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STATUS REPORT NO. 5 ON

CLINCH RIVER STUDY

Editor
R. J. Morton

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HEALTH PHYSICS DIVISION

STATUS REPORT NO. 5 ON CLINCH RIVER STUDY
Clinch River Study Steering Committee

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OCTOBER 1965

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*Succeeded A. G. Friend as a member of the Steering Committee effective August 1, 1963.

**Succeeded Vincent Schultz as an ex officio member of the Steering Committee effective August 20, 1964.

Subcommittees of Steering Committee

Water Sampling and Analysis: M. A. Churchill (TVA), Chairman, J. S. Cragwall, Jr. (USGS), R. W. Andrew (USPHS),* and S. L. Jones (TDPH). Staff Member: Wm. R. Nicholas (TVA).

Bottom Sediment Sampling and Analysis: R. M. Richardson (USGS),** Chairman, H. H. Abee (ORNL), R. W. Andrew (USPHS), J. W. Beverage (TVA), and T. Tamura (ORNL). Staff Member: P. H. Carrigan, Jr. (USGS).

Aquatic Biology: S. I. Auerbach (ORNL), Chairman, C. J. Chance (TVA), Wm. A. Brungs, Jr. (USPHS),*** and L. P. Wilkins (TGFC). Staff Member: D. J. Nelson (ORNL).

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*Succeeded A. G. Friend (see footnote, page vii).
**Succeeded P. H. Carrigan, Jr. (USGS).
***Succeeded D. B. Porcella (USPHS).

ACKNOWLEDGMENT

As explained for studies described in previous status reports on the Clinch River Study, essential parts of the work are performed by a number of groups in the Oak Ridge National Laboratory and other agencies represented on the Steering Committee. The Committee recognizes and appreciates participation of the agencies and individuals named below.

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FEATURES OF THE OVER-ALL PROGRAM

The four status reports previously issued have been based primarily on progress reports submitted at meetings of the Clinch River Study Steering Committee.[1,2,3,4] This fifth status report is mainly a summary of the study from April 26, 1962 to December 4, 1963. During this period the Steering Committee met twice, in February and December 1963, and received the progress reports upon which this report is largely based.

The cooperative nature and the basic objectives of the Clinch River Study were restated in the beginning of Status Report No. 4.[4] The agencies and individuals who have contributed to the study during the period of the present report are indicated in the acknowledgment on pages xi-xiii, and the list of contributing authors is on the title page.

Steering Committee Actions

The Steering Committee held meetings on February 6 and 7, 1963 at the R. A. Taft Sanitary Engineering Center of the U. S. Public Health Service (USPHS) in Cincinnati, Ohio. These included two open sessions for progress reports and discussions, a tour of the USPHS laboratories where radiological analyses of water samples from the Clinch River Study were made, and an executive meeting of the Steering Committee in the afternoon of February 7.

The meetings in December 1963 were at the Oak Ridge National Laboratory (ORNL). They included two open sessions and a demonstration of the counting equipment used in

analyses of bottom-sediment core samples on December 4, and an all-day executive meeting December 5, 1963.

Open Meetings

February 6-7, 1963 (Cincinnati, USPHS). — Two open sessions in the mornings of February 6 and 7 were attended by a total of 37 persons. Eight summaries on specific work projects and progress reports by the four subcommittees of the Steering Committee were presented and discussed as follows:[5] (1) "Report of Applied Health Physics Surveys in 1962," by H. H. Abee (ORNL); (2) "Progress Report No. 3, Subcommittee on Water Sampling and Analysis," by M. A. Churchill (TVA), Chairman; (3) "Hydrologic Measurements and Analyses," by R. M. Richardson, P. H. Carrigan, Jr., J. P. Monis, and R. J. Pickering (all of USGS); (4) "Data Evaluation," Progress Report of Subcommittee on Bottom Sediment Sampling and Analysis, by P. H. Carrigan, Jr. (USGS), Chairman;* (5) "Statistical Analysis of Sediment Samples Collected in June, 1961," by K. G. Busch (USPHS); (6) "Data on Sediments Collected in June and August 1961," by R. W. Andrew (USPHS); (7) "Progress Report on 1962 Bottom Sediment Coring Program," by R. J. Pickering (USGS) and P. H. Carrigan, Jr. (USGS); (8) "Use of the Swedish Foil Sampler for Taking Undisturbed Cores of River Bottom Sediments," by R. J. Pickering (USGS); (9) "Progress Report No. 2, Subcommittee on Aquatic Biology," by S. I. Auerbach (ORNL), Chairman; (10) "Data on Fish Collected in June and December 1961 and in March 1962," by D. B. Porcella (USPHS); (11) "A Pilot Study to Determine the Distribution in Space and Time of Multiple

*R. M. Richardson (USGS) later succeeded P. H. Carrigan, Jr. as subcommittee chairman. (See subcommittee membership on page x of this report.)

Radionuclides in a Seminatural Pond Environment," by William A. Brungs, Jr. (USPHS); and (12) "Progress Report No. 2, Subcommittee on Safety Evaluation," presented by C. P. McCammon (TDPH), Chairman. The report on safety evaluation studies was covered by three speakers introduced by McCammon as follows: "Application of MPC_w to ORNL-Discharged Radionuclides in Clinch River," by W. S. Snyder (ORNL), "Preliminary Evaluation of ORNL Waste Water Discharges to Clinch River," by K. E. Cowser (ORNL), and "Whole-Body Counting of ORGDP Employees," by F. L. Parker (ORNL).

December 4, 1963 (ORNL). — The open meeting was attended by a total of 27 persons. The programs of the four subcommittees were covered by progress reports as outlined below:[6]

A. Water Sampling and Analysis. - M. A. Churchill, Chairman

"Dye Tracer Studies - Summer 1963" by B. J. Frederick (USGS), F. L. Parker (ORNL), and P. H. Carrigan, Jr. (USGS); "Status of Analyses of Water Data," by R. W. Andrew (USPHS) "Stable Chemical Composition of the Clinch and Tennessee Rivers," by R. J. Pickering (USGS); and "Extraneous Sources of Release of Radionuclides to Clinch River," by R. J. Pickering, P. H. Carrigan, Jr., and W. M. McMaster (all of USGS).

B. Bottom Sediment Sampling and Analysis. - R. M. Richardson (USGS), Chairman, presented by P. H. Carrigan, Jr. (USGS).

"Bottom Sediment Cores Collected during the Summer of 1962," by R. J. Pickering (USGS); "Behavior of Radionuclides Associated with Clinch River Sediments," by W. P. Bonner (ORNL) and T. Tamura (ORNL); "Relationships in the Longitudinal Distribution of Radionuclides in the Clinch and Tennessee Rivers," by P. H. Carrigan, Jr.

(USGS); "Seasonal Changes in the Longitudinal Distribution of Radioactivity in the Bottom Sediments of the Clinch River," by P. H. Carrigan, Jr. (USGS); "Radiation Levels in Sloughs," by R. J. Pickering (USGS); "1963 Applied Health Physics Survey," by H. H. Abee (ORNL); and "Clinch River Channel Improvements: A Study of Radiological Hazards," by O. W. Kochtitzky (TVA) and H. H. Abee (ORNL).

C. Aquatic Biology. - S. I. Auerbach (ORNL), Chairman

"Use of Specific Activities in Predicting the Uptake of ^{90}Sr by White Crappie (*Pomoxis annularis*)" by D. J. Nelson (ORNL); and "Movement of Smallmouth Buffalo (*Ictiobus bubalus*) in the Vicinity of White Oak Creek," by D. J. Nelson (ORNL).

D. Safety Evaluation. - C. P. McCammon (TDPH), Chairman

"Status Report: Estimates of Radiation Exposure Doses to Man from Radionuclides Released to the Clinch River," by K. E. Cowser (ORNL).

Summation. - A summary of the information covered during the open meeting was presented by F. L. Parker (ORNL), Study Coordinator. For this summation and all the previous reports time was allowed for discussion and questions concerning the information presented.

Executive Meetings

February 7, 1963 (Cincinnati, USPHS).[7] - At this meeting the Steering Committee approved release of information and data in a paper "Use of the Swedish Foil Sampler for Taking Undisturbed Cores of River Bottom Sediments," by R. J. Pickering (USGS), for presentation at the Federal Interagency Sedimentation Conference, Jackson, Mississippi, January 28-February 1, 1963, and for publication in the proceedings of the Conference by the U. S. Department of Agriculture.

Most of the time at this meeting was devoted to program plans and recommendations presented by the chairmen of the four subcommittees. These are mentioned briefly below and given in more detail in the minutes of the meeting.[7]

Water Sampling and Analysis. - M. A. Churchill (TVA), Chairman. The chairman referred to pages 51 and 52 in the subcommittee's Progress Report No. 3, presented the day before.[8] Six recommendations were outlined and explained: (1) proportional sampling of Clinch River at Centers Ferry; (2) intensive surveys at several stations on Clinch River after Melton Hill Dam is in operation; (3) study of findings at the Centers Ferry station and decision whether there is need for additional stations; (4) establishment of a network of stations, if necessary, for monitoring radioactivity in precipitation (rain or snow) in connection with the water sampling program; (5) resolution of the problem of disagreements in analytical results between different laboratories presumably using comparable procedures on duplicate water samples; and (6) no analyses of river water samples for stable chemicals in any future water sampling studies.

Bottom Sediment Sampling and Analysis. - P. H. Carrigan, Jr. (USGS), Chairman . The subcommittee recommended and the Steering Committee approved the appointment of James W. Beverage (TVA) as a member of the subcommittee to succeed James Smallshaw of TVA who had retired. Also, H. H. Abee of the ORNL Applied Health Physics Section was made a full member of the subcommittee. (See page x).

Recommendations concerning work plans and investigations included the following: (1) joint work by the subcommittee and the Applied Health Physics Section to develop recommendations for future monitoring of bottom sediments in the river; (2) several studies (which were described) to provide information on retention of specific radionuclides by the various types of sediments in suspension or after deposition;

(3) extensive geochemical studies to delineate the physicochemical processes that lead to incorporation of radionuclides in bottom sediments; (4) cooperation of this subcommittee with other groups or subcommittees in studies of the physicochemical state of radionuclides in the bottom sediments and also in the water of White Oak Creek and Clinch River (including suspended sediments); (5) continued efforts to better define the phenomena of desorption and migration of radionuclides in sediments and of equilibrium conditions in the river; and (6) closer alliance of this subcommittee's work with that of the Subcommittee on Aquatic Biology.

It was the consensus of the Steering Committee that the proposed plan was too ambitious for the time remaining to complete the Clinch River Study but it was agreed that in general the program should be developed as recommended.

Aquatic Biology. - S. I. Auerbach (ORNL), Chairman. The subcommittee recommended: (1) Collect another series of carpsucker and buffalo fish from the Clinch River, primarily to obtain data from different methods of sample processing. Several variations of sample processing were suggested. (2) Acquire information on the quantity, kind, method of preparation, and rate of consumption of Clinch River fish eaten by people living nearby and fishing almost exclusively in the Clinch River. (3) Obtain estimates of the per capita consumption of fish in Tennessee and also, as specific information as possible regarding the kinds and quantities of fish sold in the East Tennessee areas and in Nashville and Memphis. It was recognized that to obtain accurate data regarding fish consumption is difficult.

A representative of the subcommittee on Safety Evaluation explained that for the safety evaluation maximum individual values are desired both as to consumption of fish and concentrations of radionuclides. If well-verified average values can be obtained the maximum is estimated as greater than the average by a factor of 3.

It was noted that radioactivity in fish from contaminated waters in a particular area would be diluted during marketing and consumption because fish from uncontaminated areas would be bought and mixed with them.

Safety Evaluation. - C. P. McCammon (TDPH), Chairman. The recommendations of this subcommittee were mainly about needs for data from actual measurements which would make the estimates of potential radiation exposures from various media more reliable. In brief, the subcommittee suggested that work be done to provide: data from laboratory analyses in progress (on water, sediments, and fish); measurements relative to radionuclides involved in crop irrigation; measurements relative to water immersion and contact with contaminated sediments; and the potentially exposed population from estimated water usage.

Questions were raised as to the need to obtain various data regarding levels of radiation, for example, from sediments in embayments, radionuclides accumulated in food through irrigation, and recreational use of Tennessee River reservoirs. It was agreed that under present conditions there is no significant hazard from any of these potential exposures but that methods for evaluating them should be developed as possible so that future changes can be studied more reliably. A number of gaps in the information presently available were mentioned and discussed.

The Steering Committee chairman commented that data needed by the Safety Evaluation group should be provided in so far as practicable. He suggested that attempts be made to obtain information about: (1) metabolism differences,

(2) techniques for the interpretation of data on soil and food in relation to irrigation hazards, (3) a restudy of fish using the analytical techniques already worked out but with different methods of processing the fish samples, (4) data from field measurements of radiation emitted by bottom sediments, (5) measurements of radiation in water sufficient to indicate the immersion dose, and (6) further study of assumptions and methods for calculating dose rates from various exposure media. It was agreed that during the next several months of the study efforts would be made to obtain data on these conditions.

Other Discussions and Actions. - For the information of the Steering Committee and as a matter of record Chairman E. G. Struxness discussed changes initiated at ORNL to improve the system of control and minimize discharges of radioactive wastes. He reviewed a memorandum from the ORNL Waste Effluents Committee to management officials of the Laboratory on February 1, 1963 which outlined activities and major recommendations of that committee during the previous year.

Radioactivity released to the river during 1962 was less than in 1961 and further reduction was expected. Nine "major recommendations" for control facilities and for operational and communication procedures were outlined. These included an evaporator for intermediate-level liquid wastes which had been authorized and was under construction, plans for backfilling the intermediate-level waste pits and covering them

to prevent continued seepage, and construction plans for a dam and other works, if necessary, to control the outflow from White Oak Creek to Clinch River after Melton Hill Dam is in operation. There were several specific recommendations for improvement of intercommunication among groups in the Laboratory and, concurrently, the development of safety evaluations and statements of permissible limits of discharges of radionuclides so that the advice of the ORNL health physicists might be utilized more effectively.

The Steering Committee discussed the time for completion of investigations and a final report on the Clinch River Study. It was the consensus that the study must include conditions in so-called "Phase II" (after Melton Hill Dam is in operation), that the remainder of the study should be covered by status reports including Phase I and whatever investigations were made in Phase II, and that a final report on the whole study would be necessary. The preparation and issue of Status Report No. 4 was authorized.

The problems of controlling the use by others of preliminary data from the study were discussed thoroughly. It was decided that informal progress reports prepared for the Steering Committee should be marked clearly to restrict publication or quotation without express permission from the authors and approval by the Steering Committee. It was agreed that independent analyses of the data presented in progress reports should be made only under the auspices of the Steering Committee and as a part of the Clinch River Study program. It was also agreed that status reports published in the future should be restricted by a printed notice that the information was of a preliminary nature and should not be republished without written permission.[7]

Meeting December 5, 1963 (ORNL). - The one-day executive meeting on December 5 was devoted mainly to reports and recommendations from the four subcommittees. These reports, summarized briefly below, are given in more detail in the minutes of the executive meeting.[9]

A. Water Sampling and Analysis. - The subcommittee chairman, M. A. Churchill, submitted the following recommendations:

1. The TVA should be asked to shut off flow at Melton Hill Dam completely for as long as possible, say a week or more, and the increased concentrations of radioactivity in the river expected to result from complete shutdown of flow at the dam should be studied.

2. For future monitoring of the Clinch River at least one continuous water monitoring station downstream from White Oak Creek should be established and maintained. It was stated that a station at about CRM 14.5 (near ORGDP) would be preferable; and that the cost at that location had been estimated as not more than $5,000 and probably less.

3. Based on indications that Melton Hill Dam will not cause much change in the Tennessee River at Watts Bar Dam or below, the basic water sampling program should not be reestablished as part of Phase II of the Clinch River Study.

4. When revision of the radiological data (then in progress) has been completed and the subcommittee progress report rewritten, the data on water contamination will be sufficient to complete Phase I of the Clinch River Study.

5. Every possible effort should be made to operate Melton Hill Dam so as to simulate winter releases, and to extend the program of tracer tests in order to investigate dispersion in the river under winter conditions.

The Steering Committee agreed that these five recommendations should be accepted and followed in so far as practicable.

B. Bottom Sediment Sampling and Analysis. - Subcommittee chairman, R. M. Richardson was not present and the report was presented to the Steering Committee by P. H. Carrigan, Jr. Several reports that were being prepared to complete Phase I were mentioned. Also the subcommittee outlined the studies proposed for Phase II of the Clinch River Study. These included:

1. Sediment surveys to represent the beginning of Phase II and later periodic sediment surveys, to be made by the TVA Hydraulic Data Branch.

2. Studies to identify trends in the movement of bottom sediments by special techniques with various marker materials, for example, the use of fluorescent calcite deposited on the bottom and identified fluorometrically in sediment samples collected later to investigate scouring or relocation of sediments.

3. Continued geochemical studies of bottom sediments by USGS, USPHS, and ORNL including radionuclides associated with organic materials.

4. Studies of radioactivity associated with suspended sediments in the river water, including separation of the suspended matter into inorganic and organic fractions.

5. Joint work by the several subcommittees in developing recommendations for river monitoring programs in the future. Public relations as well as legal requirements should be considered.

C. Aquatic Biology. - In presenting the report the chairman, S. I. Auerbach, commented that a major function of this subcommittee was to furnish data for use by the Subcommittee on Safety Evaluation. For completion of Phase I of the Clinch River Study

the data recommended were:

1. Results of determinations of radionuclides in fish samples already collected or proposed for completion of the program.

2. Information concerning the fish catch and consumption of fish from the TVA reservoirs, particularly downstream from ORNL.

3. An additional collection of rough fish and recomputation of data from some earlier fish analyses.

4. Further investigation of the effects of dilution factors in the Clinch and Tennessee Rivers, respectively.

It was reported that the subcommittee was continuing its study of the uptake of ^{90}Sr by white crappie through Phase I and overlapping into Phase II of the Clinch River Study. Efforts were being continued to find reliable biological indicators of radioactivity in natural waters.

For Phase II of the study the following objectives and problems were outlined:

1. Evaluation of a biological indicator, e.g., the white crappie.

2. Some study of the effects of harvesting all species of fish, including shad, and processing together for fish meal and cat food (being done at a plant in Clinton, Tennessee).

3. Study of organic detritus, including the concentrations of radionuclides and also use of this material for food by organisms, i.e., entry into the food chain.

4. Algae productivity in the river after the Bull Run Steam Plant is in operation.

D. Safety Evaluation. - The subcommittee reported discussions of the significance of: (1) short-lived radionuclides that decay away in the samples of water or sediment before analysis; and (2) long-lived radioisotopes (for example, tritium) which are not detected by the analytical methods used. It was agreed that the subcommittee should

mention these potential contaminants in its report to show that it was aware of the problems and indicate whether there could be important health hazards from these sources.

After discussion it was the consensus of the Steering Committee that the Subcommittee on Safety Evaluation should consider data on radionuclides upstream from White Oak Dam because releases of materials from above the dam might affect the levels of contamination in the rivers downstream.

The subcommittee had considered data on radiation levels in sloughs which had been presented in a progress report. There appeared to be no hazard from this source and no further study of sediments in sloughs was recommended.

Other Discussions and Actions. - The Steering Committee considered two other items of business, namely: future reports on the Clinch River Study, and arrangements for a special meeting with the Harvard Water Resources Group.

After considering various possibilities for future reports, the Steering Committee decided that: (1) the remainder of the study should be covered by one or more status reports, (2) specific investigations conducted during Phase II should be reported in topical reports or included in a status report, and (3) a comprehensive final report and a summary report of a more popular nature should be issued after the conclusion of the entire study.

It was decided that Status Report No. 5 (the present report) should be prepared on the basis of material already submitted, and that further details should be made available in supplements to Status Report No. 5 issued separately. The remainder of Phase I and any important results from Phase II of the study should be covered in

Status Report No. 6, the final status report of the series.

The Steering Committee agreed that the final report should be carefully prepared and attractively published. It was the consensus that this final report should be in two parts: (1) a comprehensive technical report, and (2) a popular-style, widely-distributed summary report. The preparation of these two reports and the extent of distribution were discussed. It was decided that the comprehensive report should be prepared first and that the form and distribution of the summary report, based on the comprehensive report, should be considered later.

The Steering Committee meeting was concluded with the general understanding that at a convenient time a special meeting would be held with Professor H. A. Thomas, Jr. of the Harvard Water Resources Group. The purpose would be discussion of an earlier proposal that the Clinch River Study data be used by the Harvard group for a systems analysis of Clinch River disposal of radioactive wastes.

WATER SAMPLING AND ANALYSIS

Eight months after the beginning of the Clinch River Study in January 1960 the Subcommittee on Water Sampling and Analysis was established (September 22, 1960). A comprehensive plan for collection and analysis of water samples during the study, prepared by this subcommittee and adopted by the Steering Committee, was described in detail in Status Reports No. 1 and No. 2.[1,2] Under this plan water sampling was begun in November 1960 and continued to December 1, 1962.

In brief the program included: (1) operation of a basic network of six (later seven) water sampling stations on the Clinch and Tennessee Rivers; and (2) compositing into weekly (or monthly) samples for analysis portions of daily subsamples of water, with each individual subsample volume proportional to the volume of the daily streamflow passing the particular sampling station.[1,2] From analyses of samples so composited the weekly or monthly mean concentration of each radionuclide or nonradioactive constituent in the water could be determined; and by combining concentrations and streamflows, the total cumulative load of particular constituents passing each station was computed. The program also included special collections and analyses of water samples as needed.

The basic network of stations at which water samples were collected in this study included the following locations:

(1) Clinch River at Oak Ridge Water Plant (CRM 41.5).

(2) White Oak Creek at White Oak Dam (WOCM 0.6).

(3) Clinch River at Gallaher Bridge (CRM 14.4) -- sampling was begun January 8, 1962.

(4) Clinch River above Centers Ferry (CRM 5.5).

(5) Tennessee River at Loudon, Tennessee (TRM 591.4).

(6) Tennessee River at Watts Bar Dam (TRM 529.9).

(7) Tennessee River at Chickamauga Dam (TRM 471.0).

Sampling procedures at each station in the basic sampling network were explained in detail in Status Report No. 2,[2] except for the station at Gallaher Bridge (CRM 14.4). Here sampling equipment was installed in the pump house for the ORGDP water plant, 100 feet downstream from the old Gallaher Bridge on the right bank of Clinch River. Every 4 hours a 1-gallon subsample of water was collected (in a separate container for each subsample) from the raw water discharge line of a specially installed sampling pump and intake pipe. Forty-two subsamples of the 1-gallon samples were composited into a weekly sample with the volume of each of the 42 subsamples proportioned to correspond with the discharge in Clinch River at the Scarboro gaging station (and later at Melton Hill Dam) during the sampling period, with time of wave travel between Scarboro (or Melton Hill Dam) and Gallaher Bridge taken into account.

Radionuclide Analyses

As recounted in previous status reports,[1,2,3] 5-gal water samples from the basic network locations were analyzed for radioactive constituents by the U. S. Public Health Service (USPHS) in Cincinnati, Ohio. These analyses consisted of determinations of ^{137}Cs, ^{60}Co, and ^{106}Ru by computations based on gamma spectrometric data and radiochemical separations for ^{90}Sr. Portions of the results of these determinations have been given from time to time in progress reports by the Subcommittee on Water Sampling and Analysis, and in status reports issued by the Steering Committee.[2,3]

Due primarily to continued improvements in the "electronic computer" analysis of the gamma spectrums of cesium-137, cobalt-60 and ruthenium-106, considerable revision of previously reported concentrations of these radionuclides has been made. The revised data on radionuclide analyses, including strontium-90, have been assembled by the subcommittee in a special report to be issued separately as a supplement to this status report (ORNL-3721, Supplement No. 1).[10] This will include all results on radionuclide determinations from the beginning of the basic-network sampling program in November 1960 through December 1, 1962.

The sampling station at the ORGDP water plant, CRM 14.4, was operated by ORNL from the latter part of 1960 until January 8, 1962. These samples and special samples from other locations were analyzed for radionuclides and stable chemicals by the ORNL Analytical Chemistry Division. Results of most of the analyses made at ORNL were given in Status Report No. 2.[2]

Stable-Chemical Analyses

The detailed data from stable-chemical analyses of samples from the basic network stations and the stable-chemical analyses made at ORNL have been reported in Status Reports No. 2 and No. 3,[2,3] in the Subcommittee's Progress Report No. 3,[8] and in and 1961 reports by the Tennessee Stream Pollution Control Board.[11,12] Altogether, the analyses included in the above reports covered two full years of systematic sampling at the original 6 basic network stations, December 1, 1960 to November 30, 1962 and 11 months at the Gallaher Bridge station (CRM 14.4), January 8 to November 30, 1962. The results showed no significant increase in either the various forms of nitrogen or in phosphates between the upper and lower Clinch River stations, and no extreme variations

in river conditions during different periods of time.

Since the detailed analytical data would be very voluminous to publish and difficult to use, the stable-chemical analyses for the period July 1961 through November 1962, given in the subcommittee's Progress Report No. 3,[8] are not included in this status report. Instead, in the following section is shown a statistical analysis of all of the stable chemical data for the several stations, including analyses by the Tennessee Stream Pollution Control Laboratory in Nashville and also stable-chemical analyses made at ORNL. It is believed that the statistical parameters will be more useful than a tabulation of the detailed data in defining conditions in the rivers.

The water samples were analyzed for stable chemical constituents in the laboratory of the Stream Pollution Control Board, Tennessee Department of Public Health (TDPH) in Nashville. The purpose of the program was to determine the effect of the stable chemical composition of the river waters upon the fate of radionuclides released to the rivers. Samples analyzed for stable chemical composition were aliquots of composite samples from which portions were also submitted for radionuclide analysis.

The large number of water samples collected and analyses performed have provided a more or less continuous picture of the stable chemical composition of the two rivers for approximately two years. Several computer programs were prepared and used to speed the processing and analysis of the large volume of data from the sampling program.

Tables 1 and 2 contain statistical summaries of the analyses for the period of record. The means which are listed in the tables have been discharge-weighted in order to make them consistent with the discharge-weighting of individual samples.

Table 1. Summary of Stable Chemical Analyses of Clinch River Water[A]

	Clinch River Mile 41.5				Clinch River Mile 14.4					Clinch River Mile 5.5				
	24 Months[C]				58 Weeks[H]					104 Weeks[I]				
	Mean	Stand.[D] Dev., Monthly	Min.	Max.	Mean	Stand.[E] Dev., Weekly	Stand.[D] Dev., Monthly	Min.	Max.	Mean	Stand.[E] Dev., Weekly	Stand.[D] Dev., Monthly	Min.	Max.
Turbidity, ppm	28	19	6	68						17	16	10	1	86
Apparent color, ppm	197	124	42	542						114	97	50	3	480
Centrifuged color, ppm	20	15	0	62						20	20	14	0	102
pH			7.1	8.2			0.14	7.0	8.1			0.17	7.2	8.5
HCO_3, ppm	117	7.41	105	130	119	11.3	6.08	87	141	112	13.4	7.86	57	135
Acidity, as $CaCO_3$, ppm	3	3	0	10						4	3	2	0	14
Hardness, as $CaCO_3$, ppm	107	17.4	78	148						106	23.8	19.7	69	169
Ca, ppm	27	4.3	18	36	21	2.4	1.8	17	27	27	5.2	3.8	17	43
Mg, ppm	9.4	2.8	5.1	18.0	7.7	1.0	0.71	4.5	10.0	9.4	3.7	2.8	4.1	22.6
Cl, ppm	5	2	1	11	1.6	0.53	0.30	1.0	4.5	3	1	0.9	1	8
SO_4, ppm	12	5	2	23	10	4	1.5	1.0	27	12	5	3	0	29
NO_3, ppm	1.0	0.59	0.2	2.4	2.7	4.0	3.0	0.3	19	1.5	1.7	2.2	0.0	12.7
Fe, ppm	3.4	2.3	0.3	9.2	0.06	0.08	0.06	0.01	0.37	1.7	1.3	0.80	0.1	7.1
PO_4, ppm	0.2	0.09	0.1	0.4	0.22	0.17	0.10	0.05	0.75	0.1	0.1	0.07	0.0	0.6
K, ppm	1.7	0.49	0.8	3.1	1.3	0.20	0.13	1.1	2.3	1.6	0.55	0.42	0.6	3.5
Na, ppm	2.3	1.1	1.0	5.2	2.4	0.50	0.39	1.8	4.7	2.4	1.3	0.90	0.0	9.5
Si, ppm	2.9	0.69	1.5	4.0	1.5	0.72	0.68	0.1	2.4	2.7	0.63	0.42	0.9	4.4
Specif. cond., μmhos/cm	195	36.5	119	263	216	14.4	9.98	190	282	196	42.8	36.5	105	312
Suspended solids, ppm	185	124	18	557	25.3	20.3	14.5	1.0	104	55	46	32	2	275
Dissolved solids, ppm	125	27	67	201	129	20.7	8.43	90	218	133	64	37	25	549
Total solids, ppm	310	121	140	677	154	23.6	14.9	127	231	188	77	49	112	601
Kjeldahl N, as N, ppm	0.7	0.2	0.3	1.3						0.5	0.3	0.2	0.2	1.7
Mn, ppm	0.4	0.3	0.0	1.1						0.1	0.1	0.08	0.0	0.6
Cr, ppm	0.02[F]	0.05[F]	0.00[F]	0.19[F]						0.01[J]	0.03[J]	0.03[K]	0.00[J]	0.18[J]
Sr, ppm[A]	0.073[G]	0.0068[G]	0.058[G]	0.086[G]	0.070	0.0090	0.0067	0.040	0.080	0.069	0.0076	0.0055	0.043	0.080
Discharge, cfs[B]	5,090	2,780	2,610	14,280	4,620	2,525	1,680	545	15,990	5,580	3,853	3,060	359	19,000

[A]Chemical analyses of samples from CRM 14.4, and of samples from all stations for Sr, by ORNL on *filtered* samples. Chemical analysis of all other samples by Tennessee Stream Pollution Control Board on *raw* samples.

