was (1) frozen in its plastic tube, (2) extruded from the tube, (3) sliced into 1-in.-long x 3/4-in.-dia cylindrical segments on a cutting block, and (4) weighed.

Cores were cut into segments for use in studies of distribution of activity in the cross section. No economical method of examining variations of radioactivity in an uncut length of core was available. The choice of 1-in. segment lengths was arbitrary. Greater refinement of distribution studies by cutting cores into shorter segments could be attained if warranted.

The gross gamma activity of each 1-in. sample was measured with a gamma scintillation detector and scaler. Each sample and control (background sample) was counted for a 10-min interval in order to provide reasonably good counting statistics.

A preliminary examination of the gross gamma results indicated that many of the 1-in. segments were too low in activity for individual radiochemical or gamma spectrometric analysis. Because of these low activities and the expense of analyzing the 870 1-in. segments, all of the segments from each cross section were mixed to form a homogeneous composite sample. The composited samples were dried at 100° C, sealed in 3-in.-dia x 1.5-in.-high plastic containers, and counted in a 256-channel gamma spectrometer. Strontium-90 activity of each composite sample was determined by radiochemical separation and beta counting.

The specific gravity of solids in selected composites was determined.

Gross gamma measurements of the 1-in. core samples showed no uniform continuous vertical distribution pattern. In general, there was a decrease

in activity with depth; however, the rate of decrease was too irregular to define the lower limit of activity in the sediment. This latter finding was surprising, because an exploratory test at CRM 4.7, upon which selection of the sampler was based, indicated that the depth of the radioactive zone was of the order of 7 in.

From measurements of length of core, subsection widths, and weight of core segments, the area of silt and average mass specific weight of sample were computed for each cross section (See sample calculation, page 48.). Results of the computations are listed in Table 14.

As shown in Table 14, the silt area increases rapidly downstream between CRM 16.9 and CRM 16.0. Upstream from CRM 16.0 bottom sediments that were fine enough to enter the sampling tube did not extend the full width of the channel. These fine sediment deposits, located near the channel banks, are shallow compared to those downstream from CRM 16.9. Downstream from CRM 16.9 the fine deposits, which are relatively thick, were observed to extend from bank to bank.

A part of the variations in mass specific weight, which may be noted in Table 14, are probably due to compaction of some samples. Tests after collection of samples indicated the likelihood of compaction, even of plugging the tube. Using an average specific gravity of 2.6 for the study reach, and assuming fully-saturated samples, computations on individual cores would indicate about a fourfold variation in mass specific weight of solids (ratio of weight of solids in sample to volume of sample).

The relative gross gamma activity of each core was calculated on a gram basis by correcting for background activity and wet weight of sample.

Sample Calculation of Sediment Area and Gross Gamma Activity in Cross Section at CRM 11.0

Distance from Initial Point (ft)	Width (ft)	Depth (ft)	Mean Core Depth (ft)	Sediment Area (ft^2)	Gross Gamma Count per Total Core Depth (counts min^{-1} ft^{-1})	Mean Gross Gamma Count (counts min^{-1} ft^{-1})	Total Gamma Count (counts/min)
					$\times 10^3$	$\times 10^3$	$\times 10^6$
0 LB*	0	0	0	0	0	0	0
50	50	0.750	0.375	18.8	87.4	43.7	2.18
150	100	0.417	0.583	58.3	73.4	80.4	8.04
250	100	0.667	0.542	54.2	153	113	11.30
350	100	0.917	0.792	79.2	135	144	14.39
450	100	0.667	0.792	79.2	160	148	14.77
550	100	0.667	0.667	66.7	145	153	15.26
630 RB	80	0	0.333	26.7	0	72.5	5.80
				383.1			71.74

*LB, left bank; RB, right bank of river facing downstream.

Specific Activities:

Area:

$$K_A = \frac{71.7 \times 10^6 \text{ counts/min}}{383 \text{ ft}^2} = 187 \times 10^3 \frac{\text{counts/min}}{\text{ft}^2}$$

Gravimetric:

$$K_g = \frac{71.7 \times 10^6 \text{ counts/min}}{4.7 \times 10^5 \text{ g}} = 152 \text{ counts min}^{-1} \text{ g}^{-1} .$$

Equation:

$$K_A = \int C \left(\frac{\text{counts/min}}{\text{ft}^2}\right) dA \ (\text{ft}^2) \approx \Sigma \ C \left(\frac{\text{counts/min}}{\text{ft}^2}\right) \Delta \ W \ (\text{ft}) \ \Sigma \ y \ (\text{ft})$$

$$= \Sigma \left[C \ \Delta \ y \left(\frac{\text{counts/min}}{\text{ft}}\right)\right] \Delta \ W \ (\text{ft}), \ \Delta \ y = \text{constant.}$$

Table 14. Clinch River Cross Sections and Mass Specific Weight of Sediment

Location (CRM)	Width[a] (ft)	Cross Sectional Silt Area Sampled (ft^2)	Cross Sectional Water Area[b] (ft^2)	Mass Specific Weight of Sample[c] (g/cm^3)
4.7	650	325	16,350	1.4339
5.8	670	375	13,525	1.3210
6.9	800	473	15,025	1.4813
8.0	705	419	14,225	1.3596
9.0	525	318	14,975	1.3139
10.0	1050	581	13,650	1.4450
11.0	630	383	10,795	1.1731
12.0	480	238	11,655	1.3079
13.0	430	267	8,644	1.2430
14.0	500	192	8,725	1.2913
14.6	455	114	7,275	1.3448
15.3	420	113	7,797	1.3650
16.0	660	307	8,310	1.5161
16.9	350	43.8	6,115	1.2210
18.1	365	73.3	6,090	1.4887
19.5	350	50.0	5,730	1.2361
20.8	400	49.6	4,773	1.4024
21.6	370	113	3,630	1.3833
22.5	400	--	4,490	1.1660

[a]Measured at surface of water.

[b]Calculated from field measurements collected during core sampling.

[c]Wet weight sample.

The relative gross gamma activity per section was calculated by substituting the corrected counting data in a point-by-point integration calculation of area and mass. An explanation of the calculation, including units, approximations, and procedure is shown in the sample calculation. The tabulated results of the gross gamma analyses are shown in Table 15, along with the results of the 1960 Applied Health Physics "flounder" instrument survey.

A qualitative comparison of the "flounder" and core gross gamma data is shown in Fig. 7. Both sets of data were plotted with reference to the maximum "flounder" readings which were at CRM 11.0. This point was a low-order maximum in the core-analysis data, exceeded by CRM 20.8 and CRM 14.0. The shapes of the two curves are similar. Discrepancies between the two sets of data are most pronounced in areas where sampling sections for the two surveys do not coincide. There is also some disagreement at coincident sampling sections, probably arising from the difference in measurement techniques. The "flounder," constructed with twelve GM tubes, detects gamma radiation at the surface of the sediment. The "flounder" count recorded for each section is the average of observed counts obtained at 50-ft intervals. In contrast, the core data are essentially a number of measurements of weighted gamma point sources averaged over the whole cross section.

Gamma spectrometric analysis showed that Cs^{137}, Ru^{106}, and Co^{60} were present in all composited samples. Spectrometric data were compared with standard soil samples containing known amounts of these radionuclides to determine absolute activities of each sample. Analyses for Sr^{90} and the total rare earths by radiochemical separations have shown these radionuclides

Table 15. Distribution of Gross Gamma Activity in Clinch River Bottom Sediment from Mile 21.6 to Mile 4.7

Cross Section Location (CRM)	1960 Applied Health Physics "Flounder" Data (counts/min)	1960 Clinch River Study Core Analysis Data (activity, counts min^{-1} g^{-1})
2.1	9,120	
2.6	5,460	
4.7	8,280	66.1
5.8	10,860	89.2
6.9		102
8.0	12,780	92.5
9.0		78.0
10.0		59.7
11.0	15,180	152
12.0		106
13.0		127
14.0	11,800	173
14.6		51.3
15.2	7,080	
15.3		66.9
16.0		20.9
16.3	9,540	
16.9		111
18.1		27.9
19.1	4,860	
19.5		32.0
20.8		858
21.5	360	
21.6		66.3
27.5	240	

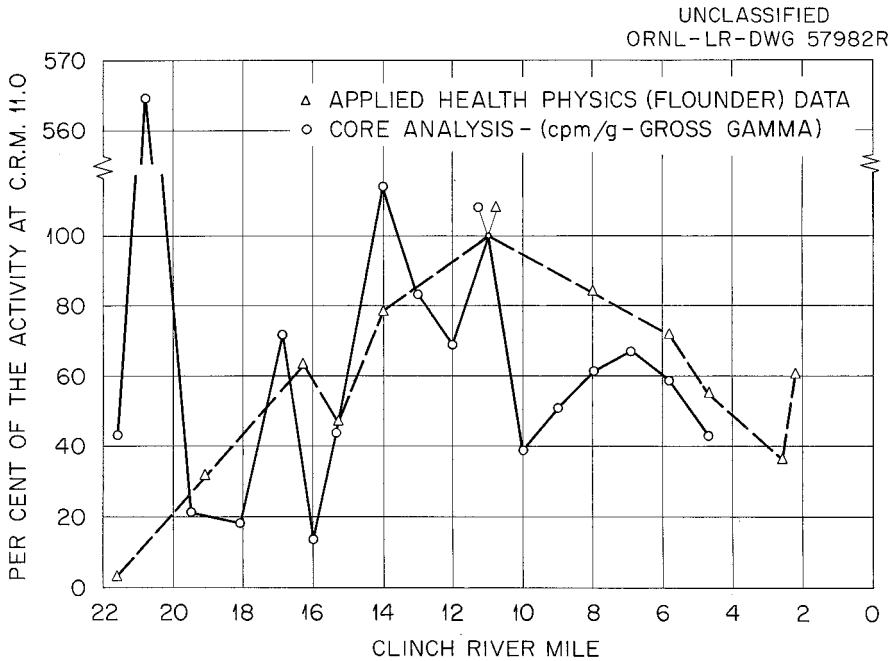

Fig. 7. Comparison of Core Data (Gross Gamma) and "Flounder" Data.

are present at all sections. Results of these analyses, expressed in microcuries per kilogram, are given in Table 16.

Cesium-137 is the predominant radionuclide at all sections of the study reach as shown in Fig. 8. The longitudinal distribution of the radioactivity (specific activity) is similar, generally, throughout the study reach with the exception of the activity due to Ru^{106}. In contrast to distributions for other nuclides, the maximum specific activity for Ru^{106} does not occur at CRM 20.8, at the mouth of White Oak Creek.

