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Preface

The energy crisis and the creation of the Energy Research and Development Administration were dominant factors affecting the activities of the Environmental Sciences Division during the past year. Planning for ERDA's new environmental, health, and safety programs was a major effort which drew heavily on the staff members from all of the ERDA Laboratories. This work coalesced into what was called the Balanced Program Plan (BPP), in which a strategy was formulated for coupling bio-environmental research to energy technology development. The Division contributed heavily to the development of this plan, especially on coal-related technologies. Coal conversion is an important part of the overall coal technology program, and our role in the BPP enabled the Laboratory to move ahead with a strong, coordinated life sciences program in this new area. Within the Division, two coal-related projects have been established and are underway: The Trace Contaminants Project, under the direction of R. I. Van Hook, places emphasis on the environmental behavior and consequences of substances derived from the combustion of coal. The Coal Conversion Effluents Project, under C. W. Gehrs, is focussed on the behavior and ecological toxicities of substances, especially complex organic compounds, produced in coal liquefaction and gasification processes. In cooperation with the Energy Division, the Regional Studies Project, under D. C. Parzyck, will devote parts of its efforts toward the National Coal Assessment, involving the entire coal fuel cycle.

Results last year reflected the Division's strengthening of its efforts on "problems of significance." The Power Plant Effects Program, under the management of C. C. Coutant, now widely recognized as one of the leading groups in this area, is broadening its scope to include the effects of impingement and entrainment on aquatic biota. With EPA "Pass-Through" funding, a power plant simulator is being built which will be one of the first of its kind.

The plutonium project, under R. C. Dahlman, which was highlighted in last year's report, has broadened its research to other transuranics. Support for new research on environmental behavior and effects of thorium and uranium isotopes has enabled the project to expand its effort in this important problem area.

The International Biological Program officially ended last year, but the Division's role as leader of the Eastern Deciduous Forest Biome Project, managed by R. L. Burgess, will continue under National Science Foundation auspices for at least three years more. This period is being used to complete syntheses of work at each of the major biome sites, in addition to various inter-biome and international syntheses of ecosystem structure and function. Meanwhile, new basic research on ecosystem processes is under way and plans are being formulated for ecosystem research as a logical continuation of the formal Biome Program.

Assessment research made a quantum jump in development this past year. The Ecological Analyses and Applications Group, now under the leadership of R. W. Brocksen, has achieved national recognition for the quality of its work. With the advent of ERDA, this group is beginning to address a broader range of energy technologies, and we look forward to its increasing contributions to the field of environmental assessment and ecological impact.

Nuclear technology environmental assessment was another area of increased Divisional activity and responsibility. The Radiological Analyses and Applications Section under S. V. Kaye is contributing to the environmental radiological assessments of a number of advanced major reactor systems such as the Liquid Metal Fast Breeder Reactor (LMFBR), the High-Temperature Gas Cooled Reactor (HTGR), and the Light-Water Breeder Reactor (LWBR). Contributions to the methodology of radiological impacts assessment have won this group wide recognition, with an increasing demand for its services from a number of divisions of ERDA and the Nuclear Regulatory Commission.

A major highlight was the groundbreaking ceremonies, held on September 12, 1975, for construction of the new Environmental Sciences Laboratory. Construction of the facilities now dominates the west end of Oak Ridge National Laboratory. Completion is scheduled for September 1977 -- an event we all are awaiting with anticipation and eagerness.

Reorganization of the Division was another major accomplishment. The Division has been restructured into a matrix of disciplinary groupings and projects. We believe that such an arrangement will give us greater flexibility in meeting the missions and goals of our sponsoring agencies, while simultaneously providing for strengthening the quality of our science. We are trying to orchestrate true integration. We have chosen scientists who have demonstrated their ability and interest to do interdisciplinary work and we have selected tasks within projects that cut across disciplines and are designed to help interdisciplinary integration. Our challenge is to develop cross-fertilization of ideas by integrating disparate disciplines into programmatic efforts.

For the Environmental Sciences Division and for many at ORNL, the sudden death of Dr. Daniel J. Nelson was a saddening experience. Much of our past success was due to his indefatigable efforts in aquatic ecology, ecosystem analysis, impact assessment, and program management. His loss to the Division is great, and his place will not easily be filled.

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PART I. COAL CONVERSION

1. Overview and Research Initiatives

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Although research related to coal has been conducted in the Environmental Sciences Division for several years, this past year has seen a concerted effort into the organization and development of an interdisciplinary research program related to coal conversion. The goal of the program is the production of a relevant data base necessary to ensure that coal conversion technologies will be developed in a manner that optimizes environmental and human health as well as economic considerations. Divisional staff members have been heavily involved in two planning activities during 1975: preparation of the Laboratory's Biomedical and Environmental Proposals related to coal conversion and DBER's 10-year Balanced Program Plan in coal conversion.

The goal of environmental research related to coal conversion is two-fold: (1) to determine the potential for effects on aquatic and terrestrial systems resulting from chronic low-level exposures to conversion materials, and (2) to provide source terms describing the potential magnitude of dose for areas surrounding a conversion facility that may be effected by effluent materials.

The term coal conversion refers to any of five types of processes for producing clean liquid, solid, or gaseous fuels and petroleum feedstocks. Each process may give rise to hundreds, even thousands, of organic compounds that could impact upon the environment. Sharkey,² for example, identified fourteen major structural types of compounds (Table 1.1) in the heavy oil and asphaltene fractions of the SYNTHOIL product. Here at ORNL³ more than 100 sulfur-containing compounds (Table 1.2) have been observed in oil from the SYNTHOIL process. To evaluate every compound individually, and in concert, for its potential environmental impact is neither practical nor feasible (many of the compounds have not been identified or are not commercially available). The approach we are taking at ORNL can be considered as having two parallel thrusts.

One facet includes an iterative process between staff in the Analytical Chemistry, Biology, and Environmental Sciences Divisions. Whole effluents are tested in rapid screening toxicity tests, fractionated, and retested, subfractionated, and again tested (Table 1.3). The most active subfractions are then examined for compound identification. Such an approach serves to rapidly identify those materials requiring more extensive investigation as to their environmental behavior and effects. The second aspect of our program is concerned with understanding the mechanisms of effect, persistence, fate, transformation products, and food chain kinetics of effluent components. It is this aspect of the program that will eventually provide the data basis necessary, assessing and predicting the potential implications of a coal conversion economy.

Research dealing with trace elements and organic contaminants in the aquatic environment and the effects of gaseous effluents has recently been initiated.

Table 1.1. Major structural types in heavy oil and asphaltene fractions from SYNTHOIL product^a

Structural types ^b	Percent of total ionization	
	Heavy oil	Asphaltene
Alkylbenzenes	11	9
Indenes	7	4
Indans	9	2
Naphthalenes	6	2
Acenaphthylenes	12	8
Biphenyls	21	11
Anthracenes; phenanthrenes	6	4
Phenylnaphthalenes	5	6
4-rings, peri-condensed	5	11
4-rings, cata-condensed	3	9
5-rings, peri-condensed	4	15
5-rings, cata-condensed	1	5
6-rings, peri-condensed	1	10
Phenols	9	4

^a Source: A. G. Sharkey, Jr., *et al.* "Mass Spectrometric Analysis of Coal-Derived Fuels," U. S. Bureau of Mines (in press).

^b Including alkyl derivatives.

Table 1.2. Sulfur compounds in SYNTHOIL oil^a

Sample or subfraction	Number of sulfur compounds observed in GLC ^b profile
SYNTHOIL oil	> 40
Neutral PAH ^c fraction	> 20
3-membered rings PAH subfraction	> 20
4-membered rings PAH subfraction	none
5-membered rings PAH subfraction	none

^a Source: W. D. Shults *et al.*, "Preliminary Results: Chemical and Biological Examination of Coal-Derived Material," ORNL/NSF/EATC-18, Oak Ridge National Laboratory, Oak Ridge, Tennessee, December 1975.

^b GLC - gas-liquid chromatographic.

^c PAH - polynuclear aromatic hydrocarbons.

Table 1.3. Acute toxicity of aqueous effluents from COED to *Daphnia*

Sample	LC ₅₀ dilution ^a	LC ₅₀ TOC ^b (mg/liter)
COED product separator liquor	222	43
Weak acid fraction	-	21
Strong acid fraction	-	360
Neutral fraction	-	47 ^c

^a Dilution factor of original liquor required to produce 50% mortality after 48 hr.

^b Total organic carbon content of LC₅₀ solution.

^c 24-hr. LC₅₀; 48-hr test invalidated due to adhesion of organisms to surface film.

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2. A. G. Sharkey, Jr., et al., "Mass spectrometric analysis of coal-derived fuels," U.S. Bureau of Mines (in press).
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2. Liquid and Solid Effluents

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TRACE ELEMENTS

We have reviewed analyses of coal and potential effluents from coal liquefaction processes and observed that greater than fifty trace elements may be released into the aquatic environment through expansion of coal technology. Little is known of the behavior of some of these elements in aquatic systems. It is therefore not possible to predict availability of the various elements to aquatic biota or the extent to which consumption of aquatic resources may pose a threat to human health. An extensive review of recent literature on the behavior of these trace elements in aquatic systems and on the toxicity of the various possible forms of these elements to aquatic biota was initiated. This review is being facilitated through cooperation with the Information Division. Factors being considered that may affect behavior and toxicity of trace elements include both abiotic (e.g., water chemistry, sediment type) and biotic (e.g., uptake and elimination rates in organisms and accumulation in populations as a function of trophic position) parameters. A thorough examination of current knowledge concerning the behavior of trace elements in aquatic systems will permit an initial assessment of specific elements that have the potential for adverse impacts on aquatic ecosystems and human health resulting from the release of trace elements by coal conversion technologies. In addition, we will suggest critical areas in which further research is needed before quantitative predictions and assessments are possible.

ORGANIC CONTAMINANTS

Literature Review

To facilitate a rational assignment of future aquatic research priorities, a systematic assessment of the environmental hazards of anticipated organic components of aqueous coal liquefaction effluents was initiated by the compilation of a critical literature review which is nearing completion. Five major classes of organic compounds have been operationally defined: (1) phenols, (2) arylamines (organic bases), (3) monoaromatic and aliphatic hydrocarbons, (4) polycyclic aromatic hydrocarbons (PAH), and (5) sulfur-containing compounds. The five groups are then subdivided into homologous compound series which qualitatively share similar environmental characteristics. Each class of compounds is then assessed on the basis of (1) concentrations and forms anticipated in coal liquefaction effluents, (2) acute and chronic toxic effects on aquatic

organisms, (3) environmental transport, and (4) potential efficacies of removal by wastewater treatment systems. Ultimately gaps in understanding and future research needs will be identified, and a preliminary prioritization of environmental hazards of effluent components will be submitted.

Characterization of organic components of effluent streams by literature evaluation has been completed, although concentrations often are necessarily restricted to order-of-magnitude predictions because of the paucity of data available. Estimates were formulated on the basis of (1) published analyses of similar industrial process waters, (2) quantitative analyses of components of synthetic coal liquids, (3) solubilities and solvent-water partitioning coefficients available from literature, and (4) qualitative identifications of compounds and homologous series in effluents. Effects of catalysis, temperature, and other process variables on the effluent composition were assessed when feasible.

The mechanisms of acute toxicity of compounds to different aquatic organisms were normalized to allow rough determination of the effects of molecular size and structure on toxicities of homologous compound series. With occasional exceptions, both anticipated effluent concentrations and threshold lethality levels to most species decrease with increasing molecular size. Aberrations, often due to anomalies in compound structure, may indicate compounds of particular concern in effluent streams.

The aquatic transport of effluent compounds is approached from the standpoints of both physicochemical and biological systems. The former includes evaluation of adsorption behavior of compounds onto suspended mineral and organic matter, sedimentation, rates of photolysis and volatilization, and other abiotic mechanisms of transport and removal. Transport by biological systems encompasses bioaccumulative potentials (which are largely a function of relative fat and water solubilities), rates and pathways of metabolism by different aquatic organisms, and rates of degradation of compounds by microorganisms in water and sediments.

Because treatment of coal conversion wastewater by some process is a virtual certainty, the efficacy of removal of compound groups is being evaluated for several treatment scenarios (i.e., solvent extraction, biological treatment, and chemical oxidation). While some removal techniques are extremely effective for certain compound classes (e.g., biological treatment of phenols), the efficiencies of removal of other classes (e.g., PAH and arylamines) may be quite limited.

Upon completion of the review of available literature data, the relative environmental hazard of the organic effluent compound classes will be evaluated. Gaps in data will be highlighted, and future areas of research will be identifiable on an efficient and rational basis.

Effluent Components

Preliminary examination of the literature suggests that phenols and arylamine bases will constitute two major classes of compounds in coal conversion effluents. Although both are known to be highly toxic, no data are available on the effects of mixtures of the two groups of compounds on aquatic organisms.

To test whether synergistic or antagonistic effects may occur, two compounds anticipated to be present in aqueous liquefaction effluents were selected: resorcinol and 6-methylquinoline. Groups of 10 two- to four-day-old *Daphnia magna* were incubated at 20°C with various concentrations of each compound in filtered spring water and were fed homogenized "Trout Chow" (Ralston Purina Co.). Numbers of dead organisms were counted after 48 hr.

Preliminary 48-hr LC_{50} values obtained for resorcinol and 6-methylquinoline were 2 and 11 mg/liter, respectively, which agree well with literature values. To test for toxic interactions between the two compounds, stock solutions of each were prepared of 10 times the LC_{50} . Mixtures of 75/25, 50/50, and 25/75 proportions of the stock solutions were also prepared, each also possessing a toxicity of 10 times the LC_{50} . Toxicity test matrices were then run in duplicate for each pure compound and for the three intermediate mixtures; six dilutions were tested and ranged from 0.06 to 0.16 times each stock solution concentration.

Results obtained by computerized PROBIT analysis are displayed in Fig. 2.1. If a strictly additive effect occurred, toxicities of intermediate mixtures should have lain along a diagonal line; a synergistic interaction would have resulted in a concave curve below the line. The data observed apparently indicate either an antagonistic effect or no effect (other than dilution) of one compound upon the other. The results are preliminary and further experimentation is required; however, there appears to be no justification for anticipating additive or synergistic toxic interactions between phenolic and arylamine components in coal liquefaction effluents.

Fig. 2.1. Acute toxicities of mixtures of resorcinol and 6-methylquinoline to *Daphnia magna*. 48-hr LC_{50} values are defined to be 1.0 toxicity units. Vertical bars indicate 95% confidence intervals. Predicted theoretical relationship (dashed lines) after Sprague [J. B. Sprague, "Measurement of pollutant toxicity to fish. II. Utilizing and applying bioassay results," *Water Res.* 4:3-32 (1970)].

Transport and Bioaccumulation of Polycyclic Aromatic Hydrocarbons in Aquatic Systems

Because of their carcinogenic potential, polycyclic aromatic hydrocarbons (PAH) have been identified by preliminary literature evaluations as compounds of particular environmental concern. Moreover, the extremely low water solubilities of many PAH suggest that bioaccumulation within food chains, which may culminate in exposure to humans, may occur. Both soluble and particulate PAH forms may occur in natural waters, and either or both may be accumulated by organisms. Initial research, therefore, has attempted (1) to characterize partitioning of a model PAH compound between soluble and particulate forms and (2) to evaluate uptake, metabolism, and bioaccumulation rates of both soluble and particulate PAH by aquatic organisms.

Partitioning of PAH Between Soluble and Particulate Forms

Because the routes of environmental transport and fate of PAH compounds may be dependent largely upon the initial compound form, an understanding of the partitioning of PAH

between soluble and particulate phases is essential. In initial studies 9- ^{14}C -anthracene has been utilized as a model PAH compound because, while not carcinogenic, its solubility does not differ greatly from those of more hazardous PAH, such as 3,4-benzpyrene and 1,2,5,6-dibenzanthracene. Autoclaved yeast cells, which have been used to simulate suspended organic matter in natural waters, were incubated with continuous shaking in 50 ml of membrane-filtered spring water containing low levels of ^{14}C -anthracene (usually 3000-4000 dpm) and appropriate concentrations of unlabelled carrier. After 2 hr, flask contents were centrifuged and each phase was extracted three times with hexane (which removed 98% of the ^{14}C -anthracene). Extracts were then combined and anthracene content determined by liquid scintillation counting.

Results indicated that the partitioning coefficient was a constant (i.e., a constant fraction of anthracene was adsorbed) over four orders of magnitude of anthracene concentrations (up to 40% saturation in the water). From the temperature dependence of the partitioning coefficient the heat of adsorption was determined to be 5.2 kcal/mole, a value characteristic of physical adsorption. The effect of the suspended solids concentration was pronounced (Fig. 2.2): the extent of anthracene adsorption decreased markedly at low-suspended-solids levels.

Fig. 2.2. Adsorption of 9- ^{14}C -anthracene by autoclaved yeast cells. Anthracene concentration $\approx 0.02 \mu\text{g/liter}$ at $24.0 \pm 0.5^\circ\text{C}$.

The results suggest that anthracene would be present in significant amounts in both soluble and particulate phases at particulate loadings commonly encountered in natural waters (10 to 100 mg/liter). Further research utilizing other labelled PAH compounds will attempt to elucidate the relationship between physical characteristics of PAH compounds (e.g., water solubility or parachor) with partitioning behavior. A joint project with the Analytical Chemistry Division will then attempt to confirm laboratory results with gas chromatographic analysis of PAH partitioning behavior in wastewater and natural waters.