[B]Not discharge-weighted. Discharge data is time-weighted.

[C]Sampling period, December 1960 through November 1962.

[D]Standard Deviation of discharge-weighted monthly samples from discharge-weighted mean for sampling period.

[E]Standard deviation of discharge-weighted weekly samples from discharge-weighted mean for sampling period.

[F]Sampled for 19-month period only, May 1961 through November 1962.

[G]Sampled for 42-week period, March 19–25, 1961 through December 31–January 6, 1962. Maximum, Minimum, Mean, and Standard Deviation are for *weekly* samples.

[H]Sampling period, November 28–December 4, 1960 through January 3–8, 1962. Maximum, Minimum, and Mean are for *weekly* samples.

[I]Sampling period, November 27–December 3, 1960 through November 25–December 1, 1962. Maximum, Minimum, and Mean are for *weekly* samples.

[J]Sampled for 85-week period only, April 16–22, 1961 through November 25–December 1, 1962.

[K]For 19-month period only, May 1961 through November 1962.

[L]Sampling period, August 1960 through November 1962.

Table 2. Summary of Stable Chemical Analyses of Tennessee River Water[A]

	TRM 591.4				TRM 529.9				TRM 471.0			
	28 Months[L]				24 Months[C]				24 Months[C]			
	Mean[B]	Stand.[B] Dev., Monthly	Min.[B]	Max.[B]	Mean	Stand.[D] Dev., Monthly	Min.	Max.	Mean	Stand.[D] Dev., Monthly	Min.	Max.
Turbidity, ppm	14	11	3	52	6	7	1	29	7	9	1	35
Apparent color, ppm	88	58	34	272	53	49	5	226	59	52	8	223
Centrifuged color, ppm	23	21	5	95	24	23	0	108	31	27	5	118
pH			7.1	8.2			7.2	7.9			6.6	8.2
HCO_3, ppm	66	10	50	95	70	7.6	52	82	63	8.8	44	87
Acidity, as $CaCO_3$, ppm	3	2	0	8	3	2	1	10	3	2	0	5
Hardness, as $CaCO_3$, ppm	75	18	49	138	75	18	47	127	70	17	44	115
Ca, ppm	21	4.7	13	34	20	4.5	14	30	19	4.3	12	29
Mg, ppm	5.5	2.8	2.7	15.8	5.8	2.8	1.7	13.1	5.5	2.1	2.4	10.2
Cl, ppm	20	9	5	39	15	7	5	32	13	5	6	24
SO_4, ppm	11	4	1	19	12	3	8	21	12	5	8	32
NO_3, ppm	1.8	1.9	0.4	10.4	1.6	2.7	0.4	14.4	1.5	3.1	0.0	16.3
Fe, ppm	1.0	0.75	0.3	3.4	0.5	0.5	0.0	1.9	0.6	0.6	0.1	2.1
PO_4, ppm	0.2	0.2	0.0	1.1	0.2	0.1	0.0	0.4	0.1	0.08	0.0	0.4
K, ppm	1.3	0.41	0.5	2.5	1.8	0.84	0.8	4.8	1.3	0.33	0.7	2.0
Na, ppm	9.5	3.7	3.9	16.0	6.8	2.7	2.9	12.0	5.8	2.4	1.7	11.3
Si, ppm	3.5	0.54	2.4	4.7	3.1	0.48	1.8	3.8	3.4	0.38	2.6	4.1
Specif. cond., μmhos/cm	170	31.9	122	247	177	33.6	115	247	162	26.9	128	221
Suspended solids, ppm	22	13	0	65	15	13	1	43	9	12	1	44
Dissolved solids, ppm	121	27	75	177	112	19	79	149	101	19	71	131
Total solids, ppm	142	25	105	189	126	18	83	156	111	17	75	138
Kjeldahl N, as N, ppm					0.5	0.2	0.3	1.1	0.4	0.2	0.2	1.1
Mn, ppm	0.1	0.1	0.0	0.2	0.0	0.02	0.0	0.1	0.0	0.05	0.0	0.2
Cr, ppm												
Sr, ppm[A]	0.063	0.014	0.039	0.088								
Discharge, cfs[B]	21,420	8,188	13,490	40,790	31,340	14,290	18,870	66,450	38,880	17,400	22,600	76,820

[A]Chemical analyses of samples from CRM 14.4, and of samples from all stations for Sr, by ORNL on *filtered* samples. Chemical analysis of all other samples by Tennessee Stream Pollution Control Board on *raw* samples.

[B]Not discharge-weighted. Discharge data is time-weighted.

[C]Sampling period, December 1960 through November 1962.

[D]Standard deviation of discharge-weighted monthly samples from discharge-weighted mean for sampling period.

[E]Standard deviation of discharge-weighted weekly samples from discharge-weighted mean for sampling period.

[F]Sampled for 19-month period only, May 1961 through November 1962.

[G]Sampled for 42-week period, March 19–25, 1961 through December 31–January 6, 1962. Maximum, Minimum, Mean, and Standard Deviation are for *weekly* samples.

[H]Sampling period, November 28–December 4, 1960 through January 3–8, 1962. Maximum, Minimum, and Mean are for *weekly* samples.

[I]Sampling period, November 27–December 3, 1960 through November 25–December 1, 1962. Maximum, Minimum, and Mean are for *weekly* samples.

[J]Sampled for 85-week period only, April 16–22, 1961 through November 25–December 1, 1962.

[K]For 19-month period only, May 1961 through November 1962.

[L]Sampling period, August 1960 through November 1962.

It will be noted from the tables that the stable inorganic chemical composition of each of the two rivers has been fairly constant, except for rather wide variations in the suspended sediments and a few other related constituents. Tennessee River water contains somewhat less calcium, magnesium, bicarbonate, and suspended and dissolved solids, and somewhat more sodium and chloride, than dose the Clinch River water. In the water of both rivers, however, the predominant constituent is the anion bicarbonate, and the predominant cation is calcium. At downstream stations the concentration of suspended materials is generally less than at upstream stations.

Statistical comparisons of variations in concentration between constituent pairs were produced by one of the computer programs used in the analysis of the stable chemical data. Correlation and regression coefficients, and squares of the standard errors of estimate, were calculated for chemical constituent pairs for each of the sampling stations. Correlations were considered to be significant if the correlation coefficients were significantly different from zero at the 99.7% confidence level and had relatively small standard errors of estimate.

Certain gross interpretations can be suggested on the basis of the calculated correlation coefficients.[13] Turbidity, apparent color, and centrifuged color have a positive correlation with suspended solids, as expected. For example, the correlation coefficient obtained from a comparison of variations in the turbidity with variations in the suspended solids content of 24 weekly water samples from CRM 41.5 is 0.76. This is well above the value 0.47 which would indicate a probability of 99.7% that the correlation is significant. Iron and manganese, and at some stations silica and potassium, appear also to vary in the same manner as the suspended

material in the water, suggesting that those constituents are present in the water primarily as solid particles.

In the Tennessee River, the specific conductance of the water appears to vary directly with the content of the major ionic constituents in the water, with notable exceptions of calcium and bicarbonate. These two constituents do not appear to be related to specific conductance in the Clinch River either. This might be taken to indicate that appreciable amounts of these two ions are in the water in the form of suspended particulate matter.

The suspended sediment content, turbidity, and color of Tennessee River water vary directly with discharge, but this pattern is not apparent in Clinch River water. At two stations, stable strontium shows a positive correlation with calcium, as one might expect if the two chemically similar elements were both derived from natural weathering processes. In the lower Clinch River, however, stable strontium varied inversely with suspended solids, suggesting that the strontium may have been associated with solids which were removed from the water during sedimentation, or was diluted by runoff with low strontium content.

Extraneous Sources of Release of Radionuclides to Clinch River

In portions of the Clinch River Study that involve radionuclide loads in the river, calculations of the loads are based on the assumption that the only significant releases of radioactive liquids to the Clinch River are the monitored discharges through White Oak Dam. It is desirable to occasionally provide assurance that no other release points exist. A four-phase investigation for this purpose was conducted during 1963.[14]

The gates in White Oak Dam were closed on April 8, 1963, and fluorescent dye was mixed with White Oak Lake water along the upstream face of the dam. After 24 hours, water samples for fluorescent analysis were collected from very small seeps and small puddles on the creek overbank immediately downstream from the dam. No fluorescent dye was detected in the samples. However, flow in the small seeps appeared to have increased slightly and the creek overbank had become more wetted as a result of the higher lake level, which suggested a minor amount of seepage through the earth-fill dam.

On March 1, 1963, a visit was made to the Tower Shielding Facility, which is the only ORNL facility outside the White Oak Creek drainage basin from which radionuclides might enter the Clinch River. It was learned that the reactor cooling water at this facility normally circulated in a closed system. When radioactive liquids were to be released from the reactor they were piped into a large closed tank, and later transferred to a tank truck and transported to the ORNL area within the White Oak Creek basin for disposal. This arrangement appeared to preclude unmonitored contamination of the river from the Tower Shielding Facility.

Several water samples were collected on February 21, 1963 from small streams draining areas adjacent to the White Oak Creek drainage basin and from the two streams that drain the Y-12 area. Sample locations are shown in Fig. 1. Gross-gamma counting of the samples showed no radioactivity above background.

The data collected in the surveys described above indicate little possibility that significant amounts of radioactive contamination is introduced into the Clinch River through surface drainage at any place in the Oak Ridge reservation except White Oak Dam and

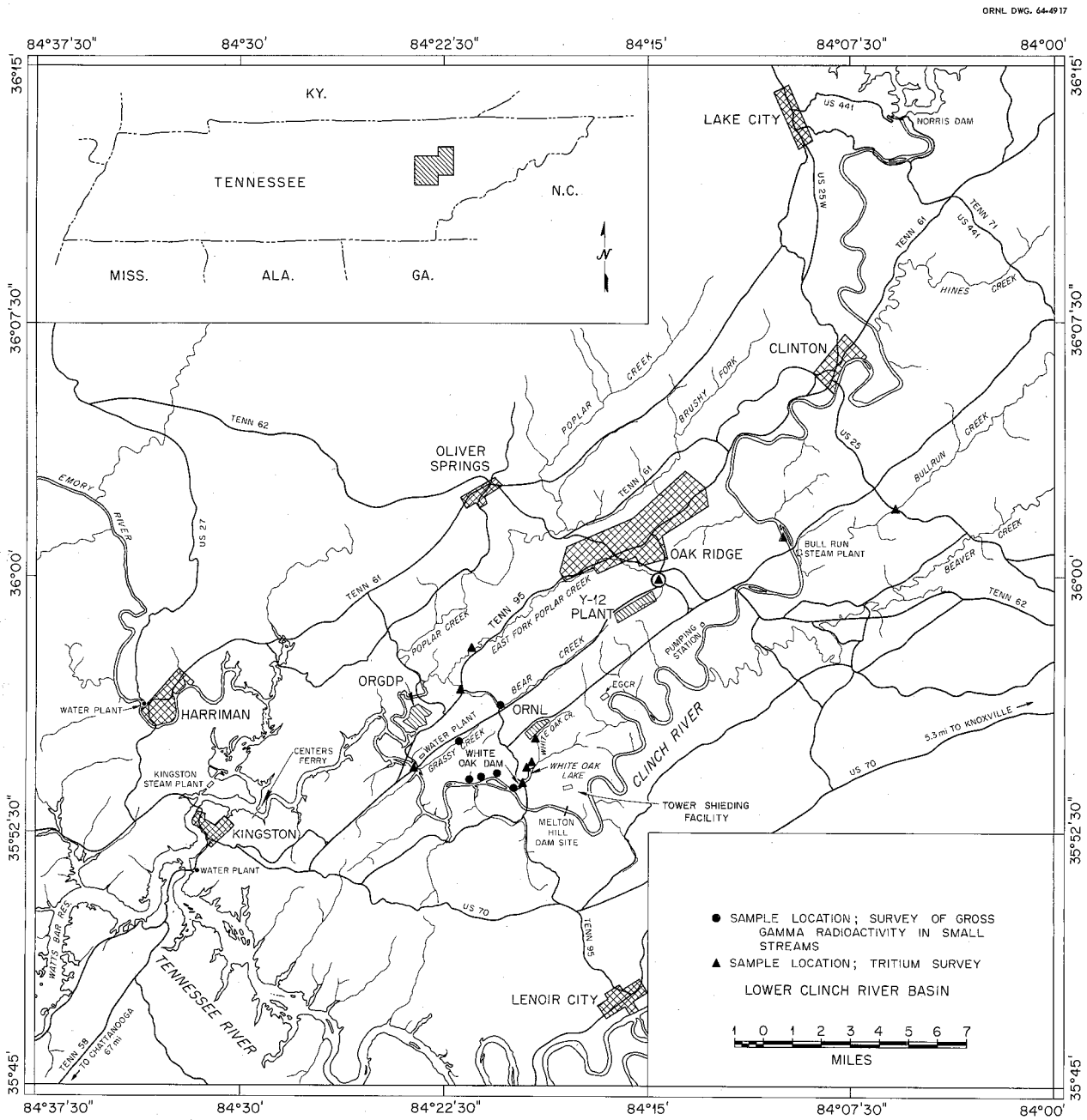

Fig. 1. Sampling Locations for Surveys of Gross Gamma Radioactivity and Tritium in Streams, Oak Ridge Area

the ORGDP area. Drainage from ORGDP is either inside the security fence or is affected by Clinch River waters, and thus could not be readily checked. However, it is known from the operations at ORGDP that gross quantities of fission products are not handled at that plant.

On February 15, 1963, ten water samples were collected from the area in and around the Oak Ridge reservation and submitted to the U. S. Geological Survey Tritium Laboratory in Washington, D. C. for determination of their tritium contents. Four of the samples were collected from sources in the White Oak Creek basin known to contain radioactive wastes. These sources were: the effluent from the process waste water treatment plant at ORNL; Well No. 57 in the waste disposal pit area; water from the weir west of the waste pit area which included surface seepage west of the area; and water from White Oak Lake at White Oak Dam. Analyses of these samples showed the tritium contents given in Table 3. The results show that tritium was present in the wastes sampled and in White Oak Lake water.

Six water samples were collected from four streams in the Oak Ridge area outside the White Oak Creek basin in order to obtain a background value for the tritium content of streams in the area. Samples were collected from the Clinch River at CRM 48.2 and 14.4, Bull Run Creek at Highway 25W, East Fork of Poplar Creek at Pine Ridge and at the gaging station near its mouth, and Bear Creek at the gaging station near its mouth. The results of the analyses of these samples are shown in Table 4. The reason for the rather high "background" concentration of tritium in the two samples from the Clinch River is not known; and the source of the even higher tritium content of Bear Creek downstream

Table 3. Tritium Analyses of Water Samples Contaminated with Radioactive Wastes

Source	Concentration	
	Tritium Units*	pc/l
Process Waste Water Treatment Effluent	105,000	336,000
Well No. 57 in Waste Pit Area	675,000	2,160,000
Weir West of Waste Pit Area	833,000	2,666,000
White Oak Lake at White Oak Dam	43,000	138,000
Maximum Permissible Concentration (water):		
MPC_W (continuous occupational exposure)	0.93×10^7	3×10^7

*Definition of Tritium Unit: A tritium unit (1TU) corresponds to a concentration ratio of 1 atom of tritium (^3H) to 10^{18} atoms of hydrogen ($^1H + {}^2H + {}^3H$). There is a tendency now to call this value the "Tritium Ratio" rather than "Tritium Unit".

The concentration of tritium in water is easily converted from tritium units to curies per volume; i.e., multiply the concentration in TU's by 3.2 to convert to picocuries ($\mu\mu c$) per liter (see last column in table above, and Table 4 below.

Table 4. Tritium Analyses of Water Samples from Streams in Oak Ridge Area

Source	Concentration	
	Tritium Units	pc/l [a]
Bear Creek at gage	1110	3550
Clinch River at CRM 48.2	430[b]	1375
Clinch River at CRM 14.4	530[b]	1695
East Fork of Poplar Creek at Pine Ridge	287	920
East Fork of Poplar Creek at gage	244	780
Bull Run Creek at Highway 25W	230	735

[a]See footnote under Table 3.

[b]Average of duplicate analyses; difference is approximate contribution from White Oak Lake.

from the Y-12 plant has not been determined. The higher concentration in Clinch River at CRM 14.4 than at CRM 48.2 may be due to tritium discharged to the river through White Oak Creek.

RADIOACTIVITY IN BOTTOM SEDIMENTS

The various studies of river sediments have taken an unusually large proportion of time and effort in the Clinch River Study during the period covered by this Status Report (April 1962 to December 1963). Sediment investigations, which are of basic importance in the river study, have included review of much existing data from TVA surveys of sediment deposition, results from extensive core-sampling of river sediments, data from laboratory analyses of the cores, experimental studies of the behavior of radionuclides in sediments, and special investigations to define relevant factors in the incorporation and retention of radionuclides in sediments.

Most of the sediment studies mentioned above are reported in the several subsections below. Only a summary is given of a voluminous report on data evaluation which was prepared by the Subcommittee on Bottom Sediment Sampling and Anslysis. Also the data from specific laboratory analyses of cores of Clinch River sediments collected during the summer of 1962 are not included. It is planned that the report on data evaluation, mentioned above, and the analytical data from the core analyses will be published separately in a two-part supplement to this status report (ORNL-3721, Supplement No. 2, Parts A and B, in preparation).[15, 16]

Summary of Report on Data Evaluation

A report evaluating the data available in January 1963 pertaining to radioactivity in sediments of the Clinch and Tennessee Rivers was prepared by the

Subcommittee on Bottom Sediment Sampling and Analysis. The subjects considered in this report included: sediment deposition, distribution of radioactivity in time and space, downstream limits of detection, physicochemical characteristics, sampling tools, retention of radioactivity in bottom sediments, radiation dosage, and recommendations. Credit for the data and reports used in this evaluation was accorded to personnel of the ORNL Applied Health Physics Section, ORNL Waste Disposal Research Section, U. S. Public Health Service, U. S. Geological Survey, and the Tennessee Valley Authority. A summary of the subcommittee's report, including the recommendations, which was presented at the meeting of the Steering Committee in Cincinnati, Ohio on February 6, 1963, is given below, (pages 29 to 41).

Factors that Influence Radionuclide Concentration

Of the many physicochemical factors that may influence the deposition and retention of radioactive materials in bottom sediments of the Tennessee River system, a few have been observed specifically though not fully defined. Two important factors that have been identified are: (1) annual variations in the radionuclide loads released through White Oak Dam, and (2) channel geometry. Other significant factors which have been investigated are mineralogy, particle size, water depth, and exchangeable calcium in the sediment.

Radionuclide Loads Released.-- Data on the total quantities of radionuclides released through White Oak Dam have been compared with data on concentrations of

radionuclides at the surface of bottom sediments downstream during concurrent periods. These data indicate that concentrations in the sediments vary directly with changes in the radionuclide loads released. This is illustrated in Fig. 2 (page 31) by comparing the concentration of ^{137}Cs in sediments at CRM 1.1 to the annual releases of this radionuclide through White Oak Dam. From records furnished by the ORNL Applied Health Physics Section, similar relationships have been found for ^{90}Sr, ^{106}Ru, and ^{144}Ce at CRM 1.1.

Plots of data for other observation sections in the Clinch and Tennessee Rivers have shown relations similar to those for CRM 1.1 illustrated in Fig. 2. These relations could be explained by either of two hypotheses regarding the incorporation of radionuclides in the bottom sediments. These hypotheses are: (1) that radionuclides are sorbed on suspended sediments prior to their release through White Oak Dam and the annual samples of bottom sediments are representative of sediment deposited during the entire preceding 12 months; and (2) that the radionuclides are released through White Oak Dam as ions in solution and that variations in the amount of a particular radionuclide released cause similar variations in its concentration in the river water and in the amount sorbed *in situ* by the bottom sediments.

The first hypothesis, "(1)" above, presupposes regular, continuous deposition of sediment during the 12 months preceding sampling. The second hypothesis, "(2)" above, presupposes rapid establishment of chemical equilibrium between the water and sediment. It, too, presupposes regular, continuous deposition of sediment over the sampling section unless there are fairly constant releases of radionuclides during the year. Without this constancy in releases, each incremental layer of sediment must be covered by other

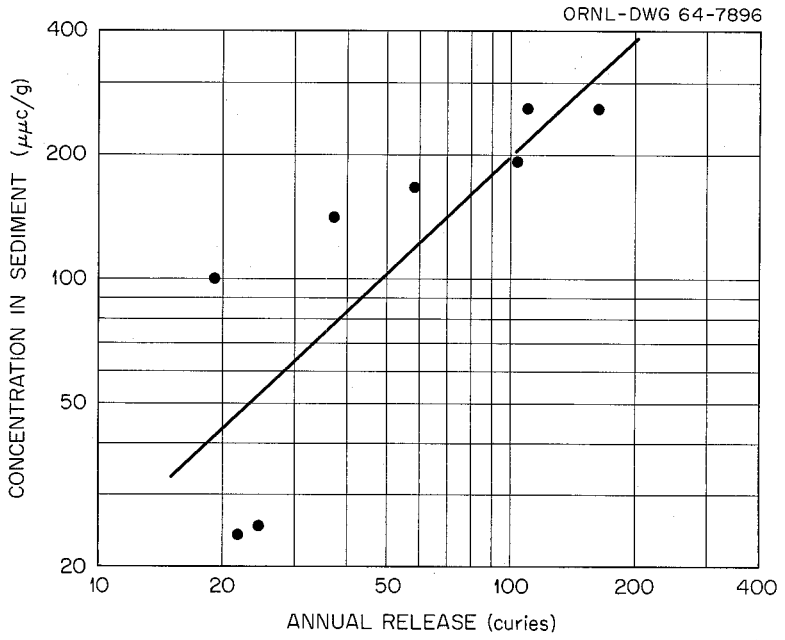

Fig. 2. Comparison of Concentrations of Cesium-137 in Bottom Sediments at CRM 1.1 Determined Annually to Annual Releases of this Radionuclide from White Oak Lake

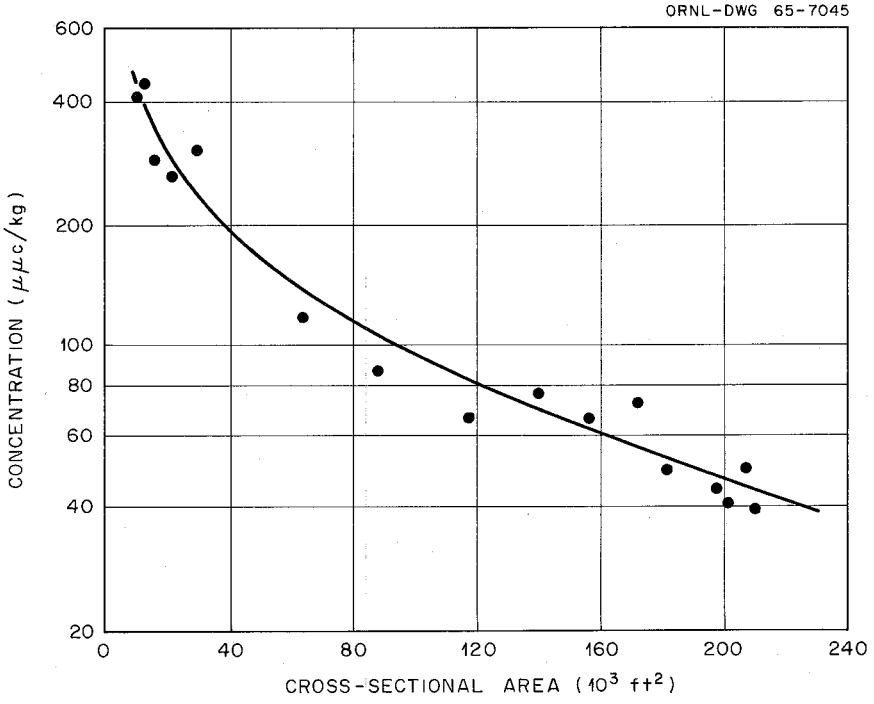

Fig. 3. Variation of Total Identified Radionuclide Concentration in Sediments with Cross-Sectional Area of Flowing Water

sediment and isolated from contact with river water; otherwise the sediment sample taken annually would represent equilibrium only with the radionuclide concentration in the river water just before sampling. In the aggregate of sediment deposition and scour over a period of time, a net increase or net loss in the sediment accumulation at a particular sampling section is not a prerequisite for either hypothesis.

It is known from monthly monitoring data that the amounts of radionuclides released through White Oak Dam have not been constant during the 12-month observation periods. Also, data from TVA sediment surveys indicate that deposition of sediment at the sampling sections is not continuous. The only part of the study reach in which net deposition has occurred in every 5-year sediment-survey period is downstream from the mouth of the Emory River. It must be assumed, therefore, that the sediment removed during periods of scour does not cause net sediment loss over a major width of the section. Pertinent TVA sediment range sections show wide zones of continuous, net accumulation of sediment on the sides of the stream channel, and only limited zones in the deeper parts of the channel which are subject to scouring. Such scouring is probably the result of a few periods of high flow in winter.

In the case of ^{137}Cs, it is known that more than 80 percent of the radionuclide in the water passing through White Oak Dam is associated with suspended solids.[8] It is also known that the reaction by which cesium is sorbed on the sediment is not readily reversible (see later section on behavior of nuclides, (pages 52 to 62). It may be assumed, therefore, that the incorporation of ^{137}Cs into bottom sediments conforms to hypothesis (1).

The direct relationship of radioactivity in sediments to the load of radionuclides released is useful in establishing the longitudinal limits of detection of fission products.

Surveys of radionuclides in bottom sediments were extended beyond Guntersville Reservoir to the Ohio in 1961. Based on these surveys, contamination of bottom sediments from the mouth of White Oak Creek to the junction of the Tennessee River with the Ohio River near Paducah, Kentucky was limited to ^{106}Ru. Contamination with ^{137}Cs, ^{90}Sr, ^{144}Ce, and ^{60}Co extended into Pickwick Landing Reservoir; and contamination with ^{95}Zr- ^{95}Nb and with ^{90}Y and trivalent rare earths extended into Guntersville Reservoir. In earlier years, the annual releases of ^{137}Cs, ^{90}Sr, ^{60}Co, and ^{144}Ce have been several times higher than in 1961. Thus, their contamination of bottom sediments (observed at the surface of the sediments) may have extended downstream to the Ohio River at some previous time.

Contamination of bottom sediments in the Clinch River has not extended upstream from White Oak Creek except in the three-year period of 1957-59. In these years radiation levels above background were detected at least 0.7 mile but less than 3.3 miles upstream from the mouth of White Oak Creek. In the Tennessee River, no radioactive contamination has been detected at an observation section a short distance upstream from the mouth of the Clinch River.

Channel Geometry.-- Two factors which have important influences on the concentration of radioactive materials in bottom sediments are the surface area of the channel bed and the curvature of the channel. These two factors come under the general term "channel geometry".

W. D. Cottrell, in 1959, noted that the concentration of radioactivity is decreased as the radioactivity is dispersed over a larger area.[17] Decrease in concentration with an increase in surface area can be inferred by the relation shown in Fig. 3, page 31, in which the concentration of radioactivity decreases with an increase in cross-sectional

area. In the Clinch and Tennessee Rivers the cross-sectional area of the river channel bears a direct relationship to the surface area of the bottom sediments because the wetted perimeter in most sections increases as the cross-sectional area increases.

The influence of velocity, or more fundamentally of turbulence, must be tacitly recognized in considering the effects of cross-sectional area upon radionuclide concentrations in sediments. In this particular river system, increases in cross-sectional or surface areas coincide with decreases in velocity. Decreases in velocity and in turbulence should permit smaller particles to settle to the stream bed. Cottrell[17] noted the tendency for the radioactivity levels in bottom sediments to be low in the first few miles downstream from a dam (higher velocities) and to increase further downstream in the reservoir (lower velocities). The decrease in concentration immediately downstream from a dam was attributed to bottom scour. The tendency for radioactivity to increase in the downstream direction within a reservoir has been observed repeatedly.

Without considering localized influences, such as variations in flow area within reservoirs and in channel curvature, the general trend in radionuclide concentration in the Tennessee River is a decrease in the downstream direction. The downstream decreases in concentration of cesium, ruthenium, cobalt, and strontium observed in bottom sediments at several points in the Tennessee River have been compared with predicted reductions based on (1) dilution by flow, and (2) dilution by uncontaminated sediments. The observed reduction in concentration of each radionuclide, except ^{90}Sr, was greater

than the predicted reduction due to dilution by flow but not as great as the reduction predicted from dilution by uncontaminated sediment. The reduction in the concentration of ^{90}Sr was about equal to that predicted by flow dilution.

The downstream variation of radioactivity in the Clinch River is more complex and both increases and decreases in concentration with distance have been observed. The general trend is for the concentration in sediments to increase in the downstream direction but there is a zone of relatively high radioactivity that seems to center between CRM 8 and CRM 12.

Channel curvature is another aspect of channel geometry which has been found to influence radioactivity in the bottom sediments. From the available data it appears that the concentration of radioactivity in the sediments decreases as curvature increases, and that more deposition of sediment with higher concentrations of radioactivity have been observed in the portions of a section that are on the inside of a bend. Some aspects of the influence of bends on sediment deposits were discussed in an earlier status report.[18]

Physicochemical Properties of Sediments. -- Physicochemical properties of bottom sediments in the Clinch River that have been investigated are size distribution, mineralogy, sorption capacity, and exchange capacity. For these investigations analytical tests have been performed only on composites of cores collected in sections spaced 1 to 3 miles apart. Definite conclusions about the influence of physicochemical properties of the sediments must await more intensive sampling programs, but some preliminary judgments can be formed.