As indicated in Table 16 and Fig. 8, ratios of specific activities (μc/kg) of cobalt, cesium, and strontium are relatively constant in the reach. The ratio of cobalt activity to cesium activity is everywhere between 0.14 and 0.08; strontium to cesium is between 0.022 and 0.011. The ratio of ruthenium to cesium is fairly constant (0.12 to 0.37) downstream from CRM 16.0. Upstream from that point the ratio is more varied: between 0.037 and 0.55. These constant ratios suggest that the same or, at least concurrent, processes govern the deposition of the nuclides (except, perhaps, ruthenium). Inasmuch as cobalt is not expected to be sorbed onto the surface of the sediment bed, most of the cobalt activity in the silt probably comes from deposition of suspended sediments and colloids. Apparently cobalt, as a complexed colloid, is being precipitated at the same time as strontium and cesium, which are sorbed on suspended sediments.

It is instructive to compare these silt analyses with others obtained earlier by the USPHS. Grab samples were taken by the PHS at four Clinch River sections with an Eckman or Pederson dredge. A comparison of the activity of these grab samples with the activity of core samples from approximately coincident cross sections is made in Table 17. In some cases the

Table 16. Analyses of Clinch River Silt for Specific Radionuclides

Clinch River Mile	Specific Activity[a] (10^{-2} μc/kg)				
	Ru^{106}[b]	Cs^{137}[b]	Co^{60}[b]	Sr^{90}[c]	TRE[c,d]
4.7	1.05	6.22	0.788	0.086	0.99
5.8	1.91	10.6	1.42	0.194	2.28
6.9	1.43	7.21	0.995	0.158	1.30
8.0	4.13	11.2	1.55	0.189	4.86
9.0	3.34	9.95	1.03	0.171	4.42
10.0	1.81	7.97	0.752	0.113	2.14
11.0	4.50	19.7	1.89	0.423	7.03
12.0	2.81	11.9	1.24	0.212	5.40
13.0	3.12	17.6	1.84	0.252	7.66
14.0	1.33	10.6	1.19	0.194	2.90
14.6	4.41	18.1	1.85	0.347	5.63
15.3	2.16	9.77	0.977	0.149	3.11
16.0	0.815	3.54	0.347	0.077	1.50
16.9	5.99	13.2	1.22	0.140	5.86
18.1	2.12	16.1	1.29	0.230	3.59
19.5	2.79	7.12	0.923	0.108	2.28
20.8	3.90	106	8.32	1.68	20.4
21.6	2.54	7.03	0.653	0.144	3.07
22.5	1.36	2.48	0.334	0.009	1.40

[a]Activity per kilogram of solids.

[b]Gamma spectrometer analysis.

[c]Chemically separated before counting.

[d]Total rare earths.

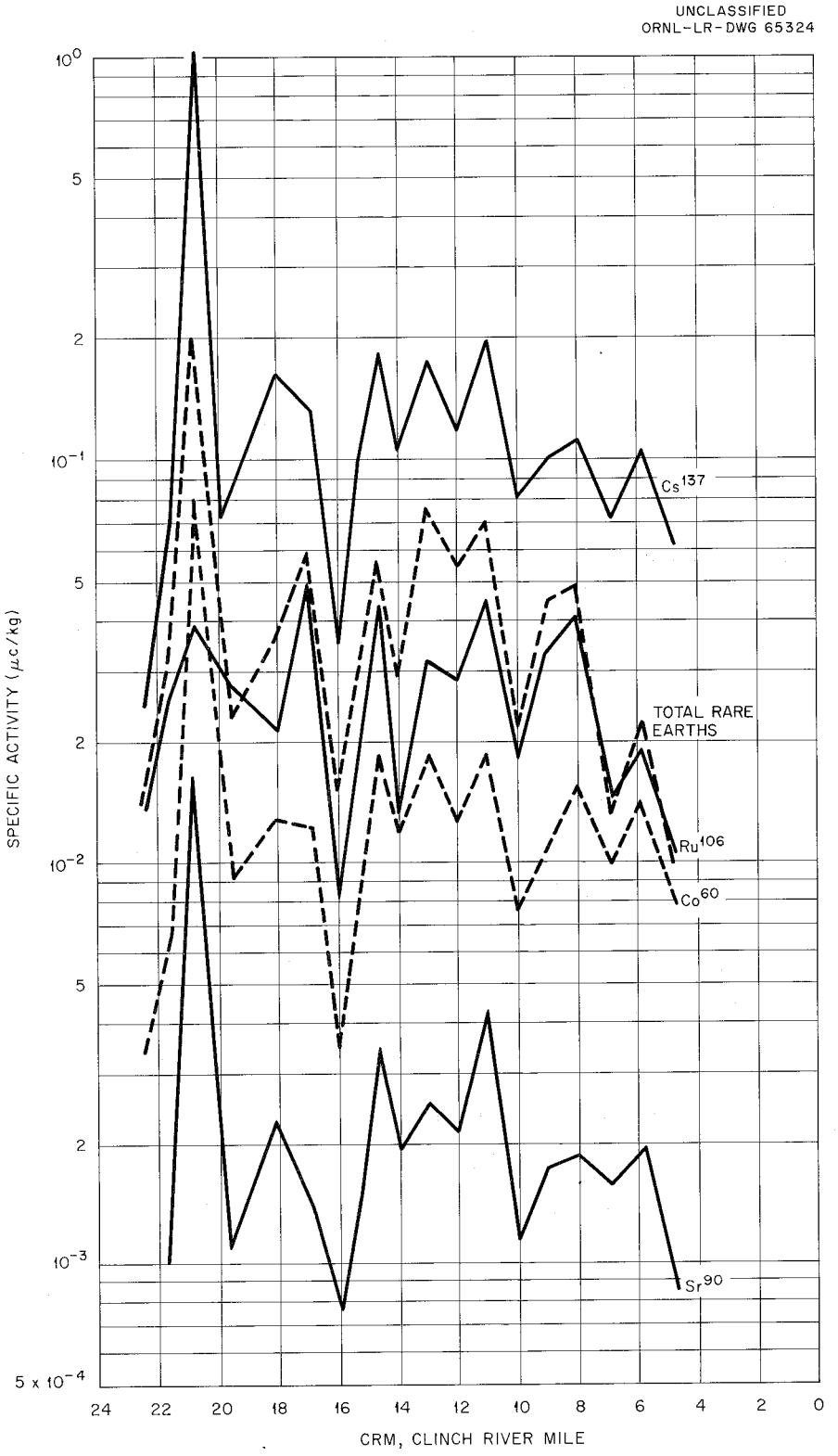

Fig. 8. Longitudinal Distribution of Specific Activity – 1960 Samples.

Table 17. Comparison of Analyses of Clinch River Silt by Oak Ridge National Laboratory and U. S. Public Health Service

Analyses By	Clinch River Mile	Nuclide Concentrations (μμc/kg)			
		Sr^{90}	Cs^{137}	Co^{60}	Ru^{106}
a	4.7	8.55×10^2	6.21×10^4	7.88×10^3	1.05×10^4
b	~ 4.4	9.00×10^2	1.21×10^4	7.71×10^2	7.97×10^3
a	14.6	3.47×10^3	1.80×10^5	1.85×10^4	4.40×10^4
b	~ 14.6	5.0×10^3	3.16×10^5	2.5×10^5	3.98×10^6
a	19.5	1.08×10^3	7.11×10^4	9.23×10^3	2.79×10^4
b	20.8[c]	8.6×10^3	3.64×10^5	2.1×10^4	1.0×10^5
a	20.8	1.68×10^4	1.06×10^6	9.32×10^4	3.89×10^4
b	20.8	9.7×10^4	8.75×10^6	5.1×10^5	2.44×10^6

[a]ORNL, Radioactive Waste Disposal Section.

[b]USPHS, Cooperative Studies Unit.

[c]One hundred fifty feet downstream from mouth of White Oak Creek.

values are in good agreement, but in some there are large differences. The discrepancies are unexplained, but may be due to changes with time.

The total radioactivity in the bottom sediments is the product of the specific activity (curies per unit of mass) and the mass of sediment. Inasmuch as the mass per unit length of reach varies throughout the study reach, the variation in specific activity with distance, shown in Fig. 8, gives no indication of the total activity which has accumulated in the unit length of reach. Accordingly, the radioactivity in curies per mile was computed for each reach. Results of the computations are listed in Table 18 and are plotted in Fig. 9. Results of the determinations of mass specific weights of solids are not listed, but in these computations variations in specific gravity of the solids were considered.

The radioactivity in a unit length of channel is greatest at CRM 20.8 for Cs^{137}, as shown in Fig. 9. For all other nuclides the maxima occur between CRM 7.0 and 10.0. With the exception of Ru^{106}, these maxima are only slightly greater than those indicated at CRM 20.8. Because of the uncertainties in depth of coring and degree of compaction in the cores, discussed previously, the maxima in the lower part of the reach may be significantly different from those computed for CRM 20.8.

The total activity in the upper horizon of sediment deposits in the reach from CRM 4.7 to CRM 21.5 has been computed by numerically integrating the areas under the curves shown in Fig. 9. The activity for Cs^{137} as computed was 43.2 curies; that for total rare earths, 14.7 curies; for Ru^{106}, 13.2 curies; for Co^{60}, 4.71 curies; and for Sr^{90}, 0.700 curies. The sum of these activities is 76.5 curies. All computations have been corrected for decay between the times of sample collection and of analyses.

Table 18. Unit Activity for Each Radionuclide in Upper Horizon of Sediment Deposits - Clinch River, CRM 4.7 to CRM 22.5

Clinch River Mile	Activity per Unit Length (Curies/Mile)				
	Ru^{106}	Cs^{137}	Co^{60}	Sr^{90}	TRE[a]
4.7	0.356	2.11	0.268	0.0290	0.377
5.8	0.543	3.01	0.404	0.0552	0.648
6.9	0.777	3.92	0.541	0.0859	0.706
8.0	1.49	4.04	0.558	0.0680	1.75
9.0	0.806	2.40	0.249	0.0412	1.07
10.0	1.13	4.99	0.471	0.0707	1.34
11.0	0.710	3.11	0.298	0.0667	1.11
12.0	0.301	1.27	0.133	0.0226	0.578
13.0	0.493	2.78	0.290	0.0398	1.21
14.0	0.179	1.43	0.161	0.0262	0.392
14.6	0.415	1.70	0.174	0.0326	0.530
15.3	0.213	0.962	0.096	0.0147	0.307
16.0	0.308	1.34	0.131	0.0290	0.567
16.9	0.188	0.412	0.038	0.0044	0.183
18.1	0.188	1.42	0.114	0.0204	0.317
19.5	0.081	2.08	0.027	0.0032	0.067
20.8	0.195	5.29	0.415	0.0838	1.02
21.6	0.274	0.759	0.070	0.0155	0.331
22.5	---	---	---	---	---

[a]Total rare earths.