Uptake of Anthracene

Zooplankton. Because zooplankters form the initial link of many aquatic food chains, rates of uptake and metabolism of PAH by zooplankton may determine largely the extent of bioaccumulation of PAH throughout aquatic ecosystems. Uptake of ^{14}C -anthracene by *Daphnia magna*, a common zooplankter in natural waters, has thus been investigated.

Cultures of two- to three-day-old *Daphnia* were incubated with 9- ^{14}C -anthracene in membrane-filtered spring water with or without an autoclaved particulate food source added. Samples of 20 organisms were removed after intervals, and labelled anthracene was extracted by grinding in acetone and measured by liquid scintillation. Anthracene partitioning was determined by centrifugation of water samples and extraction of both phases with hexane. Water-soluble metabolites were quantitated by extraction of water samples with ethyl acetate, rotary evaporation, and separation of the residue on thin-layer chromatographic plates. Developed chromatograms were then scraped and extracted and the radioactivity was determined by liquid scintillation.

Daphnia were observed to take up anthracene rapidly, reaching a maximal level within 60 min, and then declining slowly over a period of days. Extent of uptake from particulate material exceeded that from the soluble phase by about two-fold. Excretion of one or possibly two water-soluble metabolites coincided with the decrease in the fraction of anthracene present within the organisms (Fig. 2.3). Release of radioactivity from the

Fig. 2.3. Uptake and metabolism of 9- ^{14}C -anthracene by *Daphnia magna*: fractions of total activity in organisms (one *Daphnia*/20 ml) and in form of water-soluble metabolic products. Remainder of ^{14}C is present as anthracene in solution and is adsorbed onto suspended particulate matter. Initial anthracene concentration ≈ 0.02 $\mu\text{g/liter}$ at 24°C .

Daphnia when transferred to unlabelled water followed sequential first-order kinetics with rate constants of 0.53 and 0.12 hr⁻¹ respectively; the rate constants correspond nearly identically to observed rates of gut elimination and anthracene metabolite formation. Bioaccumulation at equilibrium was calculated to be approximately 200-fold.

Benthos. The potential presence of significant quantities of PAH adsorbed onto particulate material in natural waters suggests that uptake by benthic organisms may be an important mechanism of PAH transport. Nymphs of *Hexagenia* sp. were utilized in initial experimentation because they constitute an important food source for many fish, thus enabling expansion to later bioaccumulation studies.

Hexagenia nymphs were collected from the sediment of Watts Bar Lake and were maintained in laboratory aquaria. Organisms were incubated individually with 50 ml of spring water containing labelled anthracene; autoclaved yeast cells were added in duplicate experiments to determine uptake kinetics from particulate material. Organisms, water, and centrifuged particulate material were extracted, and ¹⁴C-anthracene was determined by liquid scintillation.

Although nymphs varied widely in size, initial experimentation demonstrated a direct relationship between organism mass and the amount of label accumulated after a specified time; gross counts were therefore normalized after weighing nymphs. Results (Fig. 2.4)

Fig. 2.4. Uptake of 9-¹⁴C-anthracene by *Hexagenia* sp. nymphs: fractions of total activity in organisms (one *Hexagenia*/30 ml) and in soluble and suspended particulate phases. Fig. (a): no particulate material added to membrane-filtered spring water; Fig. (b): 25 mg/liter autoclaved yeast cells added. Initial anthracene concentrations $\approx$ 0.02 μ g/liter at 24°C.

resembled those from the *Daphnia* uptake studies, although no decrease in ¹⁴C within nymphs due to metabolism was observed. Rapid initial first-order uptake occurred with or without the presence of suspended yeast cells. A much slower (although continuous) uptake corresponded to a first-order decrease in the fraction of anthracene bound to particulate material in suspension. Apparently uptake from the soluble phase is 40 times

more rapid than that from the particulate phase, while total bioaccumulation with particulate material present (3500-fold within 28 hr) is nearly double that from the soluble phase alone.

The results of uptake experiments with both *Daphnia* and *Hexagenia* underscore the importance of the initial form of PAH in determining rates and extent of bioenvironmental transformation and accumulation. Future research will be directed toward elucidation of PAH bioaccumulation through higher trophic levels in aquatic ecosystems.

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3. Gaseous Effluents

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ASSESSMENT OF EFFECTS OF MIXTURES ON TERRESTRIAL PLANTS

Activities to date on this new research effort have been heavily developmental, involving design and construction of experimental facilities with which to study effects of gaseous coal conversion effluents on terrestrial ecosystems. Design has been completed and procurement and fabrication begun for an exposure chamber and associated control and monitoring systems. Modification of existing laboratory facilities adjoining greenhouse space to provide controlled plant growth facilities, laboratory space for physiological monitoring instrumentation, and safe containment of the exposure unit has been initiated.

In close cooperation with investigators from the Chemical Technology Division, modifications of the bench-scale coal hydrocarbonization plant at ORNL have been initiated to allow collection and storage of effluent from the plant for use as the source gas in acute and chronic exposure studies. Effects of this source gas will be compared to those resulting from exposure to a synthetic mixture of gases representative of the process effluent.

A working relationship has been established with the Bio/Organic Analysis group of the Analytical Chemistry Division. This group will be instrumental in the developmental characterization and identification of effluent component gases, and will provide information regarding the stability of those gases under conditions of collection, storage, and use.

Using available information on the bench-scale process, as anticipated by Chemical Technology investigators, literature sources, and expected stack-to-ground dilution rates, has enabled the identification of possible phytotoxicants (Table 3.1).

Table 3 1 Organic effluents expected to be released to the atmosphere from coal conversion facilities and their relative toxicities to terrestrial vegetation

Effluent gas	Expected stack concentrations (A) (ppm)	Reasonable range to expect acute phytotoxicity (B) (ppm)	Dilution of (A) yielding (B) ^a	Expected phytotoxicant (without synergism ^b)
Ethylene + C ₂	60,000	0-2-5	12-300 x 10 ³	yes
H ₂ S	100-200	50-1000	0-1-2	possible
Methane	100,000	unknown	?	?
CO	80,000	200-2000	40-400	possible
CN	< 1	1000	< .001	no
NH ₃	< 1	20-50	.02- .05	no
C ₃ -C ₅	50,000	200-5000	10-250	possible
Benzene				
Xylene	2000	unknown	?	?
Toluene				

^a Stack to ground dilution range from zero to 3000 l may be expected with conventional coal combustion facilities at zone of maximum impact

^b Behavior relative to phytotoxicity of mixtures of most of these compounds is unknown. It is reasonable to assume that these pollutants and "regional background" pollutants such as SO₂, O₃, NO_x, may interact synergistically to become phytotoxic at concentrations below those presented in column (B)

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PART II. AQUATIC STUDIES

4. Power Plant Effects

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The objective of the Power Plant Effects program is to develop information that has predictive utility for assessing impacts of power plant cooling systems on aquatic life. The information sought ranges from the level of physiological effects of temperature on single organisms to the level of dynamic aquatic communities which may interact with cooling waters of power plants. The program encompasses both a search for fundamental (and yet unknown) ways in which temperature influences aquatic systems and the production of data on well-understood responses, such as thermal tolerance and growth, for which data and modified methods are needed on additional species. Principal areas of funding are for (1) thermal effects, (2) mechanical effects of entrainment and impingement, and (3) population dynamics. There is a direct communication of data and research needs between this research program and the Laboratory's environmental impact statement activities.

Research progress for the reporting year is presented below as brief summaries of the principal accomplishments of individual subprojects. The summaries are grouped according to the type of biological/ecological response. Relationships among the various subprojects, and the year-to-year continuity within subprojects, are indicated wherever possible.

REVIEWS AND SYNTHESSES

Annual bibliographic surveys of the literature on thermal effects on aquatic organisms continue to be a principal program objective. The thermal effects literature of 1974 was reviewed and two documents were published. One, largely in narrative form, was part of the review of the literature of 1974 on waste water and water pollution control prepared for the *Journal of the Water Pollution Control Federation*. The June issue of the journal is devoted to comprehensive reviews of the water pollution control literature for the previous calendar year. The second publication, issued by ORNL through the Ecological Sciences Information Center, reproduced the bibliographic information on the 1974 thermal literature that has been stored in the ORNL computer files, and contained a KWIC (key word in context) index of titles, an author index, a key-word index (for key words not in titles), and a taxonomic index. The second document was necessitated by lack of indexing in the journal version. The 1974 thermal review covered 453 references.

A critical review on temperature requirements and effects on freshwater centrarchid basses, begun in the previous reporting year,⁸ was completed, presented at the National Bass Symposium⁹ in a principal address, and prepared for publication.

EFFECTS OF TEMPERATURE TRANSIENTS

High Temperature Resistance of Independent Juvenile Crayfish, *Cambarus bartoni*

Experiments conducted in the spring of 1974 have been refined and continue to characterize the thermal resistance of a widely distributed crayfish, *Cambarus bartoni*, to acute exposure to high temperatures. Observed in local streams and reservoirs, this species occupies and is abundant in a wide range of habitats. It plays a complex role in the trophic scheme, is an active mover and sorter of materials, and is economically important as food for game fish and occasionally for man.

Juvenile crayfish were obtained in large numbers from 13 egg-bearing females (~170 eggs/female) collected between the 5th and 11th of May 1975 from a local stream. Independent juveniles developed from eggs to the 3rd to 4th instar when they are first observed to no longer permanently cling to their mother's body surface. This incipient free-living stage is easily recognized and provides a standard stage of development for testing. The juvenile crayfish were divided into a series of sample populations (10 each) and exposed to a constant high temperature for various periods of time. Each group was then held for >96 hr at its original acclimation temperature for observation of latent mortality. Observations suggest that the incipient lethal temperature lies between 32 and 33°C for crayfish acclimated for at least one week to 15, 20, and 25°C. A 72-hr latent mortality vs exposure time for 33, 34, 35, and 36°C test temperatures was determined for crayfish at each acclimation.

These binary data, mortality or survival after 72 hr, were appropriately treated by a logistic model. From this model the contours for fixed probability values of 0.30, 0.50, and 0.90 were drawn for the 15°C acclimation temperature group (Fig. 4.1).

Fig. 4.1. High-temperature resistance as 30, 50, and 90% mortality contours for independent juvenile crayfish, *C. bartoni*, acclimated at 15°C.

Latent Thermal Mortality of *Corbicula manilensis*

In order for thermal tolerance data to be conscientiously applied for control or protection of a particular species, a serious attempt must be made to estimate the total effect of a temperature change on mortality of the population. Specimens of *Corbicula manilensis* acclimated to temperatures of 5, 10, 20, 25, 30, and 32°C were exposed to higher temperatures ranging from 24 to 38°C. From graphs of probit % mortality vs log time we calculated the temperatures which yielded 50% mortality of the exposed clams after 24, 48, and 96 hr and for longer periods at which time control and experimental death rates were the same (up to ~45 days).

Use of the shorter time intervals for estimation of tolerance would not assure survival of these clams under certain conditions, as demonstrated by the comparison of the median lethal levels for the different exposure times using regression analysis (Fig. 4.2). Results obtained after 24-, 48-, and 96-hr exposures significantly overestimated ($P < 0.05$) tolerance of the clams. Estimates of the upper incipient lethal limit shifted from 38 to 34°C when long-term rather than 24-hr exposures were tested. This long time period may be particularly important in estimating the tolerance limits of clams and other invertebrates because of the difficulty in determining when death actually occurs.

Fig. 4.2. A comparison of the incipient lethal temperatures obtained from observations made at 24, 48, and 96 hr with that obtained by continuing observations until experimental and control mortality rates are equal. Regressions show relationship of incipient lethal temperatures to acclimation temperatures for clams exposed to long-term heat stress.

Effect of Cold Shock on the Vulnerability of Young Bluegill to Predation

Determining the effects of cold shock on aquatic organisms, such as could occur during sudden shutdown of a power plant, has been a major program objective over the past several years. In addition to studying the acute cold tolerance of species such as adult gizzard shad, we have examined the effects of sublethal cold shocks on susceptibility of juvenile fishes (largemouth bass and channel catfish) to a form of mortality which is secondary to the environmental stress, namely predation (see previous annual reports and published literature). This year we conducted predation experiments on the bluegill (*Lepomis macrochirus*). Results showed that after cold shocks of more than 9°C a significant difference in predation rates on shocked and unshocked fish occurred when they were tested together. Increasing temperature differentials above about 4°C caused an exponential increase in differential predation (Fig. 4.3). The pattern of response was nearly identical to those shown by young largemouth bass and channel catfish.

Fig. 4.3. Ratio of instantaneous predation rates on test and control bluegill fed to largemouth bass predators after test fish received cold shocks from the acclimation temperatures shown to a predation temperature of 16°C. Solid circles are individual trials; open circles are combined trials.

BEHAVIOR RESPONSES

Field Temperature Selection by Fish

We have continued to study behavioral thermoregulation in fishes in the field and to relate selected temperatures to temperatures determined in the laboratory to be optimal for growth, food conversion efficiency, and other physiological processes. Our studies examined hypotheses related to both thermally unmodified ecosystems and ecosystems affected by power plant thermal discharges. This was the third year in which we examined temperature selection by largemouth bass (*Micropterus salmoides*); it was the first year of successful temperature telemetry of striped bass (*Morone saxatilis*).

Temperatures selected by three-year-old striped bass (*Morone saxatilis*) tagged with the ORNL-developed ultrasonic temperature transmitter were monitored from April through September 1975 in Lambert Quarry on the Oak Ridge Reservation. In addition, one adult bass was monitored in Cherokee Reservoir, Tennessee, for a 2-day period. The spring-fed quarry lake (17 m deep) offered a steep vertical temperature gradient from about 7°C to over 30°C during midsummer.

Midsummer temperature selection was exhibited, with striped bass being found most often near 22°C (Fig. 4.4). Extensive data sets, consisting of recordings made at 10-sec intervals, are being analyzed. The striper tracked in Cherokee Reservoir in July

Fig. 4.4. Temperatures selected by two striped bass in Lambert Quarry on two mid-summer days compared to surface water temperatures. Bottom temperatures were less than 10°C. Data were recorded at approximately 15-min intervals during these manual observations.

selected water in the 21 to 23°C range in a tributary cove where water entered the reservoir from a 16°C spring stream and surface waters nearby were near 30°C. Preferred temperature in the field appears to be less than the ~24°C optimum growth temperature which we have determined in the laboratory.

A field study of the autumn movements of largemouth bass (*Micropterus salmoides*) was conducted in the vicinity of the Tennessee Valley Authority (TVA) Bull Run Steam Plant on the Clinch River near Oak Ridge, Tennessee. Temperature-sensitive ultrasonic transmitters were surgically inserted in the body cavities of four adult bass. Movements and temperature selection for each bass were followed from September through November 1974. We sought to test the hypothesis that fish tagged in the river in late summer would tend to move into the power plant discharge in the fall as water temperatures declined. Specifically, we wanted to determine if the 27°C isotherm would be followed as would be predicted from midsummer temperature selection behavior and optimum growth performance (see previous annual reports).

Individual bass exhibited a wide range of behavior that did not clearly support the hypothesis. Bass selected temperatures below 27°C even though that temperature was available in the discharge. There was little cruising behavior observed that would allow bass to encounter thermal gradients; the bass were nearly always sedentary when checked early in the afternoons. Each bass left the open river where it was tagged to spend some time in the heated effluent, but no winter residence in the discharge was established. Instead, a rotation in and out of the heated areas took place. There was distinct preference shown for certain types of habitat, a factor which probably overrode behavioral thermal regulation. An extensive tracking study planned for 1974 at the Kingston Steam Plant and in nearby reference embayments was unsuccessful due to a rash of premature tag failures in the spring and the inability to collect and tag fish in midsummer.

Susceptibility of Threadfin Shad to Impingement

Intensive studies of fish behavior related to entrapment and impingement of fish on cooling water intake screens of electric generating facilities have been initiated. In the southeast United States, threadfin shad (*Dorosoma petense*) comprise a large proportion of the fish that are impinged. Since the bulk of threadfin shad impingement occurs during the winter months, it was hypothesized that much of the impingement represents a collection of shad that were dead or dying because of cold stress. A cooperative study to examine that hypothesis was initiated by the Environmental Sciences Division and the Division of Forestry, Fisheries, and Wildlife Development of the Tennessee Valley Authority. Threadfin shad impingement at 13 TVA electric generating facilities was monitored from August 1974 through July 1975. Concurrent laboratory experiments evaluated the ability of cold-stressed threadfin shad to avoid impingement.

In the laboratory, threadfin shad were able to swim against currents (23 cm/sec), similar to those present at TVA water intakes, for long periods of time if water temperatures remained high. However, temperatures of 12°C stressed threadfin and those below 8°C caused high impingement mortality (Fig. 4.5). At 5 of 12 TVA fossil-fueled plants 90% or more of the annual threadfin shad impingement occurred when water temperatures were below 10°C. At three plants about one-half of the impingement took place during the cold period, and at four plants threadfin shad mortality was not related to low temperatures. Cooperative ORNL-TVA field studies are now underway to investigate factors other than cold temperatures that cause high threadfin shad impingement.

Effects of Water Velocity on Activity of Juvenile Striped Bass

The activity of 10-, 25-, and 50-mm juvenile striped bass (*Morone saxatilis*) exposed to water velocities ranging from static to 27 cm/sec was analyzed to determine mobility, feeding response, positional orientation, and group interaction. Increased water velocity reduced the area traveled per unit time; the presence of food also reduced the area ranged (Fig. 4.6). Rheotaxis, the orientation of a swimming fish respect to the direction of streamflow, was variable at low velocities. Positive

rheotaxis predominated at water velocities of 15 and 27 cm/sec. Distance between fish, a measure of group interaction, decreased with increasing water velocity and also decreased with the addition of food.