Sorption of radionuclides on river sediments can be expected to increase with decreasing particle size because: (1) the relative content of clay minerals, the mineral group with the highest cation sorption capacity, usually increases as the median particle size of the sediment decreases; and (2) surface area (area per unit weight) increases as particle size decreases and the exchange capacity in many minerals varies directly with surface area of the particles. A relationship between particle size and sorbed radioactivity (^{137}Cs) is shown in Fig. 4. The ^{137}Cs concentration has been adjusted for the influence of the "areal dilution" illustrated in Fig. 3 because the correlation coefficient is more significant if the areal dilution is considered.

The reasons for the generally low ^{90}Sr concentrations in the bottom sediments, and for variations in the stable strontium concentrations, have been suggested by the results of exchange capacity tests. The low strontium concentrations appear to be the result of low exchange capacity of the sediments and the high concentrations in Clinch River water of dissolved calcium, which competes with strontium in exchange reactions. Variations in concentration of ^{90}Sr in the bottom sediments appear to be directly related to the "exchangeable" calcium associated with these sediments. The results of sorption tests, exchange capacity tests, analyses of river water, and pH determinations lead to the conclusion that much of the strontium is associated with, and much of the "exchangeable" calcium is derived from, calcium carbonate incorporated in the sediments rather than calcium ions sorbed by the sediments.

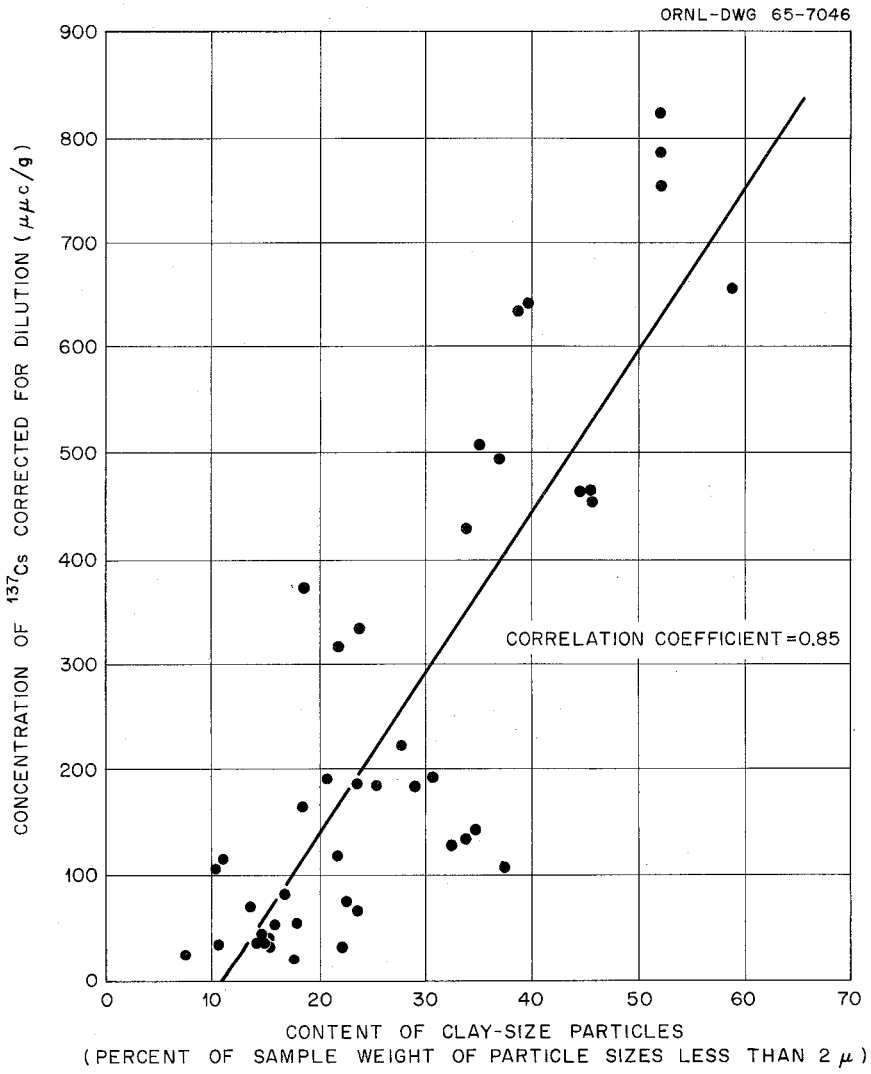

Fig. 4. Relationship between Cesium Concentration and Clay-size Particle Content of Bottom Sediments of Clinch and Tennessee Rivers

Inventory of Radioactivity in Bottom Sediments

Investigations of factors that influence the retention and deposition of radioactivity in bottom sediments have not reached a status that permits an assessment of the total activity held in these sediments. In reaches where information indicates that there has been continuous deposition of sediment, computations to assess this total may be possible, assuming constant rates of deposition and collection of representative dredge samples annually. Such computations would only be feasible in the reach of Watts Bar Reservoir extending from the mouth of the Emory River on the Clinch River to Watts Bar Dam on the Tennessee River. In this reach observations by TVA at the sediment ranges indicate a relatively long-term trend toward continuous accumulation of radioactive sediments. Upstream from this reach, in the Clinch River, alternate periods of gains and losses in sediment deposits have occurred; in the fifteen years that sediment deposition has been measured the gain has been slightly greater than the loss (from records of TVA surveys). Downstream from this reach, in the Tennessee River, the changes in the volume of sediment deposits in Chickamauga Reservoir have been almost negligible, based on review of records furnished by TVA.

In the Clinch River, upstream from the mouth of the Emory River, results of a reconnaissance coring survey did suggest that only a small fraction of the radionuclides released to the river are retained in the channel bed. Based on this survey, made in 1960, there are perhaps 70 curies of fission products in the upper 6-10 inches of sediments between the mouths of White Oak Creek and the Emory River. The coring tool used in this survey did not penetrate the entire thickness of the radioactive sediments; downstream from CRM 14 the thickness of the sediments averaged about 2 1/2-3 feet

while upstream the thickness was somewhat less. It appears that with complete penetration the results of such a coring program would indicate a total activity only a few times greater than 70 curies. This total radioactivity in the stream bed is relatively small in comparison with the gross beta activity released and passing down the river, and would indicate a small factor of retention by the sediments. For example, the annual releases to the Clinch River of gross beta activity in the two years 1959 and 1960 were 937 curies and 2190 curies, respectively.

Sediment Sampling Equipment

The coring work in 1960 and other field work provided means for evaluating equipment used in investigations of radioactivity in bottom sediments. For example, the results of the preliminary coring program showed that longitudinal variations in radiation levels were much the same by various methods of determination. However, quantitative estimates of the radionuclide content of the full depth of sediments could not be made because of deficiencies in coring equipment, especially plugging of the sampler and compaction of the core.[19]

Field evaluation of various coring devices showed good penetration and undisturbed samples were obtained if the coring tools were tubes at least 3-1/2 inches in diameter with sharp, smooth cutting edges. Sample retention in these tubes was greatly improved if spring-finger retaining rings were used. A volumetric silt sampler developed by TVA and a Phleger-type coring sampler developed by personnel of ORNL and USGS were found to be useful for full-depth sampling in this evaluation.

For reconnaissance the hand operated dredge (Ekman or Pettersson) was found to be advantageous. However, the usefulness of small dredges in studies of bottom sediments requiring quantitative determinations is limited because the sampling depth for the dredges is difficult to determine, the sample is disturbed, and the small-particle fraction of sample may be lost by washing.

Other equipment considered in the data evaluation report are devices to measure the horizontal distribution of radioactivity in bottom sediments by in-situ measurements of gamma radiation at the surface of the sediments. Most devices used for such measurements perform well in the Clinch River. Further downstream in the Tennessee River the relatively high levels of natural radioactivity and fallout as compared to levels of radioactivity released from ORNL tend to limit the usefulness of these detectors. Garner and Kochtitzky[20] felt that the variations in radiation levels observed downstream from Hales Bar Dam in 1952 were due to the variation in the deposition of naturally occurring radioactive sediments in the river. In 1961, even though fission-product contamination was observed, the variations and magnitude of the radiation levels downstream from Hales Bar Dam were about the same as in 1952.

Efforts to estimate gamma dose rates at the surface of bottom sediments from "Flounder" count rates are discussed in the report. The Flounder instrument is calibrated with a radium source. Definition of the dose rate from the Flounder count rate has proved to be very difficult because of differences in the spectrum of radiation from the radium source and from the river sediments, and also the different and indefinite shapes of the radiation sources in sediment deposits as compared to the calibration source.

Recommendations

The summary of the data evaluation report included definite recommendations for a comprehensive program of investigation of radioactivity in bottom sediments. However, since that time, the program plans have been modified to meet project time schedules and the recommendations originally submitted will not be repeated here in detail.

In brief, the recommendations urged efforts to increase information about the absolute retention of each radionuclide in bottom sediments in the Clinch River. This determination would provide a better understanding of the influence of bottom sediments on the transport of radionuclides through the river, assist in evaluation of the usefulness of streams for the disposal of radioactive materials, and provide a better basis for safety evaluations.

The importance of geochemical studies to delineate the physicochemical processes which lead to the incorporation of radionuclides in bottom sediments was emphasized. It was suggested that the geochemical studies should include investigations of the physicochemical state of radionuclides in bottom sediments and in the river water, of sorption by lithologic biotic sediment, of desorption processes, and of the depth to which chemical reactions occur in the deposited material.

Core Sampling of Bottom Sediments in the Clinch River

Introduction

Numerous undisturbed core samples of bottom sediments in the Clinch River were obtained during the summer of 1962 in order to define the horizontal and vertical distribution of radioactivity in the bed of the river. The Swedish Foil Sampler was used in the 1962 coring program.[21] This sampler, which takes cores slightly less than 3 inches in diameter, was selected as the best tool for obtaining "undisturbed" sediment samples.

It was expected that after the vertical and horizontal distribution of activity had been determined the core samples would provide information on: (1) the concentration of each of the major radionuclides in the bottom sediments at the 14 cross sections sampled and the total amount of each radionuclide present in the study reach; (2) the distribution of major radionuclides and of physicochemical components in the sediments; (3) the chemical form of radionuclides and thereby the mechanisms by which they were incorporated in the bottom sediments; and (4) characteristics of sedimentation in the Clinch River.

The primary purpose of the investigation was to obtain quantitative data concerning the fate of radioactive materials currently being discharged to the river -- the first general objective of the Clinch River Study. Also, the investigation was designed to contribute to the second general objective of the Clinch River Study, namely, to determine and understand the mechanisms of dispersion of radionuclides released to the river.

A brief summary of the coring study and an indication of the results are given below. A more detailed account is being made available in Part B of the supplement to this status report, prepared for separate distribution.[16]

Coring Operations

More than 130 cores were collected from the portion of the Clinch River downstream from CRM 23 during June, July, and August 1962. Results of the coring work were reported at a meeting of the Steering Committee on February 6, 1963.[5]

The Swedish Foil Sampler is a piston-type sampler in which thin axial strips (foils) are used to decrease friction between the sediment core and the sample tube while coring is proceeding. Cores as much as 14 ft in length were obtained in water as much as 45 ft in depth using a drilling tower mounted on a barrel float. The sampling operation was carried out by a contractor (Sprague and Henwood, Inc.) whose personnel were specialists in sampling with this device.

Cores were obtained at 4 to 12 verticals across each of 14 cross sections in the Clinch River, some of which were located at TVA sediment ranges. In addition to the cross sections sampled in the Clinch River, 2 sections in the Emory River and 2 sections in Poplar Creek were sampled. The locations of the sections where coring was done are shown in Fig. 5. Sections were selected for sampling on the basis of the longitudinal variation in radiation levels determined in 1960 and 1961 by personnel of ORNL and USGS. The location of the sampling verticals in each section was based on radiation levels measured *in situ*, and penetrometer probing of sediment depths. These two types of measurements were made immediately before coring.

From 218 coring attempts in the Clinch River, which included a number of "second tries", 136 satisfactory cores were obtained. A total of 27 cores were obtained from Poplar Creek and the Emory River. The location by river mile of each of the sections where coring was done and the number of cores obtained at each station are listed in Table 5.

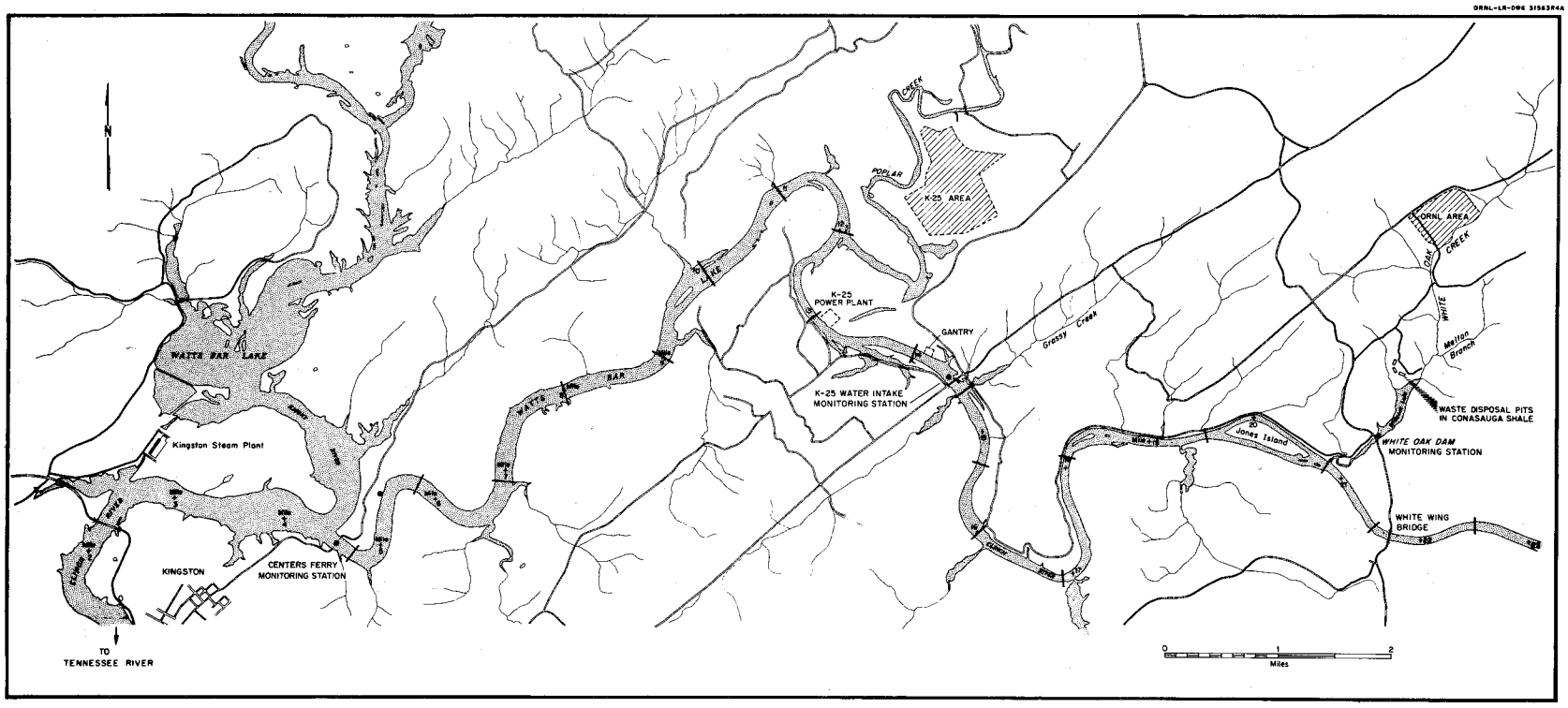

Fig. 5 Map Showing Locations of Sediment Core Sampling Stations

Table 5. Summary of 1962 Sediment Coring Program

Location Mile*	Number of Coring Sites	Number of Cores Taken**	Number of Cores Gross Gamma Scanned	Feet of Core Gross Gamma Scanned
		CLINCH RIVER		
CRM 1.3	10	13	11	37.9
4.3	12	14	11	33.5
7.5	9	10	10	50.1
10.0	10	14	14	52.8
11.9	10	14	14	58.4
12.1	11	15	12	53.5
14.0	5	6	6	38.0
16.0	7	7	7	20.6
17.5	6	8	8	40.7
19.2	5	6	6	20.0
20.5	8	12	9	17.4
20.8	5	6	5	13.6
21.0	4	6	6	22.7
22.8	5	5	4	23.1
Subtotal	107	136	123	482.3
		POPLAR CREEK		
PCM 3.1	5	5	5	26.9
4.5	6	7	7	19.6
Subtotal	11	12	12	46.5
		EMORY RIVER		
ERM 1.9	7	8	6	11.6
5.1	7	7	5	13.8
Subtotal	14	15	11	25.4
TOTAL	132	163	146	554.2

*Upstream from mouth of stream.
**Includes "second tries".

A graphical summary of experience in the coring program at CRM 7.5 is shown in Fig. 6. The cross-sectional shape, lateral distribution of surface radioactivity, depth of radioactive zone, location of core verticals, depth of penetration, and depth of core recovery are included in this figure.

Gross Gamma Scanning of Cores

The first step in the processing of the cores was measurement of incremental variations in gross gamma radioactivity with depth and analysis of the gamma spectra of individual cores for radionuclide concentrations. These measurements were made with the "core scanner" of which a schematic diagram is shown in Fig. 7.

The cores were scanned in 2-inch increments. It should be noted that the effective slit width of the 2-inch-high collimator was somewhat greater than the actual 2-inch dimension of the slit. The effective slit width was determined experimentally with a 3-inch-diameter plane source of radioactivity; and a computer program was prepared by R. P. Leinius of the ORNL Mathematics Division to compensate for the effect of the greater effective slit width in the incremental determinations of radioactivity in the 2-inch segments of core.

An example of the results of the gross gamma scans for cores obtained at CRM 7.5 is included in Fig. 6. The plots of vertical distribution of radioactivity in Fig. 6 show that there are two segments for which the gross gamma count is a negative value. Study of these plots and those for other cross-sections indicates that the negative values occur only if there is a great difference in the uncorrected gross gamma counts between adjacent segments. The failure of the computer program to compensate perfectly for these large-magnitude changes in a few cases is due to the characteristics of the computer program used and not to the physical character of the cores.

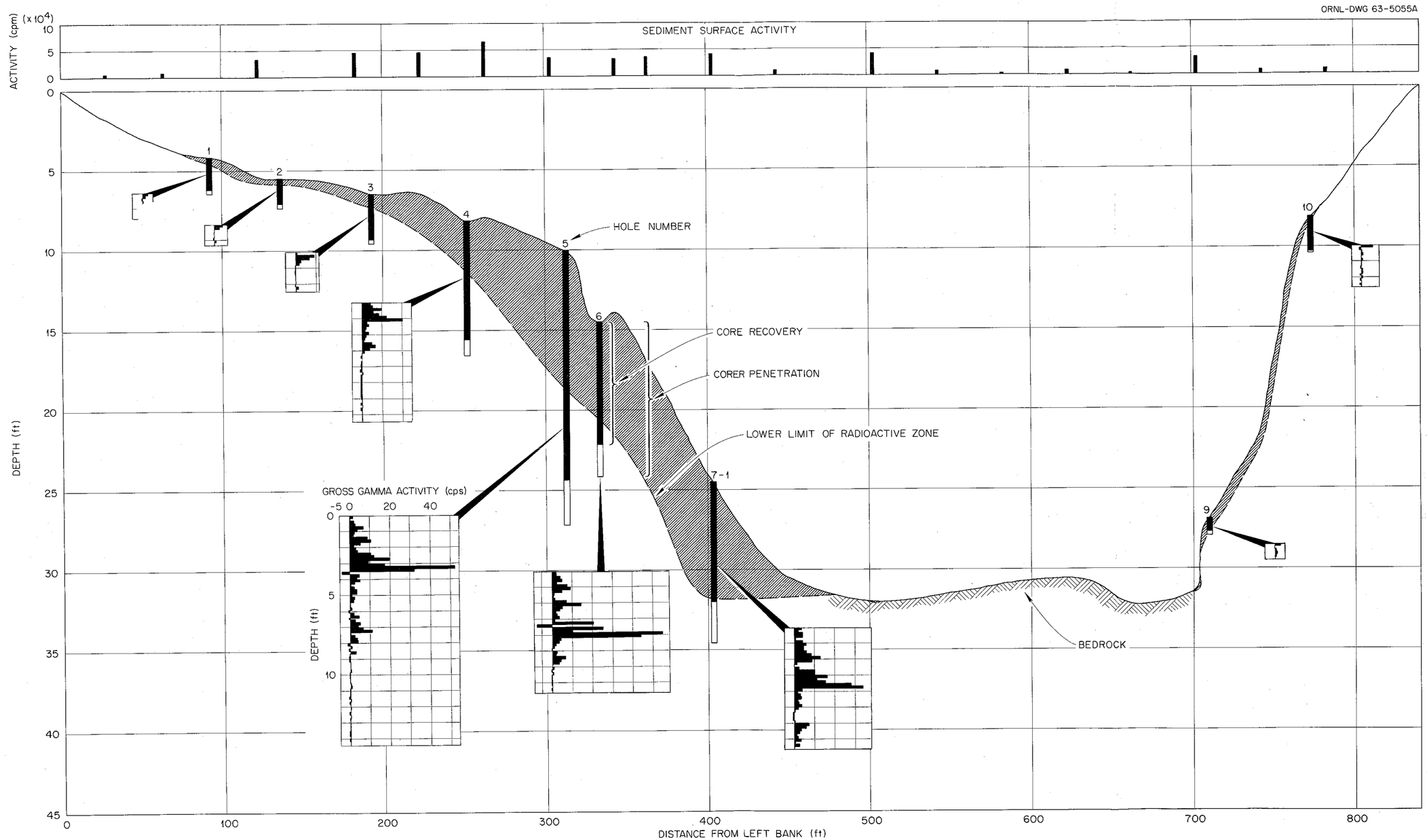

Fig. 6. Variations in Incremental Gross Gamma Radioactivity with Depth in Bottom Sediment Cores from CRM 7.5

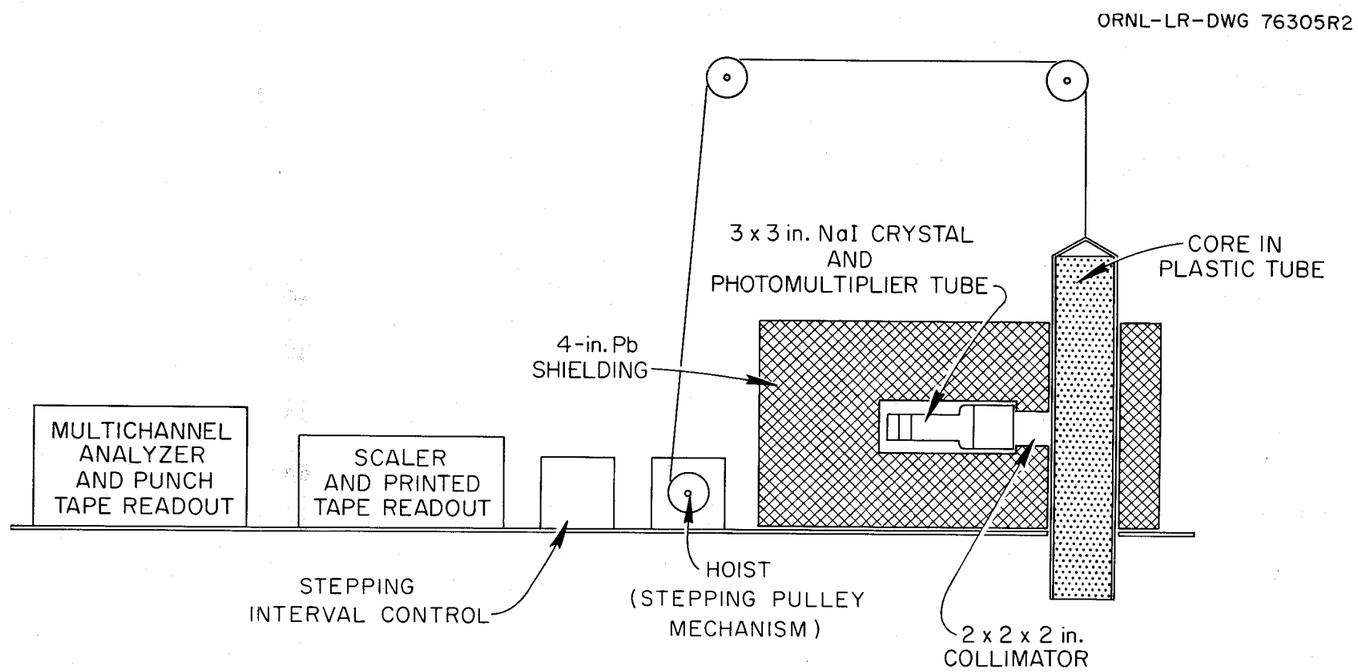

Fig. 7. Schematic Sketch of Components of Sediment-Core Scanner

Diagrams similar to Fig. 6 have been prepared for all sections at which core samples were collected during the summer of 1962. Additional diagrams and more detailed discussion of the vertical distribution of radioactivity found in the cores and the results of other analyses of the cores are given in the separate supplement mentioned above.[16]

The coring data for the section at CRM 7.5 (Fig. 6) and for the other sections indicate that the radioactive sediments are thicker downstream from CRM 14, and this is generally confirmed by the sediment range surveys made periodically by TVA. The single core showing the greatest thickness of radioactive sediment, 8.7 ft, was obtained from Hole No. 5 at CRM 7.5. Upstream from CRM 14 radioactive sediments were largely on the sides of the stream channel. Downstream they were generally thickest on the inside of a bend and on the flatter side of the channel, but extended farther out into the main part of the stream.

From the data obtained by analyses of sediment cores in the downstream portions of the study reach it appeared that there was a recurrent general pattern of variation of gross gamma activity with depth of sediment. Also, the variations of sediment activity were very similar to variations in the annual quantities of ^{137}Cs released through White Oak Dam (see Figure 8). This similarity suggests some interesting implications. Radiological analyses of water samples from White Oak Creek at White Oak Dam and from Clinch River near Centers Ferry showed that cesium present in the water was almost wholly in the suspended sediments.[22] Therefore, it would be expected: (1) that ^{137}Cs would be incorporated into river bottom sediments primarily from sedimentation of suspended matter rather than from chemical interactions in the river; and (2) that, where sediment deposition was normal, variations of radiocesium with depth in the sediments should

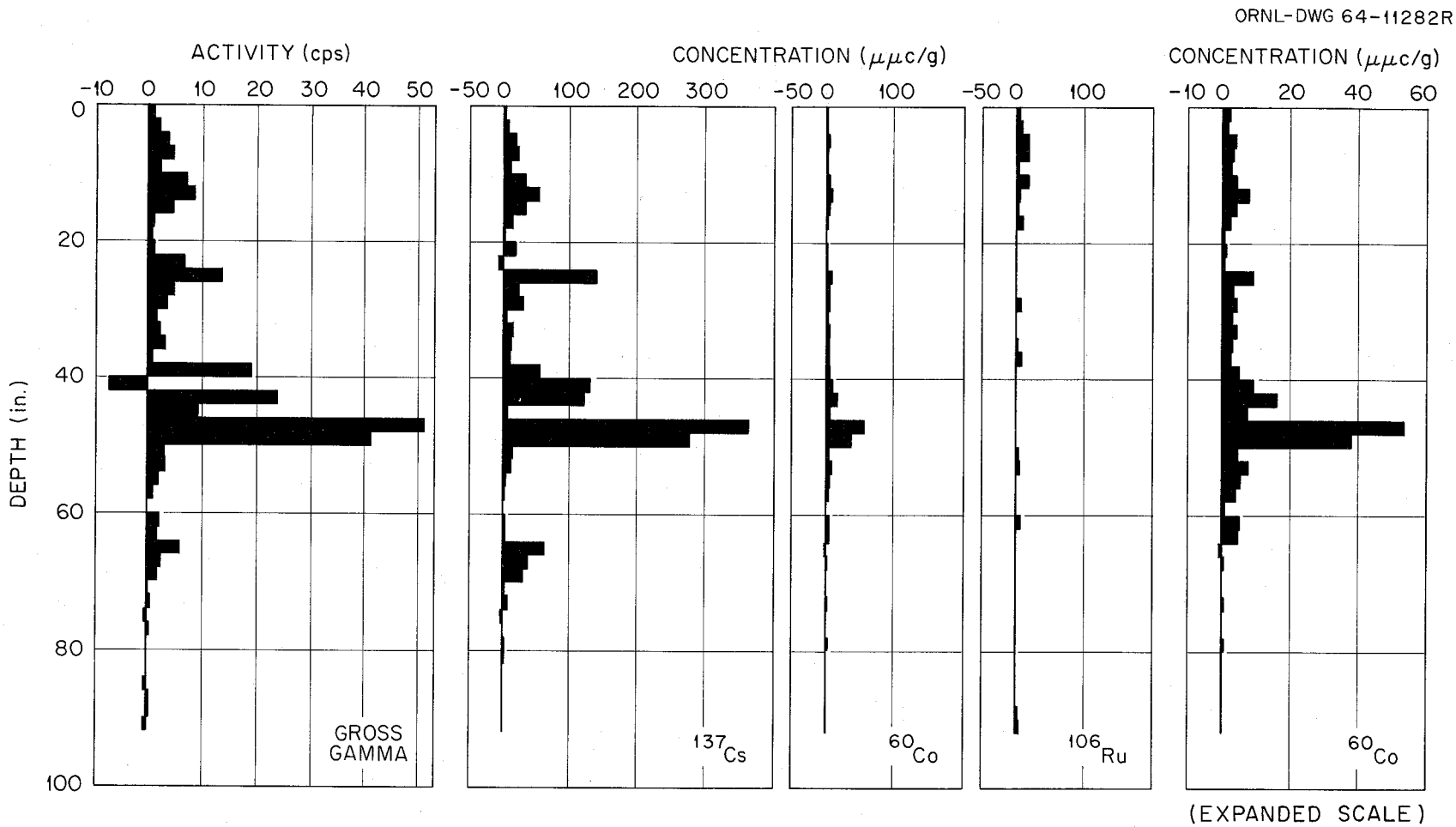

Fig. 8. Variations with Depth in Concentrations of Gross Gamma Activity, ^{137}Cs, ^{60}Co, and ^{106}Ru in Bottom Sediment Core from Hole 6, CRM 7.5.

reflect the variations in releases of ^{137}Cs in past years of which records are available for almost 20 years. In a general way the above appeared to be true.