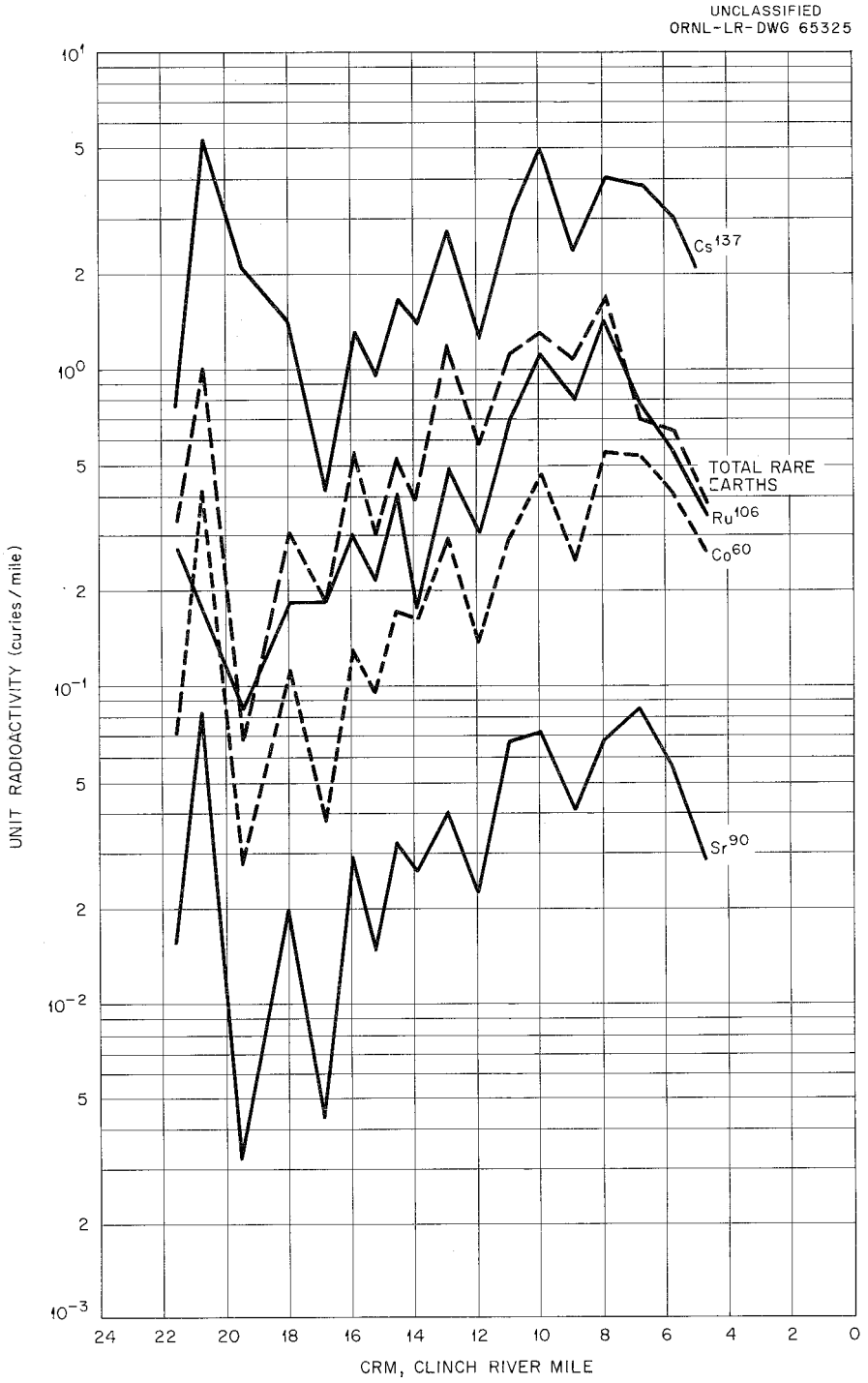

Fig. 9. Variation in Unit Radioactivity in Clinch River, CRM 4.7 to CRM 22.5 – 1960 Samples.

Consistency of Distribution Patterns

Distribution patterns of the radioactivity of bottom sediments in the length of the study reach, as developed from measurements of gamma activity *in situ*, gross gamma counting of core segments, and determinations of specific activity, are similar. Differences that are noted probably result from differences in the methods of obtaining the data and in the bases of computation. The distribution pattern estimated from "flounder" measurements may represent activity in a relatively thin stratum near the surface of the sediment. No effective thickness for this stratum has been determined. Due to limitations of the data, the distributions developed from core samples represent the activity in strata that are less than 14 in. in depth; and the estimated "total" activity between CRM 4.7 and CRM 20.8 includes only that which is associated with this upper horizon of the sediment deposits.

BIOLOGICAL PHASES

During the period represented by this report, the ORNL Ecology Section carried on studies of two important aspects of biological interest in the Clinch River Study.[4] One was a chemical study of clams collected from the Clinch and Tennessee Rivers aimed to improve understanding of the movement and accumulation of radiostrontium in the river system. The other was a continuation of the study to determine radiation effects on biota, particularly to estimate the radiation dosage of organisms living in contaminated bottom sediments. These two studies, which were reported to the Steering Committe, May 4, 1961, are summarized below.

Biogeochemistry of Strontium and Calcium in Clams

Introduction

The fate of Sr^{90} released to natural surface-water streams has not been known, because these releases have been small, and when small volumes of contaminated water are diluted by large volumes of noncontaminated water, the quantitative determination of Sr^{90} is exceedingly difficult. The Oak Ridge National Laboratory has been releasing carefully-controlled amounts of Sr^{90} to the Tennessee River system by way of White Oak Creek and the Clinch River since the Laboratory was established in 1943.[5] It was hypothesized that the $CaCO_3$ shells of clams collected downstream from the Laboratory may contain concentrations of Sr^{90} so that it would be possible to determine its behavior in this river system. The shells of a

number of species were analyzed with the following objectives: (1) to determine the content of stable strontium and calcium and Sr^{90} in several species from different locations in the Clinch and Tennessee Rivers; and (2) by considering the Sr^{90} released from the Laboratory as a tracer, to test whether clams may be used as biological indicators of the Sr^{90} concentration in the river system at various distances from the source of contamination.

Clams are excellent aquatic organisms with which to determine the fate of Sr^{90} in surface-water streams, because their $CaCO_3$ shells also include some strontium, and the clams would not be expected to differentiate between stable strontium and Sr^{90} in their metabolism. The clam shells after formation, unlike the bones of vertebrates, are not affected by subsequent metabolism. New layers of shell are laid down as the clam grows, and a section through the shell contains a history of the mineral deposition of the animal in successive annual layers. In contrast with fish, clams are relatively immobile on the river bottom; and the Sr^{90} content of the shells should be representative of the localities from which the individuals were collected. Clams pump water through their siphons during much of the year, although most of the growth occurs from March through October.

Methods

Clams were collected from seven different sites (Table 19) on the Clinch and Tennessee Rivers, and the shells were identified and analyzed for stable strontium and calcium and for Sr^{90}. A reference collection prepared by staff members of the University of Michigan was used for

Table 19. Stable Strontium and Sr^{90} Concentrations in River Clams with Calculated Strontium-Calcium Atom Ratios and Sr^{90}-Stable Strontium Atom Ratios (CRM, Clinch River Mile; TRM, Tennessee River Mile)

Unionidae	Collection Site	Stable Sr		Atoms	Sr^{90}		Atom Ratio
		Number Analyzed	Mean Sr ± SD (μg/g shell)	$\left(\frac{Sr}{Ca} \times 1000 \pm SD\right)$	Number Analyzed	Mean ± SD (μμc/g shell)	$\left(\frac{Sr^{90}}{\text{Stable Sr}} \times 10^{11}\right)$
Anodontinae							
Anodonta corpulenta	Clinch River	7	382 ± 107.9	0.437 ± 0.123	7	99.08 ± 47.41	176.1 ± 66.9
Anodonta corpulenta	Grassy Creek	4	324.5 ± 55.5	0.371 ± 0.063	4	32.41 ± 2.36	69.7 ± 17.1
Unioninae							
Dromus dromas	CRM 66	1	202	0.231			
	CRM 47	2	183 ± 8.49	0.209 ± 0.010			
Quadrula metanevra	CRM 47	1	162	0.185			
	TRM 425	3	161.7 ± 2.12	0.185 ± 0.002			
Quadrula pustulosa	CRM 47	2	186.0 ± 8.48	0.213 ± 0.010	2	1.214 ± 0.351	4.45 ± 1.48
	CRM 17	9	155.9 ± 6.57	0.178 ± 0.008	5	15.18 ± 5.74	67.5 ± 24.1
	TRM 521	2	244.0 ± 46.7	0.279 ± 0.053	2	5.33 ± 1.31	15.4 ± 6.57
	TRM 425	3	202.7 ± 14.0	0.232 ± 0.016	3	4.30 ± 1.39	14.3 ± 4.24
	TRM 100	8	199.5 ± 9.87	0.228 ± 0.011	5	2.29 ± 0.41	7.74 ± 1.22
Elliptio dilatatus	CRM 66	2	222.0 ± 9.22	0.254 ± 0.011			
	CRM 47	10	206.2 ± 16.3	0.236 ± 0.019	2	0.39 ± 0.60	0.99 ± 2.5
	TRM 425	1	218	0.249	1	4.16	12.9
Elliptio crassidens	CRM 47	10	260.9 ± 15.8	0.298 ± 0.018			
	TRM 521	15	211.4 ± 14.2	0.242 ± 0.016	10	24.9 ± 7.56	36.5 ± 11.9
	TRM 425	7	196.4 ± 16.9	0.225 ± 0.019	7	7.00 ± 1.96	
	TRM 100	5	228.2 ± 34.6	0.261 ± 0.040	5	3.96 ± 3.40	12.5 ± 11.3
Pleurobema cordatum	CRM 47	10	201.0 ± 17.8	0.230 ± 0.020	2	0.185 ± 0.26	0.525 ± 0.88
	TRM 425	11	237.3 ± 21.9	0.271 ± 0.025	2	4.24 ± 4.54	13.8 ± 14.2
Fusconaia subrotunda	CRM 47	9	184.3 ± 6.5	0.211 ± 0.007			
Amblema costata	CRM 47	2	184.5 ± 1	0.211 ± 0.001			
	TRM 425	3	201.7 ± 18.0	0.231 ± 0.021	2	12.6 ± 0.12	22.2 ± 1.8
Megalonaias gigantea	TRM 425	3	188.7 ± 5.14	0.216 ± 0.006			

Table 19. (Contd)

Unionidae	Collection Site	Stable Sr: Number Analyzed	Stable Sr: Mean Sr ± SD (μg/g shell)	Atoms ($\frac{Sr}{Ca}$ x 1000 ± SD)	Sr^{90}: Number Analyzed	Sr^{90}: Mean ± SD (μμc/g shell)	Atom Ratio ($\frac{Sr^{90}}{\text{Stable Sr}}$ x 10^{11})
Cyclonaias tuberculata	CRM 47	2	213.5 ± 5.0	0.244 ± 0.006	2	0.714 ± 0.879	1.25 ± 1.35
	TRM 521	10	242.6 ± 17.4	0.277 ± 0.020	7	4.81 ± 1.29	12.3 ± 3.75
	TRM 425	4	213.3 ± 9.87	0.244 ± 0.011	4	5.70 ± 1.47	18.9 ± 4.14
	TRM 100	5	208.8 ± 14.4	0.239 ± 0.016	4	3.13 ± 0.681	10.2 ± 2.32
Lampsilinae							
Plagiola lineolata	TRM 425	3	199.7 ± 7.04	0.228 ± 8.05			
Actinonaias carinata gibba	CRM 47	7	185.7 ± 14.7	0.212 ± 0.017			
Ligumea recta latissima	CRM 47	6	182.2 ± 8.04	0.208 ± 0.009			
	TRM 425	1	191	0.218			
Lampsilis ovata	CRM 66	7	231.1 ± 19.4	0.264 ± 0.022	2	0.790 ± 0.063	1.15 ± 0.05
	CRM 47	6	224.0 ± 27.5	0.256 ± 0.031	2	0.392 ± 0.56	1.32 ± 2.1
Proptera alata	Grassy Creek	4	220.5 ± 22.6	0.252 ± 0.026			
	TRM 521	1	248	0.284			
	TRM 425	1	190	0.217			

identifying the clams. Chemical analyses for stable strontium and calcium were made by flame photometry. The strontium determinations were further checked for accuracy by spectrophotometry, and the extreme difference between the two methods was 5%. An important point in connection with these analyses was that calcium produced in a mass spectrometer was used for the standards. This calcium was virtually pure Ca^{40} and, therefore, almost free from contamination by strontium. A radiochemical separation was used to obtain Sr^{90}, and counting was done in a low-background counter. Estimates of the average river discharges at the respective collecting stations were obtained from the U. S. Geological Survey.