Fig. 4.5. Effect of test temperature and pre-test temperature shock on survival of adult threadfin shad after 2-hr exposure to impingement in a laboratory flume.

Preliminary observations of the effects of water velocity on larval striped bass indicate that fish 8 to 10 mm long were unable to make forward progress against velocities greater than 3 cm/sec. Activity of the voracious young fish was strongly influenced by the presence of food.

Currently, activity of 80-mm juveniles exposed to water velocities ranging from static to 30 cm/sec at temperatures of 5 to 30°C is being analyzed for synergistic effects on area ranged and positional orientation. During each 5-hr observation period, the fish exhibited a 1-hr phase of exploratory activity. Greatly reduced activity was generally exhibited for the remainder of the test period. Even though fish acclimated to 5°C are highly susceptible to loss of equilibrium due to handling, they are able to make forward progress against velocities as high as 30 cm/sec.

Fish Populations in the Kingston Intake Canal

The majority of inland electric generating facilities in the Southeast draw water through intake canals, many of which contain skimmer walls to exclude warmer surface waters. To examine the commonly proposed hypothesis that skimmer walls and intake canals increase impingement by trapping fish, studies were initiated to assess fish distributions and movements in the canal at the TVA Kingston plant.

Fig. 4.6. Effect of increasing water velocity on juvenile striped bass mobility in the presence and absence of food. Each point represents the mean of ten observations. Bars represent one standard deviation.

The 1500-m long canal was divided into ten sections and each was sampled in April, June, and August by electrofishing along the shoreline. Each of the 315 fish collected was fin-clipped and released in the same section.

Gizzard shad were the species most commonly captured. No marked fish were recaptured, indicating either rapid population turnover or inefficient sampling. Fish species most commonly impinged (threadfin shad and drum, *Aplodinotus grunniens*) were not taken with this sampling method. For these reasons, electrofishing was discontinued and gill net sampling was initiated within and outside of the canal and in the skimmer wall opening.

Experimental Impingement of Bluegill

Bluegills (*Lepomis macrochirus*) are not normally regarded as strong swimmers and are commonly impinged on power plant intake screens. For these reasons experiments were carried out in a laboratory flume to assess their behavior and endurance when exposed to typical intake approach velocities. Juvenile bluegill were exposed to velocities as high as 25 cm/sec over a temperature range of 9 to 37°C.

Normally individual fish oriented into the water flow at velocities above 10 cm/sec. At temperatures between 15 and 35°C, they were capable of maintaining position for several hours with no mortality; at water temperatures colder or warmer than this range, impingement increased significantly, with smaller fish becoming impinged more quickly.

PRODUCTION RESPONSES

Comparison of *Lymnaea* Production under Constant and Varying Temperature Regimes

It is important to know if laboratory-derived production data may be validly extrapolated to field conditions. These experiments were undertaken to assay the effects of constant and varying temperatures on production of *Lymnaea oberrussa* Say, a freshwater pulmonate gastropod. Shell lengths, egg production, and mortality of snails were measured weekly over the reproductive period under constant ($K = 10, 15, 20, \text{ or } 25^\circ\text{C}$) and varying temperature regimes during the reproductive period. Varying regimes included a diurnal plus seasonal regime (natural field temperature in a pond, F) and seasonal variations alone simulated in laboratory aquaria (mean daily field temperature, $\bar{F}$, and 5 and 10°C above $\bar{F}$). Snails were initially divided into small ($<10 \text{ mm}$) and large ($>10 \text{ mm}$) size classes. Growth and egg production rates were calculated in terms of total organic carbon, using empirically derived micrograms carbon per shell length ($\mu\text{gC/SL}$) and $\mu\text{gC/egg}$ relationships, respectively. The sum of these values over the weeks that they occurred was corrected for negative growth late in the period to give a total production value for the reproductive period.

Total reproductive period production ranged from -32.4 to 880 mg of carbon per population of 100 snails. Egg production and mortality rates were similar for large and small snails; however, because the growth rates for the small snails were significantly greater ($P < 0.05$), production was calculated separately for the two sizes. The largest share of production resulted from egg output. Size and temperature were found to significantly affect production (Fig. 4.7). Production was greatest at 15°C .

Comparison of the production estimates at the different temperature regimes indicates that some factor related to exposure to daily and/or seasonal regimes negatively influences production. All the varying temperature regimes resulted in less total production than most similar constant temperatures (Fig. 4.7). Among the varying regimes, snails at F and snails at $\bar{F}$ did not differ significantly in total production, but the significantly greater egg production and growth rates found at F imply that there are differences in the effects of these two regimes. Investigations of the effects of temperature regime on production parameters of several species of fish and invertebrates are planned using computer-controlled laboratory facilities.

Mayfly Laboratory Growth Studies

Studies are currently underway to obtain an estimate of growth rates of mayfly nymphs under constant temperatures of 10, 15, 20, and 25°C . These data will be used to aid in interpreting the field data being collected near the Kingston Power Plant.

In a preliminary phase of the temperature/growth experiment, the temperature was held constant while the addition of food (Biorell flakes) was varied in order to determine whether addition of food to the lake mud in the aquaria would affect growth rates and emergence success. The mayflies were initially approximately 14.5 mm long, ranging from 12 to 17 mm. Within three months at a mean temperature of 24°C , emergence success was between 81 and 85% at all four food levels and occurred at the same time in all groups.

The effect of food level on growth was determined by measuring lengths of the cast nymphal skins. One-way ANOVA tests demonstrated a significant difference in mean length among food levels ($P < .01$) for both males and females. However, the expectation that these differences could be explained by a regression of length on food level proved not to be demonstrable from these results. The regression lines shown in Fig. 4.8 do indicate the expected trend, but the slopes are not statistically different from zero at the

Fig. 4.7. Mean total production ($\pm 95\%$ C.I.) is shown for two sizes of snail at a series of temperatures and over three temperature regimes. Lines connect mean production values at constant temperatures. Production at a mean temperature of 17°C under both the seasonal and diurnal regime and the seasonal regime was lower than expected under a constant 17°C . Maximum production occurred at about 15°C for both sizes of snail.

Fig. 4.8. Mean body lengths and standard deviations of cast nymphal skins of male and female mayflies emerging from each food level.

$\alpha = 0.05$ level. The results of the experiment suggest that for experiments of less than three months duration food addition is not necessary for growth of *Hexagenia* reared in lake mud. However, the increased mean size at the highest food level suggests that the Biorell flakes can provide nutrition to mayflies. The explanation for the lack of correlation between food level and size may be that the added food was being utilized by other organisms in the mud (oligochaetes) before it became available to the mayflies, except at the highest food level. At lower levels of food, the mayflies may have been entirely dependent upon organic matter in the mud for food. Studies will continue with wider ranges of food addition for the full life cycle.

Population Dynamics of Burrowing Mayflies at Kingston Power Plant

Thermal effluents from the Kingston Power Plant heat the bottom sediments of a recipient cove (Discharge Cove, Fig. 4.9) from 2 to 6 C° above sediment temperatures found in a thermally unaffected cove of similar depths at a nearby location (Reference Cove, Fig. 4.9). Temperature differences are even greater in some months between the Discharge and the Intake Coves (Fig. 4.9) of the power plant. Based on information obtained from monthly samples collected in the three areas from November 1974 to May 1975 and from several samples taken to answer specific questions, a final sampling program was designed (in consultation with a staff member from the Mathematics Division) and initiated with the June 1975 samples.

Fig. 4.9. Tracing from aerial photograph showing the proximity of the three sample areas to the Kingston Power Plant and division of coves for transect sampling. Depth contours are at 6-ft intervals.

The sampling program is designed to determine whether the temperature differences affect the burrowing mayfly population in any significant manner. Preliminary sampling indicated that variation in numbers per sample (0 to 44) was high, even in a single area

on the same date. This variation may be attributable to many factors, including natural nonrandom mayfly distribution patterns that result in part from egg deposition, together with the effect of particle size of substrate, depth, temperature, and organic content of sediment. Knowledge of how these factors affect population estimates will be necessary before valid comparisons between the three areas can be made. The sampling program involves division of each cove into three major areas (Fig. 4.9). A transect is taken in a subarea of each major area each month so that 21 samples are obtained in each of the intake and reference areas and 30 are obtained in the discharge cove. Samples are collected from the entire range of habitats in each cove. As each sample is taken and processed, data on depth and mud temperature and a description of substrate type are recorded. The sediment is sieved in the laboratory through a 0.6-mm mesh and the mayflies picked out of the residue by sugar flotation.

Data gathered since November 1974 indicate that the number of mayflies per square meter in the Discharge Cove is significantly lower (by 2 or 3x) than that in the Reference and Intake Coves. However, the June, July, and August 1975 population estimates are not significantly different among the three coves. Although mayflies in the Discharge Cove appear to reach their maximum mean length one month ahead of mayflies in the Intake and Control Coves, the population estimates do not indicate that a major emergence occurs earlier in the Discharge Cove than in the other two areas. The above differences suggest that the mayfly population is responding differently in the Discharge Cove, but continued bottom sampling and a careful study of emergence patterns will be necessary before interpretations of this obviously complex situation can be made.

Filtration Rate of *Corbicula manilensis*

Because of the increasing ecological and economic importance of *Corbicula manilensis*, the Asiatic clam, studies of the population dynamics and energetics of this species have been initiated. This process began with studies of the filtration rate, using a technique which has partially evolved at Oak Ridge. This involves a flow-through system that can be used in both laboratory and field. Suspended particulate matter is pumped through a watertight chamber, in which a clam can be placed. Two sets of compartments are used, experimental, with a clam, and control, without a clam. In these cages the amount of particulate matter inside is a function of one input and several outputs: to the sediment cup, to the collecting flask, and to the clam. At steady-state concentration, the only difference between experimental and control flasks is the filtration by the clam, and a series of equations lead to the solution for filtration rate (ml/clam/hr). All calculations are based on seston weight, following filtration through Whatman GF/C glass fiber filters.

Filter-feeding measurements were carried out both in the laboratory and in the field. In the laboratory, an increase in seston concentration resulted in a decreased rate of filtration (Fig. 4.10). This reduction could theoretically be attributed to either mechanical fouling of the clams or to the use of senescent cultures of *Chlorella*. Although chemical factors released by *Chlorella* have been found to inhibit other filter feeders, the limited available evidence supports the former hypothesis. *Chlorella* is only a minor component of the seston at Kingston. However, comparison of filtration rates measured at 25°C in the laboratory and in the field (427 ± 160 ml/hr and 825 ± 606 ml/hr, respectively) were not significantly different and the percent of clams that filtered in the laboratory and in the field were also similar (37 and 28%, respectively). Still more work is required to definitively differentiate between the two hypotheses and to study the effects of other pertinent factors on filtration rate.

Work is also proceeding on the design of an efficient diver-operated Venturi pump sampler so that population sampling can be carried out in the discharge and in a reference area. A pump design used in marine situations has been partially adapted for use in areas where visibility is low. A flexible intake side-arm is at the testing stage and may be in the final design phase. Sampling will begin as soon as the pump design has been completed.

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Fig. 4.10. Mean filtration rate ($\pm 95\%$ C.I.) of *Corbicula manilensis* is shown as a function of seston concentration. Filtration rate decreased with increasing seston concentration.

Growth and Survivorship of Young of the Year Crayfish, *Cambarus bartoni*, as a Function of Temperature

Crayfish are benthic organisms of limited mobility, which requires that they adapt quickly to thermal alterations in their environment or die. Their distribution along the bottom may reflect the breadth and depth of the zone affected by a power plant discharge plume. This study defines thermal requirements in terms of growth rate and survival, which is essential for understanding the possible effects of heated water discharges upon crayfish ecology. The preliminary laboratory measurements illustrate the trend of results (Fig. 4.11).

Growth Rate of Striped Bass, *Morone saxatilis*, as a Function of Temperature and Ration

An earlier laboratory study estimated the optimum temperature range for growth (23 to 26°C) and the temperature of zero growth (33.5°C) for striped bass, *Morone saxatilis*, fed an excess ration of fathead minnows, *Pimephales promelas*. The current study is developing data on the combined effect of temperature and reduced ration. To date, data have been obtained for 20, 24, and 28°C and 25, 50, 75, and 100% of maximum daily ration (Fig. 4.12). The previous estimate of zero growth temperature (33.5°C) for bass fed an excess ration was used to extend the 100% ration curve.

The actual feeding rate by weight of each of 12 groups of five individual bass over a three-week pre-experimental period was used as a base from which each of the nine experimental percent reductions in ration was calculated. Individual growth rates during the next three-week period were measured as changes in weight. Growth rates of the five individuals were combined for each combination of temperature and ration and expressed as an average percent change in weight per day with a standard error.

Fig. 4.11. Growth and survivorship of young-of-the-year crayfish, *Cambarus bartoni*, as a function of temperature.

Fig. 4.12. Growth rates of striped bass, *Morone saxatilis* as a function of temperature and ration.

These preliminary data suggest (1) a decline in the optimum and zero growth temperatures, and (2) a reduction in absolute growth rate as ration size is reduced.

Comparison of Growth Rates of Striped Bass, *Morone saxatilis*, in Constant and Fluctuating Temperature Regimes

Temperature responses in the laboratory, such as growth and feeding rate and food conversion efficiency, have traditionally been estimated using constant temperature regimes. Temperatures in a natural aquatic system, however, are characteristically subject to diurnal and seasonal fluctuations. This study compares the growth rate of five striped bass closely matched in weight (179 to 191) in a circular tank (1.2 m in diameter; 66 cm in depth) maintained at a constant 24°C with five striped bass of a similar size (weight) in an identical tank maintained in a computer-controlled fluctuating temperature regime--a 24-hr-period, sinusoidal curve varying ± 4 C° around a 24°C base, reaching minimum and maximum values at 0600 and 1800 hr. The comparison of mean growth rates in the contrasting temperature regimes over a 27-day period produced differences that were not statistically significant ($P > 0.1$), but there was a slight trend toward reduced growth rate in the fluctuating temperature regime. This and similar studies address the larger question of whether or not reasonable predictions of responses to temperature in a fluctuating regime can be made from data developed at constant temperatures.

FISH POPULATION MODELING

Development and application of single-species computer simulation models has continued in response to concern about the entrainment and impingement impact of power plants on fish populations.

Striped Bass Young-of-the-Year Model

A new computer simulation model for the striped bass young-of-the-year population in the Hudson River has been developed, validated, and documented¹⁰ (Fig. 4.13). The model considers six life stages (i.e., egg, yolk-sac larva, post yolk-sac larva, and three juvenile stages) and includes dependence of spawning rate, mortality rate, and growth rate, apparent survival probability, and maximum swimming speed on temperature, salinity, and population density. The transport of these life stages in the Hudson River is formulated in terms of a daily transient (tidal-averaged), longitudinally one-dimensional (cross-section-averaged) hydrological transport scheme. The results from this model served as one of the cornerstones of the Indian Point Unit 3 Final Environmental Statement¹¹ in which the NRC staff concluded that unless the results of the applicant's extensive research program indicated otherwise, closed-cycle cooling is required after September 1980.

Striped Bass Life-Cycle Model

An initial version of the striped bass life-cycle model has been developed and documented and a comprehensive sensitivity analysis has been performed.¹² This model includes consideration of all age classes from young-of-the-year striped bass to fifteen-year-old and older striped bass; the model is strictly time-dependent and does not include spatial considerations. The model has been used extensively in assessing the impact of power plant entrainment and impingement on the Hudson River striped bass population¹¹ and has also been used in assessing the impact of the proposed Summit Power Station (located on the Chesapeake and Delaware Canal) on the striped bass populations in the Chesapeake-Delaware system. Further developmental work on the model is in progress and involves modification of the fishing control function and incorporation of a density-dependent survival function for the young-of-the-year striped bass.

Additional population modeling that has contributed to and benefited from the above mentioned fish population modeling is summarized in the next chapter under the heading of "Models of Copepod Population Dynamics."

Fig. 4.13. Schematic representation of a discrete element as considered in the computer simulation model for the striped bass young-of-the-year population in the Hudson River.

Life-Cycle Periodicities

The application of the striped bass life-cycle model to Atlantic Coast striped bass populations has required that the commercial fisheries data for striped bass be examined for significant periodicities (e.g., 6-year cycles). Toward this end, computer programs have been written and tested, based on classical Fourier spectral analysis and maximum entropy spectral analysis. Thus far, time series for striped bass and Canadian lynx have been analyzed. The lynx data have been used as a test case because this time series covers more than 100 years, manifests regular 9- to 10-year cycles, and has a relatively well-understood biological basis. As indicated by the maximum entropy spectrum for striped bass in Fig. 4.14, the most pronounced periodicity is in the neighborhood of 20 years. What factors might account for such a cycle are not apparent, and in fact additional data are necessary to determine if a regular 20-year cycle exists. The data are being further analyzed to determine if any of the four minor peaks (one of which corresponds to a periodicity of 6.3 years) is significantly above the noise level.

The results to date of the autocorrelation analyses and spectral analyses do not support the hypothesis of a pronounced six-year cycle in the Atlantic Coast striped bass populations. With respect to impact assessments and designing field research programs involving striped bass, our conclusion is that extensive variability in year-class strength is essentially guaranteed and will continue to frustrate fisheries managers and scientists. However, on the basis of our analyses we recommend that impact assessments and research programs not be predicated on the expectation of a significant 6-year cycle in the occurrence of striped bass dominant year classes.

Fig. 4.14. Maximum entropy spectrum for the detrended data on Maryland striped bass commercial landings (lb) per fishing unit (1930-1971).