Few of the cores appeared to show a pattern of gross gamma radioactivity such as would be expected if much of the relatively large releases of ^{106}Ru during the past few years had been incorporated into the river sediments (see Fig. 8). The relatively low levels of gross-gamma radioactivity in the upper layers of the cores suggested that a very small fraction of the ruthenium released to the river was in the sediments. This conclusion was supported by radionuclide mass-balance calculations based on analyses of 1961 Clinch River water samples.[8]

Geochemical Investigations

Because no standard methods have been devised for determining the chemical form of sediment constituents, it was thought advisable to begin work on the geochemical analyses of two selected cores obtained from widely separated river sections. After scanning for gross gamma counts of all cores and gamma spectrum counting of selected cores, the frozen cores were sliced longitudinally using a specially constructed power saw. The detailed work of analysis of the two selected cores was done at various laboratories of the USGS and at ORNL.

Each of the two cores was divided into a number of 2-inch increments on the basis of visual logging and radionuclide scans of each intact core. In addition to radionuclide analyses of the two cores various physical and chemical tests were made and desorption tests were performed. Also it was hoped that as a part of the analytical work the year in which specific core increments were deposited could be identified by comparing the core scans with the pattern of annual radionuclide releases through White Oak Dam. Dating of the cores in this way would provide information on the net sedimentation rates at the sampled cross sections. The extent to which these

hopes were realized is indicated in the separate supplement.[16]

Behavior of Radionuclides Associated with Clinch River Sediments

Radionuclide desorption studies were made as a part of the Clinch River Study in order to determine the release characteristics of nuclides associated with sediments. This information is necessary in assessing the hazards of the systems. Desorption studies also are an aid in devising improved waste-disposal systems, and in defining the dominant natural forces responsible for the retention and migration of the radionuclides in the river system.

A sample of naturally contaminated bottom sediments was obtained from the mouth of White Oak Creek, CRM 20.8, where radioactivity was known to be relatively high. For laboratory studies to simulate naturally contaminated sediment, a bottom sediment sample was obtained from CRM 15.3, and standard clay minerals purchased from Ward's Natural Science Establishment were also used for some tests. Taking advantage of existing information about cesium and strontium sorption, simulated studies of these radionuclides were done with radioisotopes purchased from the ORNL Isotopes Division. Ruthenium studies were made with the ruthenium present in ORNL intermediate-activity waste (tank W-8), and the cobalt isotope was purchased from the Isotopes Division. Most of the work with the latter two elements involved characterization of their behavior in solutions.

Desorption of Radionuclides from Naturally Contaminated Sediment

Duplicate samples of the moist sediment from the mouth of White Oak Creek equivalent to 25 g of oven-dry weight were contacted with 200 ml of the various desorbing solutions. The pH was adjusted prior to contact, immediately after contact, and 4 hrs after contact. After standing for 24 hrs, the samples were centrifuged and the

supernatant liquid was decanted. In order to raise the activity level for more accurate determination of the radionuclides, the supernatants from the duplicate samples were combined, acidified with HNO_3, and reduced in volume by heating prior to radiochemical analysis.

The results obtained are shown in Table 6. The radionuclide content of the sediment was (dis/min/50 g, oven-dry basis): ^{60}Co, 16,600; ^{137}Cs, 118,000; $^{103-106}Ru$, 129,000; ^{90}Sr, 2405; ^{144}Ce, 4145; and TRE, 24,190. Cesium-137 and ruthenium-103 and -106 were the principal contributors to the activity; and the distribution of the radionuclides in this sample agreed with the earlier results obtained with samples from the vicinity of CRM 20.8.

Up to 1 M solutions of salts, such as KCl, NaCl, $CaCl_2$ between pH 6 and 8, removed less than 10% of the ^{60}Co, ^{106}Ru, and ^{137}Cs; on the other hand, between 30 % and 77% of the ^{90}Sr was removed by the salts, depending on their concentration and pH. This behavior suggests that the strontium was held primarily by simple ion exchange, whereas cobalt, ruthenium, and cesium were not. In the strongly acid systems, as HNO_3 or HCl , cobalt and strontium were released, but ruthenium and cesium resisted desorption. In strongly alkaline systems approximately one-half of the ruthenium and approximately 15% of the cobalt were desorbed. Cesium and strontium were not desorbed at the high pH; and the 20% removal of strontium at pH 8 using NH_4OH was not confirmed by later tests.

Desorption of Cesium from Sediments

Intensive investigation of the behavior of cesium in waste solutions by the ORNL waste research group has shown that cesium sorption by sediments may be regarded as an

Table 6. Removal of Cobalt, Cesium, Ruthenium, and Strontium from Clinch River Sediment by Various Solutions

Reagent	Concentration (Molarity)	pH	% Removed			
			^{60}Co	^{137}Cs	^{106}Ru	^{90}Sr
Tap Water		6 (HNO_3)	2.8	---*	3.0	21.3
Tap Water		2 (HNO_3)	64.6	---	3.1	80.9
Tap Water		1 (HNO_3)	78.1	3.3	5.5	
Tap Water		6 (HCl)	---	---	3.5	19.4
Tap Water		2 (HCl)	65.6	---	4.1	89.9
Tap Water		7.7 (Natural)	---	---	4.5	11.0
$NaHSO_3$	0.1	6	16.8	---	9.8	37.7
$K_2Cr_2O_7$	0.1	5.6	5.9	1.7	4.7	73.1
$CaCl_2$	0.1	7	6.4	---	4.1	58.6
$CaCl_2$	1.0	7	4.7	---	4.4	76.9
NaCl	0.1	6	3.5	0.8	4.1	39.2
NaCl	0.1	8	---	5.7	6.8	30.1
NaCl	1.0	6	---	0.7	3.9	63.1
NaCl	1.0	8	---	0.6	5.1	56.0
KCl	0.1	6.2	---	0.7	2.8	53.0
KCl	1.0	6.2	3.0	1.7	2.5	68.7
NaOH		8	---	0.4	5.9	6.0
NaOH		12	16.5	3.1	46.6	4.9
NH_4OH		8	---	0.7	8.2	20.0
NH_4OH		11.8	17.2	4.5	45.1	3.5
Ethyl Alcohol					0.9	<1
Acetone					1.0	

*--- Refers To Concentrations Below Detectable Limits.

ion exchange reaction complicated by exchange sites which have an extremely high affinity for cesium. These sites for cesium are present because of the layered arrangement in minerals which, in illite, provides a favorable spacing for retention of cesium ions (c-spacing $\cong 10$ Å). Desorption studies, reported elsewhere, show that minerals such as illite or muscovite can even resist the attack of acids and retain the cesium.[23]

With the mineral illite, potassium at the edges of the crystallite can be exchanged for cesium. Actually less than 1% of the total potassium in the mineral illite is exchangeable and this comprises 10% of the total exchange capacity. Once bonded in the interlayer site near the edges, cesium is difficult to replace or remove and with longer contact time the cesium diffuses further into the lattice of the mineral and removal becomes even more difficult. It is believed that the cesium on the sediment is associated with illite or mica in this manner.

If cesium or strontium is held in readily accessible sites, such as those found on montmorillonites or kaolinites, desorption can be accomplished by contacting with high concentrations of salt solutions. Hence, even with illitic material, ion exchange reactions occur at or near the surface, and ions held at these sites are readily exchanged. It is believed that strontium is held primarily by this mechanism.

Desorption of Strontium from Sediments

The data in Table 7 show that tap water at pH 2 removed more strontium than 1 M $CaCl_2$ or NaCl. Simulated tests using sediment from CRM 15.3 suggested that strontium which sorbed at pH 8 should be desorbable equally or perhaps more efficiently by $CaCl_2$ than by tap water adjusted to pH 2. At pH 8 the sample from CRM 15.3 sorbed approximately 46% of the strontium (Table 7). This gave a

Table 7. Equilibrium Sorption and 45 hr Desorption of Strontium Using 1.0 Gram of CRM 15.3 Sediment in 100 ml of Tap Water at Indicated pH

Sorption pH	8	10.8	10.2*	10.1**
Sorption (%)	46.2	93.2	94.1	68.4
Desorption (%)				
Tap H_2O; pH 2 (HNO_3)	96.3	95.3	100	89.3
Tap H_2O; pH 12 (NaOH)	14.7	5.1	3.6	
1 *M* $CaCl_2$ pH 7	97.8	68.8	61.2	5.8
1 *M* NaCl pH 8	90.2	83.0	100	85.3

*95 ml Tap Water + 5 ml Simulated Waste + Sr-85;
**95 ml Tap Water + 5 ml Simulated Waste + Sr-85; (No Sediment Added).

K_d of 85 ml/g which is a reasonable approximation of the K_d of 65 ml/g for ^{90}Sr on the naturally contaminated sediment.

On the other hand, as shown in Table 7, at pH 10.8 a much larger percentage of the strontium was sorbed (93.2%), and a K_d of 1300 ml/g was calculated. Using the desorption data in Table 6 for either NH_4OH or NaOH at pH 12, K_d's of 200 and 155 ml/g were obtained. These differences suggest that another mechanism, in addition to clay exchange, was operative when sorption occurred at high pH. It became apparent that $CaCO_3$ was being formed and the higher removal of strontium at pH 10.8 could be likened to the lime-soda softening process whereby strontium is removed from the solution mainly by the formation of $CaCO_3$.

Data on the sorption of strontium simply by diluting simulated waste with tap water without sediment is also shown in Table 7. The pH was 10.1; and the removal of strontium by the fine colloidal precipitate averaged 68.4%. The desorption data also show that $CaCl_2$ was ineffective as a desorbing agent for this precipitate. The explanation given for this was that when sorption of strontium by sediments was made to take place at pH 10, strontium was sorbed not only by the clay by ion exchange but on the precipitate of calcium carbonate. The $CaCO_3$ was formed as the carbonate ion from the bicarbonate ion in tap water. When the $CaCl_2$ solution at neutral pH was added, the strontium on the ion-exchange mineral complex was displaced but the strontium on the precipitate was not.

Studies are continuing on the role of $CaCO_3$ formation on strontium sorption. Tests with a sample of sediment from White Oak Lake suggest that $CaCO_3$ may play an important role in retaining strontium. With 1 M $CaCl_2$ only 35% of the strontium was removed, compared to 77% removal from the sediment obtained at CRM 20.8 (Table 6). The lower removal from the White Oak Lake sediment suggests that an even

greater percentage of the strontium was associated with $CaCO_3$. Further evidence to support the important role of $CaCO_3$ was found through analysis of the sediment; the sediment from White Oak Lake contained 4.22% $CaCO_3$ while the sediment from CRM 20.8 contained only 1.77%.

Desorption of Cobalt from Sediments

Although understanding of the mode of occurrence of cobalt and ruthenium is limited, certain responses of these nuclides in demineralized and tap water, and with sediment as well as resin exchanger, are given below.

When a ^{60}Co spike (approximately 10^{-7} M) was mixed with demineralized water or tap water adjusted to pH 2 and the pH of the mixture was gradually increased without any sediment present, the percentage removal of cobalt increased in both the demineralized and tap water systems until a pH of 9 was reached. Above this pH cobalt removal decreased slightly in the demineralized water system, but increased sharply in the tap water system (see Fig. 9). The high removal of cobalt in the tap water system was caused by co-precipitation of cobalt with calcium carbonate above pH 9. With the concentration of cobalt added to the demineralized water, no precipitate of cobalt hydroxide would be expected until the pH is at least above 9.5. A possible explanation of the removal of cobalt from demineralized water is adsorption on the glass sides of the container.

In the sorption of cobalt from demineralized water by sediments optimum removal was obtained between pH 6 and 8, similar to the behavior of cobalt in demineralized water without sediment. On the other hand with Dowex 50, maximum sorption occurred at pH 4 and the higher pH levels showed a gradual reduction in sorption. On desorbing the cobalt, the Dowex 50 released all of the cobalt with neutral sodium acetate; but only about 80% of the cobalt was removed from the sediment with the same treatment.

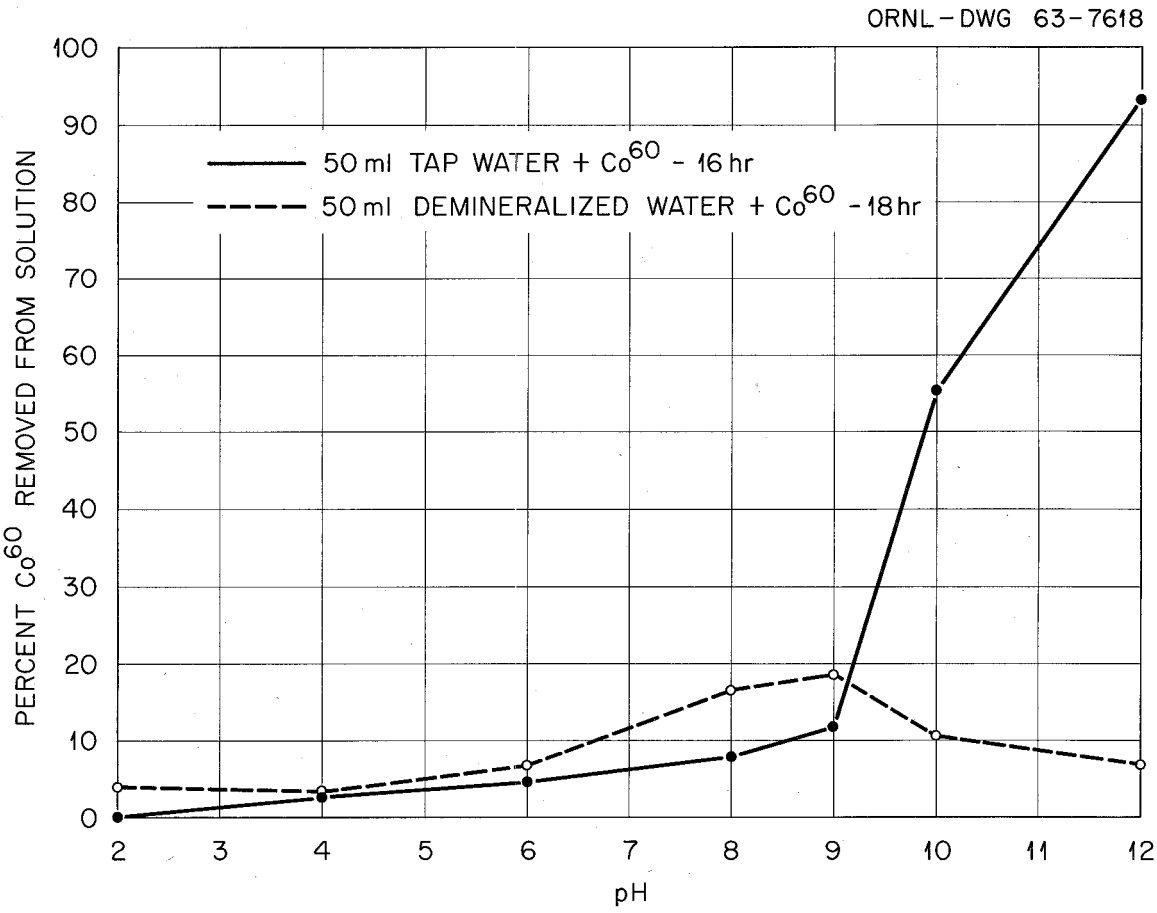

Fig. 9. Removal of Cobalt from pH-Adjusted Tap Water and Demineralized Water as a Function of pH

Since neutral salts did not remove cobalt from the naturally contaminated sediment to any appreciable degree, simple ion exchange was eliminated from consideration. Two possible factors which must be considered in more detail to gain further insight into the mechanism include: (1) an understanding of the surface features of clays and sediments, and (2) more extensive investigation of the properties of the cobalt ion at different pH levels. The latter includes the possibility of forming monohydroxy cobalt prior to the formation of the dihydroxy form.

Desorption of Ruthenium from Sediments

Alkaline pH conditions were found to be more effective for desorbing ruthenium from the sediment. Since early studies on ruthenium from waste seepage systems showed that the ruthenium is not present as $Ru(NO_3)_3$ or $RuCl_3$ salts, tests in the laboratory to simulate natural contamination were performed using ruthenium from the ORNL waste tanks. The waste contained (dis/min/ml) ^{106}Ru, 1.84×10^6; ^{137}Cs, 1.44×10^6; ^{90}Sr, 6.34×10^3 as principal radionuclides. Paper partition chromatography methods for the identification of ruthenium complexes indicated that the ruthenium in the waste was either nitrosyl ruthenium hydroxide $\left[(RuNO(OH)_3(H_2O)_2)\right]$ or mono nitrato nitrosyl ruthenium hydroxide $\left[(RuNO(NO_3)(OH)_2(H_2O)_2)\right]$. The mono nitrato nitrosyl ruthenium is reported by Story and Gloyna[24] to be cationic and exchangeable; the low desorption of ruthenium by the sediment with neutral salts suggests that the ruthenium is not easily exchangeable and further suggests that the sorbed ruthenium may be in the nitrosyl ruthenium hydroxide form.

To compare the desorption properties of ruthenium sorbed on a sediment using the waste solution, a sample of sediment from CRM 15.3 was contacted (for sorption) with a solution containing 2 ml of waste and 98 ml of tap water adjusted to pH 7. After 24-hr contact approximately 58% of the ruthenium was removed from the solution by sorption (Table 8). The samples were then leached with the solutions listed in Table 8. The desorptive behavior of the sediment was similar to that observed with the naturally contaminated sediment; however, desorption from the artificially contaminated sediment was greater than from the naturally contaminated sediment.

Observations of the waste on dilution with tap water offered a possible explanation of the higher desorption with the artificially contaminated sediment. With 2 ml of waste and 98 ml of tap water adjusted to pH 7, a colloidal precipitate was observed in the system; and centrifugation showed that approximately 20% of the ruthenium was associated with this colloidal precipitate. From analysis of the waste it was presumed that the precipitate was aluminum oxide hydrate; considerations of the solubility product precluded the formation of calcium carbonate at this pH.

When the pH of the solution containing the precipitate was lowered to pH 2, 50% of the ruthenium returned to the solution and the precipitate dissolved. If one assumes that 34% (20% ÷ 58%) of the ruthenium in the sediment is associated with the precipitate which releases one-half of its ruthenium as it dissolves at pH 2, then of the amount desorbed at pH 2, 17% is due to the precipitate and about 6% is due to desorption from the sediment. The latter value agrees well with desorption of ruthenium from naturally contaminated sediment. Further speculation is premature at this time.

Table 8. Sorption and Desorption of Ruthenium using 10.0 g of CRM 15.3 Sediment and 100 ml Solution

Test Number:	1	2	3
SORPTION:			
SOLUTION	(98 ml TAP WATER + 2 ml WASTE FROM TANK W-8)		
pH	7	7	7
4 Hr (%)	52.5	56.0	54.1
24 Hr (%)	58.8	60.1	55.3
DESORPTION:			
SOLUTION	TAP WATER	1 *M* $CaCl_2$	TAP WATER
pH (Adjusted with HNO_3 or NaOH)	2 (Adjusted with HNO_3 or NaOH)	7	12 (Adjusted with HNO_3 or NaOH)
4 Hr (%)	27.5	9.5	53.8
72 Hr (%)	23.3	12.2	61.8

Longitudinal Distribution of Radionuclides in River Sediments

Relationships in Distribution in Bottom Sediments of the Clinch and Tennessee Rivers

Similarities in the longitudinal distribution of radionuclides in the bottom sediments of the Clinch and Tennessee Rivers were studied using data from the 1961 annual survey by the ORNL Applied Health Physics Section. This sediment survey in 1961 extended from near the mouth of White Oak Creek on the Clinch River to near Kentucky Dam on the Tennessee River. Using methods described by Cottrell,[17] sediment samples were collected at 32 sections; and the concentrations of ^{137}Cs, ^{60}Co, ^{106}Ru, ^{144}Ce, other rare earths, ^{95}Zr- ^{95}Nb, and ^{90}Sr in a composite sample of the bottom sediments at each section were determined.

Preliminary graphical comparison of the concentrations of ^{137}Cs and ^{60}Co at each section indicated a straight-line relationship on log-log paper. To better measure the relationship, the index of correlation, the standard error of estimate, and the regression coefficient were computed for comparison of the logarithms of the concentrations of these two radionuclides. Similar computations were made for all pairings of the logarithms of the concentrations of radionuclides using a computer program, adapted from a general and basic correlation program prepared by A. M. Craig, Jr., of the ORNL Mathematics Division.

The results of some of these computations are shown in Fig. 10 in which the concentration of ^{137}Cs is treated as the "independent" variable. A tabulation of the several indices of correlation showed that the choice of other radionuclides for use as the independent variable in Fig. 10 would have been appropriate. It should be noted that determination of the concentration of rare earths includes ^{90}Y but excludes ^{144}Ce.

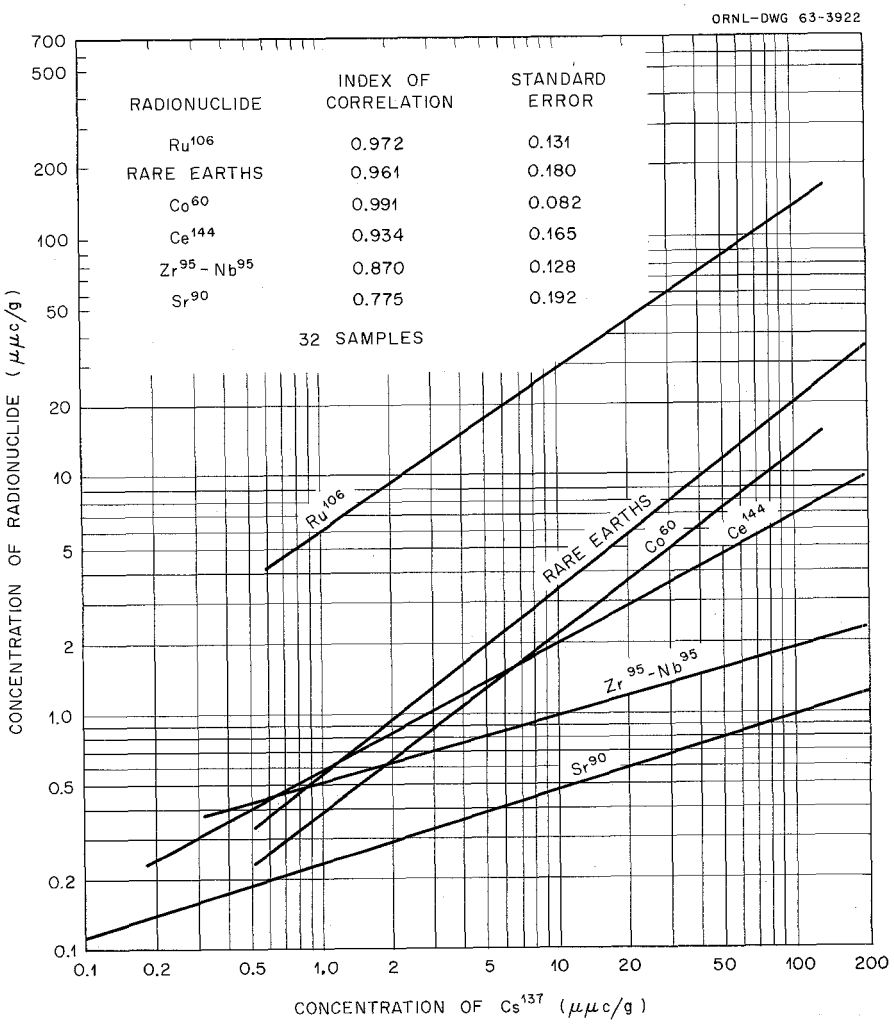

Fig. 10. Correlations Showing Similarity in the Longitudinal Distribution of Radionuclides in the Bottom Sediments of the Clinch and Tennessee Rivers

The slope of the curves is nearly the same for the logarithmic correlation of ^{137}Cs to ^{106}Ru, to the trivalent rare earths, and to ^{60}Co; and the indices of correlation for these curves are good. Thus the results shown in Fig. 10 suggest that similar mechanisms control the longitudinal distribution of these particular radionuclides.

The observed rates of decrease in concentration of cesium, ruthenium, cobalt, and the rare earths with distance downstream from White Oak Creek are much greater than rates calculated on the basis of flow dilution alone. This lack of relationship between concentration and flow dilution and the similar longitudinal distribution pattern of the radionuclides is a further indication that the mechanism controlling the distribution pattern is sedimentation rather than the chemical process of equilibration (reversible sorption) between the radionuclide concentrations in the sediments and in the water. Furthermore, work on the behavior of radionuclides associated with the sediments (pp. 52 to 62) has indicated that once the radionuclides are incorporated into the bottom sediments the potential for release of this radioactivity through desorption is negligible.

The slope of the curves of ^{90}Zr - ^{95}Nb and for ^{90}Sr in Fig. 10 is less than that for cobalt, ruthenium, or the rare earths, indicating that different mechanisms may be controlling the distribution of zirconsium-niobium and strontium in the bottom sediments.

The good correlations indicate that the longitudinal distribution of several radionuclides in the bottom sediment may be determined on the basis of the distribution of one or two of these radionuclides.

Although not specifically cited earlier in this report (pp. 34-35) the relative longitudinal changes in ^{90}Sr concentration in the bottom sediments have been found to be quite similar to changes that would have been attributed to the effects of flow dilution. It is quite probable that the most important

mechanism controlling the longitudinal distribution of ^{90}Sr is flow dilution.

Seasonal Changes in Distribution of Radioactivity in Bottom Sediments of the Clinch River

In general, the over-all longitudinal trend in levels of radiation in bottom sediments of the Clinch River is for the levels to increase as the distance downstream from White Oak Creek increases (see Fig.11). This tendency has been ascribed to hydraulic factors that may influence sediment deposition: larger flow areas, lower velocities, and greater surface area. However, the change in radiation levels with distance is not regular. In particular relatively high levels of radiation have been observed, in summer surveys, at several sections downstream from CRM 12.

Possibly the higher zones of radiation levels downstream from CRM 12 are the result of seasonal variations in these and other hydraulic factors; in the winter season greater discharges and increased velocities of flow occur; in the summer thermal stratification occurs under certain conditions.

From early fall to late spring the minimal water levels in the Clinch River below CRM 20.8 are about 6 feet lower than in the remaining portion of the year. On several days during this winter period, discharges may exceed 15,000-20,000 cfs. During the summer period, from late spring to early fall, the discharge has rarely exceeded 10,000 cfs. Because of the greater discharges and lower water levels the velocities in the winter period are greater than in the summer throughout the study reach.

Cold waters released from Norris Reservoir in the summer period cause the flow in the study reach to be thermally stratified and these cold waters underflow the

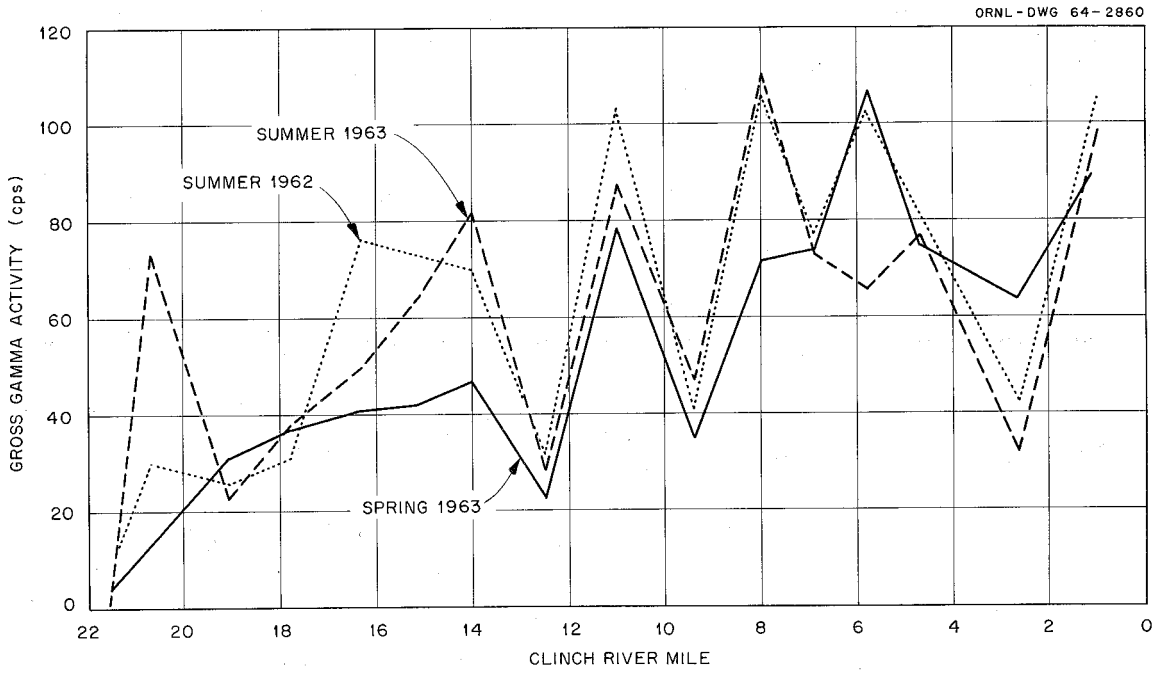

Fig. 11. Longitudinal Variation in Average Sectional Gamma Count Rate at the Surface of Bottom Sediments in Clinch River.

essentially stagnant warm water backed up from the main body of Watts Bar Reservoir. This condition which tends to restrict the effective flow area in the river is shown schematically in Fig. 12. On the basis of median discharges for the summer months during the period 1947-61 it may be estimated that the duck under centers around CRM 9.5 (see Fig. 13).