Calcium in Clam Shells

The aragonite shell of clams is reasonably pure $CaCO_3$ which should yield 400 mg Ca/g of shell. The initial analyses of the ashed shells showed the calcium content to be as expected; consequently, in subsequent analyses only one in ten shells was analyzed for calcium. A total of 25 shells was analyzed for calcium, and the mean calcium content was 401.7 ± 6.51* mg/g (± SD) of shell. These deviations from the expected value are within the limits of variability of the analytical technique.

Strontium in Clam Shells

In making the strontium analyses for this study, it was assumed that as in marine species there was no difference in strontium content with the age of the clams.[6] The data and subsequent analyses showed that in fresh water clams the strontium content is at least partially age-dependent. In

---

*± Standard deviation (SD).

the collection of Elliptio crassidens from Tennessee River Mile (TRM) 521, the strontium content of five clams 4 to 6 years old was compared with that of ten clams 10 to 15 years old. The mean strontium concentration in younger clams was 204.6 ± 4.87 ppm (± SD) and that of older clams was 214.8 ± 16.2 ppm. These differences are not significant. However, three 2- to 3-year-old Anodonta corpulenta had a strontium concentration ranging from 232 to 294 ppm (mean 263 ± 31 ppm), and four 4-year-old clams of the same species had a strontium concentration ranging from 353 to 426 ppm (mean 382 ± 77.6). Since it was not possible to obtain a complete age series of any one species, several E. crassidens shells were sectioned, and each annual increment of growth was separated. The strontium concentration in nacreous layers deposited when the clam is 1 to 6 years old is one-half to two-thirds as much as in the layers deposited in years 7 to 9. These differences could not be detected unless one analyzed clams representing different year classes or sectioned the shell. Until further work has been done, with respect to the chemical morphology of clam shells, only tentative suggestions can be made regarding the deposition of strontium in the $CaCO_3$ shells of fresh-water clams.

The mean strontium concentration of collections of different species was variable and ranged from 382 ppm (A. corpulenta) to 156 ppm (Quadrula pustulosa) (Table 19). The highest strontium content in A. corpulenta was 518 ppm, and the lowest strontium content in Q. pustulosa was 146 ppm. These values, which differ by a factor of 3.5, also represent the extreme range for all strontium determinations. The collections of these two species were obtained in the Clinch River downstream from White Oak Creek; therefore, they should have been in similar chemical environments. These

differences in strontium content must be due to factors other than environment alone, since the strontium-calcium atom ratio in the water throughout the portions of the Tennessee River system from which clams were collected is similar.[7,8,9] Swan[10] suggested an inverse relationship between growth rate and strontium deposition, but the average growth rate of A. corpulenta was 8.6 g per year and that for Q. pustulosa was 2.2 g per year. In A. corpulenta the 2- and 3-year-old clams, 4-year-old clams, and 6- to 11-year-old clams had respective growth rates of 5.2, 6.3, and 10.5 g per year. The strontium content increased with age as did the rate of shell deposition. Similar aged Pleurobema cordatum collected from CRM 47 and TRM 425 had respective shell growth rates of 2.5 and 4.9 g per year and respective strontium concentrations of 201 and 237.3 ppm. The Tukey Test indicated a significant difference of 18.1 ppm at the 5% level. Therefore, these populations with different growth rates also contained significantly different amounts of strontium.

Strontium deposition is governed by factors in addition to growth rate. Elliptio dilatatus (CRM 47) had a strontium content of 206 ppm and a shell-growth rate of slightly less than 1 g per year, while E. crassidens (TRM 521) with a similar strontium content had a shell-growth rate of 4.8 g per year. The increase in the strontium content with age in nacreous layers of E. crassidens shells may be related to a decreasing surface-volume relationship. A young clam would have a greater surface in proportion to its volume, and, consequently, ionic exchange between the depositional tissues and the external environment would be more rapid. Since there is an exclusion of strontium relative to calcium in shell deposition, the tissues surrounding the site of deposition become relatively enriched with

strontium. In a clam with a high surface-volume relationship, there would be a greater opportunity for the strontium excluded from the crystal deposition to escape to the environment. The slowly growing E. dilatatus also has an elongated, flattened shell. This combination should produce a low strontium content, but the shells analyzed contained as much strontium as faster growing species. These data suggest there are inherent species differences associated with the nonhomogeneous distribution of strontium in clam shells.

Strontium-90 - Stable Strontium Atom Ratios

To test whether clams could be used as quantitative biological indicators of Sr^{90} in the Tennessee River system, Sr^{90}-stable strontium atom ratios were used instead of Sr^{90}-calcium ratios. The use of Sr^{90}-calcium ratios for interpretation of Sr^{90} behavior in biological systems is questionable because of the demonstrated variation in the stable-strontium concentrations of the clam shells analyzed.

The Sr^{90}-stable strontium ratios in clams collected from the Clinch River upstream from White Oak Creek, subject only to fallout levels of Sr^{90}, were compared with those ratios in clams collected in the Clinch River downstream from White Oak Creek and from three locations in the Tennessee River. Atom Ratios observed and expected on the basis of dilution of Clinch River water by Tennessee River water are shown in Table 20. The Sr^{90}-stable strontium atom ratio from clams collected in the Clinch River downstream from White Oak Creek was divided by the dilution factor of Clinch River water by Tennessee River water to obtain the atom ratio expected on the basis of dilution. The agreement between expected and

Table 20. Observed and Expected Sr^{90}-Stable Strontium Atom Ratios in Clams as a Function of the Dilution of Clinch River Water

Collection Site	Dilution Factor for Clinch River Water	Sr^{90}-Stable Sr Atom Ratio x 10^{11}		Number Analyzed	Atoms Fallout Sr^{90}: Laboratory-Released Sr^{90}
		Expected on the Basis of Dilution	Observed by Stable Chemistry and Radiochemistry		
CRM 47[a] (Upstream from White Oak Creek)			1.67 ± 0.50	12	
CRM 17 - 4.7 (Downstream from White Oak Creek)	1	130.8[b]	130.8 ± 22.7	12	1:78
TRM 521[a]	5.6	23.4	25.74 ± 3.36	19	1:15
TRM 425	7.05	18.6	19.78 ± 1.71	19	1:12
TRM 100	12.3	10.6	10.14 ± 1.81	14	1:6

[a]CRM, Clinch River Mile; TRM, Tennessee River Mile; the Clinch River joins the Tennessee River at TRM 568 (river miles measured from mouth of the river); ±, one standard error of the mean.

[b]Sr^{90}-stable strontium atom ratio in clams from the Clinch River downstream from White Oak Creek is the basis for the atom ratios expected because of dilution.

observed atom ratios is excellent, considering that the low-level releases of Sr^{90} are in effect a tracer experiment over almost 500 river miles. It must be assumed that there is a relatively constant stable strontium content in the water throughout the portions of the Tennessee River drainage system from which clams were obtained, and chemical analyses of water from the Clinch River and from the Tennessee River near Paducah, Kentucky, indicate that this is the case. The accrual of fallout Sr^{90} in the river system is assumed to be proportional to runoff, and the fallout Sr^{90} is then constant. Any departures from the Sr^{90}-stable strontium ratio due to fallout may be attributed to releases of Sr^{90} from the Laboratory.

The contribution of Laboratory releases of Sr^{90} to the Clinch and Tennessee Rivers may be compared with that from fallout through use of Sr^{90}-stable strontium atom ratios in clams collected upstream from White Oak Creek and the atom ratio in clams collected downstream from White Oak Creek. Each upstream ratio is divided into the downstream ratios to determine the relative abundance of Sr^{90} from each source. The Laboratory contributed 78 atoms of Sr^{90} for each atom of fallout in the Clinch River downstream from White Oak Creek. This ratio decreases at downstream localities in proportion to dilution of the Clinch River water.

The releases of Sr^{90} from the Laboratory have not been constant, so this was not an ideal tracer experiment, but by using Sr^{90}-stable strontium atom ratios, many of the uncertainties involved in the uptake of Sr^{90} in clam shells can be resolved. There are very few atoms of Sr^{90} present in the environment as compared with stable strontium atoms. Therefore, small variations in the quantity of Sr^{90} released do not affect the total amount of strontium present in the water. When the Sr^{90}-stable strontium

ratio is established in the flowing water by the low-level releases, the ratio of the two isotopes will remain unchanged in the shell regardless of the magnitude of Sr^{90} uptake. The only other factor which could effect the results would be the length of time that the clams had lived in the river; and in this study the groups of clams from each location selected for Sr^{90} analyses were of a similar age distribution.

Radiation Effects on Biota - Estimated Radiation Dose Received by Diptera with Life Stages in Bottom Sediments

A relatively high frequency of chromosomal aberrations was observed in the salivary gland chromosomes of *Chironomus tentans* Fabr. larvae collected from White Oak Creek and the Clinch River.[11] While *C. tentans* normally has four pairs of chromosomes, individuals were found with three pairs of chromosomes. These preliminary results indicated the need for calculations of the radiation dose in the environment of Diptera with bottom-dwelling life stages. This report compares the natural background radiation with that received by the *C. tentans* larvae living in the bottom sediments of White Oak Creek and the Clinch River.