LARGEMOUTH BASS PRODUCTION MODEL

As part of the power plant thermal effects program, mathematical modeling is being undertaken to integrate the many research efforts in the field and laboratory. The focus of the modeling is the largemouth bass. Equations for the number density and growth rate of the bass have been hypothesized. In addition to helping us determine which field measurements are essential, these equations may also suggest laboratory experiments. The extensive data on the influence of temperature on fish behavior which have been collected at ORNL will enable us to introduce behavioral characteristics into the largemouth bass equations. The effects of heated discharge from power plants on the population dynamics will be assessed.

The modeling of cooling ponds and reservoirs may also benefit the field of ecology in general. These systems are complex enough to be interesting but simple enough to measure the important components. It is hoped that the modeling can be extended to include more aspects of the complete aquatic ecosystem.

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5. Aquatic Effects and Material Transport

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This program is comprised of research on radionuclide cycling in aquatic environments, effects of radiation and energy-related pollutants on aquatic ecosystems, toxicant formation in condenser cooling systems, and biogeochemical cycling in aquatic ecosystems of trace elements in coal. Research in radionuclide cycling involves the distributional patterns of radionuclides in the abiotic and biotic compartments of the aquatic ecosystem, food chain kinetics, and the routes of entry into food chains from abiotic compartments. Part of the research effort on radionuclide cycling was reprogrammed to investigate the biogeochemical cycling in aquatic ecosystems of trace elements in coal. Research in these programs provides information necessary for assessing the behavior of potentially hazardous radionuclides and trace elements released to the aquatic environment. Radiation effects studies are directed toward quantifying the effects of radiation exposure to aquatic organisms to provide continued assurance that radiation standards are not erroneous for aquatic life. Emphasis is placed on determining the effects of chronic low-level radiation on the fitness of natural and laboratory populations of aquatic organisms. Investigation of the toxicants formed in condenser cooling systems is focused on identifying and determining the range of various chlorinated organic and other constituents in natural water. After identification, the degree of toxicity of specific compounds is determined on appropriate aquatic species.

CHLORINATED ORGANICS

Concentration of Chloro-Organics in Chlorinated Effluents

Cooling water for electric-power-producing plants is commonly chlorinated to remove biological surface films from condenser tubes to maintain high production efficiencies. This practice is being evaluated with respect to the formation of environmentally significant chloro-organic compounds.^{3,4} Separation of the chlorinated organics from concentrates of cooling water samples is achieved by using high-resolution liquid chromatography, and the reaction yields are quantified by using the radioactive tracer ³⁶Cl.

For reaction conditions similar to those used at the Allen Steam Plant (operated by the Tennessee Valley Authority), the chlorination yield of chlorinated organics in terms of chlorine associated with the compounds was 3.1% of the chlorine dosage. In this experiment Mississippi River water samples from the unchlorinated cooling water inlet for the plant chlorinated in the laboratory with 3.4 mg/liter of ³⁶Cl-tagged chlorine [1.2

mg/liter chlorine residual (orthotolidine)]. Over 50 chlorine-containing organics were chromatographically separated from the 1470-fold concentrate of the chlorinated water sample. Based on the correspondence of elution positions and chromatographic pattern, the chromatographic peaks separated from the chlorinated Mississippi River water sample were correlated with the peaks separated from a chlorinated Watts Bar Lake water sample (cooling water for the Kingston Steam Plant operated by the Tennessee Valley Authority)⁴ and a typical chlorinated effluent from the secondary stage of a municipal sewage treatment plant.^{3,5} Several peaks were tentatively identified and quantified. The concentrations for these peaks were calculated, assuming complete isotopic dilution of the ³⁶Cl-tagged chlorinating agent with the inert chloride in the water sample. These identifications and values are given in Table 5.1. In order to evaluate the gross effect of

Table 5.1. Tentative identifications and estimated concentrations of chloro-organic constituents in a typical chlorinated effluent from a municipal sewage treatment plant and chlorinated cooling water from electric-power-producing plants

Tentative identification	Concentration of organic compound (µg/liter)		
	Sewage effluent ^a	Watts Bar Lake	Mississippi River
2-Chlorobenzoic acid	0.3	1.1	10
3-Chlorobenzoic acid ^b	0.6	0.2	8
4-Chlorobenzoic acid	1.1	0.3	8
8-Chlorocaffeine	1.7	1.1	6
6-Chloro-2-aminopurine	0.9	1.0	3
3-Chloro-4-hydroxybenzoic acid	1.3	0.8	3
4-Chloromandelic acid	1.1	1.8	6
4-Chloro-3-methylphenol	1.5	0.2	0.7
2-Chlorophenol	1.7	0.2	4
3-Chlorophenol ^b	0.5	0.2	6
4-Chlorophenol	0.7	0.2	2
4-Chlorophenylacetic acid	0.4	3	20
4-Chlororesorcinol ^c	1.2	0.5	7
5-Chlorosalicylic acid	0.2	3	18
5-Chlorouracil ^c	4	0.6	3
5-Chlorouridine	1.7	0.6	7
8-Chloroxanthine	1.5	3	--

^aEnvironmental Sciences Division annual progress report for period ending September 30, 1973. ORNL 4935 (1974).

^bPresent as mixture. Concentrations are calculated as if each was the only compound in the chromatographic peak.

^cSelected for initial biotoxicity studies.

chlorination of cooling water on the nation's aquatic ecosystems, the chlorine used annually to chlorinate cooling water has been estimated to be in the range 50,000 to 100,000 tons. It is apparent that, even at the low reaction yields determined in these studies, several hundred tons of chlorinated organics are produced annually by chlorination anti-foulant treatment. The formation of similar-type chloro-organics in sewage treatment and their release to receiving waters⁵ increases the possible environmental impact by several fold.

With the premise that international concern about the effects of chlorination during water treatment requires increased attention from the scientific community, the Conference on the Environmental Impact of Water Chlorination has been organized and will be held at the Oak Ridge National Laboratory, October 22-24, 1975.

Photolytic Degradation of Chlorine-Containing Organics in Aquatic Ecosystems

5-Chlorouracil, a potentially hazardous substance formed during chlorination of natural waters, is subject to photolysis in solution when irradiated by naturally occurring wavelengths of ultraviolet (uv) light. Since the pK_a of 5-chlorouracil is 8.0, an appreciable percentage of both undissociated and monoanionic forms would be present in the pH range common to most natural waters. The undissociated species of 5-chlorouracil does not degrade in solution even when irradiated by shorter uv wavelengths than penetrate the earth's atmosphere, but the monoanion, which predominates above pH 8, disappears at a first order rate when irradiated by 290 to 320-nm light. Variations in pH and temperature have pronounced effects on the rate of photolysis, with higher pH and temperature resulting in more rapid breakdown (Fig. 5.1). The abrupt change in rate of photolysis with pH

Fig. 5.1. Rate of photolysis of aqueous 5-chlorouracil vs pH at 10, 20, and 30°C (6300 $\mu\text{W}/\text{cm}^2$ cool white fluorescent light); 20 and 30°C curves are coincident.

in the pH 6 to 8 range essentially constitutes a "threshold" pH below which photolysis is environmentally insignificant. The major effect of increasing temperature is to lower this "threshold" pH.

Environmental conditions would play a significant role in determining the importance of 5-chlorouracil photolysis in aquatic systems. Attenuation of uv wavelengths by dissolved substances would probably restrict photolytic breakdown to the uppermost meter of the water column in all but the most transparent of water bodies. Seasonal and diurnal variations in pH, temperature, illumination, and transparency would interact to determine the rate of photolysis of 5-chlorouracil in a given body of water. The photolytic half-life of 5-chlorouracil could be as low as two days under some sets of environmental conditions; however, in most cases the rate of degradation would be considerably slower.

TOXICITY STUDIES

Effects of Mixtures of Chlorinated Organics on Aquatic Biota

This study was designed to evaluate the acute and sublethal effects of a mixture containing all identified chlorinated constituents of a chlorinated sewage effluent in their respective proportions.⁶

Previous studies have been conducted for testing individual components of the chlorinated mixture, and the results indicate that very low concentrations of 5-chlorouracil in water can decrease the hatching success of carp eggs,⁷ increase the frequency of abnormalities in carp embryos,⁸ and delay the onset of reproductive maturity in *Daphnia*.⁹ The *Daphnia* and carp egg test systems and methods used in these previous studies were also used in this investigation.

Acute toxicity of the synthetic effluent to *Daphnia* is not manifest as mortality until the effluent concentration exceeds 2 mg/liter. At subacute concentrations, no change in fecundity or onset of reproductive maturity was observed. In these studies 5-chlorouracil concentrations ranged as high as 2 mg/liter in sublethal effluent concentrations, which was above the lower level that produced adverse effects in test organisms when administered as the only toxicant in the system.^{7,8}

Thus, in experiments utilizing both *Daphnia magna* and *Cyprinus carpio* as test organisms, the adverse effects produced by sublethal concentrations of individual chlorinated organic compounds were not observed when these compounds were administered in conjunction with a mixture of other chlorinated organic compounds. Although adverse effects were not detected in these experiments, we cannot assume that chlorinated effluents do not impact the environment. Instead, these data show the necessity for obtaining information on the fate of specific chlorinated compounds to determine whether biological components are contacted only by the chlorinated composite or by specific chlorinated compounds.

Toxicity of Chlorine in Power Plant Discharges

A review of the literature pertaining to the toxicity of chlorine to aquatic life, both marine and freshwater, has been completed. Progress toward this review involved compilation, in cooperation with the Information Division, of a bibliography of abstracts on chlorine toxicity as well as of selected papers pertaining to the chemistry of chlorine and the methods of measuring chlorine residuals. The bibliography was prepared for the beginner in the field and included a KWIC (key word in context) index of titles as well as various other indices to aid in identification of pertinent papers. The bibliography is in press. The review paper, which is aimed at users with some toxicology background, proposes and supports a tool for analysis of the toxicity of chlorinated discharges and has been submitted for publication.

Toxicity of Hexavalent Chromium to *Daphnia magna*

Hexavalent chromium is widely used as a corrosion inhibitor in closed-cycle cooling systems of nuclear power plants. Blowdown released from these plants may contain 25 to

50 mg/liter chromate. A considerable amount of literature exists on the acute and chronic toxicity of chromium compounds, and it has been shown that toxicity varies widely with the species studied. The cladoceran *Daphnia magna* appears to be one of the most sensitive organisms yet studied. The purpose of this study was to determine a threshold expression of chronic sublethal effects of hexavalent chromium in a population of *Daphnia magna*.

Groups of 20 adults or juveniles (12 ± 12 hr old) were exposed to 0, 10, 50, 100, or 1000 $\mu\text{g/liter}$ of hexavalent chromium (sodium chromate). Measurement (atomic absorption spectrophotometry) indicated that the chromium combination in the culture media (spring water) did not vary by more than 10% during the experimental interval. Animals were censused daily for mortality and weekly for production of young.

A highly significant ($P < 0.01$) deleterious effect of chromium exposure on both life span and fecundity occurred at all concentrations tested (Table 5.2). Although most of

Table 5.2. Mean survival time and total production of young in *Daphnia magna* initially exposed to sodium chromate as juveniles (12 ± 12 hr old) or adults (≥ 7 days old)

Chromium concentration ($\mu\text{g/liter}$)	Mean survival time ^a (days)		Production of Young	
	Juveniles	Adults	Juveniles	Adults
Control	27.7 ± 4.13	23.6 ± 6.58	1470	1234
10	14.8 ± 5.24^b	7.40 ± 3.72^b	501	238
50	3.55 ± 0.54^b	4.50 ± 0.97^b	0	97
100	2.40 ± 0.48^b	3.25 ± 0.69^b	0	7
1000	0.5 ± 0.5^b	0.5 ± 0.5^b	0	0

^aWith associated 95% confidence limits.

^b $P < 0.01$ that the observed differences are due to change. Based on t-test (hypothesis $\bar{x}_{\text{control}} = \bar{x}_{\text{test}}$).

the reduction in young production can be accounted for by life-span shortening, a significant effect on gonadal productivity also occurred. In the absence of studies on species of zooplankton other than *Daphnia magna*, and in light of these results, additional research is needed before the recommendations in Water Quality Criteria 1972¹⁰ become established for the protection of freshwater aquatic life.

POPULATION MODELING

Model of Copepod Population Dynamics

Development of two computer models and a set of submodels of copepod population dynamics has been completed.¹¹⁻¹³ COPEPOD2 is a model derived from the Leslie matrix and from the Markov theory and consists of one compartment for each age-class within an instar or group of instars (Fig. 5.2). The number of compartments used for each instar corresponds to its duration in the life cycle. The model keeps track of the number of copepods in each compartment, using a one-, one-half-, or one-quarter-day time step. In a preliminary version of the model, population parameters--instar durations, mortality rates, clutch sizes--are assumed constant. Events in the annual life cycle are modeled as explicit functions of season, rather than as responses to environmental factors, such as water temperature and food. Parameter values used were estimated from data gathered

Fig. 5.2. Schematic diagram for computer simulation model of a copepod population.

during a one-year field study of *Diaptomus clavipes* in a small pond in Oklahoma. The model output gives a plausible representation of annual changes in *D. clavipes* numbers, following the temporal pattern and average magnitude of the field data, but not the fluctuations around the mean. Analysis of the model's sensitivity to selected parameter values suggests that the model is most responsive to changes in egg mortality and clutch size.

COPEPOD2 is well suited to incorporating detailed information on mortality and development of the subadult instars. Although the large number of compartments makes it somewhat cumbersome to work with, the equations are straightforward and easily modified.

RADIATION EFFECTS

Laboratory Studies of Chronically Irradiated Populations

Studies were initiated in 1966 to examine the fitness of the chronically irradiated mosquito fish, *Gambusia affinis*, population in White Oak Lake. A significantly larger brood size and an increased frequency of dead embryos and abnormalities were observed.¹⁴ In 1972, populations of *Gambusia* collected from White Oak Lake and from four control areas were established in laboratory living streams. Young produced by these populations were isolated from the parents and were reared to maturity. The first broods from the laboratory populations were collected and examined according to techniques previously described.¹⁴ The fecundity of the White Oak Lake population was not significantly higher than the controls; however, the frequency of dead and abnormal embryos was significantly higher. This finding was attributed to radiation-induced recessive lethals which still persisted in the gene pool of the White Oak Lake population.

The present study was an attempt to determine the effect that the exposure to chronic irradiation for many generations would have on the ability of the White Oak Lake population to tolerate environmental stress. Mature males were collected from the previously established laboratory populations for determination of critical thermal maxima (CTM), which is the arithmetic means of the collective thermal points at which an animal loses its locomotary ability to escape from conditions that will promptly lead to its death. There was no significant difference in the mean CTM among the four control populations. However, the mean CTM for the White Oak Lake population was significantly ($P < 0.01$) lower than that for the pooled control group and the variance was significantly greater ($P < 0.01$) (Fig. 5.3). The CTM for approximately 25% of the individuals from White Oak Lake population were at lower temperatures than those found for any of the individuals from the

Fig. 5.3. The ability of laboratory-reared mosquito fish, *Gambusia affinis*, populations to tolerate environmental stress, critical thermal maxima (CTM), is shown in the frequency distribution.

control population. This variability in response to temperature can be explained by the semi-dominant effects of recessive lethals in the heterozygous condition in the *Gambusia* from White Oak Lake. These data support the supposition that radiation-induced recessive lethals still persist in the gene pool of the laboratory population from White Oak Lake and contributed to the high frequency of dead and abnormal embryos observed in 1972.¹⁴

Comparative Radiosensitivity of Embryonic and Naupliar Calanoid Copepods

Zooplankton play an important role in the aquatic ecosystems of lakes and oceans, serving as an important source of food in grazing food chains. Until our recent investigations¹⁵ which indicated that calanoid copepods were more sensitive than Cladocera to acute irradiation, radiation effects studies had not been conducted on a species of sexually reproducing zooplankton. In our previous study it was determined that an acute dose of 1 kilorad affected embryonic development significantly and reduced the percentage of eggs that hatched. This effect has been examined at lower doses (0.1 and 0.5 kilorad) and the radiosensitivity of naupliar stages of copepod development examined. The purpose of this study was to compare the sensitivity of embryonic and naupliar stages of *Diaptomus clavipes* Schacht, a sexually reproducing calanoid copepod, to acute ionizing radiation.

To determine the sensitivity of an early naupliar stage to acute ionizing radiation, eight groups of 30 individuals 14 ± 6 hr old (post hatch) were exposed to either 0, 0.1, 0.25, 0.5, 1.0, 5.0, 10.0, or 50.0 kilorads of ^{60}Co gamma radiation. The nauplii were then maintained and observed in 100-ml beakers to determine the number of nauplii that developed to the Copepodid I stage and the number that continued development through the Copepodid VI stage (mature adults).

Results of the experiments are given in Table 5.3. Nauplii were observed to have reached the Copepodid I stage in groups that received <1.0 kilorad. All groups receiving

Table 5.3. Observed effects of acute ionizing radiation on naupliar *Diaptomus clavipes*

Dose (kilorad)	Percentage			Mean time (days)		
	Nauplii reaching copepodid I	Copepodid I reaching copepodid VI	Total reaching copepodid VI	To copepodid I	To copepodid VI	Survival $\pm$ 95% confidence interval
0	95.6	57.1	53.3	5.9	11.6	26.4 ± 7.6
0.1	76.7 ^a	39.1 ^a	30.0 ^a	5.7	12.8	13.8 ^b
0.25	66.7 ^a	35.0 ^a	23.3 ^a	5.5	13.8	13.0 ^b
0.5	21.6 ^a	30.7 ^a	13.3 ^a	7.4	13.6	7.3 ± 1.9^a
1.0	0	0	0	0	0	6.6 ± 1.3^a
5.0	0	0	0	0	0	5.3 ± 0.9^a
10.0	0	0	0	0	0	3.6 ± 0.7^a
50.0	0	0	0	0	0	1.8 ± 0.04^a

^aP < 0.05 when compared to controls.