The influence of the seasonal changes in the various hydraulic factors was investigated by a survey of gamma radiation at the surface of bottom sediment by the ORNL Waste Disposal Research Section and USGS in the spring of 1963 (April 30 to May 8). This spring survey (1963) was made as soon after the winter high flows as practicable using the method reported by Cottrell.[17]

In Fig. 11 the variations in average gamma count rate at the surface of the sediment at the various cross-sections in the Clinch River is shown for three surveys: summer surveys of 1962 and 1963 and spring survey of 1963. The results of the surveys in Fig. 11 do not indicate that the decrease in effective flow area due to thermal stratification in the summer period causes any major change in the longitudinal variation of radioactivity in the bottom sediments. If the relative pattern of longitudinal variation in gamma count rates had been influenced by thermal stratification the general longitudinal trend toward increasing radiation levels in the downstream direction for summer conditions would have been reversed in the vicinity of CRM 9.5.

It can only be considered as being somewhat fortuitous that the absolute variations as well as the relative variations in gamma count rates shown in Fig. 11 are about the same for all curves. Study of data for the releases of radioactivity through White Oak Dam indicate that this is because the loads of radioactivity released were generally on the decline throughout the period preceding the three surveys.

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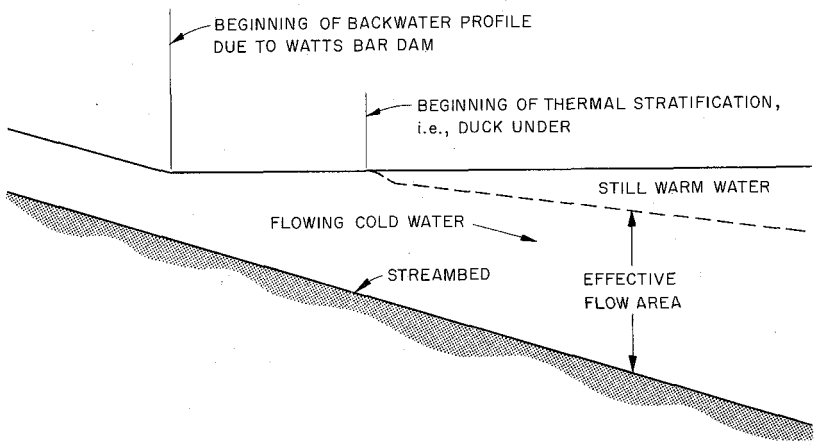

Fig. 12. Schematic Sketch Showing Effect of Thermal Stratification on Effective Flow Area in Clinch River

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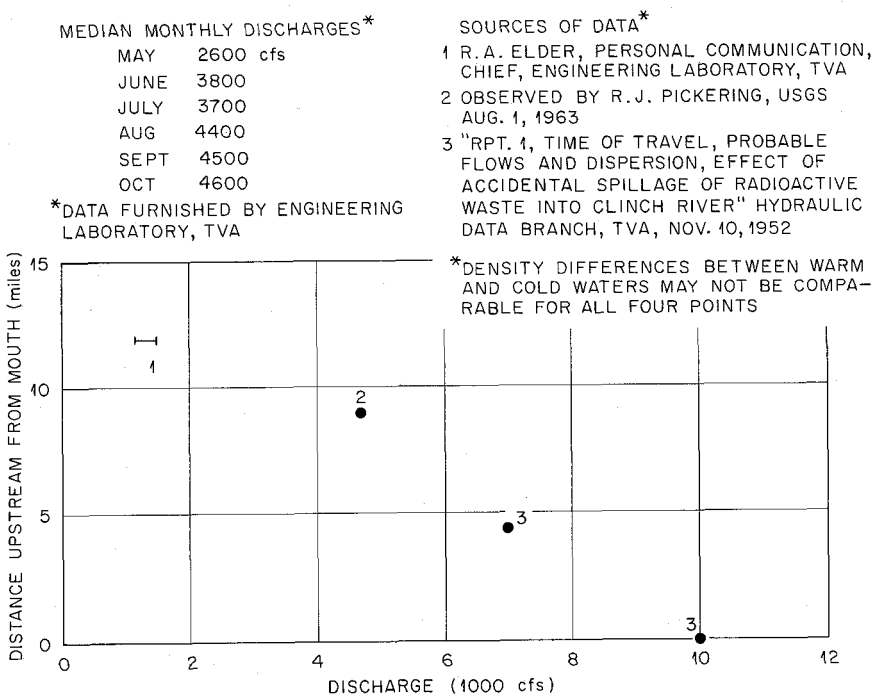

Fig. 13. Approximate Relation for Location of Duck Under

Survey of Bottom-Sediment Radioactivity in Clinch River Sloughs

During May, 1963 a survey of bottom-sediment radioactivity was made in six large sloughs (drowned tributary stream mouths) of the Clinch River and one slough of the Emory River (see Fig. 14). The primary purpose of the survey was to determine whether the sloughs represent repositories of fine sediment with higher surface radioactivity than that in the main channel of the river. Radioactivity readings were made with the Flounder instrument, obtained from the ORNL Applied Health Physics Section. The results of the survey are shown in Table 9.

The results indicate that the radioactivity of sediment in the sloughs surveyed is within the range of radioactivity in the main river channel and in some places is several times the "background" (surface soil) radioactivity. However, in none of the sloughs surveyed was the maximum radioactivity as high as the maximum radioactivity in adjacent portions of the main channel.

Plots of bottom sediment radioactivity versus depth of water indicate that in several of the deeper sloughs, there is a direct relationship between those two variables. Although the causes of this relationship are not definitely known, it is probable that two erosional processes are largely responsible: (1) exposure of the portions of the sloughs less than six feet deep to subaerial erosion during the winter period of low water in Watts Bar Reservoir, and (2) washing of sediment down the sides and into the deeper portions of the sloughs during periods of high rainfall and high surface runoff.

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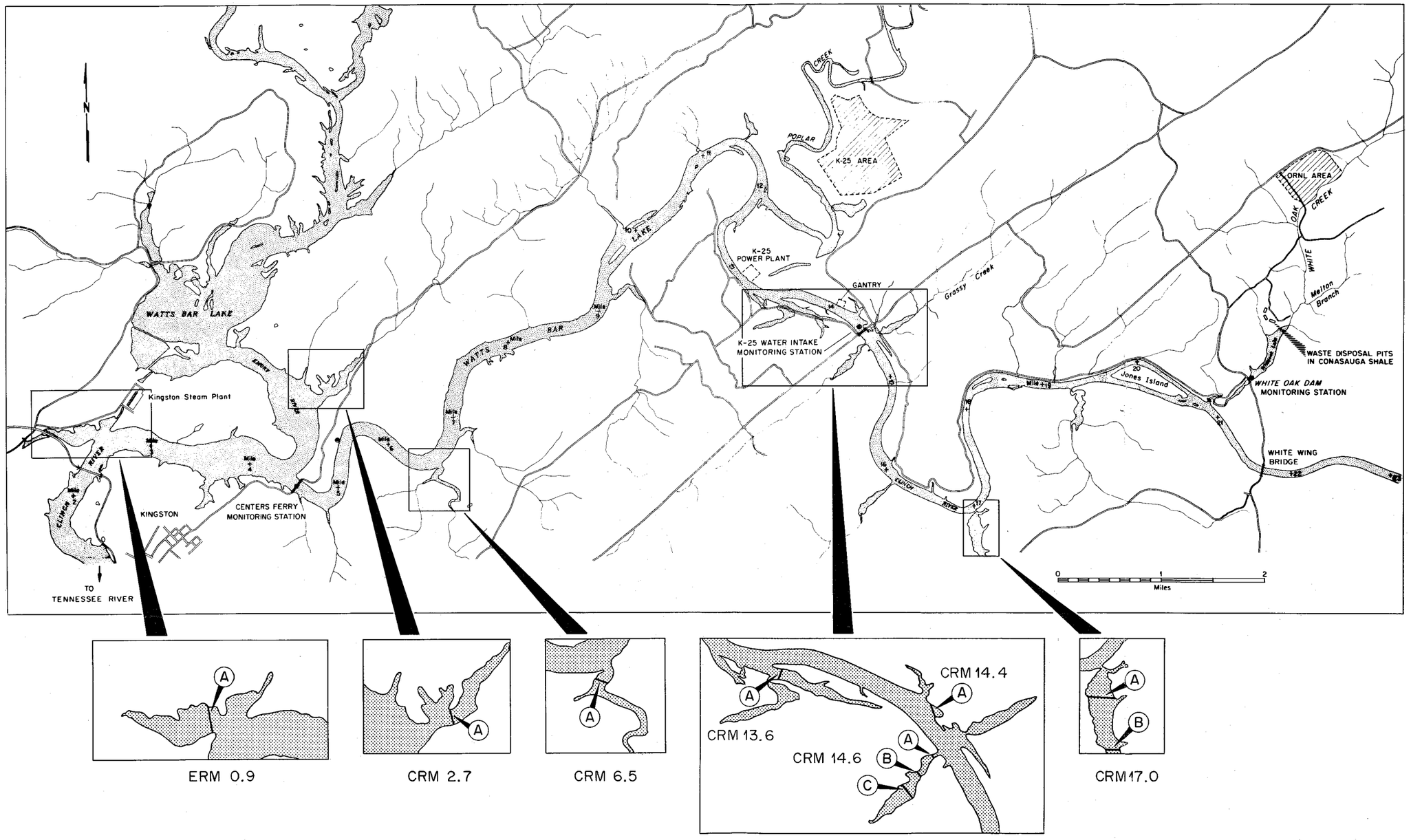

Fig. 14. Location Map, Survey of Bottom Sediment Radioactivity in Clinch River Sloughs

Table 9. Bottom Sediment Radioactivity in Sloughs

			Radioactivity cps			
River	Mile*	Section	Average	Maximum	Minimum	Background**
Clinch	17.0	A	13.0	17.2	9.7	7.8
		B	7.9	9.4	5.1	N.D.
	14.6	A	16.0	42.0	7.9	6.5
		B	15.2	26.9	6.9	6.6
		C	15.3	20.8	10.6	N.D.
	14.4	A	28.6	54.4	11.1	N.D.
	13.6	A	34.5	53.3	11.1	6.5
	6.5	A	21.3	32.8	4.1	6.2
	2.7	A	19.8	38.1	5.8	N.D.
Emory	0.9	A	15.0	20.8	8.2	7.2

N.D. - Not determined.

* Miles upstream from mouth of the river.

** Background determined on surface of soil at bank of slough.

Sediment Survey of the Clinch and Tennessee Rivers

Annual surveys of sediments in the Clinch and Tennessee Rivers were made by the ORNL Applied Health Physics Section during the summers of 1962 and 1963. In both years, the survey of the Tennessee River extended from Fort Loudoun Reservoir (TRM 615.8) into Guntersville Reservoir (TRM 354.4). The 1963 survey of the Clinch River extended upstream from the mouth of the river to CRM 42.8 (~ 20 miles above Melton Hill Dam). The techniques and procedures used were those described in 1959 by Cottrell.[17]

Figures 15 and 16 show the gamma count rate at the surface of the Clinch and Tennessee River bottom silt according to river miles for the years 1961, 1962 and 1963. The longitudinal dispersion of gamma emitting radioactive materials in the silt of the Clinch River in 1962 (Fig. 15) was essentially the same as that in 1961 but the levels of radioactivity measured were lower. The lower levels detected correlate with the decrease in the total amount of radioactivity released to the river in 1962. A total of 2187 curies was discharged to the Clinch River during the 12-month period just prior to the 1961 survey, while only 1700 curies were released during the corresponding period in 1962.

The increase in gamma count rate of the Tennessee River silt in 1962 (Fig. 16) appears to be due primarily to fallout from weapons testing. This conclusion is supported by the fact that background readings in the Tennessee River silt (Fig. 16) and Fort Loudoun Reservoir silt (not shown) were higher in 1962. Fort Loudoun background readings increased from 8.9 c/s in 1961 to 16 c/s in 1962.

Table 10 shows the average concentrations of the major radionuclides found in Clinch River water, upstream from White Oak Creek, at the mouth of White Oak Creek, and downstream from White Oak Creek, respectively. The data in Table 10 (A) also support the conclusion that the 1962 river survey data were influenced by fallout. Increased average concentrations of ^{90}Sr, $^{103-106}Ru$, ^{95}Zr- ^{95}Nb, and ^{144}Ce were detected in the Clinch River (CRM 41.5) upstream from the mouth of White Oak Creek. Such increases can only be attributed to weapons fallout. The increased concentrations of fallout material in the river water would have very little effect upon the relatively high gamma count rate in the Clinch River but would influence significantly the relatively low count rate of the Tennessee River silt.

The 1963 survey showed the dispersal pattern of radioactive silt in the Clinch River to be essentially the same as in 1961 and 1962 (Fig. 15) except for the stretch of river immediately downstream from the mouth of White Oak Creek and immediately upstream from the point of entry of the Emory River. The average of all gamma measurements taken in the Clinch River, downstream from CRM 21.5, was approximately the same in 1963 (47 c/s) as in 1962 (49 c/s). The total number of curies discharged to the river, however, decreased from 1700 for the 12-month period just prior to the 1962 survey to 794 during the corresponding period in 1963.

When compared to the 1962 data, the gamma count rate on the bottom silt of the Tennessee River in 1963 showed decreases in Watts Bar and Hales Bar Reservoirs and essentially no change in Chickamauga and Guntersville Reservoirs (Fig. 16).

Table 10. Average Concentrations of Major Radionuclides in Clinch River Water at Three Stations, 1961 and 1962.

(Units of 10^{-8} μc/ml)

Period	Radionuclide					
	^{90}Sr	^{144}Ce	^{137}Cs	$^{103-106}Ru$	^{60}Co	$^{95}Zr-Nb$
A. UPSTREAM FROM WHITE OAK CREEK, CRM 41.5[a]						
Third Qtr.,1961	0.10	0.05	*	0.45	*	*
Fourth Qtr.,1961	0.08	0.04	0.05	0.59	0.06	0.32
First Half, 1962	0.20	0.17	0.01	0.90	*	0.68
B. AT MOUTH OF WHITE OAK CREEK, CRM 20.8[b]						
Third Qtr., 1961	0.23	0.02	0.17	9.0	0.13	3.1
Fourth Qtr.,1961	0.28	0.10	0.25	37	0.30	4.9
First Half, 1962	0.22	0.03	0.12	18	0.24	0.24
C. AT CENTERS FERRY, CRM 4.5						
Third Qtr, 1961	0.25	0.11	0.05	5.9	0.02	*
Fourth Qtr., 1961	0.33	0.18	0.09	21	0.36	0.90
First Half, 1962	0.41	0.27	0.12	21	0.41	0.74

[a]Sampling station moved from CRM 33.2 to CRM 41.5 about January 1, 1962.

[b]Values given for this location are calculated concentrations resulting from ORNL waste releases based on concentrations of radionuclides in White Oak Creek and the dilution afforded by the river; they do not include amounts of radioactive materials (e.g., fallout) that may have entered the river upstream from CRM 20.8.

*None detected.

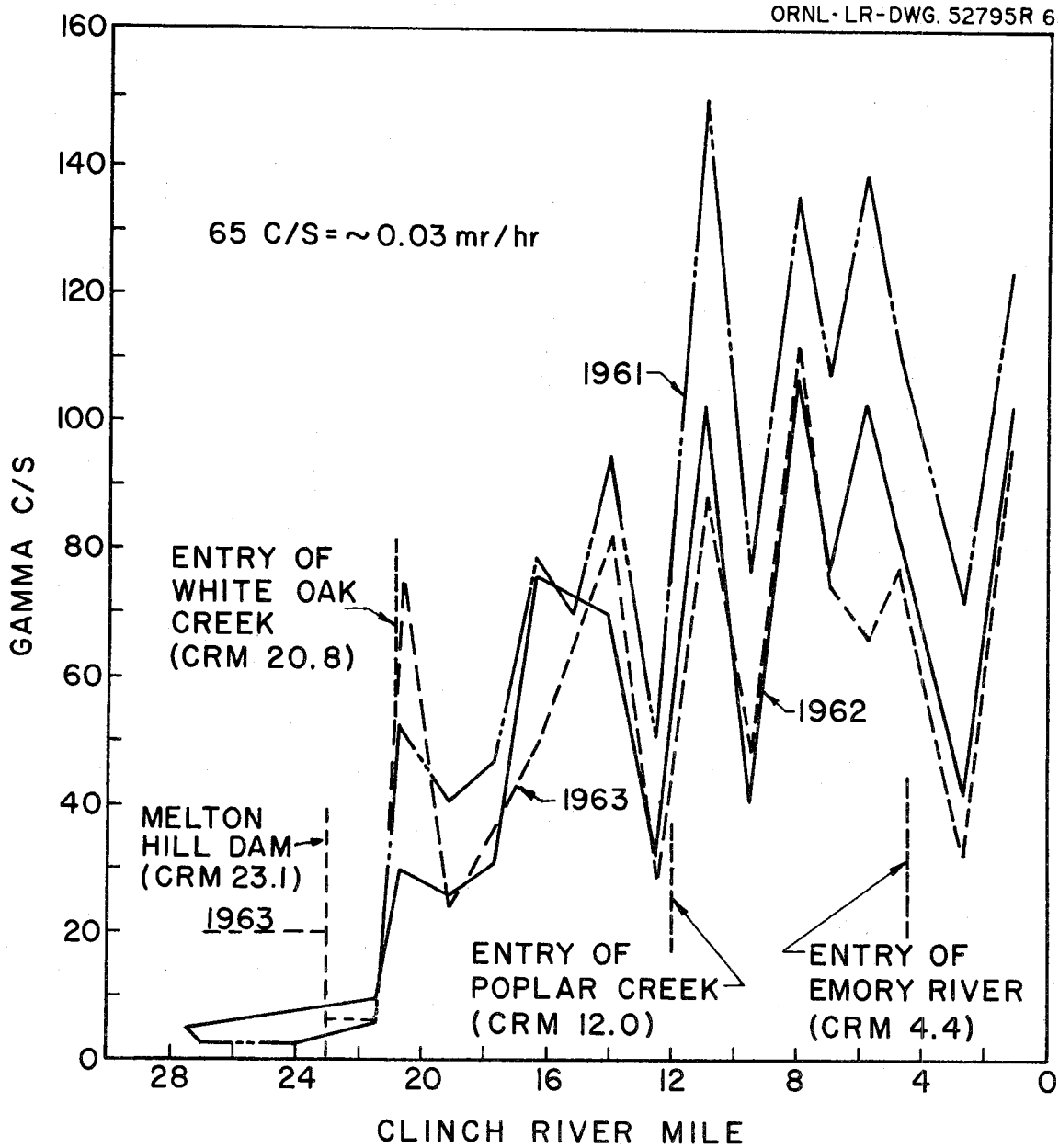

Fig. 15. Gamma Count at Surface of Clinch River Silt

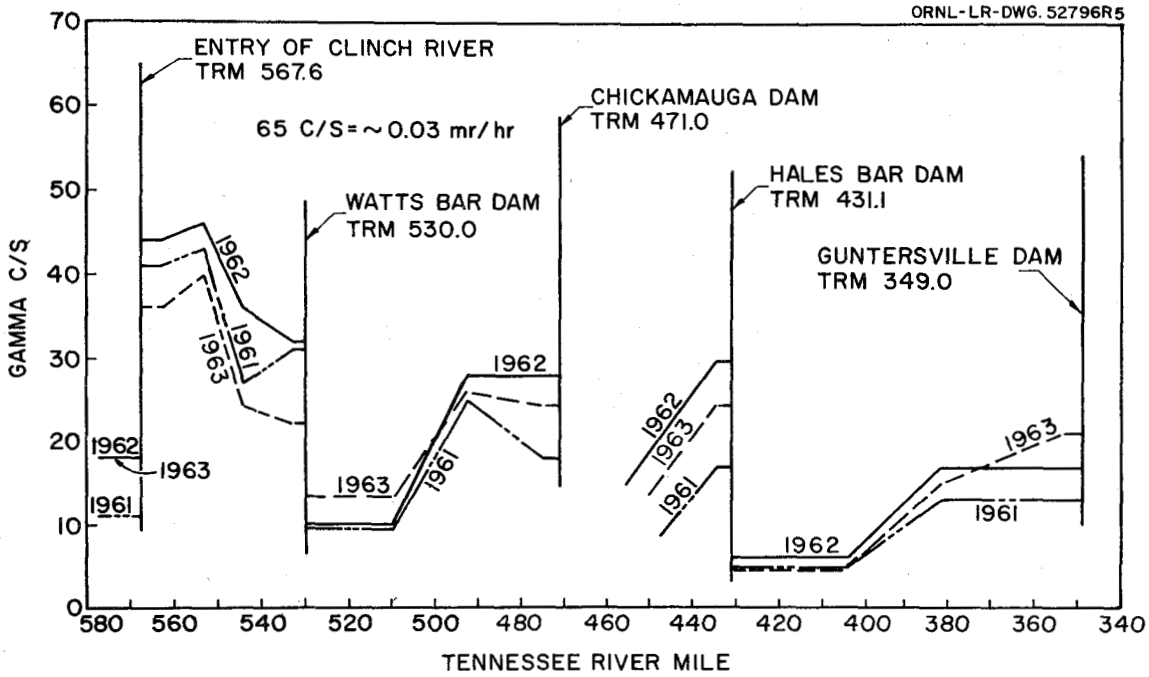

Fig. 16. Gamma Count at Surface of Tennessee River Silt

A comparison of the number of curies of each radionuclide discharged to the Clinch River with the average concentrations (μ c/g) of these radionuclides found in samples of the Clinch and Tennessee River silt during the period 1954-1961 is given in Status Report No. 3, Fig. 13.[3] The data on radionuclides discharged represent the number of curies of each radionuclide discharged during the year (July-June, inclusive) prior to each survey.

Tables 11 and 12 respectively, show the concentrations of radionuclides found in the Clinch and Tennessee River silt at various river-mile locations for the years 1962 and 1963. Fort Loudoun Reservoir background data are given for comparative purposes in Tables 12.

Radioactivity in Dredged Material Removed from Clinch River During Channel Improvement*

In connection with the Melton Hill Project of the Tennessee Valley Authority (TVA), a navigation lock was constructed at the dam. To facilitate navigational use, channel improvement below the dam was required in three reaches (see Fig. 17): (1) CRM 18.3 to CRM 18.8--adjacent to Grubb Islands; (2) CRM 19.5 to CRM 20.8--adjacent to Jones Island (sometimes called Blue Springs Island); (3) CRM 22.4 to CRM 23.0--immediately below Melton Hill Dam (CRM 23.1). Radiological hazards that might be encountered in the dredging and disposal of presumably contaminated sediments were investigated. The results of this investigation were reported to the Steering Committee on December 4, 1963.[6]

*Based on a report by O. W. Kochtitzky, Chief, Radiological Health Staff, Division of Health and Safety, Tennessee Valley Authority at open meeting of the Steering Committee, December 4, 1963.[6]

Table 11. Radionuclides in Clinch River Silt - 1962-1963

(Units of 10^{-6} μc/g of Dried Mud)

Location	^{137}Cs		^{144}Ce		^{90}Sr		^{60}Co		$^{103-106}Ru$		$^{95}Zr-^{95}Nb$		TRE + ^{90}Y (as ^{90}Y)	
	1962	1963	1962	1963	1962	1963	1962	1963	1962	1963	1962	1963	1962	1963
CRM 42.8		2.6		17		0.29		*		14		14		15
39.1		1.3		7.7		0.49		*		6.4		6.3		6.3
34.7		2.6		19		0.34		*		14		16		16
31.1		2.7		16		0.36		*		13		12		9
29.0		2.7		16		0.52		*		12		13		9
27.0		3.0		22		0.50		*		16		19		15
24.9		3.0		20		0.52		*		15		17		14
23.4		0.90		3.8		0.43		*		2.8		3.4		3.3
Average		2.4		14		0.43				12		13		11
CRM 21.5	3.2	2.7	11	0.43	0.36	0.63	*	*	11	0.45	16	0.14	10	0.89
19.1	5.2	2.9	3.8	0.90	0.41	0.74	0.72	1.9	6.1	4.4	6.2	0.90	3.5	5.2
16.3	58	218	5.2	4.2	0.72	3.1	8.1	16	50	17	3.9	2.2	14	34
15.2	55	16	5.2	3.5	0.90	0.81	7.3	2.8	46	13	4.2	3.8	13	5.6
14.0	237	150	6.2	5.0	1.8	1.7	20	12	43	29	3.6	3.4	31	23
11.0	63	75	6.9	8.8	1.0	1.2	8.6	8.0	68	35	5.4	7.4	16	22
8.0	59	62	8.5	8.8	1.0	0.90	8.6	8.9	70	48	5.4	6.9	18	16
5.8	94	67	8.4	12	1.6	1.3	12	9.5	68	49	6.5	10	22	19
4.7	86	53	9.5	11	1.2	1.4	14	8.5	86	44	6.0	9.7	22	17
2.6	73	63	7.7	6.7	0.72	0.81	10	7.7	77	26	5.6	5.4	16	17
1.1	56	68	13	17	0.72	1.4	9.0	8.5	76	50	11	17	16	23
Average	72	71	7.7	7.1	0.95	1.3	9.8	8.4	55	55	6.7	6.1	17	17

[a]Total Rare Earths minus cerium

*None detected

Table 12. Radionuclides in Tennessee River Silt - 1962-1963

(Units of 10^{-6} μc/g of Dried Mud)

Location		^{137}Cs		^{144}Ce		^{90}Sr		^{60}Co		$^{103-106}Ru$		$^{95}Zr-^{95}Nb$		TRE[a] ^{90}Y (as ^{90}Y)	
		1962	1963	1962	1963	1962	1963	1962	1963	1962	1963	1962	1963	1962	1963
TRM	570.8	1.4	1.8	3.9	7.2	0.45	0.61	*	0.45	2.1	7.5	1.2	6.3	3.0	4.1
	562.7	23	18	4.3	12	0.45	0.77	3.0	2.7	18	21	2.1	9.8	5.0	9.2
	552.7	29	26	5.1	14	0.77	0.65	3.8	3.4	18	26	2.2	12	6.0	13
	543.8	33	14	6.4	11	0.32	0.52	5.3	2.3	27	14	2.8	11	6.7	11
	532.0	29	13	5.9	10	0.45	0.56	4.2	2.3	24	13	2.9	9.5	4.6	8.8
	491.9	13	10	3.6	10	0.36	0.52	2.0	1.8	14	10	2.3	8.1	3.5	9.8
	475.1	9.9	9.9	2.7	11	0.36	0.74	1.7	1.8	9.9	9.9	1.8	9.0	1.7	8.9
	434.1	9.5	8.1	4.2	20	0.32	0.23	1.6	0.90	15	8.1	2.4	22	3.1	19
	381.2	5.3	5.9	1.8	9.1	0.18	0.61	0.90	0.90	6.4	5.9	0.60	9.0	0.80	8.4
	354.4	4.9	5.0	2.7	13	0.27	1.1	0.95	0.90	11	5.0	1.4	11	2.6	12
Average		16	10	4.1	12	0.39	0.63	2.3	1.7	14	12	2.0	11	3.7	10
Fort Loudoun Background Data															
TRM	604.4	1.8	2.2	4.8	10	*	0.61	*	*	5.1	9.4	3.0	6.8	2.7	5.9
	615.8	--	2.1	--	9.5	--	0.54	--	*	--	8.5	--	5.5	--	9.5
Average		1.8	2.2	4.8	9.8		0.58			5.1	9.0	3.0	6.2	2.7	7.2

[a]TRE - total rare earths minus cerium

*None detected

-- No samples taken in 1962

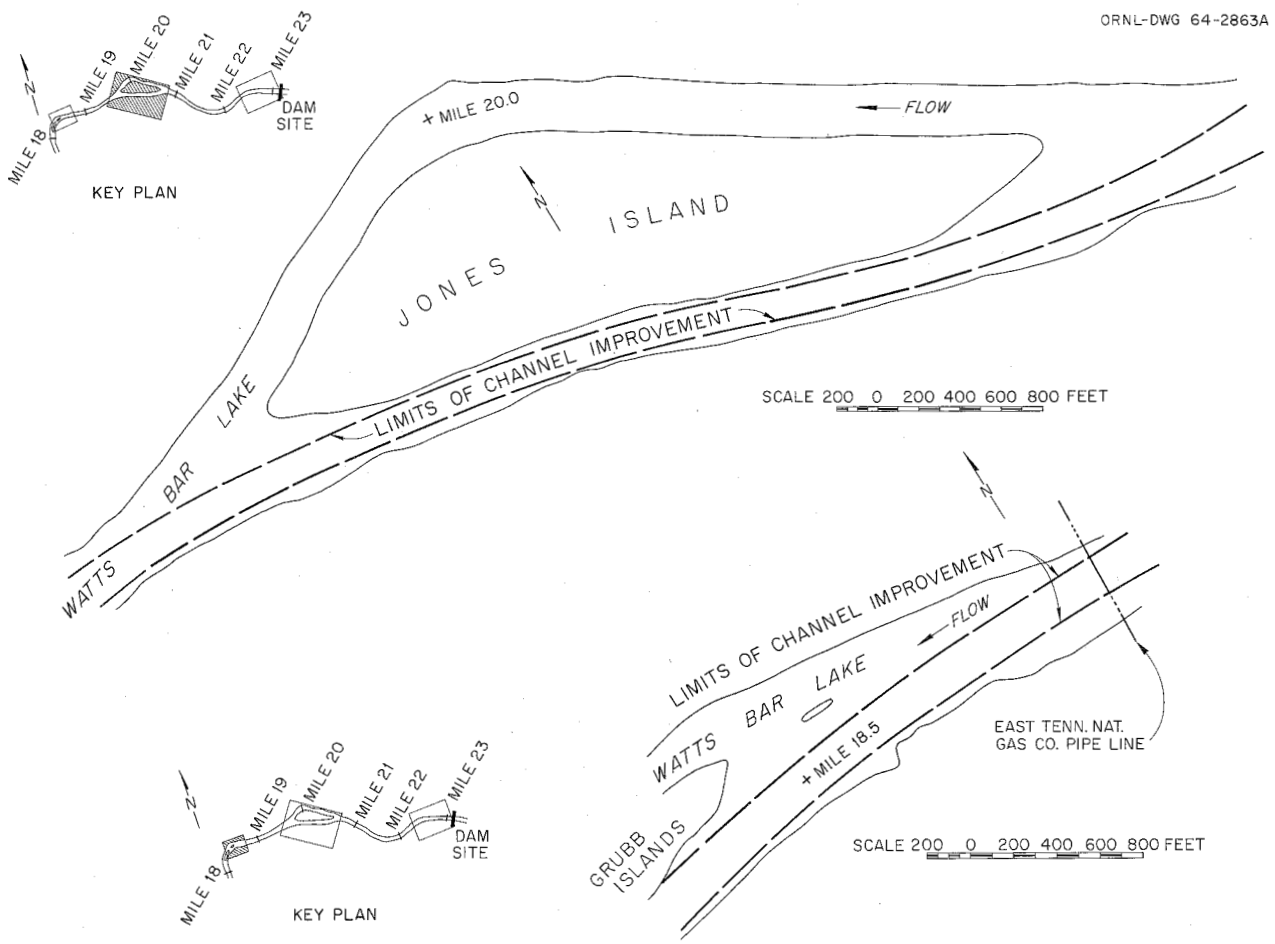

Fig. 17. Location Map-Areas of Channel Dredging near Jones and Grubb Islands

Potential Exposures from Radioactivity in the Sediments

Several special surveys have been made during the past several years and the results of the analyses of samples collected during these surveys are shown in Table 13.