Dose Rate Calculations

Absorbed dose to the bottom organisms was calculated by assuming that they received a submersion dose of beta disintegrations and a one-half submersion dose of gamma emissions. *Chironomus tentans* larvae build mud tubes in the bottom sediment; and, since the sediment contains about four orders of magnitude greater concentrations of radioactivity than does the overlying water,[12] the radioactivity in the water can be disregarded for

purposes of these calculations. The submersion dose calculation assumes that the organisms are in the center of a sphere and receive equal quantities of radiation from all directions. The penetration distance of beta particles in a dense material, such as mud, is short with respect to the depth of C. tentans; therefore, the complete submersion dose calculation was utilized. With more penetrating gamma emissions, the one-half submersion dose is used, because the organisms receive radiation from one-half of a sphere.

The standard dose rate equations were used for these calculations.*

$$\text{Dose rate (rad week)} = \mu c \times 3.70 \times 10^{4} \times 6.05 \times 10^{5} \times 1.6 \times 10^{-8} \times Ei \qquad (1)$$

where

μc = $\mu c/g$ of mud,

3.70×10^{4} = dis/sec/μc,

6.05×10^{5} = sec/week,

1.6×10^{-8} = rad x g/Mev, and

Ei = effective absorbed energy per disintegration for a radionuclide.

An empirical formula was used to estimate the average effective absorbed energy of a beta disintegration (ICRP 1960).

$$Ei = 0.33\ E_m\ f\left(1 - \frac{\sqrt{Z}}{50}\right)\left(1 + \frac{\sqrt{E_m}}{4}\right) \qquad (2)$$

where

E_m = maximum energy of a beta disintegration,

---

*W. S. Snyder and the Internal Dose Estimation Group, Health Physics Division, assisted with dose-rate calculations.

f = fraction of disintegrations at a particular energy, and

Z = atomic number.

The effective energies of gamma disintegrations were calculated as follow:

gamma energy = 0.5 x E x f

where

0.5 = factor for one-half submersion,

E = gamma energy peak,

f = fractions of disintegrations at E, the energy peak.

Background Radiation

Organisms living in their natural environments are subject to radiation from three sources:

1. External emitters - there are a large number of naturally occurring radioisotopes which contribute to background radiation.[13] Of these, only the radiation contributed by K^{40} and Rb^{87} has been evaluated in this study, because these radioisotopes are the most abundant in the earth's crust,[14] and both have high specific activities.

2. Internal emitters - the naturally occurring radioisotopes, when contained in the tissues of organisms, irradiate the tissues when these isotopes disintegrate.

3. Cosmic radiation.

These three sources of radiation were evaluated with respect to doses which each may contribute to bottom organisms living in the Clinch River, and the total natural background radiation was obtained.

The calculated background radiation to which bottom organisms are exposed was derived as follows:

The external emitters occur in both the water and mud. An average potassium content of 2.6% for the river has been assumed in lieu of specific analyses. This assumption is based on the abundance of this element in various rocks of the earth's crust:[14] igneous, 2.6%; sandstone, 1.1%; shale, 2.7%; limestone, 2.7%. The sediments in the river bottom are derived primarily from local shale and limestone with an admixture of sand. Potassium (K) with a specific activity of 8.4×10^{-4} μc/g K gives a dose rate of 3.6 mrad/week. The average potassium content of the river water is 0.0014% which would not result in a significant dose. The average rubidium (Rb) content of river sediments estimated on the same basis as potassium was 0.03%. The specific activity of naturally occurring Rb^{87} is 1.9×10^{-2} μc/g Rb which results in a dose rate of 9.5×10^{-3} mrad/week. The calculated doses are summarized in Table 21. The potassium content of a composited sample of Chironomus larvae, whose gastro intestinal tracts were devoid of sediment, was 0.2%. The specific activity of potassium results in a K^{40} activity of 1.7×10^{-6} μc/g dry weight. The dose rate from this source is 2.9×10^{-4} mrad/week.

Cosmic radiation decreases from 35 mrad/year at the surface of water to 10.1 mrad/year at a depth of 10 m.[15] Chironomus larvae have been found to depths of about 12 m in the Clinch River; however, most collections were made in depths of 30 cm to 5 m. An estimate of 25 mrad/year of cosmic radiation has been used as this portion of the total background radiation.

Doses Expected from Clinch River and White Oak Creek Sediments

Radioanalyses of bottom sediments[12] have been used in calculating the dose rates. The bottom samples analyzed were collected at 11 transects

Table 21. Summary of Natural Background Radiation to Bottom Organisms in the Clinch River

Source	mrad/week	mrad/year	% of dose
External emitters			
Mud			
K^{40}	3.6	187.2	88
Rb^{87}	9.5×10^{-3}	0.5	0.2
Water	Insignificant		
Internal emitters			
K^{40}	2.9×10^{-4}	1.5×10^{-2}	
Cosmic radiation	4.8×10^{-1}	25	11.8
Total		212.7	100

from Clinch River Mile (CRM) 21.5 to 1.1, and the average radionuclide content for these transects was used to calculate dose rates (Table 22). The concentration of radioisotopes from CRM 16.3 to 19.1 is approximately twice the average value for the entire river. Thus, over several miles of river, there are areas where doses are about twice as high as the average in the river from CRM 21.5 to 1.1. Radioassays of the sediments under the standing pool behind White Oak Dam[16] indicate that radioisotope concentrations in the creek are about fifty times those in the river.

Total Dosage and Potential Mutagenic Effects

The Diptera populations are subject to the following estimated doses of radiation:

	Rad/Year	Times Background
Background	0.213	1.0
Average CRM 21.5 to 1.1	4.37	20.6
Average CRM 19.1 to 16.3	8.52	40
White Oak Creek	213.0	1000

The study of the chronic effects of radiation in natural environments is complicated by the release of mutagenic chemicals in industrial waste effluents to surface waters. While a number of chemicals are known to be mutagenic, there are many limitations in their action. When compared with ionizing radiation, most chemical mutagens produce very few mutations and may affect one species and not another. These various chemicals are known to be effective only at certain stages of mitosis or at a particular stage in the development of an organism, and they may even work on one sex and not on the other.[17] The seemingly erratic mutagenic behavior of chemicals is probably associated with the ability of the chemical to penetrate the

Table 22. Dose Rates Calculated on the Basis of Radionuclide Content of the Clinch River Bottom Sediments

Isotope	mrad/week	rad/year	% of Dose
$Cs\text{-}Ba^{137}$	50.3	2.61	59.8
Sr^{90}	0.350	0.018	0.4
Y^{90}	1.74	0.090	2.1
$Cs\text{-}Pr^{144}$	1.38	0.072	1.6
TRE*	7.85	0.408	9.3
$Ru\text{-}Rh^{106}$	5.96	0.310	7.1
Co^{60}	16.1	0.839	19.1
Zr^{95}	0.371	0.019	0.4
Nb^{95}	0.092	0.005	0.1
Total	84.1	4.37	99.9

*Trivalent rare earths exclusive of Y^{90}.

living cell and come in contact with the cell nuclear material. In addition, some chemicals are known which are capable of protecting organisms from damage by ionizing radiation.[18,19] With present knowledge it is as logical to assume that organisms are protected from ionizing radiation by chemicals in the environment as to assume that mutations are induced by them. In contrast with chemicals the action of ionizing radiation is well-defined. The waste releases from the Oak Ridge National Laboratory include a heterogeneous mixture of stable and radioactive chemicals,[20] and the organisms in the environment of White Oak Creek and the Clinch River are exposed to both kinds of materials.

Summary

The radiation from radionuclides sorbed on the river and creek bottom sediments in the environment of the larvae is 20 to 1000 times that of natural background. The larvae are also exposed to a heterogeneous mixture of stable chemicals in the effluent released to the environment. However, the mutagenic effect of chemicals is erratic when compared with the effect of ionizing radiation. Larvae from the creek and river have not been compared with larvae from areas not contaminated with radioactive wastes.

HYDROLOGIC ACTIVITIES

The U. S. Geological Survey provides stream-flow information which is vital to the Clinch River Study and to waste-disposal operations at ORNL. In cooperation with the Laboratory through AEC, the Survey has continued the operation of stream-gaging stations on the Clinch River near Scarboro, established in 1941; White Oak Creek below ORNL, established in 1950; Melton Branch near White Oak Lake, established in 1955; and the Settling Basin effluent into White Oak Creek, established in 1950.

The station on White Oak Creek at White Oak Dam was re-established as a discharge station when the lower gate was completed in June 1960. A tail-water gage was installed below White Oak Dam in August 1960 to determine when the lower gate is submerged by backwater from Watts Bar Reservoir. A rating for the flow through White Oak Dam was developed, using a theoretical approach, in which the gate openings were treated as weirs or orifices, depending on the stage of White Oak Lake. This rating was closely verified by discharge measurements below White Oak Dam during the fall and winter of 1960.

Sites for new gaging stations were selected in the Poplar Creek basin to provide local inflow data to the Clinch River and to ultimately define the stream-flow characteristics on the Oak Ridge reservation. Construction was completed, and the stations were put into operation on Bear Creek, East Fork Poplar Creek, and Poplar Creek near Oak Ridge, during the months of July and August 1960. Discharge measurements over a wide range in stage

have been made at each station to define the relation between stage and discharge.

A station for recording stage only was put into operation at CRM 19.1 on the Clinch River in October 1960. Various methods have been investigated in an attempt to provide continuous records of discharge, at least part of the time, at this location.

Brief descriptions of all the gaging stations currently in operation that support the Clinch River Study are given in Appendix A.

Provisional mean daily gage heights and discharges have been sent to the Radioactive Waste Disposal Section, Health Physics Division, ORNL, on a monthly basis for Clinch River near Scarboro, White Oak Creek below ORNL, White Oak Dam, and Melton Branch; and copies of these data for the period, October 1, 1960, to March 31, 1961, to members of the Steering Committee and staff of the study.

The modified controls at the stations on Melton Branch and White Oak Creek below ORNL were replaced with weirs by the Operations Division, ORNL, during the period, October 3 to 14, 1960. These changes necessitated rerating the stations throughout their entire range of discharge.

Staff gages were installed at fourteen sites on the Clinch River from CRM 1.5 to CRM 27.6 and on the Emory River at ERM 1.5, ERM 4.3, and ERM 5.0, as reference marks for future sampling, temperature, and velocity studies.

Hydrologic assistance was provided in the river sampling program, in cooperation with the staff of the Clinch River Study, by obtaining velocity and temperature profiles at Clinch River Miles 4.7, 5.5, 8.0, 14.0, 19.1, 19.2, 22.5, and 23.2. Observations were made for a range in discharge

from near 0 to 21,000 cu ft per sec, from full to low Watts Bar pool level, and from warm weather to cold weather conditions. Charts of temperature and velocity profiles at selected cross sections for October 12 to 13, 1960, are shown in Figs. 10, 11, 12, and 13 for four sections, Clinch River Miles 5.5, 14.0, 19.1, and 22.5, respectively.

No appreciable temperature variations were observed in the sections at CRM 14.0, CRM 19.1, and CRM 22.5. Slight temperature gradients were found to exist in the vicinity of the banks in these sections. At CRM 5.5 the temperature decreased 1° F from near the water surface at the right bank to a zone near the stream bed and banks in the left portion of the main channel.