^bDetermination not completed because of equipment malfunction.

>1.0 kilorad suffered 100% mortality. A comparison of the percent of nauplii reaching the copepodid stage at dose levels <1.0 kilorad showed an increase in the percentage of the successful nauplii with decreasing dose. A similar result was observed when comparing the percent of nauplii that reached Copepodid I and completed their development to the mature adult stage, Copepodid VI.

The most significant finding was that early nauplii are apparently more radiosensitive than the embryonic stages when the chosen biological endpoint is transformation to the next developmental stage. A dose between 0.25 and 0.5 kilorad reduced the percentage of nauplii reaching the copepodid stage to 50% of the control. However, a dose of 1.0 to 5.0 kilorad was required to produce the same effect on embryonic development. One possible explanation is that nauplii are more sensitive, owing to a higher metabolic rate

during the first 24 hr, when they undergo a number of successive molts. Another possibility is that the embryonic stages were irradiated during a less radiosensitive, later period of development and, that, in fact the very early embryonic stages are more radiosensitive. Additional work in which calanoid embryos are irradiated at different time intervals after egg sac formation would be required to determine if the very early embryonic stages are more sensitive than the stage tested.

Penetration of Carp Eggs by Plutonium-238 and Uranium-233

A study was conducted to determine the penetration of plutonium and uranium through the membrane of fish eggs. This experiment provided data for four specific objectives: (1) to determine if plutonium and uranium in soluble form penetrate the egg membrane; (2) to quantify the activity associated with the egg membrane and the cytoplasm and yolk material inside the egg; (3) to evaluate plutonium and uranium transport through the egg membrane; and (4) to establish the extent of localization of plutonium and uranium inside the egg.

Carp eggs from gametes spawned in the laboratory¹⁶ were placed in solutions of ^{238}Pu or ^{233}U (citrate complex) at the following times after fertilization: 0, 2, 23, and 46 hr. The concentration of radioactive solution was approximately $1 \times 10^{-2} \mu\text{Ci/ml}$, which is sufficiently low to preclude any effect on embryo development. Samples of eggs were taken after eggs had been in the radioactive solution for periods of approximately 2, 9, 25, 49, and 60 hr. The normal development time for carp eggs is 72 hr at 25°C .

Samples were divided into two basic groups. The first group was rinsed with distilled water; the second group was rinsed with an EDTA solution. Each group of eggs was further divided into samples of egg membrane, cytoplasm and yolk material, and whole egg. Each sample consisted of from 30 to 100 eggs to assure good statistical results. Samples were digested in nitric acid, evaporated, and counted for alpha activity.

The results for ^{238}Pu activity associated with the total egg, following EDTA rinse, are shown in Fig. 5.4. This study indicated that (1) both ^{238}Pu and ^{233}U readily penetrate the egg membrane; (2) concentration of activity in the cytoplasm and yolk material is approximately equal to that of the test solution; and (3) transport through the membrane occurs continuously and is not a function of initial water hardening of the egg. Autoradiographs are being prepared to evaluate localization of activity inside the egg. These data were used to calculate the dose to fish eggs exposed to plutonium and uranium in the environment as well as to eggs exposed to ^{238}Pu and ^{233}U in toxicity experiments.

Effects of ^{238}Pu , ^{244}Pu , ^{232}U , and ^{238}U on Carp Embryos

Experiments were conducted to determine the chemical and radiological effects of plutonium and uranium on fish embryos. Plutonium-238 (17.1 Ci/g) and ^{232}U (21.4 Ci/g) were used to study the effects from high specific activity alpha-emitting radionuclides; ^{244}Pu ($1.77 \times 10^{-5} \text{ Ci/g}$) and ^{238}U ($3.36 \times 10^{-7} \text{ Ci/g}$) were selected to evaluate the effects from low specific activity alpha-emitting isotopes. One purpose of this study was to establish an upper limit, based on observable effects at the time of hatching for radiological and chemical toxicity of plutonium and uranium. Previous experiments had failed to establish an upper limit at a maximum concentration of ^{239}Pu of $5 \times 10^{-2} \mu\text{Ci/ml}$.¹⁷

Gametes were fertilized in the laboratory and placed in solutions containing the radionuclides as a citrate complex. Tests were scored on the basis of percent hatch, abnormalities of the larvae, and survival of larvae for a 60-day period. All experiments were conducted in a glove box.

Effects on hatching of larvae and abnormalities were observed at the following concentrations: ^{238}Pu , 7.5 $\mu\text{Ci/ml}$; ^{232}U , 5.0 $\mu\text{Ci/ml}$; ^{244}Pu , 19 ppm; and ^{238}U , 68 ppm. The low specific activity of ^{244}Pu and ^{238}U precluded any effect from the alpha radioactivity; therefore, it was concluded that chemical toxicity was responsible for the upper limit, based on hatching of the embryos in ^{244}Pu and ^{238}U . These experiments are also being conducted on fathead minnows, but the results are not yet available.

Fig. 5.4. Accumulation of ^{238}Pu by carp eggs.

In addition to the data on toxicity provided by this experiment, two other aspects were also important. First, observation of abnormal larvae was a difficult test to score, because of the large number of eggs involved. Second, larvae should be observed for survival for a period of at least seven days before the test is ended.

Biological Test System Using Fathead Minnow Eggs

A biological test system using fathead minnow eggs, *Pimephales promelas*, was developed to study the effects of plutonium and uranium on fish eggs. Shelters were prepared (see Fig. 5.5) by attaching sheets of polyethylene to the underside with tape (A) and placed in an aquarium in the laboratory (B). Soon after the eggs were laid the polyethylene was removed and cut into two pieces, each containing approximately 100 eggs (C). The polyethylene was then floated with the eggs downward in 100 ml of test solution and 100 ml of filtered spring water for a control (D).

The eggs hatch in approximately seven days at 23.5°C. Hatchability, abnormalities of larvae, and survival of larvae after hatching were indications of the toxicity of the test solution. During development of the embryo, dead eggs were removed daily from the polyethylene and the solution changed.

Table 5.4 lists the results of tests with ^{232}U (citrate). This radionuclide is being investigated because of its potential radiological importance in the HTGR fuel cycle.¹⁸ Hatchability for control groups was approximately 80%. Three groups were used for each concentration of test solution, resulting in sample sizes ranging from 154 to 533.

There are several advantages to this test system: fathead minnows lay eggs throughout the year under carefully controlled laboratory conditions; a good supply of breeders provide eggs on a daily basis; the technique used for collecting eggs and floating the eggs on polyethylene in the test solution is similar to a natural system; and, if test solution is changed daily and dead eggs are removed, a relatively high percent hatch results.

Fig. 5.5. Technique used to obtain *P. promelas* eggs for toxicity environment.

Table 5.4. Results of ^{232}U toxicity tests based on percent hatch using fathead minnows

Sample No.	Test solution	No. eggs	% hatch	95% confidence interval
1	4.43 $\mu\text{Ci/ml}$	315	0.0	0.0 - 1.0
Control-1	water	257	90.0	93.7 - 86.3
2	2.91 $\mu\text{Ci/ml}$	425	0.0	0.0 - 0.7
Control-2	water	321	72.3	77.2 - 67.4
3	1.14 $\mu\text{Ci/ml}$	320	0.0	0.0 - 0.9
Control-3	water	307	81.5	85.8 - 77.2
4	0.5 $\mu\text{Ci/ml}$	154	0.0	0.0 - 1.9
Control-4	water	169	79.8	85.9 - 73.7
5	0.21 $\mu\text{Ci/ml}$	415	76.0	80.1 - 71.9
Control-5	water	260	94.0	96.9 - 91.1
6	0.05 $\mu\text{Ci/ml}$	238	83.0	87.8 - 78.2
Control-6	water	266	87.8	91.7 - 83.9
7	0.01 $\mu\text{Ci/ml}$	269	87.8	91.7 - 83.9
Control-7	water	252	78.8	83.8 - 73.8

MATERIAL TRANSPORT

Distribution and Concentration of Trace Elements
in Walker Branch Embayment

Walker Branch embayment on Melton Hill Reservoir is used as a study site to investigate the distribution and internal kinetics of several trace elements in reservoir ecosystems typical of the southeastern United States. Sediments in deeper areas of the embayment not subject to wave action are dominated by finer particles ($<53\mu$) with most sediments in the 2 to 53μ size class. The distribution of most trace elements associated with sediments is similar to the particle size distribution with the finer particle sizes containing both higher concentrations and higher percentages of the total amount of trace elements associated with sediments (Table 5.5). Differences in trace element concentrations between the various particle sizes are probably due in part to differences in exchange capacity for sorption of dissolved metals. In addition to the silt and clay minerals contained in $<53\mu$ size classes, these finer particles contain hydrous oxides of iron and manganese and organic particulates, both of which are important in the exchange capacity of lake sediments. Detailed mineralogical analyses of these sediments to determine the clay content have not been conducted. Average organic content of the silt (2 to 53μ) and clay-size ($<2\mu$) fractions in Walker Branch embayment sediments, however, is $4.5 \pm 1.4\%$ (± 1 SD) and $12.2 \pm 3.8\%$, respectively. In view of the significant direct relationship between cation exchange capacity (CEC) and organic content of these sediments and the higher organic content in the finer size classes, the finer particles that dominate the sediments in this embayment could be exchanging significant quantities of dissolved metals with the overlying water. Because metal concentrations include both the exchangeable components and the fraction bound in sediment minerals, the relative importance of ion exchange processes on metal enrichment in these sediments is unknown. Additional studies are underway or planned, however, to determine the exchangeable fraction and the biological availability of select metals associated with sediments in the Walker Branch embayment.

Table 5.5. Total concentration (in $\mu\text{g/g}$ dry weight) and percentage distribution of manganese, iron, cobalt, cesium, chromium, and vanadium as a function of particle size in surface bed sediments from Walker Branch embayment of Melton Hill Reservoir

Particle size class (μ)	Mn		Fe		Co		Cs		Cr		V	
	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%
>1680	329	0.7	15200	1.3	6.21	1.5	0.22	0.2	36.6	1.22	28.8	1.3
500-1680	1330	2.5	58200	4.2	22.6	4.6	1.04	0.8	120.0	3.32	69.1	2.7
250-500	764	3.4	19700	3.4	7.22	3.5	0.44	0.8	56.9	3.7	22.4	2.0
125-250	536	2.2	12600	2.0	9.72	4.3	0.29	0.5	45.0	2.7	15.3	1.3
53-125	675	6.1	8750	3.0	9.68	9.4	0.48	1.7	33.5	4.4	15.2	2.8
2-53	1290	72.0	33100	71.0	8.97	54.3	3.71	80.0	83.4	68.7	64.2	73.6
<2	2250	13.1	67800	15.1	35.4	22.3	7.24	16.2	186.0	15.9	137.0	16.3

Contribution of Gut Contents to the Concentration and Body Burden
of Elements in a Benthic Invertebrate from a Spring-Fed Stream

Element concentrations in aquatic organisms, particularly zooplankton, benthic invertebrates, and small fish typically are based on whole-body analysis, including contents of the gastrointestinal (GI) tract. The question arises as to whether the whole-body element content most accurately reflects tissue concentrations or concentrations in gut and/or surface contaminants. To assess the contributions of gut contents to whole-body concentrations of elements in an aquatic consumer, the concentrations and body burdens of 30 elements (see Table 5.6) in *Tipula* spp. larvae, a detritus-feeding aquatic insect, were analyzed before and after the larvae evacuated the GI tract. The larvae were analyzed by nondestructive neutron activation analysis.

Final concentrations (guts evacuated) of five elements (Zr, Tb, Nd, Lu, and Ta) were below detection limits so comparisons of mean concentrations for these elements could not be made. Of the remaining 25 elements, all but Na, Cr, Se, Hg, and Zn had a significantly lower ($P < .01$) concentration after gut evacuation, with the percentage decrease in concentration ranging from 18% for K to 70% for V, Hg, and some of the rare earths. The higher concentration of zinc after gut evacuation is apparently due to sample contamination. The significantly greater variance of initial concentrations for several elements indicates that gut contents are a major source of variation in measured whole-body concentrations (Table 5.6).

Table 5.6. Mean whole-body concentration (± 2 SE) of elements in *Tipula* spp. larvae before (initial) and after (final) gut evacuation, percent change in concentration, and the ratio of variances of the initial to the final concentration

Element	Concentration ($\mu\text{g/g}$, dry weight)		Percent change	Significance	Variance initial/final	Percent body burden associated with gut content (± 2 SE)
	Initial ^a	Final ^b				
Na	14730 $\pm$ 874(10)	14989 $\pm$ 911(10)	+ 1.8	c,d	0.2	0.30 $\pm$ 0.02
K	17720 $\pm$ 841(10)	14540 $\pm$ 785(10)	-18.0	e	1.1	8.5 $\pm$ 10.9
Rb	5.73 $\pm$ 0.53(10)	3.01 $\pm$ 0.51(7)	-47.5	e	1.5	45.8 $\pm$ 7.7
Cs	0.24 $\pm$ 0.02(10)	0.13 $\pm$ 0.02(10)	-45.8	e	1.0	60.3 $\pm$ 1.9
Ca	7070 $\pm$ 2245(5)	2446 $\pm$ 402(10)	-64.5	d,e	15.6	78.6 $\pm$ 4.9
Ba	55.1 $\pm$ 7.3(10)	17.4 $\pm$ 2.8(8)	-68.4	d,e	8.8	74.3 $\pm$ 1.9
Zr	26.1 $\pm$ 4.6(6)	<20.0	—	—	—	89.1 $\pm$ 25.0
Hf	0.32 $\pm$ 0.06(10)	0.09 $\pm$ 0.03(9)	-71.9	d,e	6.2	83.3 $\pm$ 4.2
Th	0.45 $\pm$ 0.04(10)	0.22 $\pm$ 0.02(10)	-51.1	e	4.0	66.8 $\pm$ 10.6
V	9.1 $\pm$ 1.1(10)	2.5 $\pm$ 0.3(10)	-72.1	d,e	18.1	68.7 $\pm$ 4.5
Ta	0.029 $\pm$ 0.004(5)	<0.020	—	—	—	81.2 $\pm$ 18.1
Cr	13.1 $\pm$ 1.0 ^f (2)	14.2 $\pm$ 0.5 ^f (2)	+8.9	c	3.1	40.1 $\pm$ 2.5
Mn	658 $\pm$ 68(10)	196 $\pm$ 9(10)	-70.2	d,e	59.5	63.9 $\pm$ 4.3
Fe	2132 $\pm$ 177(10)	1088 $\pm$ 92(9)	-49.0	e	4.1	54.8 $\pm$ 3.3
Co	4.12 $\pm$ 0.28(10)	2.93 $\pm$ 0.17(9)	-28.9	e	2.9	40.2 $\pm$ 1.4
Zn	90.1 $\pm$ 6.6(10)	106.4 $\pm$ 4.7(9)	+18.0	e	2.1	66.4 $\pm$ 10.8
Hg	0.17 $\pm$ 0.05(9)	0.22 $\pm$ 0.06(10)	+29.4	c,d	0.5	73.8 $\pm$ 10.0
Al	2732 $\pm$ 195(10)	1822 $\pm$ 9 ^f (2)	-33.3	e	3.4	61.9 $\pm$ 3.9
Se	1.02 $\pm$ 0.13(10)	0.95 $\pm$ 0.11(10)	- 6.9	c,d	1.4	22.9 $\pm$ 3.0
Cl	3442 $\pm$ 183(10)	1774 $\pm$ 262(10)	-48.5	e	0.5	13.3 $\pm$ 1.1
Br	60.8 $\pm$ 7.7(10)	34.3 $\pm$ 2.2(10)	-43.6	d,e	12.2	54.3 $\pm$ 1.8
I	8.83 $\pm$ 1.72(4)	4.10 $\pm$ 0.60(8)	-53.6	e	4.1	40.3 $\pm$ 0.6
Sc	0.80 $\pm$ 0.12(10)	0.35 $\pm$ 0.02(10)	-56.2	d,e	22.6	60.0 $\pm$ 3.9
La	5.32 $\pm$ 1.40(8)	2.11 $\pm$ 0.10(2)	-60.3	d,e	800.0	56.4(n = 1)
Ce	4.71 $\pm$ 0.37(10)	1.77 $\pm$ 0.17(10)	-62.4	e	4.6	69.8 $\pm$ 2.6
Nd	5.27 $\pm$ 2.15(7)	<5.01	—	—	—	43.2 $\pm$ 7.2
Eu	0.118 $\pm$ 0.025(10)	0.033 $\pm$ 0.003(10)	-72.0	d,e	64.0	69.3 $\pm$ 4.7
Tb	0.093 $\pm$ 0.024(10)	<0.026	—	—	—	73.4 $\pm$ 9.1
Yb	0.31 $\pm$ 0.06(10)	0.093 $\pm$ 0.011(8)	-70.0	d,e	44.4	65.4 $\pm$ 7.0
Lu	0.108 $\pm$ 0.023(10)	<0.097	—	—	—	72.5 $\pm$ 0.3
						56.5 $\pm$ 8.2 (n = 30)

^aTo convert concentrations to ash-weight basis, divide by 0.1494. Numbers in parentheses indicate sample size.