Table 13. Radioactivity in Clinch River Sediment

Isotope	Emitter	Units of 10^{-6} $\mu c/gm$				
		1960		1960		May 1962
		ORNL-3202[25]		USPHS[26]		ORNL[27]
		Mile 19.5	Mile 20.8	Mile 19.0	Mile 20.0	Mile 20.0-20.3
^{106}Ru	β	27.9	39.0	68.5	42.4	17.5
^{137}Cs	γ	71.2	1060	150.2	70.2	70.9
^{95}Zr-Nb				5.4	0.4	4.6
^{60}Co	γ	9.23	83.2	12.0	8.2	5.4
TRE	β	22.8	204.0			20.0
$^{89-90}Sr$	β	1.08	16.8	1.84	0.6	1.87

While there are considerable differences between specific analyses for these several samples, it appears that the concentrations of the 1960 samples by ORNL[25] at CRM 19.5 and the 1960 samples by USPHS[26] at CRM 20.0 are comparable to the 1962 samples by ORNL[27] between CRM 20.0 and CRM 20.3.

The general plan of channel improvement was to remove the bottom material from under water by a hydraulic dredge or a dipper dredge and depcsit it on nearby land

areas in spoil banks or beds. The potential exposures that were visualized, depending upon the radionuclides present and their concentration and also upon the subsequent use of the spoil areas, included the following:

(1) External radiation exposure of animals or humans

(2) Radionuclides taken up by vegetation growing in the spoil areas which might find a channel of transfer to man. Media of transfer might include beef from cattle grazing upon spoil-area vegetation, tobacco grown in the spoil areas, milk from cattle grazing in the contaminated areas, or vegetables grown in the contaminated soil. Data were collected and these potential exposures were analyzed as stated later in the conclusions.

Channel Improvement Dredging

The Grubb Islands were selected as disposal areas for the material dredged between CRM 18.3 and 18.8 and Jones Island for material dredged between CRM 19.5 and 20.8. The dredging operation (hydraulic only) was begun in the Grubb Islands area in October 1962. In the Jones Island area hydraulic dredging was begun in May and completed during June, 1963. A dipper dredge was used for rock excavation immediately below the dam and for other channel work that could not be handled by the hydraulic dredge.

Finer material was excavated in the Grubb Islands reach than in the Jones Island reach and no blasting for rock excavation was required. Virtually the entire area of the Grubb Islands was used for spoil deposits and there was some extension of the island. Figure 18 shows typical spoil beds on Grubb Islands several months after they were deposited. Vegetation had begun to be established and although much of the spoil material was gravel it is expected that in a few years the area will be completely covered with vegetation. Beginning in May 1963 the hydraulic dredge worked in the

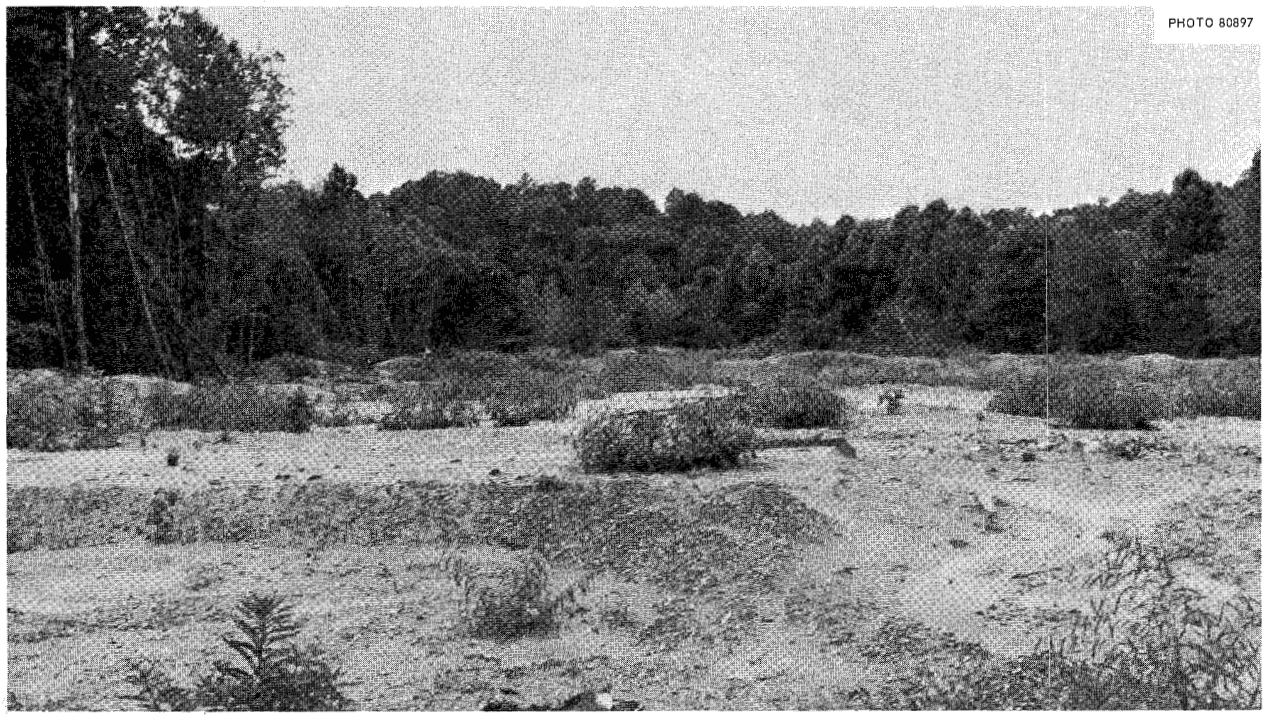

Fig. 18. Main Spoil Area - Grubb Islands. Photograph courtesy of TVA.

Fig. 19. North-Shore Spoil Area - Middle of Jones Island. Photograph courtesy of TVA.

Jones Island reach depositing spoil at the head of the island first. The operation then moved progressively down the channel to deposit spoil in ponds excavated on the north side of the island about the middle of the reach and at the lower end of the island. The north-shore spoil area near the middle of Jones Island is shown in Fig. 19.

Radiological Measurements and Hazards Analysis

From the beginning of dredging in October 1962 to the end of the operation of June 1963 direct radiation measurements, usually immediately above the dredged material, were made at selected points. Also radiochemical analyses of samples from the dredged materials were made at intervals, including determinations of gross beta, TRE beta, Sr beta, $^{103-106}Ru$, ^{137}Cs, ^{95}Zr-Nb, and ^{60}Co. The results of these measurements were given in the report to the Steering Committee.[6]

The water overflowing from the spoil pond back into the river carried with it much turbidity. Tailings built up in the river below the overflows and had to be subsequently removed. The spoil ponds on Jones Island retained very little fine silt or the silt that was retained was subsequently covered by sand and gravel (see Fig. 19). The sorptive capacity of sand and gravel for fission products is low as compared to that of silt. The large volumes of water used in the hydraulic operations not only carried back into the river most of the "fines" and their sorbed load of radionuclides, but also washed off "fallout" contaminants from the ground and surface vegetation.

Almost without exception the direct radiation measurements made above the spoil material were lower than the measurements made the same day over the river bank or pasture areas which were not affected by the spoil deposits. The atmospheric fallout, presumably from nuclear weapons testing, produced a background radiation greater than did the spoil deposits.

The Federal Radiation Council[28] has estimated that the annual radiation dosage from natural sources is 80-170 millirem. It recommends Radiation Protection Guides for normal peacetime operations, which would limit the annual dose to an individual in the general population to 500 mrem above background. The highest measurement made over the spoil deposits (0.052 mr/hr) would produce a total dose of only 455 mrem per year, including background. For comparison, at least three measurements made over undisturbed areas of the island indicated a dose from fallout that was this great or greater.

Of the fission products found, ^{90}Sr, ^{137}Cs, and ^{131}I are of most concern as a potential hazard to man. Because of its short half-life (about 8 days), ^{131}I could not pass from the soil to vegetation to beef animals to man in a short enough time to cause an appreciable hazard.[29] Cesium is so strongly bound to the clay that plant uptake of ^{137}Cs from soil is slight. Since ^{90}Sr is important as a potential human hazard, has a long half-life (about 25 years), and may be transferred from soil to plants to man (or animals), this radionuclide required careful review.

For purposes of the hazards analysis, assumptions were made as shown below. They are based on information from various sources to which the available references are given.

Soil depth	6-2/3 inches
Soil density	1.32 grams/cc
Soil to crop transfer	1 per cent[30,31]
Crop production	1 kg/sq meter[30,31]

Intake of grazing cow	10.9 kg/day[32]
Observed ratio (body-diet)*	0.25[33]
Calcium intake of cattle	50 grams/day/head[34]
Value for diet (calculated)	0.00049 μ c ^{90}Sr/g Ca
Calcium content of meat	0.116 gm/kg[35]
Meat consumed by man	0.114 kg/day[36]

*Observed ratio is in this case, the hypothetical ability of cattle to assimilate metabolically the ^{90}Sr from its diet.

It was calculated that in the bodies of cattle the ratio of ^{90}Sr to calcium is 0.00012. For each picocurie (10^{-12} curies) of ^{90}Sr present per gram of soil, there would be transferred to the cow 14 picocuries of ^{90}Sr per kilogram of meat, and, even if it is assumed that all meat eaten is from cattle grazed on Jones Island, the resultant intake to man via meat would be less than 1.6 picocuries per day. The highest concentration of $^{89-90}$Sr as reported by the analytical laboratory for any spoil deposit sample was 0.58 picocurie per gram. These samples were selected from the finest deposits on the surface of the spoil beds and were more concentrated than the average spoil consisting of sand and gravel. Furthermore, the soil depth of 6-2/3 inches assumed for purposes of calculation is many times the actual depth of the fine deposits on Jones Island. This maximum calculated intake is in the lowest 10 per cent of Range I designated by the Federal Radiation Council as being such that only periodic surveillance is required.

Conclusions

The excavation of material from the Clinch River channel and its deposition in spoil pools or banks on Grubb and Jones Islands resulted in the development of

potentially radioactive areas. Fine solids were flushed back into the river or subsequently covered by larger material so that the exposed areas consisted almost entirely of sand and gravel, particularly on Jones Island. Vegetation has taken root and become established on the spoil deposits.

A consideration of the potential hazards led to the following conclusions:

(1) Hypothetical calculations of metabolic transport of ^{90}Sr from the spoil deposits to man via vegetation and beef cattle did not indicate a radiological hazard.

(2) There is no current reason to limit the use of Jones Island for beef cattle grazing. Observations should be made periodically to determine the concentration of radionuclides in vegetation which develops or is planted on the spoil beds.

(3) Any change from beef cattle grazing to dairy cattle grazing, or any proposal to grow vegetable crops for human consumption, would require further study before such use of the spoil beds should be permitted.

(4) The tobacco crop in its present location does not create a problem of strontium uptake from the spoil bed. No study was made of the possible intake from inhalation or ingestion of materials from the tobacco but it is inconceivable that a person could have as large an intake by this mode of transfer as by the consumption of beef from the area.

BIOLOGICAL PHASES

Biological investigations in the Clinch River Study are concerned primarily with immediate or long-term potential hazards to human populations. Their chief objectives are to provide data on the quantities of radionuclides in the food-chains links that lead directly to man, mainly in fish which are the primary sources of human food from the Clinch River; and to present these data in a form that can be utilized by the Subcommittee on Safety Evaluation in its analyses of Clinch River conditions.[37, 38]

In order to achieve this, joint teams from the Oak Ridge National Laboratory (ORNL) and the U. S. Public Health Service (USPHS) have cooperated in the collection and analysis of fish from the river system, more or less continuously since the study was begun in 1960. These two agencies joined in making a large collection of fish in the Clinch River during the period May 16-24, 1962. The aim was to collect 40 individuals of at least 11 common species of food and game fish, of which half were to be analyzed by the USPHS in Cincinnati and half at the ORNL analytical laboratories.[38]

The following year, during the period May 20-22, 1963, an additional collection of food fish was made from both the Clinch and Tennessee Rivers, and the work of analysis was again shared by ORNL and the USPHS. The major objectives of this additional collection were:

1. To recheck the value of the water dilution factor previously observed in comparing the radioactivity of fish from the Clinch River and from Watts Bar Reservoir.

2. To determine the relationship of methods of sample preparation (particularly the elimination of bone) to the concentrations of radionuclides found in the analyses of fish specimens.

The analytical data from the large collection of fish in 1962, from the additional collection in 1963, and from the earlier collection and analysis of river fish (1960-1962) have been tabulated and submitted to the Subcommittee on Safety Evaluation for use in the further definition of safety factors and completion of the safety evaluation by this subcommittee. A summary of the evaluation is given in a later section of this status report (see page 130 et seq.).

To assure that the results of analyses of fish samples by the USPHS and ORNL would be comparable, identical aliquots of more than 20 samples were analyzed by both agencies. When the means of the concentrations of ^{137}Cs and ^{90}Sr were compared and the equality of the analyses tested statistically, the results from the two laboratories were found to be equal within the 5% level of significance.

In summary, fish samples from the Clinch and Tennessee Rivers were collected and analyzed by ORNL and USPHS during 1960-1963, and the Subcommittee on Aquatic Biology collected additional data on the harvest and use of fish downstream from ORNL from both commercial fishing and sport fishing. Also, special studies which were made in the ORNL Ecology Section on (1) the use of specific activities in predicting the uptake of ^{90}Sr by white crappie, and (2) the movement of smallmouth buffalo in the vicinity of White Oak Creek are of particular interest in the Clinch River Study. The above studies are summarized or references to more detailed reports are given in the subsections below.

Fish Studies Reported by Subcommittee on Aquatic Biology

Collection and Analysis of Fish from Clinch and Tennessee Rivers

For convenience the sampling and analysis of river fish will be considered in three periods: (1) from the beginning of the Clinch River Study, January 1960, through April 1962; (2) in May 1962 and later during that year; and (3) in May 1963. These three periods correspond with the major work projects in the study of Clinch and Tennessee River fish.

During the period February 1960 through April 1962 fish were collected during various seasons and were processed and analyzed according to the current practices of the USPHS and ORNL laboratories which cooperated in these studies. The results of the analyses by the USPHS were given in preliminary reports by Friend, et al,[26,39,40] and in Status Report No. 3 on the Clinch River Study, ORNL-3370, pp. 81-85.[3] More intensive studies of fish populations and movement and accumulation of radionuclides in fish were made by the staff of ORNL during this period, and the results were reported to the Steering Committee and to the Subcommittee on Safety Evaluation.[41]

The major cooperative effort in collection and analysis of fish from Clinch River in May and later in 1962 by the USPHS and ORNL, will be described more specifically. Of a total of 390 fish caught from the Clinch River and prepared for analysis during May 16-24, and to some extent subsequently, the number of individuals of the various species of fish collected and allocations for analysis by the USPHS or ORNL are shown in Table 14.[38] Fishing was limited to one portion of the Clinch River (CRM 19.1 -

Table 14. Fish Collected and Analyzed for Use in Safety Evaluation

SPECIES	Number and Allocation of Fish Analyzed		
	USPHS	ORNL	TOTAL
White Crappie (Promoxis annularis)	20	20	40
Bluegill (Lepomis macrochirus)	20	20	40
White Bass (Roccus chrysops)	20	20	40
Largemouth Bass (Micropterus salmoides)	13	0	13
Sauger (Stizostedion v. vitreum)	13	4	17
Drum (Aplodinotus grunniens)	20	20	40
Catfish (Iactalurus punctatus)	20	20	40
Carp (Cyprinus carpio)	20	20	40
Smallmouth Buffalo (Ictiobus bubalus)	20	20	40
Carpsucker (Carpiodes carpio)	20	20	40
Golden Redhorse (Moxostoma erythrurum)	20	20	40

CRM 4.5). Although a variety of collection devices, including gill nets, hoop nets, trammel nets, and an electric shocker were used, some species were not taken in sufficient numbers to fulfill the goal of 40 individuals of 11 common species of food and game fish; the goal was not attained in the cases of largemouth bass and sauger. A majority of the large game fish were taken for analysis by the USPHS in expectation that more specimens would be forthcoming which would be handled at ORNL.

Sample Processing. A uniform sample processing scheme was developed by the USPHS and ORNL groups (see Fig. 20). The major factor governing the method used in processing a fish species was the way in which the species is normally prepared for human consumption. On this basis the flesh and bone of the bottom feeders were ground together which accounts for the significantly higher ^{90}Sr burdens

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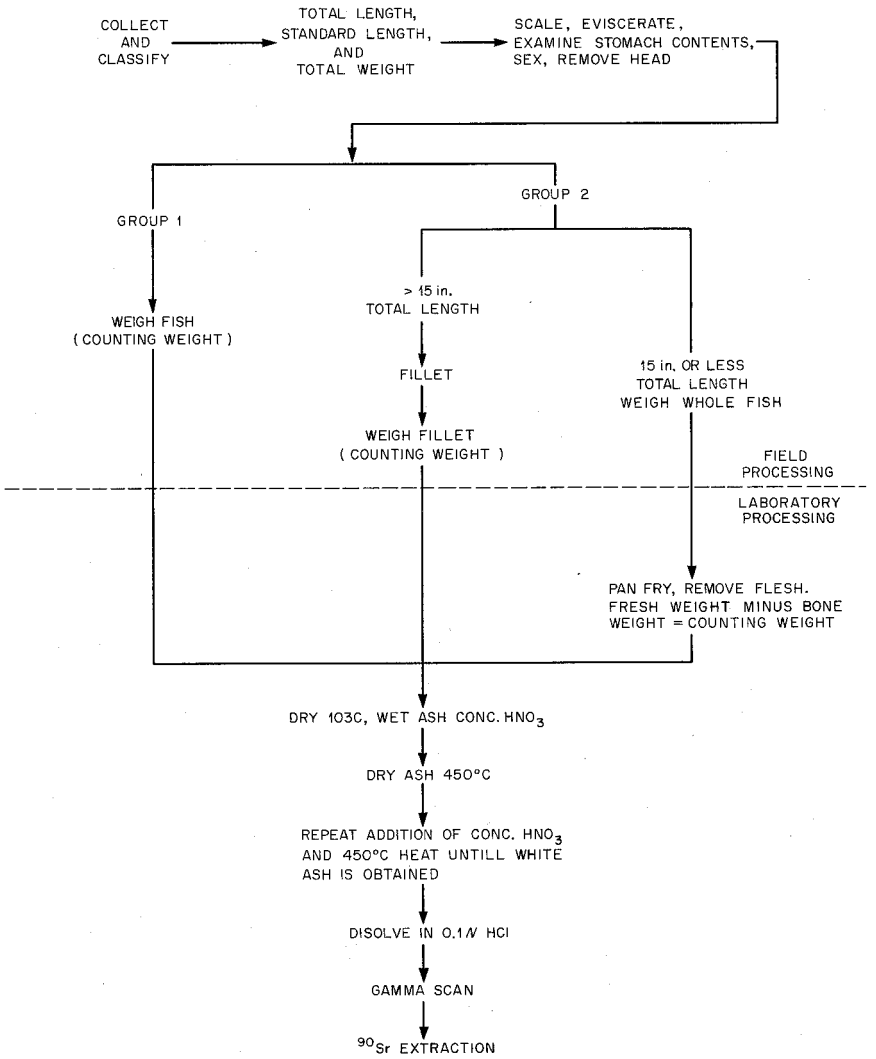

Fig. 20. Flow Sheet for Preparation of Fish Samples for Radioanalysis.

in the "Total" samples of these species (see Table 15). Thus, the exact processing method employed in the field and laboratory depended upon information regarding the fish species and method of preparation for eating and, with game fish, the size of the individual. All the fish were weighed, measured, scaled, and cleaned (including removal of the head) in the field.

The fish were divided into two groups. Group 1 included carp, carpsucker, smallmouth buffalo, and golden redhorse. Group 2 included white bass, white crappie, largemouth bass, bluegill, sauger, drum, and catfish. The catfish were channel catfish with the exception of one flathead catfish.

If fish in Group 1 were greater than 15 inches in total length they were filleted and the fresh weight of the fillet was used as the sample weight. Group-1 fish 15 inches or less in length were pan-fried and the cooked flesh was removed for analysis. The sample weight was the fresh weight minus the bone weight. Group-2 fish 15 inches or less in length were processed in their entirety, including bones. The sample weight was the fresh weight of the whole fish.

The processing of the fillets and fried flesh of Group-1 and Group-2 fish was essentially the same. All samples were dried at 103°C, wet ashed with concentrated HNO_3, and ashed with heat at 450°C. The ash was further treated with concentrated HNO_3 and heated until a white ash was obtained. This was dissolved in 0.1 N HCL with a final volume of 25 to 1000 ml, depending upon the size of the fish. Samples were scanned for gamma emitting radionuclides and strontium was precipitated for ^{90}Sr determinations.

Table 15. Concentration of Radionuclides in Clinch River Fish

(pc/kg fresh weight)

Fish Species	SAMPLE PERIOD	^{90}Sr Flesh	^{90}Sr Total[a]	^{137}Cs Flesh	^{137}Cs Total[a]	^{106}Ru Flesh	^{106}Ru Total[a]	^{60}Co Flesh	^{60}Co Total[a]
Carp	1960 - 1962	(17)[b] 500 ± 140	(40) 5100 ± 1700	(71) 510 ± 57	(39) 560 ± 79	(69) 170 ± 18	(39) 290 ± 78	(67) 66 ± 6.1	(39) 49 ± 9.9
	1963	(20) 91 ± 22		(20) 320 ± 110					
Carpsucker	1960 - 1962	(18) 540 ± 190	(39) 940 ± 120 (39) 4800[d]	(122) 1200 ± 460	(37) 640 ± 67	(22) 120 ± 30	(37) 56 ± 16	(22) 120 ± 19	(37) 32 ± 6.8
	1963	(20) 22 ± 4.4		(20) 460 ± 82					
Buffalo	1960 - 1962	(3) 240 ± 89	(30) 830 ± 110	(5) 480 ± 94	(30) 590 ± 92	(5) 110 ± 32	(30) 150 ± 38	(5) 78 ± 21	(30) 32 ± 6.8
	1963	(20) 43 ± 14		(21) 560 ± 84					
Sight Feeders[c]	1960 - 1962	(109) 180 ± 83		(126) 680 ± 120		(127) 120 ± 32		(127) 22 ± 11	

[a]Total fish consists of flesh and bone.

[b]Parenthetical values are numbers of fish analyzed.

[c]Sight feeders include white crappie, bluegill, white bass, largemouth bass, sauger, and drum; catfish also included.

[d]Includes four carpsuckers (composited) collected at CRM 19.6.

Table 16. Concentration of Radionuclides in Flesh of Tennessee River Fish

(μμc/kg fresh weight)

Fish Species	Sample Period	^{90}Sr	^{137}Cs	^{106}Ru	^{60}Co
Carp	1960-1962	(13)[a] 120 ± 33	(14) 180 ± 55	(14) 80 ± 27	(14) 71 ± 17
	1963	(20) 5.1 ± .75	(19) 61 ± 17		
Carpsucker	1960-1962	(10) 99 ± 28	(10) 130 ± 27	(10) 69 ± 23	(10) 62 ± 18
Buffalo	1963	(20) 8.9 ± 2.9	(20) 73 ± 12		
Sight Feeders[b]	1960-1962	(24) 250	(24) 170	(24) 48	(24) 66

[a]Parenthetical values are numbers of fish analyzed.

[b]Sight feeders include white crappie, bluegill, white bass, largemouth bass, sauger, and drum; catfish also included.

The same processing procedures were used for the fish collected in May 1963 except that, for comparison with the 1962 analyses, the bone was not included in the processing of selected portions of the fish. The purpose was to determine what influence, if any, the inclusion of bone in the preparation of fish would have on the concentration of radionuclides.

Analytical Results. Results of analyses of fish collected from Clinch River in 1960-1962 are shown in Table 15 [42] and the fish collected from the Tennessee River in 1960-1962 are shown in Table 16.[42] These tables also give the results of analyses of carp, carpsucker, and buffalo collected from the Clinch River and of carp and buffalo obtained from the Tennessee River in May 1963. In the calculations for safety evaluation studies, estimates were made of the intake of radionuclides by a man who consumed, at a specific assumed rate, Clinch River fish or Tennessee River fish containing the concentrations of radionuclides shown in Tables 15 and 16 respectively.

Data on Harvest and Use of Fish

Because of the observation mentioned earlier that inclusion of bones in the preparation of bottom feeders for eating resulted in significantly higher ^{90}Sr burdens in these species, the Subcommittee attempted to develop further information on the total quantities of bottom feeding fish harvested from Watts Bar Reservoir. These data were compared with the total East Tennessee harvest, including the relative amounts shipped to various market centers, and were summarized in Progress Report No. 2 of the Subcommittee on Aquatic Biology.[38] Data on the commercial fish harvest are shown

in Table 17 and the distribution of commercial fish from East Tennessee is shown in Table 18. Of particular interest is the fact that all of the carp were marketed within the state of Tennessee, in the cities of Nashville and Memphis.

The Subcommittee was not able to obtain as definite information about sport fishing and the data on capture and use of game fish are meager in comparison with those on commercial fishing. The progress report [38] summarizes and tabulates what data were obtained regarding sport fishing and game fish. Although incomplete these data give some indication of the distances from which fishermen come to fish in the Tennessee River, the total number of various species of fish caught by fishermen who had traveled various distances to fish in Watts Bar Reservoir and the Clinch River, and the area of maximum consumption of Clinch River fish caught either in the Clinch River or in Watts Bar Reservoir. For example, the Tennessee Game and Fish Commission conducted a partial creel census on Watts Bar Reservoir from March 1 through May 15, 1961 and during this period cards were issued to 1213 fishing parties. The returns, for only a part of the year, represented approximately 2444 fishermen, of which 3.85% were not residents of Tennessee. Using the data derived from ORNL fish tagging studies performed in 1962 an estimate of the area of maximum consumption of Clinch River fish was attempted. It appeared that, of the fish tagged, the greatest percentage (72.5%) were utilized within 50 miles of the site of capture.

One small enquiry about use of fish by people in this area was made by means of a questionnaire filled out at a country-wide meeting of home demonstration clubs. Of 53 individuals who answered the questions: 39 stated that they did use fish caught from local lakes and rivers while 14 said they did not; the kinds of fish used included bass, bream, crappie, carp, catfish, and others but the majority (30) listed crappie;

Table 17. Commercial Fish Harvest from Watts Bar Reservoir and the Total Harvest from East Tennessee

	Carpsucker	Carp	Smallmouth Buffalo
Watts Bar Reservoir	15,608 lbs	23,667 lbs	161,304 lbs
East Tennessee	61,676	135,016	327,302
Fish Dilution Factor*	3.95	5.70	2.04

$$*\text{Fish dilution factor} = \frac{\text{Lbs of East Tennessee Fish}}{\text{Lbs of Watts Bar Fish}}$$

Since there is no commercial fishery on the Clinch River, an average water dilution factor of 5.6 may be applied to the Watts Bar fish in addition to the fish dilution factor.

Fish and Water Dilution Factor	22.12	31.92	11.37

Table 18. Distribution of Commercial Fish from East Tennessee to Consumer Markets*

Species	Consumer Markets	Percentage
Smallmouth Buffalo	Chicago, Illinois	40
	Louisville, Kentucky	30
	Memphis, Tennessee	30
Carp	Nashville, Tennessee	50
	Memphis, Tennessee	50
Carpsucker	Chicago, Illinois	10
	Nashville, Tennessee	45
	Memphis, Tennessee	45

*Estimates from Mr. Harold LaTendresse of Johnny's Fish Company, Knoxville, Tennessee

as to methods of preparation a majority indicated pan-fry and fry in deep fat, but broil, bake, and other methods were also listed; and estimated quantities of local fish used per family averaged 10 pounds per month. Regarding frequency of use, 19 said that they served fish caught from local waters about once per week, and 20 said once per month.

Use of Specific Activities in Predicting the Uptake of ^{90}Sr by White Crappie (*Pomoxis annularis*)

In Status Report No. 4 the section on biological studies reported a series of determinations of stable strontium (Sr) in white crappie (*Pomoxis annularis*) flesh and bone.[43] These determinations were completed and the observed activities were compared with calculations of expected body burdens of ^{90}Sr in these fish. Samples were taken at monthly intervals to determine whether there were seasonal changes in Sr concentrations in fish flesh and bone. Also, bone and flesh samples were analyzed for Ca, and bone samples were analyzed for ^{90}Sr.