Normal velocity distributions were found in the sections at CRM 5.5, CRM 14.0, and CRM 22.5. At CRM 19.1, maximum velocities were found to occur in a zone near the right bank.

A study was made of the fluctuation in discharge of the Clinch River near Scarboro to determine the best sampling time for the water sampler at the Oak Ridge water plant. Variation of flow in the Clinch River at the water plant intake (CRM 41.5) and the Scarboro gaging station (CRM 39.0) is influenced by two main factors: (1) operation of the TVA hydroelectric plant at Norris Dam and (2) variations in natural runoff between Norris Dam and the Scarboro gaging station. A statistical analysis was made of the occurrence of mean daily discharges and the discharges at half-hour intervals. From this analysis the times of day when an instantaneous discharge within 10% to 20% of the mean daily discharge would be most probable was determined. On the basis of this analysis, it was recommended that the sampler be programmed to take samples at 11 a.m. and at 9:30 p.m.

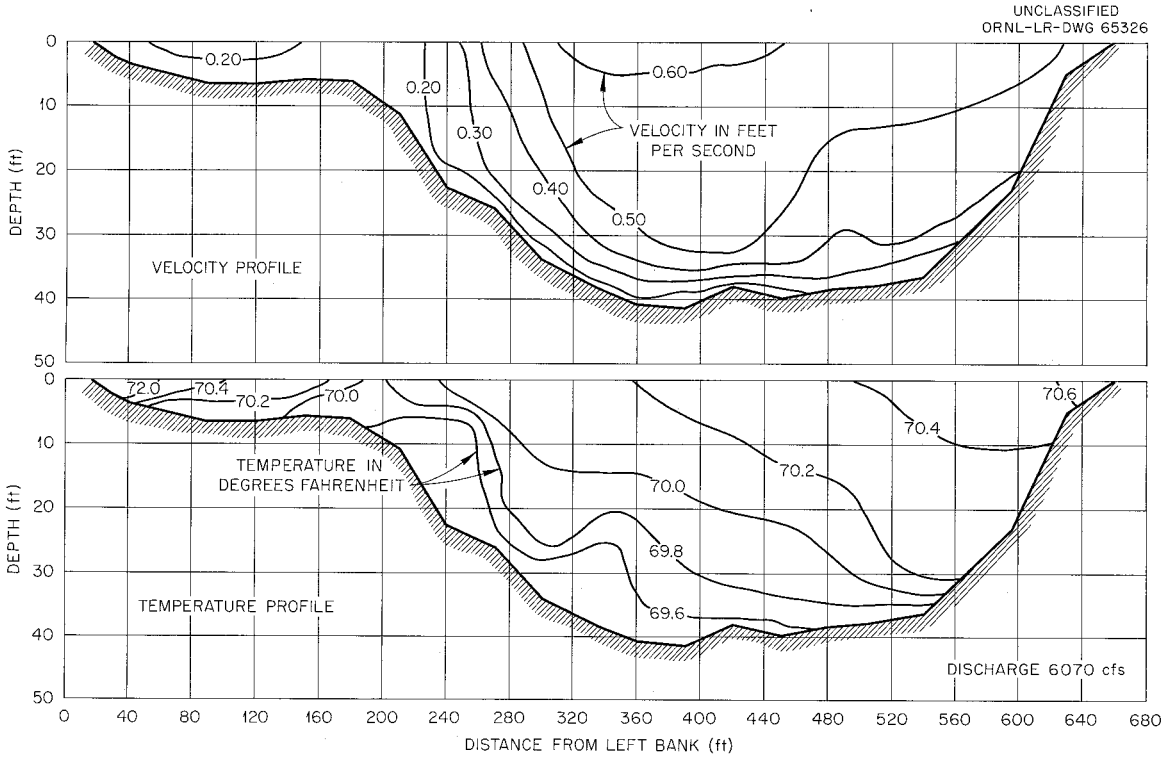

Fig. 10. Velocity and Temperature Distribution in Clinch River, Section at CRM 5.5, October 13, 1960.

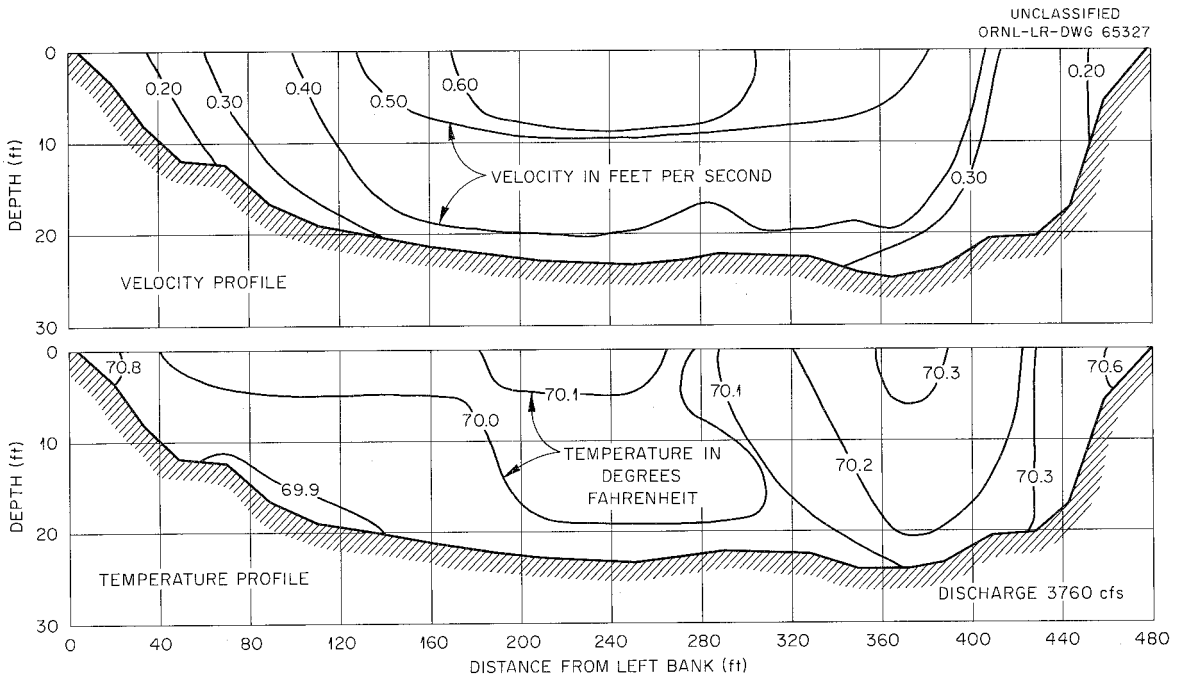

Fig. 11. Velocity and Temperature Distribution in Clinch River, Section at CRM 14.0, October 13, 1960.

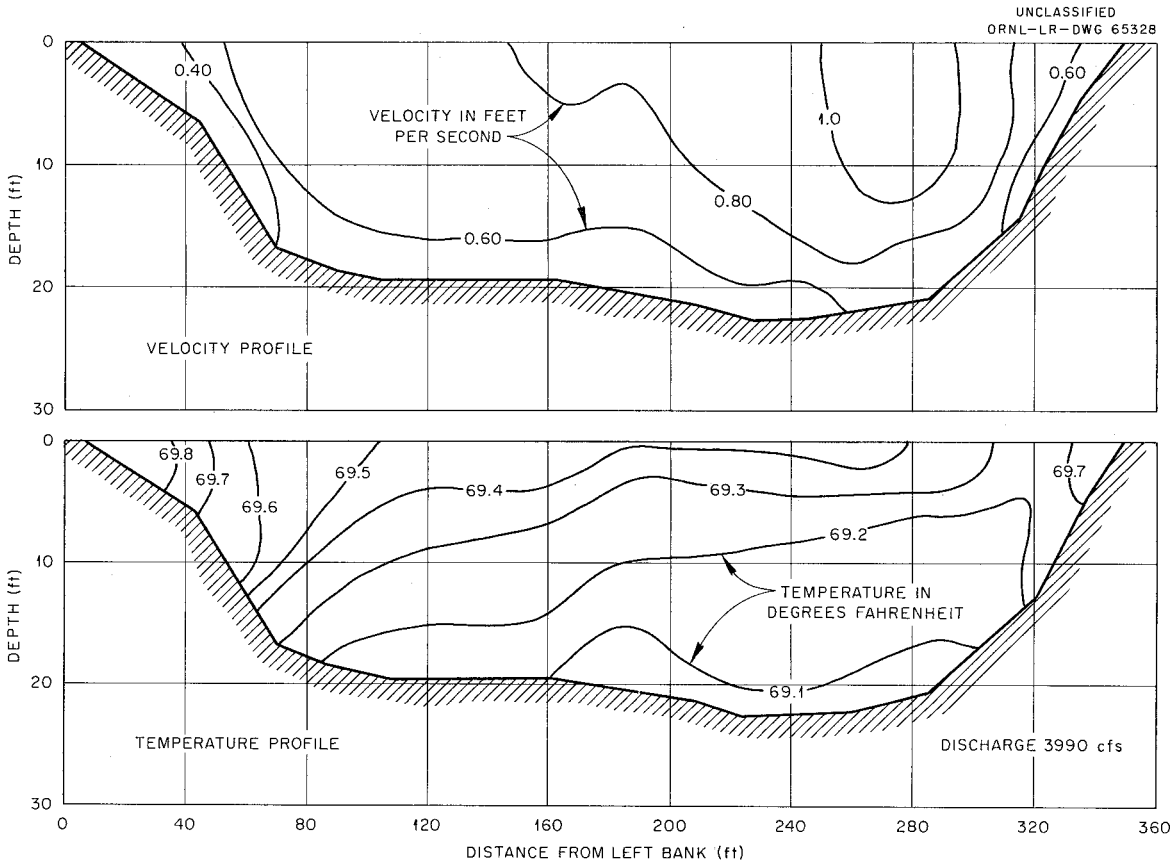

Fig. 12. Velocity and Temperature Distribution in Clinch River, Section at CRM 19.1, October 12, 1960.