^bTo convert concentrations to ash-weight basis, divide by 0.1087.

^cNon-significant ($P < .10$).

^dModified two-sample t-test

^eSignificant ($P < .01$).

^fValues calculated using regression equations between concentration and dry/weight/individual.

Percentage of the initial whole-body burden associated with gut contents ranged from <1% for sodium to 89% for zirconium, with an average for all 30 elements analyzed of $57.8 \pm 8\%$ (± 2 SE). Over 50% of the whole-body burden was associated with gut contents in 70% of the elements analyzed (Table 5.6). These results show that gut contents are a major source of contamination for most of the 30 elements analyzed. While based on less than 30% of the elements, examples from most element groups in the periodic table were analyzed. Thus, it is unlikely that the percentage distribution would change significantly if the remaining elements were included. While the problem of contamination can largely be overcome in large organisms from which selected organs and tissues not subject to surface or gut contamination can be removed for analysis, it is a problem for small aquatic organisms where the whole body is analyzed. Correction for the natural sources of contamination depends in part on whether one is interested only in total element transfer between trophic levels or in the biological availability and accumulation within and between trophic levels. In both cases, however, the contribution to whole-body content of elements associated with gut and/or surface contaminants or their availability for absorption into tissues should be determined in order to assess the consequences of elevated releases to the environment of trace contaminants such as heavy metals and radionuclides.

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PART III. TERRESTRIAL ANALYSES, EFFECTS, AND MATERIALS TRANSPORT

6. Ecosystem Analysis

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FUNDAMENTAL ECOSYSTEM RESEARCH

Research on ecosystems and ecological processes continued apace this year with equal emphasis on collaborative analyses with other ecosystem research teams across the country and initiation of new lines of investigation. Syntheses of results obtained during participation in the US-IBP program led to staff participation in several symposia and international meetings with the explicit purpose of interbiome and international comparison of ecosystem structure and function. A sample of these synthesis topics is highlighted in the discussion which follows.

Several new research projects were initiated this year. One project is examining the role of consumers in the regulation of ecosystem function, particularly decomposition and element content of detritus. A second project involves examining the significance of the coupling between below-ground autotrophic processes (root sloughing) and heterotroph activities to the stability of annual element cycles. A third project includes the examination of seasonal allocation of photosynthate in mature *Quercus alba* (white oak). The hypothesis here is that microbial processes are essential to maintain autotroph balance of limited carbohydrate reserves with metabolic demand while conserving essential nutrients. Finally, using the large data base on woodland ecosystems from all IBP sites, several analytical studies are in progress to evaluate the common properties of ecosystem function, statistical distribution of ecosystem parameters, and covariate relationships among ecosystem parameters.

Significance of Root Production and Turnover to Grassland and Deciduous Forest Ecosystem Function

A major challenge to ecosystem science is the identification of the general properties of ecological systems which aid in the formulation of a general theory of ecosystem

function to integrate our insights on essential ecosystem behavior and to aid in focusing the direction of future research. Simple comparisons of ecosystem behavior are first steps toward this goal. In collaboration with David C. Coleman,⁶ the metabolism of grassland and forest ecosystems was examined with emphasis on the below-ground portions (Table 6.1). Such a comparison suggests common properties underlying the observed metabolic patterns.

Table 6.1. Comparative metabolism (in g carbon/m²) of short-grass and deciduous forest ecosystems

	Short-grass ^a prairie	Deciduous ^b forest
Gross primary production (GPP)	1270	2150
Autotrophic respiration (R_A)	330-430 ^c	1440
Net primary production ($NPP=GPP-R_A$)	840-940	720
Heterotrophic respiration (R_H)	660	670
Ecosystem respiration ($R_E=R_A+R_H$)	995-1090	2105
Net ecosystem production ($NEP=NPP-R_H$)	180-275	50
Total standing biomass	765	8760
Total detrital mass	2470 (89%) ^d	12490 (98%) ^d
Production efficiency (R_A/GPP)	0.30	0.67
Effective production (NPP/GPP)	0.70	0.33
Maintenance efficiency (R_A/NPP)	0.43	1.95
Respiration allocation (R_H/R_A)	1.73	0.47
Ecosystem productivity (NEP/GPP)	0.18	0.02

^aModified from Andrews *et al.* pp. 22-28 in *Proc. First Intl. Congress on Ecology*, The Hague, Netherlands, September 1974. (1974).

^bHarris *et al.* pp. 116-122 in *Proc. of the Symp. on Productivity of World Ecosystems*. September 1972. In conjunction with the Fifth General Assembly of Special Committee for the IBP. Seattle, Washington. National Acad. Sci. (1975).

^cEstimates based on model-derived or laboratory data.

^dValues in parentheses are percentages of detrital mass as soil organic matter; 0-20 cm depth in prairie, 0-60 cm depth in forest.

Although the gross primary production (GPP) of the example forest ecosystem is 1.7 times greater than that of the short-grass prairie ecosystem, net primary production (NPP) of the two systems is comparable (890 vs 720 g carbon m⁻² year⁻¹). The similarity in NPP of the two structurally diverse ecosystems is attributable to the large allocation of photosynthate to autotrophic respiration (R_A) in the forest ecosystem. Per unit NPP, maintenance of the massive forest structure requires 4.5 times greater allocation of photosynthate.

Heterotrophic respiration (R_H) of the two systems also are comparable. Microbial mineralization of detrital organic matter dominates R_H (98%) in both systems. Both ecosystems are characterized by a large pool of organic detritus; 90% or more of the detrital pool is amorphous soil organic matter. A relatively large, stable pool of organic matter is a typical, and perhaps essential, feature of all ecological systems.

Another major similarity between the two ecosystems is the allocation of photosynthate below ground as biomass accumulation and as maintenance respiration. This allocation exceeds 50% of total biomass production. A further similarity between the two ecosystems is the saprophagic activity on this root substrate. Annual accumulation of large amounts of organic matter below ground in both ecosystems is offset by significant catabolic activity. Data indicate that below-ground herbivory can account for from < 5 to 10% of the observed turnover of root organic matter. Clearly, the timing and causative factors associated with root turnover are several and might include such phenomena as internal autotroph energetics and climatic cycles and perturbations. This evidence nonetheless supports the conclusion that the evolution of the terrestrial life form has occurred only at a large "cost" relative to the available photosynthetic capacity.

Taken by itself, the possible advantages of below-ground allocation and turnover are not readily apparent. Not only do such allocation patterns represent large expenditures of energy, but element return to the soil is also dominated by root detritus (Table 6.2).

Table 6.2. Annual return of organic matter and nitrogen to soil (in kg/ha/year)

	Deciduous forest		Short-grass prairie	
	Organic matter	N	Organic matter	N
Litterfall	3310	42.2	510	10
Below ground	7500	85.0	4200-5300	39-49

In the forest ecosystem 67% of the annual nitrogen return to soil occurs as root detritus. The proportion is even greater in the short-grass prairie ecosystem (80%). This large annual loss to the soil occurs, even where species have evolved complex mechanisms to retain and conserve elements, after initially incurring considerable energy expenditure in the uptake of elements through complex biological relationships such as mycorrhizal associations.

Some explanation of these diametrically opposed functional behaviors may be afforded by examining the conditions essential to the persistence of ecological systems. We propose that the significance of root sloughing in diverse terrestrial ecosystems is seen in the development and maintenance of a "big-slow" alternate energy and nutrient reservoir, such as provided by soil organic matter. Such a reservoir is an essential ecosystem component; its purpose being to enhance the persistence of the ecosystem through long-term, stable storage of chemical energy and essential elements. The energy "costs" of such a reservoir are high and impose severe constraints on "maximum" yield potentially obtained through management of terrestrial ecosystems. Furthermore, the rapid microbial catabolism of detritus results in immobilization of elements in microbial tissue. As discussed in the following section, seasonal patterns of microbial immobilization suggest an element conservation mechanism that permits short-term retention of essential elements.

Implications of Microbial Immobilization Patterns to Ecosystem Processes

Forest ecosystems exhibit patterns of capture, distribution, and conservation of elements essential to system persistence. The currency for translocation and retention of nutrient elements is carbon allocated for maintenance of the primary producers and decomposers (Table 6.1). While the biochemical form of carbon limits the rate of microbial and faunal catabolism, the total availability of carbon is not limiting to decomposers

during any period of the year (Fig. 6.1). The significance of microbial immobilization of elements to seasonal conservation of these essential nutrients was examined,⁷ using the data base from the *Liriodendron tulipifera* forest.

Fig. 6.1. Microbial immobilization of carbon O1 litter, O2 litter, and soil calculated monthly through the year. Carbon pools of O1 and O2 litter are indicated monthly. Periods of maximum litterfall and root sloughing (↓) and maximum and minimum CO₂ efflux (↑) are noted.

Nitrogen is preferentially accumulated over carbon in all forest floor strata. While calculations of microbial immobilization of nitrogen suggest that almost all O1 litter nitrogen could be within microbial cells during May, translocation of nitrogen from O2 litter and from soil⁸ and nitrogen fixation processes in woody litter could supplement nitrogen availability.⁹ It may be hypothesized that translocation of nitrogen and nitrogen fixation rates in substrates are controlled by substrate nitrogen concentrations.

Minimal decomposer nitrogen immobilization (Fig. 6.2) occurs at the season (February-March) of maximum root growth in the *Liriodendron* stand.¹⁰ This is also the season

Fig. 6.2. Comparison of microbial nitrogen immobilization with that of mesofaunal arthropods, earthworms, and nematodes. While microbial immobilization is much greater than that of faunal, faunal immobilization is much more constant.

when nitrate and ammonia are readily available from soil solution for root uptake due to nearly saturated soil conditions.¹¹ Even though considerable soil water percolation occurs during this period (February-March), less than 3% of the annual detrital nitrogen input is lost to groundwater. The phase shift between high microbial immobilization and maximum assimilation of nitrogen in new root tissue is strong evidence that the interaction of autotroph and decomposer populations within this forest ecosystem represents a system-level mechanism for effective nitrogen retention and controlled remineralization and redistribution to support sustained autotroph productivity. Phosphorus is preferentially accumulated over carbon in O1 litter. This element is probably limiting to litter microbial populations from March through July. We have no direct evidence that this limitation is met by translocation from O2 litter and soil or by decreased microbial phosphorus concentrations. By contrast, potassium inputs are dominantly soluble and are not retained in O1 litter. While this forest retains 38% of the annual potassium input in O1 litter, other forest types retain an average of 20%. This suggests limited biological control of potassium movement in litter. Further, potassium is limiting to O1 litter populations from April through July (immobilization estimates > available pool). However, ground-water losses of potassium are less than 10% of the annual detrital input. Therefore, it would seem that control of potassium retention is in soil. Well-known soil chemical reactions involving ionic equilibria of soil solution and the organic-inorganic exchange complex could account for conservation of potassium in the soil.

The strategy of elemental retention and redistribution within the forest system, we hypothesize, is dependent upon maintenance of the forest floor (litter and soil) detrital

pools and its decomposer community. The cost to the forest is primarily in the carbon lost in heterotrophic respiration. Seasonality of microbial immobilization of carbon, nitrogen, phosphorus, and potassium within forest floor strata with maximum immobilization synchronized with likely periods of maximum root uptake resulted in low amounts of nutrient export from the forest. Decomposer invertebrates, while possessing smaller immobilized pools of these elements may regulate microbial immobilization and release rates through harvest¹² or indirectly via substrate influences.¹³ Maximum growth of *Liriodendron* roots (defined to include the accompanying root community of mycorrhizal fungi and root surface microbes) occurs at the time of minimum decomposer nutrient immobilization. This harmony between plants and decomposers is the major mechanism underlying forest nutrient conservation to support sustained productivity.

Watershed Nutrient Budgets -- A Comparison Among Three Appalachian and Cascade Mountain Catchments

Experimental watersheds are used to study the interrelationships of the physical, biological, and chemical components of ecosystems and their relationships to various material cycles (e.g., hydrologic, nutrient, and energy cycles). Within the International Biological Program (IBP), research has been conducted on gauged catchments in both the coniferous and deciduous forest biomes to investigate nutrient element cycles and the processes that influence nutrient movement within and from forested watersheds. The following highlights are derived from an effort to compare the results of findings from three watersheds, two vegetated with deciduous species and one with coniferous species. The researchers involved in the comparison are C. Grier (Coniferous Forest Biome), and W. Swank, J. Waide, and G. Henderson (Eastern Deciduous Forest Biome).

Nutrient additions from the atmosphere were greatest at Walker Branch (mixed oak-hickory forest), intermediate at the Coweeta Hydrologic Laboratory (mixed oak-hickory and cove hardwood forest), and lowest at the H. J. Andrews Experimental Forest (Douglas fir forest) even though precipitation was greatest at the Andrews and least at Walker Branch (Table 6.3). A comparison of inputs at Coweeta and Walker Branch indicates that

Table 6.3. Comparison of average annual water, calcium, magnesium, potassium, sodium, ammonium, and nitrate input-output balances among the H. J. Andrews, Coweeta, and Walker Branch watershed ecosystems

	H. J. Andrews	Coweeta	Walker Branch
Water (cm)			
Precipitation (P)	233.0	204.0	152.0
Streamflow (S)	152.5	117.0	90.5
Net difference (P-S)	80.5	87.0	61.5
Calcium (kg/ha)			
Deposition	5.0	5.0	14.2
Streamflow loss	52.0	7.4	146.1
Difference	-47.0	-2.4	-131.9
Magnesium (kg/ha)			
Deposition	1.0	1.1	2.2
Streamflow loss	12.6	3.4	77.2
Difference	-11.6	-2.3	-75.0
Potassium (kg/ha)			
Deposition	0.2	2.3	3.4
Streamflow loss	1.7	5.6	6.7
Difference	-1.5	-3.3	-3.3
Sodium (kg/ha)			
Deposition	1.8	4.4	4.0
Streamflow loss	29.7	10.3	4.4
Difference	-27.9	-5.9	-0.4
Ammonium-n (kg/ha)			
Deposition	0.5	0.5	2.0
Streamflow loss	<0.1	<0.1	0.3
Difference	~0.5	~0.5	1.7
Nitrate-n (kg/ha)			
Deposition	0.2	2.9	3.9
Streamflow loss	<0.1	<0.1	0.1
Difference	~0.2	~2.9	3.8

dry particulate fallout can be an important input process, depending on the element and locality. Site comparisons of inputs showed that there is a great deal of variability in the amount of input; this variability is likely due to local conditions such as the proximity to industrial areas and oceanic influences.

Nutrient losses in streamflow from the three watersheds compared are primarily controlled by bedrock weathering and are not closely related to atmospheric inputs. This conclusion is based on the relative proportions of cations discharged from the three catchments. At Walker Branch the Ca:Mg ratio is about 2:1 which is similar to that of the dolomite bedrock; at the Andrews the Ca:Na ratio in streamflow is 1.75:1 and also is similar to that of the andesite bedrock (Ca- and Na-rich feldspars); and at Coweeta all four cations measured account for a significant proportion of the total discharge, reflecting the chemistry of the underlying mica shists and granite. The total cation discharge shows that the dolomite bedrock at Walker Branch is weathering faster (235 kg/ha/year) than the andesite at the Andrews (96 kg/ha/year) and the shists and granite at Coweeta (27 kg/ha/year).

Whereas the cations Ca, Mg, K, and Na are lost from all watersheds in greater quantities than they are deposited due to bedrock dissolution, ammonium and nitrate are being accumulated in the catchments (Table 6.3). Because a bedrock source of nitrogen is lacking, biological processes dominate in controlling nitrogen discharge; these processes result in net annual accretion of the element for all three watersheds.

Distribution among ecosystem components and annual cycling of nitrogen, potassium, and calcium were also compared for the three catchments (Table 6.4). These distributions are strikingly similar, considering the diverse composition of the three ecosystems. Larger quantities of exchangeable K and Ca are present in the mineral soil horizons at the Andrews because of both a greater exchange capacity and a developmentally younger (less leaching) soil than the highly weathered soils of the southern Appalachians. The forest floor at the Andrews contains six times more biomass than either of the other two sites, which also results in greater nutrient incorporation in this ecosystem component.

The relative importance of the various annual transfers for N, K, and Ca is consistent among the three ecosystems. Of the transfers compared, litterfall was the most important return (recycle) process for N and Ca, while canopy leaching was as or more important for K. Comparison of the litterfall returns also reveals the degree of translocation of nutrients from leaves to woody components in the three ecosystems. Nitrogen and K are recycled back into the vegetation in the coniferous (Andrews) system to a greater extent than in the two deciduous systems, resulting in lower returns in litterfall. This is due to the longer residence time on the tree of senescing conifer foliage. Translocation of Ca does not occur to as great an extent, and therefore the relative return in litterfall is less influenced by the evergreen nature of the conifer system.

The general picture that emerges from this comparison is that all three forested watershed ecosystems are functioning similarly with regard to nutrient distribution, cycling, and discharge. All three systems release only a small proportion of their nutrient capital, and it appears that all are more conservative of nitrogen than of cations.

ECOLOGICAL EFFECTS OF POLLUTANTS

In response to the organization of the Energy Research and Development Administration during the year, ongoing research programs were evaluated in order to achieve a balance of timely research effort on ecological effects of nonnuclear as well as nuclear energy technology effluents. This appraisal led to reprogramming research efforts in the Transport and Effects Program in two new directions.