The Ca and Sr concentrations in fish flesh and bone were practically constant throughout the year as shown by the average annual concentrations and standard deviations given in Table 19. Relatively constant concentrations were expected in fish bone because of the long biological half-life of Ca and Sr in bony tissue. No seasonal variation was detected in the Ca and Sr concentrations in the fish. This is probably a reflection of the relative constancy of these elements in Clinch River water as reported earlier from stable-chemical analyses of water samples.[3]

Of particular interest was the fact that the average concentration of Sr in fish flesh was essentially the same as that of river water. This concentration factor of 0.01

Table 19. Calcium and Strontium Concentrations in White Crappie Flesh and Bone and in Clinch River Water

White Crappie	No. of Samples	Ca	Concentration Factor	Sr	Concentration Factor
Flesh ($\mu g/g$)	113	135 ± 2.43	6.34	0.068 ± 0.035	1.01
Bone (mg/g)	105	365 ± 7.77	17,136	0.268 ± 0.064	3941
Clinch River Water ($\mu g/g$)		21.3 ± 3.0		0.068 ± 0.0094	

All values are average annual concentrations ± one standard deviation

$$\text{Concentration Factor} = \frac{\text{concentration/g tissue}}{\text{concentration/ml water}}$$

Table 20. Specific Activity Relationships of ^{90}Sr between Clinch River Water and White Crappie Bone (Calculation)

$$\frac{^{90}Sr}{Sr} \text{ Water} = \frac{^{90}Sr}{Sr} \text{ fish bone}$$

$$\frac{4.3 \times 10^{-3}\ \mu\mu c/ml}{6.8 \times 10^{-2}\ \mu g/ml} \cong \frac{1.446 \times 10^{1}\ \mu\mu c/g}{2.684 \times 10^{2}\ \mu g/g}$$

$$6.23 \times 10^{-2}\ \mu\mu c/\mu g \cong 5.39 \times 10^{-2}\ \mu\mu c/\mu g$$

was far less than that of 20,000 to 30,000 times, which was reported from an earlier study of fish in White Oak Lake.[44] In fact, it is difficult to understand fully such a large concentration factor since (as shown in Table 19) Sr was concentrated only by a factor of 3941 times in bone, the tissue that would be expected to have the highest concentration.

To test whether specific activity ratios of ^{90}Sr in fish tissue were related to those in water, the concentrations of ^{90}Sr and Sr in bone were compared by use of the proportion given in Table 20. The data on ^{90}Sr concentrations in water, obtained from the Applied Health Physics Section,[45] were for the period of time these fish lived in the river water; and data on concentrations of stable Ca and Sr in Clinch River water are shown in Table 19.[3] There was relatively good agreement between the specific activities in fish bone and in water. These comparisons suggested that for any constant release of ^{90}Sr to the river, the consequent ^{90}Sr content of fish bone could be predicted.

The studies of the applicability of specific activities to predict ^{90}Sr concentrations in fish tissue were supplemented with investigations of the biological half life of Sr in white crappie. Knowledge of the biological half life in fish flesh or bone will permit calculations of the rate at which ^{90}Sr concentrations in fish tissues will respond to changing environmental concentrations of ^{90}Sr. Using ^{85}Sr and whole-body counting techniques no significant loss of Sr from bone was detected. On the other hand the biological half-life of Sr in the flesh of different individual fish has ranged from 12 to 48 minutes, much shorter than was anticipated.

Measurement of the turnover of ^{85}Sr in fish flesh was complicated by the rapid deposition and high concentration of Sr in fish bone, which literally masked the Sr in soft tissues. This difficulty was circumvented by constructing a fish-holding assembly, which was inserted into the detector chamber of a small-animal whole-body counter. Water was pumped through the assembly during experiments to remove excreted ^{85}Sr and to provide a supply of oxygenated water.

The long biological half-life of Sr in fish bone suggests that ^{90}Sr concentrations in the bone of river fish will reflect the average environmental concentrations during the lifetime of the fish. The short biological half-life of Sr in flesh means that fish flesh will reflect very quickly any changes in ^{90}Sr concentrations in the environment. This information is important in connection with the expected operating mode of Melton Hill turbines and releases of radioactivity from White Oak Creek.

Movement of Smallmouth Buffalo (*Ictiobus bubalus*) in the Vicinity of White Oak Creek

In the White Oak Creek embayment between White Oak Dam and the mouth of the creek, the levels of radioactive contamination in the water and bottom sediments are generally much higher than in the river. This portion of the embayment is in the controlled area which is subject to patrol, and fishing in this reach is prohibited. Fish are free, however, to move from the controlled area of White Oak Creek

embayment into the Clinch River where they may be taken by fishermen and used for food.

This possibility has caused some concern that the movement of contaminated fish into the open river might contribute to the radiation exposure of the adjacent population. Some pertinent information with a direct bearing on this problem was obtained in the course of a study of the smallmouth buffalo (*Ictiobus bubalus*) population in the Clinch River and adjacent downstream portions of the Tennessee River.[46]

A part of the objective in this study was to test the hypothesis that fish residing in White Oak Creek would deposit radionuclides in their scales in sufficient quantities to be detected by gross beta or gamma counting and autoradiography. On the other hand fish residing in less contaminated areas would not be expected to have readily detectable radioactivity in their scales. It was further hypothesized that fish having once lived in White Oak Creek would retain radioactivity in their scales because of the long biological half-life of mineral elements in bony tissue.

Fish scales are used in conventional age and growth studies to interpret past growth histories of fish because growth of the scales is proportional to growth of the fish. If a fish spent any appreciable amount of time in White Oak Creek embayment and radioisotopes were deposited in the scales, it should be possible to use the growth proportionality between scales and fish and, from radioactive rings in the scales, determine when a fish entered the embayment and how long it stayed there.

Eleven smallmouth buffalo were found that had sufficient radioactivity in their scales to produce autoradiograms. Of these fish, eight were caught in White Oak Creek embayment, one at CRM 21.7, one at CRM 16.0, and one at TRM 542, 12 mi upstream from Watts Bar Dam. There were 146 fish in the Clinch River-White Oak

Creek embayment sample and 1271 fish from Watts Bar Reservoir between TRM 539 and TRM 544; and of these 6.8% and 0.08%, respectively, contained sufficient radioactivity for autoradiography.

In the ORNL report on this study,[46] the case history, including the movement, of each of the 11 fish examined autoradiographically is discussed separately. Of the 11 fish, there were 16 instances where movement occurred between noncontaminated and contaminated areas. Twelve of these moves coincided with resumption of growth at the time of annulus (scale-ring) formation which would indicate that the majority of the moves occurred during late winter or early spring. None of the fish left the area where it was spawned before it was two years old. The area of spawning is referred to as being either contaminated or noncontaminated. The discussion and an autoradiogram for one of the 11 fish (smallmouth buffalo No. 8) taken from the ORNL report are given below.[46]

"Smallmouth buffalo[8] (Fig. 21) was hatched in the spring of 1957 in a noncontaminated area. It entered a contaminated area immediately after formation of its second annulus, probably in the spring of 1959. This fish was 271 mm long at formation of the second annulus. It remained in the contaminated area until some time during the winter of 1959-1960 when it left the contaminated area at a length of 304 mm. The animal was in a noncontaminated area until its capture on June 29, 1962, just prior to the formation of its fifth annulus. This fish was captured at CRM 16.0 at a length of 460 mm and weight of 1,410 g. Scales averaged 6 beta cpm per scale over background at capture." The autoradiogram of scales from this fish is shown in Fig. 21.

The data from this and the other 10 fish indicate the extent of smallmouth buffalo movements between White Oak Creek embayment, the Clinch River, and the

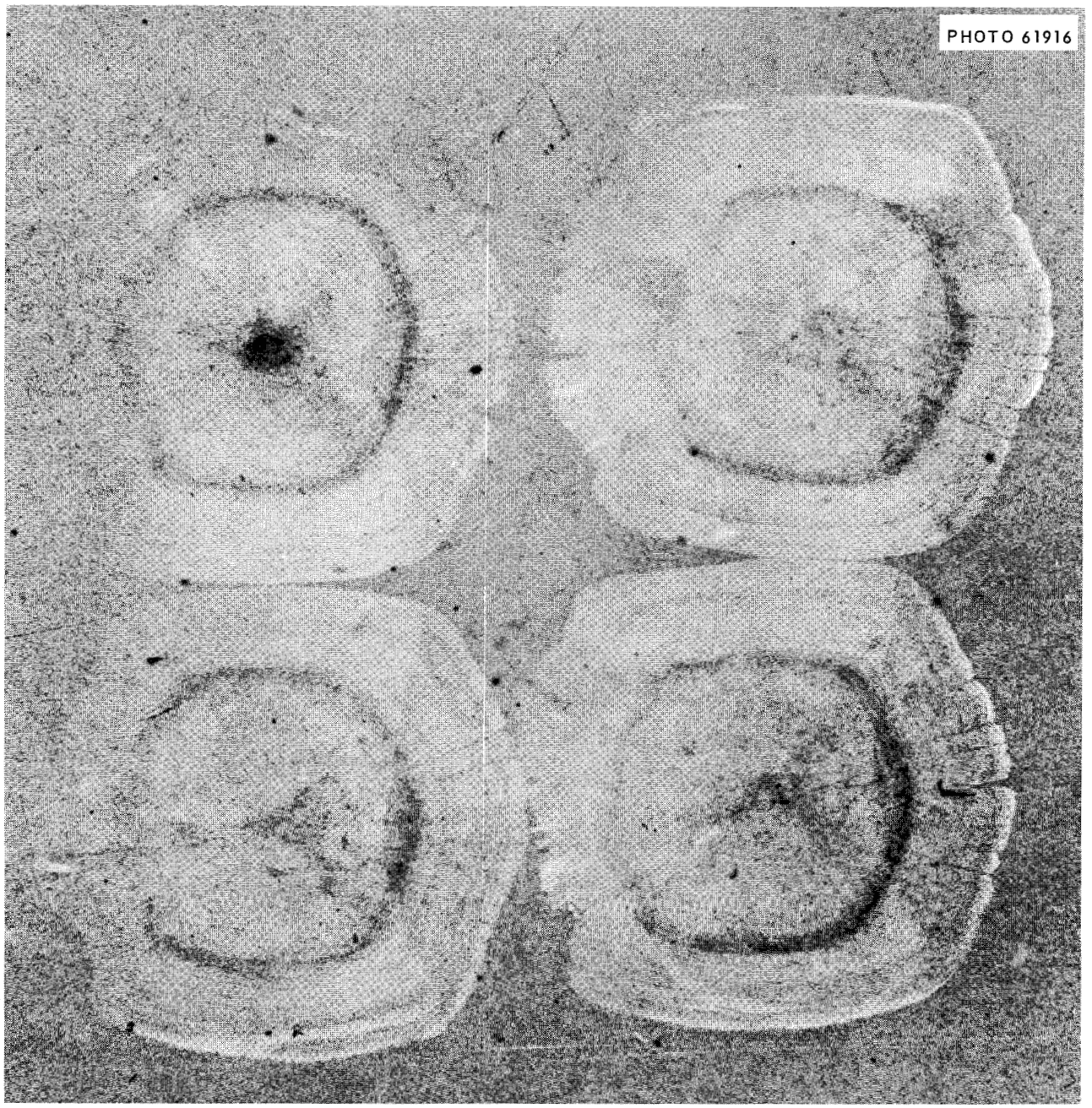

Fig. 21. Autoradiogram of Scales from Smallmouth Buffalo 8

Tennessee River portions of Watts Bar Reservoir. Use of radioactive rings permits interpretation of the history of fish movement in considerably more detail than from conventional tagging methods. Conventional tagging techniques permit the recovery of fish movement data only at points in time coincident with initial tagging and subsequent recaptures. Radioactive scale rings provide a continuum of information concerning the movement of the fish with respect to radioactive areas.

This study of the movement of this commercially important species of fish is significant because a new technique of study was developed and found to be superior to conventional tagging methods. A hazards analysis, if made, relating fish movements to the spread of radioactive contamination should be interpreted in the light of information on the biological half life of particular radionuclides in fish tissues.

HYDROLOGIC MEASUREMENTS AND ANALYSES

Cooperative Program of USGS

During the period covered by this report, April 1962 to December 1963, the U. S. Geological Survey (USGS) has continued its cooperative program of routine measurements and special observations relative to surface water hydrology in the Oak Ridge area. The USGS program in this area was summarized in Status Report No. 4 on the Clinch River Study.[47]

A primary role of the USGS in its relations with the Clinch River Study Steering Committee is to provide the basic data and the analyses that are necessary for a clear understanding of the dispersal of the radioactive wastes discharged into the Clinch River. It was for this purpose that the network of 8 gaging stations was established and 24 partial record stations were operated as described in Status Report No. 4. As explained in previous reports, the information collected at each of the stream gaging stations generally includes a continuous record of stage, discharge, and temperature. A temperature recording station at CRM 5.5 was operated for a temporary period (1961-1962) by ORNL and USGS personnel to obtain information on water temperatures at various depths in the river. In addition two special investigations conducted by the USGS jointly with other agencies engaged in the Clinch River Study are reported in subsequent subsections, namely, "Dispersion Investigations" and "Dye Tracer Studies - Summer 1963."

During the period covered by the present report there has been one major change in the gaging station network. The gaging station on Clinch River at Scarboro, Tennessee was discontinued on September 30, 1962 as a result of the filling of the reservoir above Melton Hill Dam to spillway level. This station was replaced by a station at Melton Hill Dam for which records of headwater elevations are furnished by the TVA and a continuous record of discharge through the spillway gates is provided by the USGS to all interested committee members and staff personnel of the Clinch River Study.

Dispersion Investigations

Several studies have been made or are in progress for investigation of the effects of power waves on dispersion. Most of this work has been undertaken to define the influence of power releases from Melton Hill Reservoir on the transport of radionuclides in the river system downstream.

Assuming that present methods of releasing radioactive materials from White Oak Lake are continued, a reservoir of radioactivity will accumulate in Clinch River waters in the vicinity of White Oak Creek during periods of no flow from Melton Hill Reservoir. During periods of power releases from the reservoir, this radioactive accumulation will be swept downstream in a cloud. The concentration of radioactivity in the cloud may be considerably higher than present levels.

Preliminary Observations in the Clinch River

During the summer of 1962 two periods of essentially no flow occurred in the lower Clinch River. During each of these periods water samples were collected to determine the dispersion of releases from White Oak Creek into the still pool.

This work, done by personnel of the ORNL Applied Health Physics Section, indicated that the releases from White Oak Lake tended to be dispersed upstream toward Melton Hill Dam during the period of no flow in early August. Although the exact cause of the upstream movement is not known, it could have been adverse hydraulic gradients or upstream winds which were observed at times during this period. Winds probably caused an observed upstream movement of debris on the water surface.

A period of no flow in August 1962 was established to allow the closure of a diversion channel at Melton Hill Dam. Personnel of TVA advised the investigators on the Clinch River Study when flow over the spillway would be resumed; and that the start of flow would be somewhat similar to a power release from the reservoir.

At the start of flow a fluorescent dye, Rhodamine B, was injected as a tracer, and movement of the tracer was observed for 3 days from the section of injection at the mouth of White Oak Creek (CRM 20.8) to Gallaher Bridge (CRM 14.4). The results of this test were considered as preliminary information and were used in the planning of the comprehensive series of dye-tracer studies in August 1963. The detailed results of the test were analyzed by the U. S. Geological Survey in Washington, D. C.

Laboratory Flume Study

A series of distorted-model dispersion tests were made in a flume operated by the U. S. Geological Survey at the Hydraulics Laboratory, National Bureau of Standards, Washington, D. C. These tests were undertaken to acquire immediate qualitative information on the effects of power waves on dispersion of radionuclides

and to develop numerical methods of describing the diffusion process.

The flume was 150 ft long, 3.5 ft wide, and 1.5 ft deep, divided into a 1.5 ft-wide test channel and a 2.0 ft-wide bypass channel. The flume could be tilted to any desired gradient. Discharges were obtained from a 300,000-gal recirculating system and depths in the flume were controlled by a tail gate. A double-notch weir plate was installed in the forebay so that the flow could be instantaneously diverted from the bypass channel to the test channel by operation of simple slide gates at the weir.

The discharge, bed slope of the flume, water depth for no-flow conditions, and bed roughness were adjusted to conform, at distorted scales, to anticipated conditions in the Clinch River. Horizontal distortions were approximately 250:1, and vertical distortions were about 20:1.

In the test procedure, the desired flume slope and water depth for no-flow conditions in the test channel and the desired discharge in the bypass channel were established. The power wave was created by suddenly diverting the established discharge from the bypass to the test channel. At the instant the wave was created, a tracer was released. In most tests the tracer was a mixture of dissolved potassium chloride, water, and ethyl alcohol, the density of the solution being the same as of the laboratory water. The variation of salt concentration with time was measured continuously at several points in the flume, using recording conductivity bridges. At the completion of a wave test, a steady-flow test was run. The discharge, slope, tracer, and water depth were the same as for the wave test.

The variation of concentration with time and distance in the model for one complete test is shown in Figure 22. The results from this test indicate that

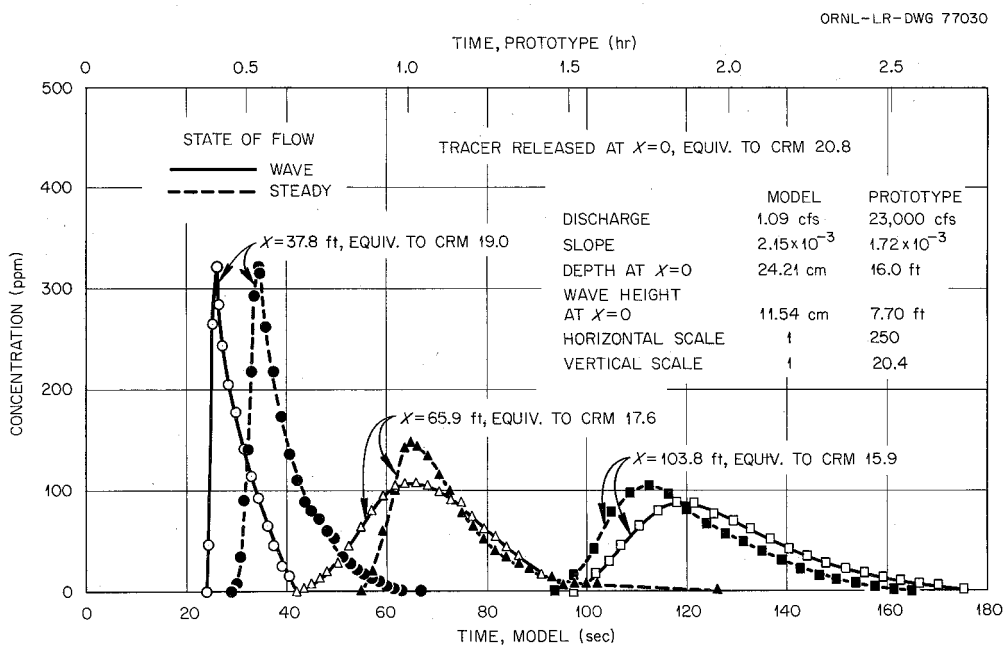

Fig. 22. Variation of Tracer Concentration with Time and Distance

the dispersion process due to power releases is not greatly different from that for steady flow, especially at sections that are considerably removed from the tracer-injection section. At equivalent CRM 15.9, about 1 1/2 miles upstream from the intake for the ORGDP water plant, the peak concentrations and the durations of the tracer cloud for the wave and steady-flow conditions were about the same.

As a check on model similitude, wave height and travel time for the model were compared to height and times predicted by TVA for the Clinch River. For flow conditions shown in Fig. 22 the equivalent wave height was 7.72 ft, as compared to the predicted height in the river of 7.70 ft. The equivalent travel time for the scale ratios indicated in Fig. 22 was about 3% greater than the time interpolated from information furnished in reports by the TVA.

Dye-Tracer Studies - Summer 1963*

Introduction

Past experience has shown that the dilution afforded by the flow of water in the Clinch River has been effective in reducing the concentration of radioactive wastes from White Oak Lake to acceptable levels. The radionuclide concentrations in river water at the Gallaher Bridge sampling station (CRM 14.4) during the past few years has been less than 1% of the maximum permissible occupational concentration in water.[48] Drastic changes in the flow regime of the Clinch River after the Melton Hill power station is put into operation are expected. During the summer months of 1963 a series of tracer studies was conducted to investigate the effects

*Based on a report by B. G. Frederick (USGS), F. L. Parker (ORNL), and P. H. Carrigan, Jr. (USGS), presented at open meeting of the Clinch River Study Steering Committee, December 4, 1963.[49]

that power releases from Melton Hill Reservoir will have on the dispersion in Clinch River of radioactive releases at White Oak Dam.

Although of relatively short duration, these studies were a rather large undertaking involving the efforts of between 25 and 50 workers either on the Clinch River or in supporting roles. It is impracticable to name the individuals who contributed, but the studies were a truly cooperative effort by the U. S. Geological Survey, Oak Ridge National Laboratory, U. S. Public Health Service, Tennessee Department of Public Health and Tennessee Valley Authority.

The studies were made by means of a nontoxic, red-colored fluorescent tracer, either Rhodamine B or Pontacyl Brilliant Pink B dye, and releases of water over the gated spillway of Melton Hill Dam at rates of discharge to simulate the expected power releases through the turbines after the electric-generating equipment is installed and operative. The estimated summer-discharge pattern of power releases at Melton Hill Dam is shown in Fig. 23.

It was assumed: (1) that proper gate releases at the dam would satisfactorily simulate power releases in the temperature and hydrologic effects produced below the dam and (2) that the tracer material (the fluorescent dye) would behave in a manner similar to radioactive wastes in the water phase of the river-study system. From preliminary surveys of temperatures at various depths in Melton Hill Reservoir upstream from the dam and also consideration of the probable conditions that might affect the dye, it was believed that the above two assumptions were acceptable.

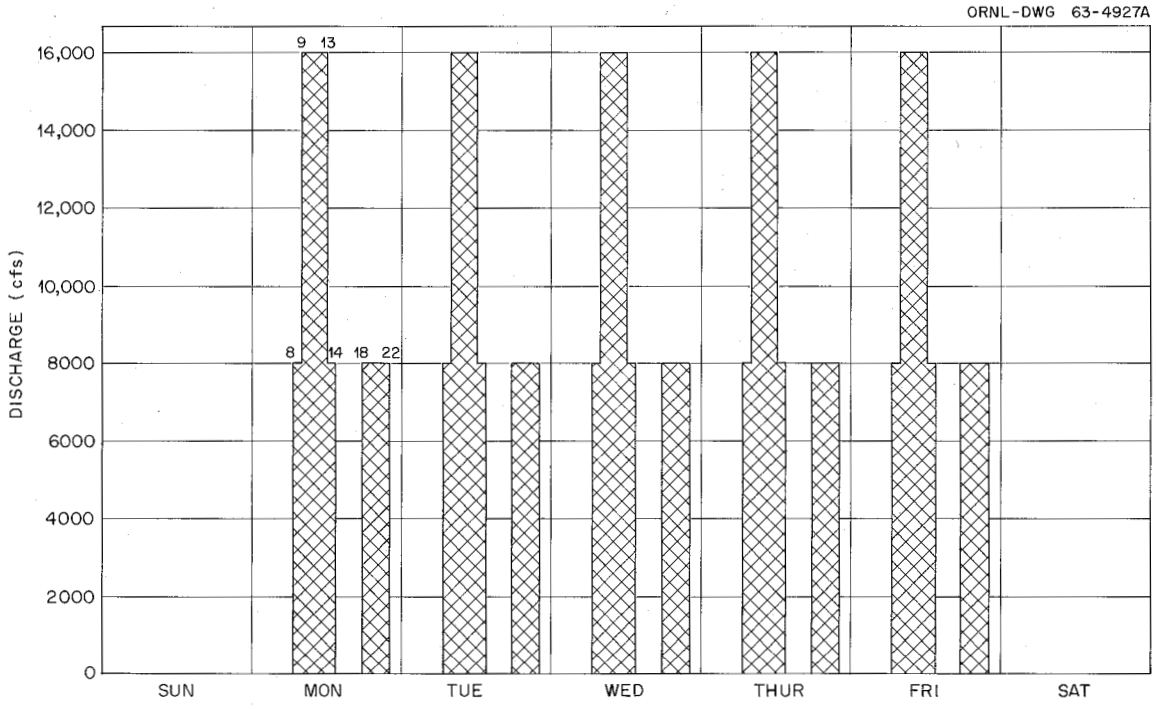

Fig. 23. Estimated Summer Discharge Pattern at Melton Hill Dam

Limited preliminary investigations also indicated that the dye would not be visible in any public water supply and would not be adsorbed on condenser tubes in the Kingston steam plant of TVA.

Following release of the fluorescent dye into the creek or river, the concentrations of the tracer in the water were determined at fixed observation sections in the stream. These determinations were made and recorded, either continuously or periodically, using Turner Model 111 Fluorometers equipped with flow-through doors and recorder attachments.*

One of the principal advantages of fluorometric instrumentation is the extremely low concentrations of fluorescent materials that may be measured. The instrument is capable of reliable detection, under field conditions, of dye concentrations ranging from 0.1 ppb (parts per billion) to about 400 ppb.

Experimental Releases and Field Observations of Dyes

Two tests were conducted under summer power-release conditions. Regulated flow in the Clinch River below Melton Hill Dam was provided, through cooperation of the Tennessee Valley Authority, by manual operation of the spillway gates at the dam. The rates of discharge at Melton Hill Dam and the weekly time schedule of intermittent power releases were as shown in Fig. 23.

In the preparatory stages of the tracer studies and prior to the power-release tests, three preliminary tests were conducted to determine the quantity of tracer needed

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*Procured from G. K. Turner Associates, 2524 Pulgas Avenue, Palo Alto, California.

in succeeding tests and to assess the reliability of the instrumentation under field conditions. Two of the preliminary tests were made with steady releases of water from Melton Hill Reservoir and a third with simulated power releases. Subsequent tests were run with the typical pattern of summer water releases (see Fig. 23)[50] and with Rhodamine B dye as the tracer.

The two tests conducted under summer power-release conditions differed largely in the duration of injection of the tracer.

1. In the first test the dye was injected continuously for 24 hr into the nappe of the effluent over the weir at White Oak Dam.

2. In the second test the dye was injected continuously for one week -- from 2:00 a.m., Wednesday, August 21, to 2:00 a.m., Wednesday, August 28, 1963 -- into the nappe at White Oak Dam.

Calculated predictions of the dispersion expected during the tests under the various conditions of water flow and dye releases were made by methods mentioned later under "Theoretical Investigations." The predicted values were compared with the actual concentrations which were observed during and following each of the first and second tracer tests. The dispersion with time which occurred in the Clinch River during the two tests was very similar to the predicted dispersion of radioactive wastes from White Oak Creek after power generation is begun at Melton Hill Dam.

In the first test (see "1" above) it was the intention that dye be injected continuously for a 24-hr period at White Oak Dam at a rate proportional to the discharge from White Oak Lake and that during this period typical releases of water from Melton Hill Reservoir be made. The dye-release apparatus did not perform properly, and the injection was not accurate, but valuable data were obtained at several points along the Clinch River. A comparison of predicted and observed dye concentrations at CRM 16.2 for four days following the release of dye in the first test has been shown graphically by a chart in the radioactive waste progress report for May-October 1963.[50]

In addition to fluorometer measurements, the progressive dispersion of the dye in the creek and river was observed visually as the intermittent releases of water were made. The spread of the red dye was easily followed by viewing from the ground or by aerial photography in the vicinity of White Oak Creek. The progressive spreading of the dye pulse in the stilled water was observed in aerial photographs taken on Wednesday afternoon, August 28. A sketch of the results is shown in Fig. 24 which indicates the extent of visible dye after the cessation of water release in the river.

At the time when flow suddenly began in the river, a rapid rise in the river water level occurred at the mouth of White Oak Creek. As a result of the increased water level, a reverse hydraulic gradient was created in the creek from its mouth to White Oak Dam; and an upstream flow occurred. For a considerable part of the time when water was being released through Melton Hill Dam, there was little or no flow from the creek

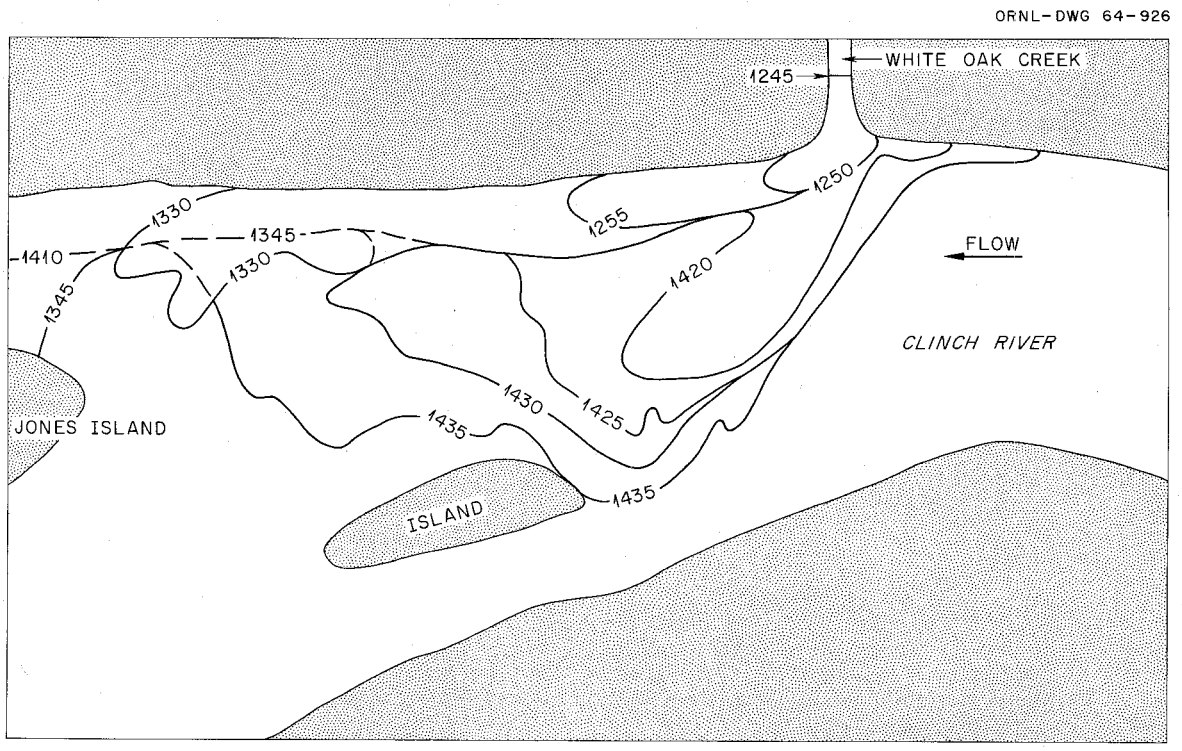

Fig. 24. Sketch of Time Development of Dye Front at and After the End of a 16,000 cfs Release in Clinch River at Mouth of White Oak Creek

into the river. When the release was stopped, the water level in the river quickly dropped, and a sudden rush of water from the White Oak Creek embayment ensued. A discrete pulse of dye accompanied this rush of water from the creek. Because there was no flow in the river, the dye mass remained close to the mouth of the creek. At the beginning of the next Melton Hill release, the slug of dye in the river was swept downstream as a reasonably intact mass, and flow up White Oak Creek again occurred. As the dye was moved downstream the color density rapidly decreased, and became practically indiscernible after about 7 miles of movement.