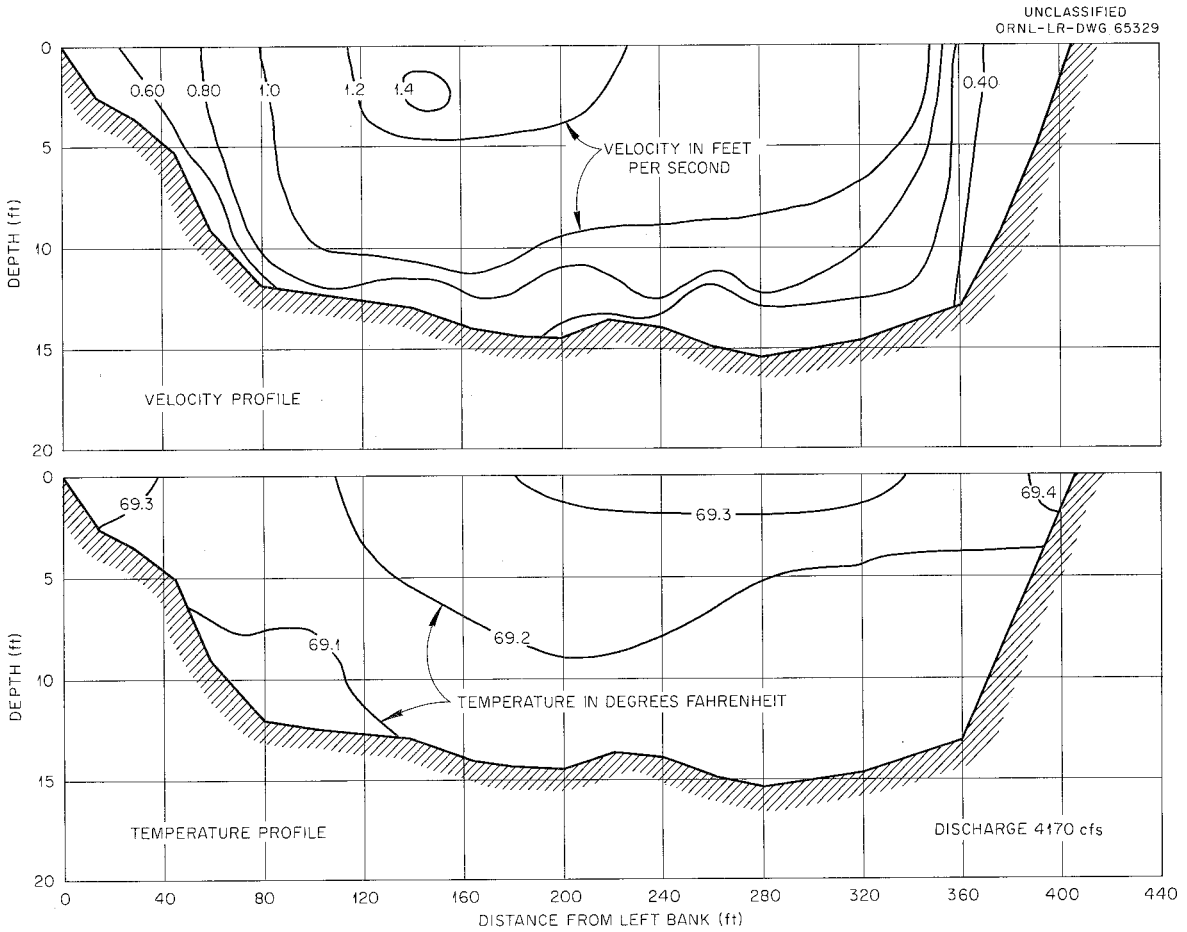

Fig. 13. Velocity and Temperature Distribution in Clinch River, Section at CRM 22.5, October 12, 1960.

each day. This program can be expected to be 76% efficient within 10% limits of variation and 89% efficient within 20% limits.

To assist in evaluation studies of the White Oak Creek basin, a duration study of White Oak Lake stages for the years, 1956 to 1959, was made, using the summation of discharges past the stations on White Oak Creek and Melton Branch with the lower gate at White Oak Dam set at an elevation of 741.05 ft. A tabulation of these data was given to members of the Steering Committee and the staff of the study. Also, a number of special measurements at monitoring sites on streams in the ORNL area were made.

APPENDIX A - DESCRIPTION OF GAGING STATIONS

The eight stations listed below were established by the U. S. Geological Survey in cooperation with the U. S. Atomic Energy Commission in behalf of ORNL. They are variously classified as water management, operational, research and experimentation, and areal secondary gaging stations. The data are needed for use by the AEC and ORNL in evaluating the flow in the Clinch River and in evaluating the effluent inventory from ORNL to the Clinch River; by ORNL in evaluating the flow from White Oak Creek to the Clinch River; and by the various agencies engaged in the Clinch River Study as essential information for the study. These stations also provide for other hydrologic needs of the Oak Ridge reservation.

Clinch River near Scarboro, Tenn.

Location.-- Lat 35°56'45", long 84°13'17", on right bank of Clinch River, 0.75 mile downstream from mouth of Beaver Creek, 2.5 miles south of Scarboro, Anderson County, 4.75 miles downstream from Solway bridge and 17 miles west of Knoxville.

Drainage area.-- 3300 square miles

Records available.-- January 22, 1941, to date

White Creek below Oak Ridge National Laboratory Near Oak Ridge, Tenn.

Location.-- Lat 35°54'44", long 84°18'59", on right bank, 0.1 mile upstream from Melton Branch, 1 mile south of Oak Ridge National Laboratory, Roane County, and 7 miles south of Oak Ridge, Anderson County.

Drainage area.-- 3.62 square miles

Records available.-- June 1, 1950, to July 10, 1953, July 14, 1955, to date

Melton Branch near Oak Ridge, Tenn.

Location.-- Lat 35°54'38", long 84°18'54", on right bank, 0.1 mile above mouth, 1 mile south of Oak Ridge National Laboratory, Roane County, and 7 miles south of Oak Ridge, Anderson County.

Drainage area.-- 1.48 square miles

Records available.-- August 22, 1955, to date

White Oak Creek at White Oak Dam near Oak Ridge, Tenn.

Re-established June 1, 1960

Location.-- Lat 35°53'57", long 84°19'15", at White Oak Dam, on White Wing Ferry Road, 0.9 mile downstream from Melton Branch, 2 miles south of Oak Ridge National Laboratory, Roane County, and 8 miles south of Oak Ridge.

Drainage area.-- 6.01 square miles

Bear Creek near Oak Ridge, Tenn.

Established August 17, 1960

Location.-- Lat 35°56'50", long 84°21'48", on left bank on downstream side of county road bridge, 200 ft west of State Highway 95, 0.8 mile upstream from mouth, and 3.9 miles southwest of intersection of State Highway 95 and Anderson County line in Oak Ridge. Bethel Valley Quadrangle 130 NE.

Drainage area.-- 7.15 square miles

East Fork Poplar Creek near Oak Ridge, Tenn.

Established August 19, 1960

Location.-- Lat 35°57'58", long 84°21'30", on left bank on upstream side of county road bridge, 0.3 mile north of State Highway 95, 1.7 miles upstream from Bear Creek, and 2.8 miles southwest of intersection of State Highway 95 and Anderson County line in Oak Ridge. Bethel Valley Quadrangle 130 NE.

Drainage area.-- 19.5 square miles

Poplar Creek near Oak Ridge, Tenn.

Established August 26, 1960

Location.-- Lat 35°59'55", long 84°20'23", on right bank 1000 ft upstream from county road bridge, 0.4 mile downstream from Indian Creek, and 1.2 miles northwest of intersection of State Highway 95 and Anderson County line in Oak Ridge. Bethel Valley Quadrangel 130 NE.

Drainage area.-- 82.5 square miles

Clinch River near Oak Ridge, Tenn.

Established October 14, 1960

Location.-- Lat 35°53'58", long 84°21'33", on right bank on county road, 800 ft downstream from Pawpaw Creek, 6.7 miles southwest of intersection of State Highway 95 and Anderson County line in Oak Ridge, and at mile 19.1. Bethel Valley Quadrangle 130 NE.

Drainage area.-- 3365 square miles

REFERENCES

[1]R. J. Morton (ed.) et al., Status Report No. 1 on Clinch River Study, Clinch River Study Steering Committee, ORNL-3119 (July 27, 1961).

[2]W. D. Cottrell, Radioactivity in Silt of the Clinch and Tennessee Rivers, ORNL-2847 (November 18, 1959).

[3]J. M. Garner and O. W. Kochtitzky, "Radioactive Sediments in the Tennessee River System," J. Sanit. Engr. Div., Proc. Am. Soc. Civil Engrs. 82, SA 4, 1-20 (August 1956).

[4]Morton (ed.), op. cit., p 43-44.

[5]Morton (ed.), op cit., p 9-11.

[6]T. G. Thompson and T. J. Chow, "The Strontium-Calcium Atom Ratio in Carbonate-Secreting Marine Organisms," Papers in Marine Biology and Oceanography, Supp to vol 3 of Deep-Sea Research, p 20-39, 1955.

[7]Tennessee Valley Authority, Industrial Water Supplies of the Tennessee Valley Region, TVA, Knoxville, Tennessee, 137 p, plus Appendix, 1948.

[8]M. W. Skougstadt and C. A. Horr, Occurrence of Strontium in Natural Water, U. S. Geol. Survey Circular 420, 1960.

[9]P. H. Carrigan, personal communication, 1961.

[10]E. F. Swan, "The Meaning of Strontium-Calcium Ratios," Deep-Sea Research 4, 71 (1952).

[11]Morton (ed.) op. cit., p 58-65.

[12]J. C. Hart, Applied Health Physics Annual Report for 1959, ORNL-3073 (March 20, 1961).

[13]M. W. Lowder and L. R. Solon, Background Radiation - A Literature Search, Health and Safety Laboratory, NYO-4712 (1956).

[14] L. T. Alexander, E. P. Hardy, Jr., and H. L. Hollister, "Radioisotopes in Soils: Particularly with Reference to Strontium-90," p 3-22, Radioisotopes in Biosphere, edited by R. S. Caldecott and L. A. Snyder, University of Minnesota, Minneapolis, 1960.

[15] T. R. Folsom and J. H. Harley, "Comparison of Some Natural Radiations Received by Selected Organisms," p 28-33, The Effects of Atomic Radiation on Oceanography and Fisheries, NAS-NRC Publication 551, Washington, D. C., 1957.

[16] E. G. Struxness, Detailed Assessment of Solid- and Liquid-Waste Systems - Hazards Evaluations, vol 4, ORNL CF-60-5-29 (May 1960).

[17] E. Altenberg, Genetics, p 317-318, Henry Holt, New York, 1957.

[18] D. G. Doherty, "Chemical Protection to Mammals Against Ionizing Radiation," p 45-86, A. Hollaender, Radiation Protection and Recovery, Pergamon Press, New York, 1960.

[19] G. E. Stapleton, "Protection and Recovery in Bacteria and Fungi," p 87-116, A. Hollaender, Radiation Protection and Recovery, Pergamon Press, New York, 1960.

[20] L. A. Krumholz, A Summary of Findings of the Ecological Survey of White Oak Creek, Roane County, Tennessee, 1950-1953, USAEC-ORO-132 (1954).

ORNL-3202
UC-70 — Waste Disposal and Processing
TID-4500 (17th ed.)