One new project deals with the environmental effects of air pollution from coal combustion. In this research, we are studying the effects of acidic precipitation on plant-soil systems and the physiological effects of mixtures of gaseous pollutants on plants. Recent controlled experiments using sulfuric acid solutions to simulate rainfall have indicated possible effects from leaching of nutrients from foliage and alteration of host (plant)-parasite relationships (including symbiotic nitrogen fixation), perhaps as the result of altered carbon metabolism.¹⁴ Experiments are planned to investigate these preliminary findings, using a rainfall simulation apparatus.¹⁵

Table 6.4. Comparison of the distribution and annual cycling of nitrogen, potassium, and calcium in three watershed ecosystems

	H. J. Andrews	Coweeta	Walker Branch
<u>DISTRIBUTION (kg/ha)</u>			
Nitrogen in:			
Vegetation	420	570	490
Forest floor ^a	570	140	270
Mineral soil ^b	4500	10,200	5100
Potassium in:			
Vegetation	280	330	330
Forest floor ^c	70	40	20
Mineral soil ^c	860	340	170
Calcium in:			
Vegetation	760	820	910
Forest floor ^c	440	120	350
Mineral soil ^c	4500	510	710
<u>ANNUAL CYCLING (kg/ha/year)</u>			
Nitrogen transfers as:			
Litterfall	27	33	38
Canopy leaching	2	5	4
Woody increment	9	18	15
Uptake	d	132	124
Potassium transfer as:			
Litterfall	8	18	19
Canopy leaching	22	31	19
Woody increment	10	13	18
Uptake	d	85	123
Calcium transfer as:			
Litterfall	67	44	46
Canopy leaching	2	8	14
Woody increment	8	23	25
Uptake	d	184	196

^a01 and 02 horizons (organic).^bKjeldahl N to a 60-cm depth.^cExchangeable to a 60-cm depth.^dData not available.

Research on physiological effects of gaseous pollutant mixtures is directed toward further understanding of the influence on plant response of short-term exposures to SO₂ as actually occur in the field, particularly in the presence of background levels of other pollutants such as ozone. Construction is underway on a plant exposure system which will be capable of simulating actual exposure kinetics in the presence of known amounts of other gaseous pollutants.¹⁶

The second new research area is part of the Division's new program on the Environmental Effects of Coal Conversion Processes (see Part I, Chapters 1, 2, and 3). The objective of research in this program is to provide initial dose-response data which will permit early assessment of the potential effects on vegetation that result from release of gaseous effluents from coal conversion processes. Through cooperation with the Analytical Chemistry Division, we have determined the feasibility of collecting the gaseous effluent mixture and the most practicable chemical characterization. Initial experiments

involve examining the potential of bulk gaseous effluents for causing acute injury to vegetation. Later phases of the research will include identification of the phytotoxic components and evaluation of the potential effects that arise from chronic exposure.

Activities in the project on effects of radioactive fallout on the 0800 area arthropod community emphasized analysis and documentation of results to date. Part of these results were reported at the Fourth National Radioecology Symposium.¹⁷

Research on the fate and effects of cooling tower drift continued as a cooperative effort between the ESD and the NOAA/ATDL. Staff research focused on validation of atmospheric transport models applied to cooling tower plume dispersal and the potential for transport and accumulation of chromium in foodchains.

Distribution and Retention of Chromium in Small Mammals from Cooling Tower Drift

Recirculating water of the cooling system contains a chromate, zinc-phosphate corrosion inhibitor. A fraction of the cooling water is entrained in the exit air flow and is deposited as drift on the landscape. Surface contamination by the airborne pollutants and subsequent ingestion and inhalation of the contaminants are potential pathways for incorporation of trace quantities of chromium into food chains. The magnitude of contamination of foliage by drift suggests a potential hazard to native mammals.¹⁸

Cotton rats (*Sigmodon hispidus*) were live-trapped in a fescue field adjacent to large, mechanical-draft cooling towers. Each animal was dissected into major organs and tissues for analytical determinations. A 10-fold increase in chromium concentration in hair and pelt between treatment and control animals indicated that the increased concentrations were derived from direct deposition or physical transfer from plant surfaces during feeding activities. Elemental analysis by organs or tissues further suggested little increase in chromium through ingestion or inhalation. Significant differences ($P < 0.01$) in chromium concentration of pelt, hair, and bone were identified between treatment and control animals (Table 6.5). Concentration in bone of treatment and

Table 6.5. Comparison of the distribution pattern of chromium in cotton rats (*Sigmodon hispidus*) exposed to cooling tower drift and in control animals

Organ or tissue	Number of animals (n)		Concentrations ($\mu\text{g/g} \pm 1 \text{ SE}$)	
	Control	ORGDPA	Control	ORGDPA
Heart	6	6 ^b	0.105 $\pm$ 0.013	0.124 $\pm$ 0.016
Liver	6	6 ^b	0.046 $\pm$ 0.016	0.160 $\pm$ 0.039
Kidney	6	6 ^b	0.087 $\pm$ 0.014	0.124 $\pm$ 0.040
Spleen	6	6 ^b	0.493 $\pm$ 0.123	0.713 $\pm$ 0.084
Lung	6	6 ^b	0.289 $\pm$ 0.072	0.292 $\pm$ 0.063
Bone	6	6 ^b	0.160 $\pm$ 0.008	0.460 $\pm$ 0.024 ^c
Muscle	6	6 ^b	0.234 $\pm$ 0.043	0.288 $\pm$ 0.029
GI tract	6	6 ^b	1.046 $\pm$ 0.277	1.006 $\pm$ 0.183
Pelt	6	24	0.092 $\pm$ 0.007	1.056 $\pm$ 0.133 ^c
Hair	6	24	0.395 $\pm$ 0.021	4.397 $\pm$ 0.555 ^c
Residual ^d	6	24	0.200 $\pm$ 0.032	0.311 $\pm$ 0.025

^aOak Ridge Gaseous Diffusion Plant.

^bIndicates 6 pooled samples of 4 animals each.

^c $P < 0.01$ significant difference.

^dBlood, reproductive organs, brain, salivary and thyroid.

control animals ranged from 0.46 ± 0.02 ppm to 0.16 ± 0.04 ppm, whereas hair and pelt of animals exposed to drift ranged from 4.4 ± 0.56 ppm to 1.06 ± 0.13 ppm respectively, as contrasted to 0.4 ± 0.02 ppm and 0.09 ± 0.01 ppm in control animals.

Even though these tissues showed statistically significant differences ($P < 0.01$) in chromium concentration, the mechanism of incorporation or biological significance of the increased levels was not known. The significance of chronic exposure by ingestion to drift-contaminated food was determined by feeding twenty adult animals fescue grass labeled with isotopic chromium in a chemical form ($\text{Na}_2^{51}\text{CrO}_4$) similar to the form maintained in the recirculating cooling waters. Each animal was fed grass containing 3.75 μCi of ^{51}Cr , and was measured radiometrically for retention during two weeks post feeding. Initial whole-body radioactivity (A_0) was $0.0073 \mu\text{Ci/g} \pm 0.001$ SE. The elimination of ^{51}Cr by the cotton rats resulted in a two-component curve which was resolved into a short component representing gut clearance, and a long component illustrating loss of the assimilated fraction. The retention data were fitted to an exponential model¹⁹ described by the equation,

$$A_t = A_0 (a_1 e^{-\lambda_1 t} + a_2 e^{-\lambda_2 t}),$$

where A_t represents whole-body activity at time t , A_0 is the initial whole-body activity, and a_2 and a_1 describe the assimilated and nonassimilated radionuclide eliminated at rates λ_2 and λ_1 , respectively.

The percent assimilated as determined from the intercept of the long component is 0.79 or $0.06 \times 10^{-3} \mu\text{Ci/g}$, where $a_2 = 1 - a_1$ or $a_2 = 1 - 0.9921$. Within three days post feeding, greater than 99% of the initial whole-body radioactivity was eliminated through gut clearance ($\lambda_1 = 1.94 \text{ day}^{-1}$), whereas the remaining fraction ($< 1\%$), that represents loss by body tissues of the assimilated radionuclide, was eliminated at a much slower rate ($\lambda_2 = -0.001 \text{ day}^{-1}$). By 16 days post feeding, approximately 0.7% or 113 dpm/g of the initial body activity remains.

The low assimilation (0.8%) and rapid initial loss of the hexavalent chromium suggest the nonessential nature of the element in cotton rats. The retention data also confirm the lack of any significant bioaccumulation as depicted in stable analyses (Table 6.5), and further suggest the reduced probability of a toxic effect through ingestion of drift-contaminated vegetation or inhalation of drift-contaminated air. The estimated fraction absorbed by man through ingestion²⁰ (< 0.005) is similar to the fraction assimilated by the native rat (0.008). Similarly, the biological half-times of chromium assimilated by man²⁰ and cotton rats are 616 and 693 days, respectively. The magnitude of the half-times suggests a high potential for biological interactions to chromium derived from a chromate. However, the fraction assimilated is very low and reduces the likelihood of toxic effects. The data suggest that extrapolations from the small mammals to man are reasonable for chromium. These data also aid in understanding the behavior of chromium in vertebrates from both nuclear (fission products) and nonnuclear sources, because the biological half-times for both stable and radioactive chromium are nearly the same.

ECOLOGICAL MODELING AND APPLICATIONS

Mathematical modeling of ecological systems continued to be an active and productive research area. In addition to completing process-level research models, such as the element transport and assimilation model described below, new programs in regional ecological studies necessitated the development of a model of forest development. Certain of the features and capabilities of these new model tools are summarized in the following sections.

While much of the ecological modeling research is closely associated with fundamental field research programs, it is important that the knowledge gained from developing advanced ecological models as well as their analytical capabilities be promptly applied to ecological assessment or other related problems. Involvement of staff in the assessment of ^{14}C releases from a HTGR fuel reprocessing facility led to examining carbon assimilation where episodic excursions of $^{14}\text{CO}_2$ concentration occur as a function of atmospheric stability conditions and windspeed. The objective of this application of models of physiological processes is to determine if assumptions and specific activity relationships applicable to constant $^{14}\text{CO}_2$ atmospheric concentration hold when episodic excursions occur.

Analytical Model of the Plant-Soil System

An analytical model of nitrogen, phosphorous, and potassium seasonal dynamics and utilization in the plant-soil system was developed and tested with extant data.²¹ There were three main objectives of the model. The first was to predict the first-order interactive growth response of particular plant species to any combination of these macronutrients supplied in the soil medium. Species parameters required by the model include root absorption rate and certain cell chemistry reaction rates. The second objective was to make the model sufficiently general to describe a broad range of species. The model was built upon common-denominator principles of physiology condensed from available experimental data on corn, bean, pine, etc. In this generic sense it is a measure of what plants have in common. The third objective was to use the model to test several well-known theories of plant growth.

Starting from specified natural or artificial sources in the soil, element transport to root absorption surfaces is modeled in terms of diffusion, mass flow, and soil buffering mechanisms. Element uptake is described by carrier theory formalism, and assimilation is based on simplified premises about the roles of N, P, K, and photosynthate in cell chemistry. Development of this model of essential element transport and assimilation completes a suite of similarly scaled models of plant-soil-water relationships and energy flow and utilization. Work is in progress to combine these models of essential resources as a means of studying critical component and resource interactions of terrestrial ecosystems.

Development of the FORET Model

Recognizing a need for a theoretically robust ecological model, capable of extending short-term laboratory and field information on responses of trees to potential long-term effects on forests, the staff developed a stand-development model called FORET. The model (Fig. 6.3) follows a rationale outlined by Botkin et al.²² to model a forest stand by considering the birth, growth, and death of individual trees as explicit stochastic functions. To be effective, such a simulation model must be relatively straightforward in parameter estimation, but must include differences that permit the expression of discrete roles of the individual species. The FORET model considers 33 species typical of lower slope forest in eastern Tennessee (in situations in which the soil is reasonably deep and in which water shortages typically are not a dominant factor in eliminating certain species).

Subroutine BIRTH (Fig. 6.3) evaluates the stand each year and, depending upon (1) the presence or absence of litter at the site, (2) whether or not there is a drought, and (3) whether or not deer or other mammals are heavily browsing selected sensitive species, "plants" small saplings of species that are appropriate to the site conditions for that year. If during the previous year, a tree of the appropriate size and species has died, then subroutine SPROUT determines the stump sprouting of this tree. Considering the shade-tolerance, shading, crowding, and relative growth rates under the stochastically varying climate, subroutine GROW increments the dbh of each of the trees on the plot. Subroutine KILL randomly kills trees, depending upon the mortality probability of each tree (the probability of mortality is a function of the species and the growth rate for the given year of each tree). The model is currently running in two forms:

- (1) A production version which simulates a large number of stands over time and computes averages to indicate the expected trends in a forest.
- (2) An interactive version that follows a single stand through time, giving a detailed inventory of the stand composition. The interactive version was used initially to develop the model computer code, but currently is a demonstration program.

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Fig. 6.3. Flow sheet of the FORET forest model. The darker lines indicate sections that have been modified rather extensively from the "JABOWA" model [Botkin, D. B., J. F. Janak, and J. R. Wallis, *J. Ecol.* 60:849-872 (1972)].

As an example of typical FORET model output, Fig. 6.4 shows the two common species of maple for the area, in a sequence that runs from bare ground (at year zero) for 1000 years. Values in Fig. 6.4 are the means of 100 independent simulations. The shade-intolerant fast-growing red maple (*Acer rubrum*) peaks early in the succession, although it is never completely eliminated, even after 1000 years. The shade-tolerant sugar maple (*A. saccharum*) generally peaks much later in the stand development and tends to increase under conditions in which the red maple decreases. Note that the biomass of both of these species is in a constant state of change throughout the entire 1000-year sequence.

Fig. 6.4. Changes in biomass of red maple (*Acer rubrum*) and sugar maple (*A. saccharum*) over 1000 years as simulated by the FORET model. Year zero represents a bare plot.

WALKER BRANCH WATERSHED: BIOGEOCHEMICAL CYCLES OF POLLUTANTS

In the past, Walker Branch Watershed studies have focused on the analysis of atmospheric inputs and stream outputs of essential nutrient elements and on research on internal cycles within component forest and stream ecosystems. Synthesis and comparison of these results continued this year. In addition to these contributions to our understanding of the biogeochemistry of essential elements, the watershed has served in more recent years as a focus for lead-time research on trace elements. In response to the expanded research mission of ERDA, much of the research on Walker Branch Watershed was reorganized this year to provide a greater emphasis on trace element biogeochemistry, particularly the processes influencing deposition, accumulation, and export from the forested landscape. The following discussion highlights preliminary results on the sulfur budget of Walker Branch and the input-output relationships of sulfur as sulfates.

This type of timely analysis with respect to a particular pollutant, such as sulfates, exemplifies the mode of operation which we hope to develop further in the Walker Branch Watershed Project.

The Sulfur Cycle of Forest Ecosystems

Experimental watersheds such as Walker Branch form basic study units for the evaluation of integrated pollutant transport pathways from the atmosphere through terrestrial and aquatic ecosystems. Walker Branch is located within the area of influence of large coal-fired electric power generating stations. These facilities appear to be major contributors of sulfate inputs to Walker Branch. Limited information is available on the biogeochemical cycle of sulfur, particularly on a watershed scale. Such knowledge is required to assess the impact of sulfate on forest ecosystems and their productivity, element cycles, and interactions with aquatic ecosystems. The objective of this study is to quantify the biogeochemical sulfur cycle of a forested landscape in order to relate the fate of sulfur releases to the environment to its distribution in biota and soils and its annual transfers, accumulation, and export to surface waters.

Sulfate inputs to the watershed have been measured at each of five gauging stations from 1973-1975, and analyzed for SO_4 -sulfur using Technicon Auto-analyzer methodology. Streamflow sample analyses were identical to precipitation. Total sulfur in biomass pools and mineral soil was analyzed by means of the Leco automated combustion sulfur analyzer. Sulfur contents in biomass pools were calculated, using previously determined estimates.^{23,24} Biomass samples analyzed for this preliminary budget were either collected in the field in 1975 or selected from Walker Branch reference collections.

Four throughfall (net removal = nutrient leached + nutrient washed²⁵) collectors were located on each of the four study plots representative of major forest types (chestnut oak, oak-hickory, pine, and yellow poplar). Analyses of monthly throughfall samples were identical to those for precipitation and streamflow. Because the net removal term is measured on a seven-month basis (growing season, April-October), it is a conservative estimate of this transfer pathway when expressed on an annual basis.

The quantities of sulfur in the major ecosystem components and the transfers between those components are outlined in Fig. 6.5. Most of the sulfur in the terrestrial system (92%) is located in the mineral soil horizons. Of the remainder, 5 and 3% are in the vegetation and O_1 and O_2 components, respectively.

Contrary to the nitrogen cycle²⁶ where root mortality was found to be the most important mechanism in annual restitution of nitrogen to the soil, aboveground processes (net removal and litterfall) are of greater importance to the annual sulfur cycle than is root mortality.

Uptake of sulfur exceeds metabolic requirement (as defined by Henderson and Harris²⁶). A primary reason for this may be the inclusion of an enriched net removal term in the calculation of uptake. Sulfur that enters the cycle through atmospheric scavenging of particulate matter and through gaseous uptake of sulfur dioxide could inflate the uptake calculation without correspondingly augmenting the requirement estimates. Nevertheless, there appears to be enough sulfur available in the system to make internal cycling less important than is the case for other essential elements.

Inputs and losses of sulfur to the forest floor allow an estimate of net sulfur dynamics within this component. Based on the difference between the amount of forest floor S in May (after spring litterfall) and September (prior to autumnal litterfall), there is a net annual accumulation of sulfur associated with the forest floor component. Again, substantial turnover in the form of net removal and litterfall appears to influence the transfer of sulfur through the O_1 and O_2 layers into the mineral soil, resulting in retention of 0.8 kg/ha.