In the second and main test, dye was injected continuously into the effluent at White Oak Dam for 7 days, August 21-28, 1963. During this period the discharge from White Oak Lake was 6.9 cfs ± 2% (1.17×10^7 g/min*), and, except for the first 4-5 hrs at the start of the test when the injection pump did not operate properly, dye was injected at a rate of 32 g/min, resulting in an average dye concentration in White Oak Creek just below White Oak Dam of 2.73×10^3 ppb (parts per billion).

Dye Concentrations, Predicted and Observed. - Samples for dye analyses were taken every two hours from White Oak Creek below White Oak Dam during the third test, and continuous observations of the dye concentrations were made at CRM 14.4, CRM 5.5, and at the Kingston Steam Plant. Also, a dye concentration survey in the channel of Emory River was made on Friday, August 30. Samples for radionuclide analysis were taken every two hours from the nappe of White Oak Lake outflow and every six hours and at times of peak dye concentrations at CRM 14.4 and CRM 5.5. At the Kingston Steam Plant a continuous sample of raw river water was taken from a tap on a condenser intake pipe.

*g/min = grams per minute.

Primary effort has been directed to an analysis of the data on dye concentrations, particularly at CRM 14.4 and CRM 5.5. As mentioned earlier, both the dye injection rate and the discharge from White Oak Lake were constant during the study period. The predicted values for these two stations (CRM 14.4 and 5.5) were calculated on the basis of estimated dispersion and dilution, and the observed values were compared with the predicted values. Figure 25 shows the comparison for CRM 14.4, and Fig. 26 for CRM 5.5. The maximum observed dye concentration at the Kingston Steam Plant was about 12.0 ppb at 2:45 p.m. on Wednesday, August 28, and the maximum dye concentration observed during the August 30 fluorometer traverse of Emory River was about 5 ppb at ERM 0.4.

A comparison of the predicted concentrations at CRM 14.4 (Fig. 25) and CRM 5.5 (Fig. 26) with the observed values shows that the predictions were reasonably good, even though the predicted concentrations, in general, were slightly higher than the observed concentrations. A better knowledge of the dispersion characteristics would enable more accurate predictions to be made, and some further field observations under "winter conditions" have been proposed. Further measurements will be necessary to define the minimum effective dilution in the Clinch River under the variety of conditions that will occur during power releases of water at Melton Hill Dam. On the basis of results from the dye tracer tests, the momentary dilution as affected by power releases will be about 10 times less than the median (see page 125). It was concluded tentatively that the radionuclide concentrations at Gallaher Bridge will remain below MPC_W during the summer months after power releases from Melton Hill Reservoir have begun.

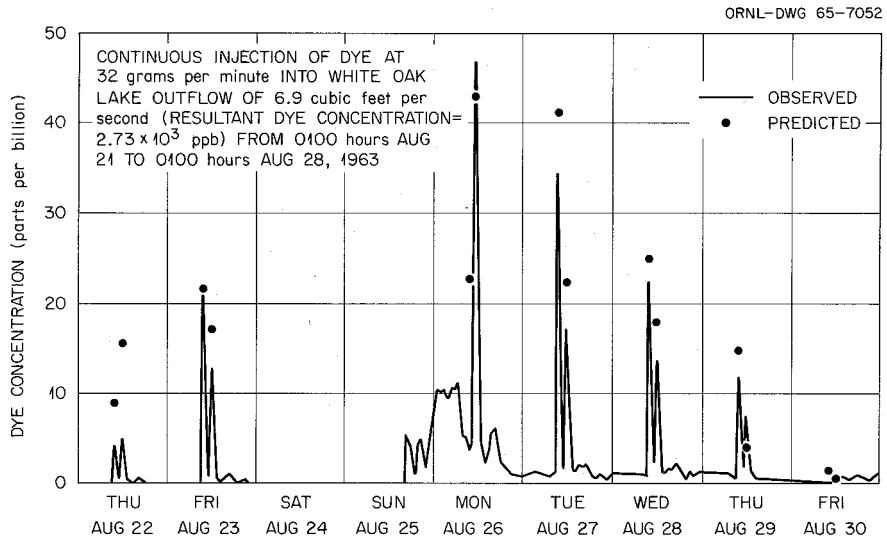

Fig. 25. Variation in Rhodamine B Concentration with Time During Period August 22-30, 1963, at Clinch River Mile 14.4

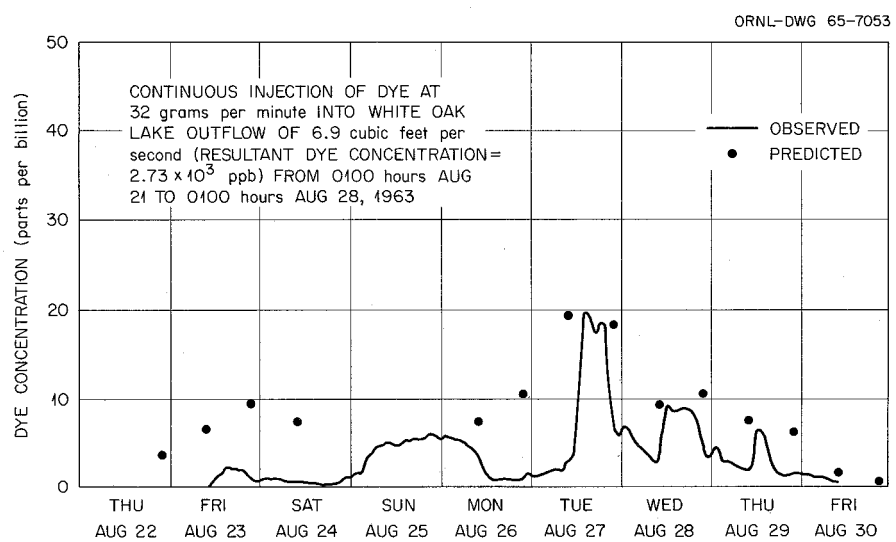

Fig. 26. Variation in Rhodamine B Concentration with Time During Period August 22-30, 1963, at Clinch River Mile 5.5

Temperature Observations. - In addition to the calculations and observations of dye concentrations, 24-hr observations of the movement of the temperature stratification line in Clinch River between CRM 4.5 (Centers Ferry) and CRM 23.1 (Melton Hill Dam) were made. These observations, made with the cooperation of TVA, were begun on Thursday, August 22, and continued on Sunday, August 25. Temperature profiles were made at about 5-mile intervals from CRM 20.8 downstream to the junction of Clinch River and Emory River and at 3-mile intervals from that point upstream in the Emory River to ERM 12 on August 21, 22, 25, 26, 27, and 28.

The temperature profile of the river during the 8,000-cfs flow showed that the temperature was uniform, 19°C, from CRM 23 to CRM 10. When the flow ceased on Friday afternoon, there was an unstable situation in the Clinch River, with 19°C denser water in the upper part of the river and warmer, lighter water, 29°C, downstream. Consequently, the heavier water drained out of the reach, and the lighter water flowed in until a more stable configuration was reached.[51] Later profiles showed that by 11:00 a.m. on Sunday, August 25, 22°C water had reached upstream to CRM 23. Therefore, 0.48 feet per second (fps) was the minimum velocity at which the heavier (colder) water could have drained out of the reach and the lighter water flowed upstream into the reach.

Theoretical Investigations--Calculations of Predicted Concentrations During the First and Second Dye Tests. - In order to make calculations and to predict concentrations and times of arrival in Clinch River of known releases of a dye or radioactive material at White Oak Dam, it was necessary to assume a normal pattern of discharge at Melton Hill

Dam and a steady outflow from White Oak Creek through White Oak Dam. A regular pattern of expected power releases at Melton Hill Dam is shown in Fig. 23. For purposes of these calculations, it was assumed that the steady flow in White Oak Creek through White Oak Dam was 7 cfs.

The ebb and flow of water in White Oak Creek embayment due to the power releases at Melton Hill Dam are much the same as flow in a tidal estuary. With techniques of tidal flow analysis, it was possible to compute the total mixing in the embayment and the net rate of movement through the embayment into the Clinch River. Also, it was possible to compute the predicted maximum concentration of the dye pulse as discharged from the creek and at downstream sections in the river and to estimate the travel times of the pulse to these sections. A method similar to the Woods Hole Analysis based on the "tidal-flushing" theory as advocated by Ketchum was adopted.[52] Variations of dye concentrations with time during the second test as predicted by this method are compared with the observed values at CRM 14.4 and at CRM 5.5 in Figs. 25 and 26 respectively. The basis for these calculations is summarized below. The methods of calculation were summarized in a report on the 1963 dye-tracer studies, presented to the Steering Committee on December 4, 1963.[49]

It was assumed that there would be: (1) complete mixing in the embayment during the tidal cycle; (2) no flow out of White Oak Creek into the river during releases from Melton Hill Dam; and (3) a constant outflow of 7 cfs from the creek through White Oak Dam into the embayment. The 0.6-mi-long reach of the White Oak Creek embayment was divided into 12 sections, all of equal volume, which in the calculations

corresponded with the "volume-segment" subdivisions used by Ketchum in evaluation of an estuary.[52]

The embayment has an average cross section, when the river elevation (el) is 741 feet above MSL (mean sea level), of 265 sq ft with a volume of 6.3×10^6 gal. At el 745 ft the average cross section is 875 sq ft, and at el 750 the average cross section is 2360 sq ft, with proportionately greater volumes in the embayment. When the Melton Hill Dam releases 16,000 cfs, this causes a rise in the water surface elevation at the mouth of White Oak Creek of 2.8 ft to el 743.8. A release of 8,000 cfs causes a rise of 1.6 ft to el 742.6. These rises are equivalent to water-volume increases of 9.4×10^6 gal and 4.5×10^6 gal, respectively.

Using the above assumptions and available information on river elevations and embayment volumes, the pollutant (dye) could then be routed section-by-section through the embayment during successive tidal cycles, and the time and concentration of its flow into the river could be calculated. Assuming that each injection of dye into the Clinch River would remain together and function as a single unit, it was possible to route the mass of contaminant (the dye) downstream.

At 10 p.m. on Friday (August 23) the weekend shutdown of water releases occurred and continued for 58 hours until 8 a.m. the following Monday. Flow of water and dye from the White Oak Creek embayment into the still river water commenced soon after the shutdown began and continued until the startup of Melton Hill releases at 8 a.m. Monday morning. On Sunday afternoon, August 25, at about 3 p.m., aerial observations were made. It was observed that a continuous mass of dye extended from CRM 20.0 to CRM 22.5; the mouth of White Oak Creek is in this reach at CRM 20.8.

The effective dilution in the Clinch River of discharges through White Oak Dam is less during the conditions associated with power releases. The minimum effective dilution factor was about 50 during the test period of intermittent releases and a weekend shutdown at Melton Hill Dam. On the basis of the concentration of tracer injection at White Oak Dam and the peak concentration observed on Monday, August 26, the effective dilution at the Gallaher Bridge sampling site was reduced by a factor of about 10 as compared with a median dilution of 570 for the period 1950-1960.[53]

The twice-daily pulses of dye from the creek were observed on the week days during the test period between about 10 a.m. and 11:45 a.m. at the Gallaher Bridge observation station (CRM 14.4). During the weekend increased concentrations unexpectedly occurred at this station on Sunday afternoon (see Fig. 25). When there is no release from Melton Hill Reservoir, upstream flows might occur because of river-control operations in the Tennessee River, re-establishment of thermal stratification in the Clinch River, or as a result of a combination of both processes. These upstream flows, though minor, could move a mass of dye short distances. It is believed that the mass of dye that passed the Gallaher Bridge section at 11:45 a.m. on Friday of the first week and was stagnated about CRM 12, slowly moved upstream later during the weekend and finally stagnated in the vicinity of the sampling site beginning on Sunday afternoon.

It has been shown that reasonable prediction of the effects of a sequence of power releases from Melton Hill Reservoir could be made if the dispersion characteristics of the releases were empirically known.[50] A more general analytical

method of predicting dispersion due to these power releases is being sought. One possible method of prediction is to assume that the factors which influence variations in the dispersion characteristics are the same for the unsteady nonuniform flow occurring in the Clinch River as for steady uniform flow. In steady flow no variation in flow or in velocity occurs with time. In uniform flow no change in velocity occurs with distance; that is to say, there is no convective acceleration either in the direction of flow or in the direction normal to flow.[54]

For the predictions of concentrations in the stream, the diffusion coefficients and also the energy gradients for the prevailing conditions must be determined or assumed. Data for evaluation of these two factors are presently very limited. In a waste treatment and disposal progress report [54] mention of the variables relevant to prediction of stream concentrations and a discussion of possible approaches and equations that may be applicable to determine the diffusion coefficient are given. Figure 27, taken from this progress report, shows the variation in the diffusion coefficient as computed for a number of points at which observations were made during tracer studies in August 1961 and February 1962. The variation of the diffusion coefficient for the same tests with velocity of flow, one of the relevant variables is shown in Fig. 28. The flows in the river during these studies were steady.

To provide a better basis for analysis of unsteady and nonuniform flows the authors of the report to the Steering Committee[49] have stated several conclusions and recommendations which are summarized below.

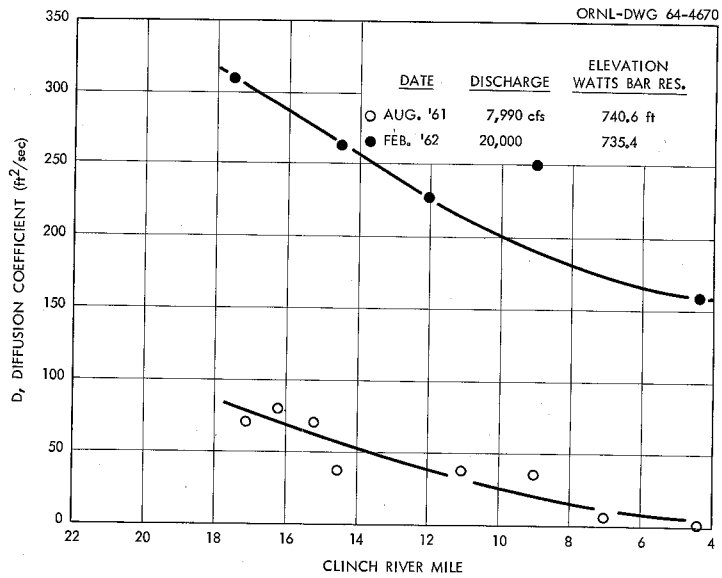

Figure 27. Longitudinal Variation in Diffusion Coefficient for Two Conditions of Steady Flow in the Clinch River

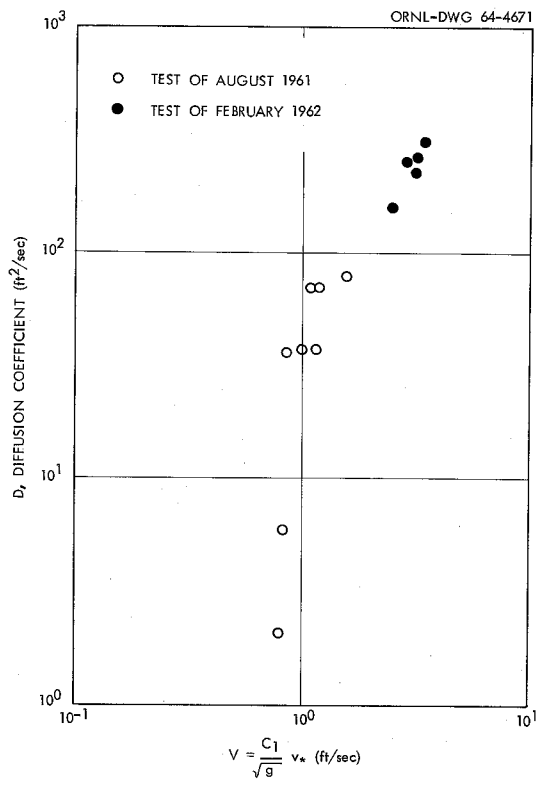

Figure 28. Relation of Diffusion Coefficient with Mean Velocity

Conclusions and Recommendations Regarding Further Field Studies of Dispersion in the Clinch River

Both local and general needs for better information are adequate justification for further field studies of the dispersion characteristics and behavior of discharges from White Oak Creek into the Clinch River, particularly studies under "winter" conditions and with unsteady and nonuniform flows.

Complete general analytical treatment of dispersion problems of the complexity encountered in the Clinch River will be very diffucult to achieve. In addition to difficulties in predicting the diffusion coefficients, mentioned above, there are uncertainties as to the degree of dispersion that will occur in the stilled pool of the Clinch River during periods of long shutdown such as prevailed on the weekend of August 24 and 25, 1963 during the second dye test.

Tests with tracers, as previously described, will indicate the general magnitude of dilution, rates of travel, and duration of appreciable levels of contaminants at critical locations for particular conditions. However, more exact determinations of the effects of power releases on the dispersion of radioactivity in the Clinch River for the variety of flow conditions might be better obtained by a materials balance study based on the input and output of contaminants in the study reach. This approach was recommended.

For the materials balance study the input load of radionuclides to the study reach could be determined at White Oak Dam and at Melton Hill Dam. A continuous proportional water sampling station is in operation at White Oak Dam and, also, in the tailrace of Melton Hill Dam. Analyses of samples from these two stations could be made to provide the input data required for a materials balance study.

On the basis of previous work during the Clinch River Study, the output load for the materials balance study might be determined at two locations, the intake to the water plant of ORGDP (CRM 14.4), and above Centers Ferry (at CRM 5.5). It was recommended that continuously operating proportional samplers be used at these sites. The development and fabrication of such equipment would cost about $5,000 for each station.

Because of the high cost, the construction of more than one downstream sampling station may not be feasible. From the standpoint of problems in the development, installation, and maintenance of one such station only, the preferred site is the one at CRM 14.4. General methods of actuating the equipment at either of the two downstream stations mentioned above were suggested in the report to the Steering Committee. It was recommended that, with these sampling facilities available, a system of coordinated sampling and analysis upstream and downstream from the mouth of White Oak Creek should be established to provide comparative data on radionuclide concentrations in the river. This should be carried on for several months selected to represent both summer and winter conditions after the Melton Hill Dam power station is in operation.

In the report it was concluded that, with the development of better information for determining diffusion coefficients and energy gradients for various conditions, much better predictions of dispersion and resultant concentrations of contaminants released to the river could be made. It was recommended that any opportunities for further field studies that would aid in the quantitative definition of these parameters should be considered, and followed up if possible.

SAFETY EVALUATION STUDIES

Analyses of the safety of conditions that result from discharges of radionuclides to the Clinch River and the potential exposure of people to ionizing radiation from these discharges have been made by the Subcommittee on Safety Evaluation. This subcommittee was established by the Steering Committee October 27, 1961, "to study available information and additional data that may be obtained and evaluate the potential hazards of discharges of radioactive wastes from Oak Ridge installations in the Clinch and Tennessee Rivers."[55]

The work of this subcommittee and some of the results obtained were summarized in Status Report No. 4 on the Clinch River Study.[56] In this summary the bases of safety evaluation, the objectives of the subcommittee, an outline of additional information needed, data on the radionuclides released and concentrations in the rivers, the avenues of human exposure, the critical organs considered, and the radioactivity in the water of the Clinch and Tennessee Rivers in terms of MPC_w were reviewed. Also, the estimated potential radiation dosages from drinking water, water immersion, and radioactivity in bottom sediments were given.

The summary in Status Report No. 4[56] was based on a preliminary safety analysis prepared by the subcommittee in 1963. Since that time the subcommittee has completed its evaluation and submitted to the Steering Committee its final report which contains the revised version of the entire safety analysis.[57] In addition to the explanatory sections and estimates of dosages outlined above the subcommittee's final report includes calculated estimates of radiation dosages for various populations which might result from drinking water

from the Clinch or Tennessee River, eating contaminated fish, or eating food from crops irrigated with contaminated river water.

Regarding the limitations of its analysis, the subcommittee recognized that any biological form may receive some degree of radiation exposure but this study confined its efforts to calculation of radiation dosages to man. Since data on direct measurements of dosages were not available and could not be obtained, the exposures were calculated from determinations of the amounts of radioactive material in the various environmental media and by the use of assuptions as to the fraction of this material that might cause internal exposure of the affected population. Not all of the desired information was available. For example, in order to complete some calculations it was necessary to estimate the dietary habits and amounts of principal food stuffs consumed as well as occupational and recreational patterns. Several estimates of external radiation exposures were calculated from measured concentrations of radionuclides in environmental media but these should be confirmed by direct measurements where possible.

The tabulated estimates of exposure values from various media derived by the subcommittee will not be included in the present report because: the preliminary analysis was described and partially summarized in Status Report No. 4;[56] and (2) the final report of the subcommittee is being prepared for release as a supplement to the present report (Status Report No. 5) and should become available about the same time.[57]

As a summary of its final report the subcommittee included at the end a section on conclusions and recommendations which were based on the detailed data in the

earlier sections of the report. The comments below are based mainly upon the subcommittee's conclusions, particularly those regarding the estimates that were not summarized in Status Report No. 4.[56]

Estimates of Radiation Dosages

On the basis of concentrations of radionuclides in the various environmental media, and using the approach and assumptions described in the final report,[57] the subcommittee calculated the potential dosages to the skeleton, total body, and thyroid of man due to consumption of contaminated water and fish. These were found to be the critical exposure possibilities but estimates were also made of external radiation dosages from water immersion or contaminated sediments in the rivers, and from radionuclide concentrations in water treatment plants and systems. A hypothetical analysis of possible future hazards that might develop from irrigation of food crops was made although the present practice of irrigation is limited.

As a basis for interpretation of the potential effects from the calculated exposures from the individual vectors and the aggregate overall exposure from all of the vectors the subcommittee used the criteria of the International Commission on Radiological Protection (ICRP),[58] and the Radiation Protection Guides (RPG) recommended by the Federal Radiation Council (FRC) for normal peacetime operations.[59] The recommended limits from reports by ICRP and FRC were compared by the subcommittee in its report.[57] It was shown that the differences were minor and within the precision of the data employed by these agencies in arriving at the suggested limits; and that differences in the acceptable rates of intake were not significant.

In its analysis of the potential hazard of internal dose from ingestion of water or contaminated fish the subcommittee concluded that ^{90}Sr has been the most important of the critical radionuclides released to the Clinch River, contributing more than 99% of the dose to the skeleton and total body and 70% of the thyroid dose. However, it was noted that in the recent Publication 6 of ICRP[60] the recommended permissible intake of ^{90}Sr by standard man was increased because it was considered that the metabolic data provided a better estimate of acceptable values for ^{90}Sr (in bone as the critical organ) than the single exponential model used previously. This change will result in an overestimate in this report of the potential exposures from ^{90}Sr to the total body and the skeleton by a factor of about 2 and 4 respectively. It was estimated that the total dose to the skeleton of the critical population was smaller by a factor of about 5 than the allowable dose from contaminated drinking water; improved waste management at ORNL has resulted in a decrease in ^{90}Sr released to the Clinch River.

A table in the report gives the estimated cumulative dose received by critical organs of males from use of Clinch and Tennessee Rivers for drinking water, recreation, and production of food fish and, for comparison, a statement of the recommended maximum permissible dose to the skeleton and total body is given. In commenting on this table the subcommittee again noted that: (1) the calculated internal dose from ingestion of drinking water and contaminated fish were the critical exposure pathways; (2) immersion in water, contact with bottom sediments, and occupational work within a water treatment plant were not significant from the standpoint of comparative exposure; and (3) the total cumulative dosages received by the critical organs have been well within

the limits recommended by ICRP, either for occupational exposure or for the general population.

The report also mentions the several assumptions upon which the calculations were based and the consequent limitations in use of the data. Because of the inadequacy of quantitative information presently available and the conservative assumptions, it is apparent that the estimated dosages would be less if better information were available and were factored into the calculations. One excellent example is the recent change in the MPC_w for ^{90}Sr mentioned above which would reduce the estimated dose to the skeleton by a factor of 4 and to the total body by a factor of 2.

Crop Irrigation

The subcommittee noted and gave references to show that irrigation of a variety of crops has been practiced in Tennessee, for at least 50 years, and that during the period 1950-1955 irrigation with water from the Tennessee River was significantly increased. From a survey in 1958 it appeared that of 1,021 irrigation units in operation at that time, 20% were used for irrigating truck crops and 30% for irrigating feed crops (corn, silage, and hay). In West Tennessee, west of the Tennessee River, ground water is the principal source of water for irrigation but surface water is predominantly used in East Tennessee. More than 15 inches of water have been applied to truck crops during the growing season.

Currently crop irrigation along the Clinch River is nonexistent and there is little practice of irrigation along the Tennessee River downstream from Oak Ridge. Therefore, a safety analysis of the possible transfer of fission products from contaminated river water to foods by crop irrigation is largely a hypothetical exercise. It is considered justifiable, however, in order to point out future problem areas and, where possible, to uncover

long-term problems that may result from currently unpredictable usage of this natural resource. The subcommittee made suitable conservative assumptions and calculated potential exposures in spite of the lack of specific data regarding such vital factors as: types of crops irrigated, quantity of water applied per year, percentage of total production that might be affected by irrigation, the concentrations of particular radionuclides that might be accumulated in the soil, the factors of plant uptake of radioactive elements from the soil, the concentrations of radioactive materials that might be found in foodstuffs, and the proportion of food crops irrigated with river water that might be used by the average population as compared with unirrigated food crops. The probable present and the potential future radiation dosage to the population that might be attained from the use of irrigated crops was estimated.

In its interpretation of these estimates the subcommittee concluded that at the present time there is no danger of significant quantities of fission products entering man's diet because of crop irrigation. Truck crops in this environment contribute little to the total quantity of produce and are grown only on small plots and for a short period during the year. In areas where climatic conditions are more conducive to year-around irrigation of large agricultural plots, however, crop irrigation with contaminated water could take on greater importance. Some use can be made of data provided by fallout studies but there is need for data from experiments that will define radionuclide entry into man's diet from contaminated irrigation water. Analyses of samples of soils and crops that are irrigated with Tennessee River water, although difficult, might assist in defining the extent of fission product concentrations due to such practice.

Some Comments on the Subcommittee's Conclusions

From the four pages of conclusions and recommendations to be published in the subcommittee report,[57] the following are selected for brief comment:

1. Disposal of radioactive wastes to the Clinch River has resulted in radionuclide concentrations in the river water below FRC recommendations. Most important as a potential source of radiation exposure was consumption of contaminated water and fish, but no population groups subjected to these critical exposure pathways received excessive dosages. If the practice of irrigation with river water continues to develop, the long-term effects of crop irrigation with the contaminated water could become the most important avenue of exposure.

2. The calculation of internal dose to critical organs should be revised using the actual concentrations of radionuclides in the river water as determined by the Subcommittee on Water Sampling and Analysis. Internal dose calculations based solely on exposure of so-called standard man would underestimate the dose likely to be received by critical population groups (the most highly exposed groups) by a factor of at least 2. Improvements in dose estimates are possible if better information can be obtained. For example, when information becomes available concerning the differences in metabolic rates and processes in children and adults as they relate to the important radionuclides it can be factored into the mathematical models (given in the report) and the dose to the critical organs recalculated.

3. Strontium-90 has been by far the most important of the critical radionuclides in the liquid wastes released to the Clinch River. As mentioned earlier, it has

contributed more than 99% of the dose to the skeleton and the total body and 70% of the thyroid dose. Ruthenium-106, ^{137}Cs, and ^{60}Co contributed significantly to the dose received by the GI Tract. The doses are well below and often are only a small percentage of the permissible dosage limits. The actual values of the estimated dosages received are given in the report.[57]

4. Routine environmental monitoring should emphasize mainly the critical pathways of human exposure which currently are the consumption of contaminated water and fish. Periodic review is needed to confirm the adequacy of the monitoring program and assure that exposures from radionuclides of short half life as well as of long half life are considered. Minor sources of exposures such as contaminated water and bottom sediments should be monitored, although less intensively, in order to be sure that the over-all potential of human exposure is assessed periodically.

5. There is need for continued research studies to investigate radionuclide transfer to fish and to irrigated crops. The types of data needed have been summarized earlier. A potentially important source of entry of ^{90}Sr into man's food chain can be eliminated if fish can be prevented from inhabiting White Oak Creek or White Oak Lake and then entering the Clinch River. An adequate analysis of crop irrigation as a critical exposure pathway requires knowledge of fission product behavior in soils and plants as well as of the extent and methods of irrigation.

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