INTERNAL DISTRIBUTION

1. H. H. Abee
2. W. A. Arnold
3-7. S. I. Auerbach
8. A. F. Becher (K-25)
9. R. E. Blanco
10. F. R. Bruce
11. P. H. Carrigan (USGS)
12. W. B. Cottrell
13. W. D. Cottrell
14. J. A. Cox
15. F. L. Culler
16. M. F. Fair
17. B. R. Fish
18. J. C. Hart
19. A. P. Huber (K-25)
20. R. G. Jordan (Y-12)
21. W. H. Jordan
22. M. T. Kelley
23. F. Kertesz
24. C. E. Larson (K-25)
25. J. C. Ledbetter
26. T. F. Lomenick
27. J. D. McLendon (Y-12)
28. W. M. McMaster (USGS)
29. K. Z. Morgan
30-31. R. J. Morton
32. J. P. Murray (K-25)
33-34. D. J. Nelson
35. M. L. Nelson
36. F. L. Parker
37. R. J. Pickering (USGS)
38. M. E. Ramsey
39. R. M. Richardson (USGS)
40. M. J. Skinner
41. W. S. Snyder
42. J. A. Swartout
43. T. Tamura
44. A. M. Weinberg
45. E. J. Witkowski
46-55. E. G. Struxness
56. W. G. Belter (AEC-Wash)
57. J. S. Cragwall (USGS)
58. A. G. Friend (USPHS)
59. F. E. Gartrell (TVA)
60. Glenn Gentry (Tenn. State Game and Fish Commission)
61. S. Leary Jones (Tenn. State Health Department)
62. C. S. Shoup (AEC-ORO)
63. Vincent Schultz (AEC-Wash)
64. G. M. Fair (consultant)
65. J. C. Frye (consultant)
66. W. B. Langham (consultant)
67. Eugene P. Odum (consultant)
68. R. E. Zirkle (consultant)
69. Biology Library
70. Central Research Library
71. Reactor Experimental Engineering Library
72-96. Laboratory Records Department
97. Laboratory Records, ORNL R. C.
98. ORNL - Y-12 Technical Library Document Reference Section

EXTERNAL DISTRIBUTION

99. Robert C. Ball, Department of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan
100. Kenneth D. Carlander, Department of Zoology, Iowa State College, Ames, Iowa
101. David C. Chandler, Department of Zoology, University of Michigan, Ann Arbor, Michigan

102. Emil T. Chanlett, School of Public Health, University of North Carolina, Chapel Hill, North Carolina
103. Lauren R. Donaldson, School of Fisheries, University of Washington, Seattle, Washington
104. Kare Elgmork, Department of Limnology, University of Oslo, Blindern, Norway
105. John C. Geyer, Professor of Sanitary Engineering, The Johns Hopkins University, Baltimore, Maryland
106. Edward D. Goldberg, University of California, Scripps Institute of Oceanography, Berkeley, California
107. E. F. Gloyna, Department of Civil Engineering, University of Texas, Austin 12, Texas
108. Warren J. Kaufmann, Department of Engineering, University of California, Berkeley, California
109. Louis A. Krumholz, Department of Biology, Louisville University, Louisville 8, Kentucky
110. R. A. Lauderdale, Civil Engineering Department, University of Kentucky, Lexington, Kentucky
111. Donald C. Scott, Department of Zoology, University of Georgia, Athens, Georgia
112. M. A. Shapiro, Department of Public Health Practice, University of Pittsburgh, Pittsburgh 13, Pennsylvania
113. Harold A. Thomas, Jr., Department of Sanitary Engineering, Harvard University, Cambridge, Massachusetts
114. A. R. Zafar, Hydrobiological Laboratory, Osmania University, Hyderabad DN. 7, India
115. H. M. Roth, Division of Research and Development, U. S. Atomic Energy Commission, Oak Ridge, Tennessee
116-117. U. S. Atomic Energy Commission, Biology Branch, Oak Ridge, Tennessee (1 copy each to R. L. Hervin and J. A. Lenhard)
118. A. A. Schoen, Division of Operational Safety, U. S. Atomic Energy Commission, Washington 25, D. C.
119. Charles L. Dunham, Division of Biology and Medicine, U. S. Atomic Energy Commission, Washington 25, D. C.
120. I. E. Wallen, Environmental Science Research, Division of Biology and Medicine, U. S. Atomic Energy Commission, Washington 25, D. C.
121. John Wolfe, Division of Biology and Medicine, U. S. Atomic Energy Commission, Washington 25, D. C.
122. C. J. Chance, Fish and Game Branch, Division of Forestry Relations, Tennessee Valley Authority, Norris, Tennessee
123. M. A. Churchill, Environmental Hygiene Branch, Division of Health and Safety, Tennessee Valley Authority, Edney Building, Chattanooga, Tennessee
124. F. E. Gartrell, Division of Health and Safety, Tennessee Valley Authority, Edney Building, Chattanooga, Tennessee
125. O. W. Kochtitzky, Division of Health and Safety, Tennessee Valley Authority, 717 Edney Building, Chattanooga, Tennessee
126. James Smallshaw, Tennessee Valley Authority, 704 Union Building, Knoxville, Tennessee
127. William T. Lammers, Biology Department, Davidson College, Davidson, North Carolina

128. P. C. Benedict, Water Resources Division, QW, U. S. Geological Survey, Washington, D. C.
129. G. A. Billingsley, Water Resources Division, QW, U. S. Geological Survey, Raleigh, North Carolina
130. R. W. Carter, Water Resources Division, SW, U. S. Geological Survey, Washington 25, D. C.
131. W. R. Eaton, Water Resources Division, SW, U. S. Geological Survey, U. S. Courthouse and Customs House, 1114 Market Street, St. Louis 1, Missouri
132. B. J. Frederick, SW, U. S. Geological Survey, Room 663, U. S. Atomic Energy Commission, Oak Ridge, Tennessee
133. D. Hubbell, Water Resources Division, QW, U. S. Geological Survey, Colorado State University, Fort Collins, Colorado
134. Harry E. LeGrand, Radiohydrology Section, U. S. Geological Survey, Washington 25, D. C.
135. E. P. Mathews, Water Resources Division, SW, U. S. Geological Survey, Knoxville, Tennessee
136. Eric Myers, Water Resources Division, SW, U. S. Geological Survey, Washington 25, D. C.
137. Raymond L. Nace, Water Resources Division, U. S. Geological Survey, Washington 25, D. C.
138. Joe L. Poole, Water Resources Division, GW, U. S. Geological Survey, 90 Whitebridge Road, Nashville 5, Tennessee
139. K. Slack, Water Resources Division, QW, U. S. Geological Survey, Washington, D. C.
140. John E. Munzer, U. S. Public Health Service, Room 453, 50 Seventh Street, N.E., Atlanta 23, Georgia
141-148. Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio (1 copy each to C. P. Straub, A. H. Story, M. Howell, C. Henderson, E. Tsivoglou, Donald B. Porcella, S. Cummins, and Leo Weaver)
149. James G. Terrill, Jr., Division of Radiological Health, U. S. Public Health Service, Washington 25, D. C.
150. Glenn Brown, Hanford Atomic Products Operation, Richland, Washington
151. Jared J. Davis, Biology Operation, Hanford Atomic Products Operation, Richland, Washington
152. R. F. Foster, Biology Operation, Hanford Atomic Products Operation, Richland, Washington
153. Wayne C. Hanson, Biology Operation, Hanford Laboratories, General Electric Company, 146-FR Building, 100-F Area, Richland, Washington
154. C. W. Christenson, Health Physics Group, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
155. Karl Herde, Savannah River Operations Office, Aiken, South Carolina
156. C. M. Patterson, Health Physics Section, Works Technical Department, Savannah River Plant, E. I. du Pont de Nemours and Company, Aiken, South Carolina
157. Louis J. Cherubin, Knolls Atomic Power Laboratory, Schenectady, New York
158. John R. Horan, Idaho Operations Office, Idaho Falls, Idaho
159. Lee Gemmell, Brookhaven National Laboratory, Upton, New York
160. C. P. McCammon, Tennessee Department of Public Health, Cordell Hull Building, Nashville, Tennessee

161. F. V. Durand, Tennessee State Game and Fish Commission, Cordell Hull Building, Nashville, Tennessee
162. Clifford E. Ruhr, D-J Coordinator of Fish Restoration, Tennessee State Game and Fish Commission, Cordell Hull Building, Nashville, Tennessee
163. L. P. Wilkins, Tennessee State Game and Fish Commission, Cordell Hull Building, Nashville, Tennessee
164. William R. Bechmann, Sport Fishery Abstracts, U. S. Fish and Wildlife Service, Washington 25, D. C.
165. Theodore R. Rice, Fishery Research Biologist, U. S. Fish and Wildlife Service, Beaufort, North Carolina
166. Frank F. Hooper, Institute for Fisheries Research, Museum Annex, Ann Arbor, Michigan
167-168. Woods Hole Oceanographic Institute, Woods Hole, Massachusetts (1 copy each to V. T. Bowen and B. H. Ketchum)
169. Curtis L. Newcombe, U. S. Naval Radiological Defense Laboratory, 8 Middle Road Hidden Valley, Lafayette, California
170. George Sprugel, Jr., Program Director for Environmental Biology, 3729 South 13th Street, Arlington, Virginia
171. Union Carbide Corporation Patent Office
172. Irvin M. Lourie, Radiological Health, Pan American Health Organization, 1501 New Hampshire Avenue, N.W., Washington 6, D. C.
173. E. J. Cleary, Ohio River Valley Water Sanitation Commission, 414 Walnut Street, Cincinnati, Ohio
174. Henri Jammet, Service of Hygiene, Atomique-et-de-Radiopathologie, French AEC, Saclay, France
175. S. Lindhe, Atomic Energy Company, Studsvik, Tystberga, Sweden
176. U. Tonolli, Instituto Italiano di Idrobiologia, Pallanza (Novara), Italy
177. O. M. Skulberg, Norwegian Institute for Water Research, Blendern, Norway
178. Vanderbilt University, Nashville, Tennessee (Physics Library)
179. University of Rochester, Rochester, New York (Library)
180. University of Kansas, Lawrence, Kansas (Library)
181. University of Washington, Seattle, Washington (Library)
182. University of California, School of Public Health, Berkeley 4, California (Library)
183. University of California at Los Angeles, School of Public Health, Los Angeles 24, California (Library)
184. Columbia University, School of Public Health and Administrative Medicine, New York 32, New York (Library)
185. Harvard University, School of Public Health, Boston 15, Massachusetts (Library)
186. The Johns Hopkins University, School of Hygiene and Public Health, Baltimore 5, Maryland (Library)
187. University of Michigan, School of Public Health, Ann Arbor, Michigan (Library)
188. University of Minnesota, School of Public Health, Minneapolis 14, Minnesota (Library)
189. University of North Carolina, School of Public Health, Chapel Hill, North Carolina (Library)

190. University of Pittsburgh, Graduate School of Public Health, Pittsburgh 13, Pennsylvania (Library)
191. University of Puerto Rico, Department of Preventive Medicine and Public Health, San Juan 22, Puerto Rico (Library)
192. Tulane University Medical School, Division of Graduate Public Health, New Orleans 12, Louisiana (Library)
193. Yale University, Department of Public Health, New Haven, Connecticut (Library)
194-779. Given distribution as shown in TID-4500 (17th ed.) under Waste Disposal and Processing Category (75 copies - OTS)