A summary of sulfur in the soil components shows inputs of 48.6 kg/ha (18.8 atmospheric, 12.7 net removal, 8.4 litterfall, 0.6 tree mortality, and 8.1 root mortality) minus losses of 43.4 kg/ha (11.3 outputs and 32.1 uptake) are equal to a total soil

Fig. 6.5. Annual sulfur budget for Walker Branch Watershed. Amounts (pools) of sulfur are given in kg/ha while transfers are expressed as kg/ha/year.

component accumulation of 5.2 kg/ha/year. This total soil component accumulation may be subdivided into litter retention (0.8 kg/ha) and the remainder (4.4 kg/ha) which we attribute to mineral soil accumulation.

Overall, sulfur pools appear to conform to the N:S ratio of 7:1 predicted by Deevey.^{2,7} Net removal is less than the 24 kg/ha reported by Eaton et al.^{2,5} for the growing season on the Hubbard Brook Watershed. Element pools, distributions, and transfers for Walker Branch are similar to those reported by Nihlgard^{2,8} for a beech forest in southern Sweden.

During a two-year period (Sept. 1, 1973 to Aug. 31, 1975) Walker Branch Watershed demonstrated a low retention capacity for sulfate sulfur. The watershed received an average annual sulfur input of 18.8 kg/ha as sulfate of which 18% was as dry particulate fallout (dryfall) and the majority (82%) as rain scavanged (wetfall) input (Fig. 6.5). An equivalent of 60% of the input was lost in streamflow, resulting in only a 40% net retention of sulfur. Monthly dryfall inputs were slightly greater during the June through September period than during the remainder of the year, but differences were generally less than 0.1 kg/ha/month. Monthly total sulfate-sulfur inputs correspond closely with monthly precipitation (Fig. 6.6), because wetfall accounts for the majority of atmospheric input. Sulfate concentrations in wetfall are slightly elevated during summer months and this is reflected in weighted monthly rainfall acidity (Fig. 6.6). Rain is slightly more acid during summer months (pH 4.0 to 4.4) than the remainder of the year (pH 4.3 to 4.6) and acidity of individual storms has been measured as low as pH 3.3.

Fig. 6.6. Sulfate (expressed as sulfur) input-output balances over a two-year period (September 1, 1973 to August 31, 1975) for Walker Branch Watershed. Inputs are the total of dryfall and wetfall inputs. Complementary data on amount and acidity of rainfall and amount of streamflow are also shown.

Sulfate outputs are closely related to the amount of streamflow, with most of the output occurring during winter and early spring. During a five-month period (December through April), outputs frequently exceed inputs (Fig. 6.6); the excess discharge is probably due in part to net accumulation during other times of the year. Another significant finding is that sulfate concentration increases during stormflow (Table 6.6). This pattern is different from that found at other sites^{29,30} where sulfate concentrations varied little with changing flow rates. However, in those studies the sampling interval may not have been short enough to observe the patterns seen for Walker Branch.

Table 6.6. Influence of stormflow on sulfate concentrations in streamflow from Walker Branch Watershed. (Storm occurred on November 26-27, 1973, following 22 cm of rain.)

Position on stream hydrograph	Time since storm initiation (hr)	Streamflow rate (m ³ /sec)	Sulfate concentration (ppm)
Pre-storm	0	0.01	3.2
Ascending	24	0.13	5.4
Ascending	25	0.77	6.3
Peak	26.5	1.70	8.9
Descending	29	0.70	7.2
Descending	40	0.15	5.4
New base flow	89	0.03	3.9

The soil chemical and physical relationships that govern this release pattern are not entirely understood, but soil solution sulfate commonly exceeds 10 ppm and is probably leached from the profile during storms. The subsequent recharge of sulfate in the soil solution may depend largely on atmospheric additions. However, much remains to be resolved concerning the long-term potential of soils to act as a buffer and the consequences of continued leaching with a strong anion such as sulfate.

In conclusion, Walker Branch Watershed is experiencing an annual accumulation of approximately 7.5 kg/ha/year, about 59% of which is accumulating in the mineral soil and the remainder in the biomass pools of the vegetation and litter components. Indirect evidence suggests an important role of vegetation-scavenged atmospheric sulfates in this enrichment, adding to the magnitude of sulfur inputs to the system from fossil-fuel combustion by way of wet- and dry-fall inputs. As studies continue on Walker Branch Watershed, the effects of sulfur enrichment of the ecosystem will be routinely evaluated in order to follow long-term changes in forest ecosystem response which results from sulfur loading of the region.

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7. Regional Environmental Assessment Studies

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Environmental assessment studies are a component (with socioeconomic and demographic) of the ORNL Regional Studies Project coordinated through the Energy Division. Two primary thrusts are contained within the environmental component: assessment of the impact of Appalachian coal extraction and development of regional siting criteria for development of energy technologies in southeastern United States. There are two levels of sequential resolution which are simultaneously being developed. One is a regional screening analysis by which environmental constraints (e.g., water resources, land suitability, and air quality) and sensitive regional environment effects components (endangered species, water quality, potential ecological and agricultural impacts) are being quantified. These analyses will permit identification of regional exclusion areas based on environmental criteria. The other efforts are devoted to development and application of analytical methodologies for those areas potentially suitable for development to provide guidelines for optimal siting, intensity of development, and rational choices of energy technology alternatives. Environmental transport models and critical pathway analyses, combined with optimization techniques to address constraining ecological effects, are being tested to evaluate changes in ambient environmental conditions from proposed energy-related activities.

FUEL CYCLE CHARACTERIZATION AND ASSESSMENT

An assessment framework was developed to examine the environmental impact of the various fuel cycles involved in regional-scale energy production alternatives for future development. The assessment methodology begins with an identification of those fuel cycle technologies which are of current importance to the production of energy in the Tennessee Valley and the southeastern United States. Among the technologies currently in operation are coal combustion, light-water nuclear fission, and hydroelectric generation. Technologies on the horizon for near-term implementation include the coal conversion technologies, the liquid-metal fast breeder reactor, solar power, and fusion. In an initial analysis, only coal combustion and light-water nuclear fission were addressed.

Following identification of the relevant energy technologies for a region, the assessment framework characterizes each technology in terms of its various fuel cycle elements. The categories under the heading of fuel cycle elements include extraction,

milling, conversion, isotope separation, fuel fabrication, utilization, reprocessing, waste storage, and transmission. It is assumed that the fuel cycle elements of all present and most future technologies were included in the list. Thus, the fuel cycle elements for a specific technology can be specifically identified. In this manner, it is possible to examine each technology in terms of its various fuel cycle components. As an example, the fuel cycle elements of extraction, milling, utilization, waste storage, and transmission may be applied to the coal combustion technology, while all of the aforementioned categories may be applied in the case of light-water nuclear fission plants.

The next step in the assessment involves an investigation of the environmental impact of each fuel cycle element from each energy technology. It is at this point that a detailed description of nuclear and nonnuclear effluent source terms is required for each of the energy technologies. These source terms were obtained from the scientific literature, and the quantitative and qualitative aspects of each source term were used to develop general categories for impact on air, land, and water for the various energy technologies. Thus, the environmental impact of each fuel cycle element is examined in terms of its impact on air, land, and water. Impacts on biota are contained within these three categories. For example, we can then illustrate the fact that coal combustion has an impact on particulate loading in the atmosphere, and that coal extraction affects erosion of land and water quality. Similarly, we can identify the potential impact of nuclear power plants on atmospheric levels of specific radionuclides, land use, or temperature effects on aquatic biota. This identification of critical areas of impact enables the regional study to concentrate only on those areas of significant environmental impact.

If the critical impact areas for each fuel cycle element are identified, the systems affected by these environmental impacts can be examined. These systems may include ground cover as it is impacted upon by airborne particulates released at the coal extraction facility, or a species of fish subjected to thermal stress in the liquid effluents of the nuclear power plant. The system effects are examined under the same major category headings of air, land, and water as the critical impact areas and, like the previous step, this particular assessment involves only identification of effect and not quantification.

The quantification of impact from the various energy technologies occurs in the next step in the assessment framework. A measure of effect is attached to each environmental system where a critical impact has been identified. The atmospheric concentration of particulates from a coal extraction facility or the thermal impact of a nuclear power plant is associated with quantitative effects on specific biological systems. The impact relation which serves to quantitate effect may be versed in terms of a single value describing the threshold level for a deleterious impact on ground cover from particulate deposition; or it may be a linear equation which relates thermal stress to mortality in fish.

Quantitative measures of effect in air, land, and water are then compared to reference levels established for the region under consideration. These reference standards may be generated from ambient levels established at some previous time, or they may be derived from statutory limits established by the government. In whatever fashion they are generated, the reference standards provide the assessment framework with a method to arrive at a net measure of environmental effect which can be identified with a specific fuel cycle element as part of a total fuel cycle technology.

REGIONAL HYDROLOGIC ANALYSIS OF REGIONAL ENVIRONMENTAL COSTS OF ENERGY DEVELOPMENT

The problem of choosing a site for energy facility development and the type and level of activity at that site is not new. Traditional approaches to the problem have relied very heavily on economic analysis. Where environmental "costs" have been considered, the method has employed commensuration of environmental quality variables and money. In the process of equating money and environmental variables, such as atmospheric turbidity or population of a rare and endangered species, the analyst becomes a decision-maker and assigns an absolute price for items that possess other than monetary value.

This has been done in the past as a necessary step in finding the least-cost solution to the problem of selecting a location, size, and type of energy facility from among a variety of possibilities.

Recently, however, an analysis technique, called the Surrogate Worth Tradeoff (SWT) method, was developed and used in water resources systems management. The SWT method avoids the necessity of placing dollar values on things that are nonmarketable.

The most important feature of the method is that it provides for the changing worth of environmental variables and allows for expression of the variables in their basic units of measure. We think the method is directly transferrable to regional environmental assessment. For example, the concern over the loss of a few hundred members of a particular animal species depends in large measure on the existing total population. If there is an excessively high population, one is usually willing to accept a drop in population in return for additional amounts of another item in shorter supply. When the SWT method is used, it is possible to express the trade-off quantitatively in terms of the basic units of commodities that are traded. When the SWT method is combined with multi-level, multi-objective optimization techniques, it becomes possible to define marginal trade-offs between pairs of objective functions and to define the preferences of decision-makers as a function of the current state of the system. Translated into the energy facility siting problem, this means it is possible to find the set of solutions that will not violate environmental quality standards (e.g., air concentrations of SO_2 , water temperature rise, etc.) and then select a "preferred choice" from the set of feasible solutions. During the selection process, the decision-maker chooses a balance between pairs of objectives, and each choice is a function of the current state of the system.

In the past year we have worked toward reformulating the analysis of environmental costs into the framework of the SWT method. To illustrate the approach, consider a highly simplified version of a regional environmental assessment problem that considers environmental costs and trade-offs in selecting location(s) and level(s) of activity, given two feasible sites for fossil-fuel energy development. Only a general framework of the problem methodology is presented here.

SWT Analysis Illustration

A complete analysis for sake of illustration is unnecessary for understanding and would be an unwarranted level of detail. Thus the example presented will indicate the minimum information to convey the methodology. Suppose that two sites, A and B, are under consideration. We are interested in deciding a *preferred* use of the sites, given the possible choice of developing either one or both of them. The focus here will be on environmental cost, so one of the several objectives to be optimized might be related to the total incremental change in a nearby river water temperature. We wish to minimize the change, given the fact that both sites will have a direct impact, together with effluents from manufacturing industries and heated runoff from areas that will be urbanized as a secondary result of energy site development. Thus the temperature-related objective function, f_1 , would depend on which sites were used and the level of activity at the site. A second objective function, f_2 , might represent the incremental change in human consumption of a specific heavy metal that results via the pathway from plant emission through atmospheric transport, deposition, and uptake by food crops to ingestion and retention. The goal would be to minimize the change regardless of the fact that the standards would never be exceeded for any feasible solution. In any actual analysis, several additional objectives would be specified and would enter into the final decision.

The first step of the SWT optimization would be to find the region of "noninferior" solutions. In this region, it is impossible to improve upon one objective function without degrading at least one other. Thus, the preferred solution we seek lies at the point where the decision-maker believes the marginal or incremental gain in any objective is just balanced by the loss in another objective.

For the illustration presented here, we may look for the even trade-off point between rise in water temperature and the increase in heavy-metal exposure to agricultural crops

from cooling tower drift. Thus, we might develop a table relating f_1 , f_2 , and their trade-off relationship, λ_{12} :

f_1	f_2	λ_{12}
Temperature change (C°)	Heavy-metal ingestion (mg/year)	C°/(mg/year)
+0.02	10	0.01
+0.04	8	0.02
+0.10	6	0.03
+0.20	3	0.10
+0.40	1	0.40

The first row of the table indicates that when the conditions are chosen such that the temperature increase will be 0.02 C°, the minimum heavy-metal ingestion will be 10 mg/year. At that state of the system, a reduction of 1 mg/year of heavy-metal ingestion will result in a 0.01-C° temperature rise in the stream.

A few key points are evident at this stage of the analysis. First, we are dealing with objectives, rather than the decision variables that combine to produce the objective. This reduces the number of considerations for the decision-maker. Note that we work with the optimal value of the objectives at all times. Second, the objectives are expressed in meaningful units, rather than dollars or some other "common" normalized unit. Finally, the trade-off ratio is a function of the state of the system, and thus changes. This is important because it allows the decision-maker to evaluate his choices with full recognition of how close any solution comes to violating standards.

Once the table has been constructed, the decision-maker becomes involved. He or she is asked to express preference for each solution on a scale ranging from +10 to -10. For example, the decision-maker might say that when $f_1 = 0.02$ C° and $f_2 = 10$ mg/year he would be very anxious to trade 1 mg/year average ingestion decrease for a 0.01-C° temperature rise, perhaps with a preference of +9. On the other hand, when the temperature change is already +0.4 C°, he is very unwilling (-8) to trade 1 mg/year ingestion decrease for another 0.4-C° temperature rise.

Thus, by an iterative process, one could derive a table of the form

f_2 (mg/year)	$W_{12}(f_2)$
10	+9
8	+7
6	+1
3	-2
1	-8

where

f_2 = values of the objective function, f_2 , and

$W_{12}(f_2)$ = Surrogate Worth Tradeoff (SWT) value, which depends on f_2 .

The indication would be that a solution where $f_2 = 5$ mg/year represents the indifference point or band (where $W_{12} = 0$) for trading the two objectives. Once this point is known,

the corresponding values of f_1 and all decision variables that lead to the solution can be found. In the example shown, only two objectives were included. In actual practice, many more objectives can be considered simultaneously. The process is very similar, especially insofar as the decision-maker is concerned. He or she must express preference for trade-offs between pairs of variables, given the trade-off ratio and the existing state of the system. The preferred solution is found when the indifference band ($W_{ij} = 0, j = 2, \dots, n$) has been identified. Once again, the preferred solution will represent the optimal combination of decision variables that also satisfy the preferences of the decision-maker.

We think the technique is well suited for finding preferred solutions to problems where environmental costs must be assessed. It allows each impact to be expressed in its common units of measure, and recognizes that the worth of environmental variables is not fixed.

Hydrologic Data Analysis and Assessment

One of the most important hydrologic questions in regional energy development assessment deals with water availability. It is important to know average-flow rates and the low-flow rate to be expected for a given recurrence interval (e.g., the 20-year, 7-day low-flow rate). This is important because the allowed maximum consumptive withdrawal rate for cooling tower water relates low flow (as a specified fraction) and the upper limit to energy that can be produced at a site (consumptive demand per unit energy yielded). We have developed the capability to extract water resource data from USGS tapes as a first step in evaluating locations where water supplies are adequate for energy facility development.

We have also implemented the Corps of Engineers Streamflow Synthesis and Reservoir Regulation (SSARR) model on the ORNL system to assist us with the manipulation of the USGS water supply data. One important application is the treatment of streamflow data to develop a consistent record. For example, in a river basin with 30 years of data and where a new reservoir was constructed midway through the period, a low-flow frequency analysis on the entire data set may be misleading at best. Furthermore, if additional storage is to be constructed in conjunction with the energy facility, it is necessary to develop an adjusted record for frequency analysis. The SSARR model can be used for this purpose.

ATMOSPHERIC TRANSPORT AND AIR QUALITY

We now have available a versatile set of models to simulate the regional atmospheric transport of toxic materials. These models are based on the Gaussian plume formulation and can calculate on a climatological (e.g., monthly averages) or episodic (i.e., hourly duration) basis. Experience gained on a number of research projects has improved the efficiency of the models and substantiates that they represent the best available methodology. Current work with the Atmospheric Transport Models involves the selection of sites in eastern Tennessee where energy generating facilities can be located and, with these projected scenarios, the models are being exercised to give toxicant concentration values throughout the region.

A model for the calculation of deposition rates for gaseous toxicants was developed. This model considers vegetative ground-cover type and its condition as a function of time of year. The calculated deposition rates are within the expected range of values. Since a plume traversing a vegetative surface will be depleted at a rate dependent on the type of surface, the efficient coupling of this model with those models which calculate atmospheric dispersion is being studied. In principle, this is not a difficult problem, but it can become computationally cumbersome in cases of fine spatial resolution.

In parallel with this activity, we are addressing the overall spatial resolution problem in air quality calculations. There are much detailed data in existence on ground-cover types for many areas of the country; such data for eastern Tennessee are already available. The spatial resolution of these data is probably much too detailed for regional atmospheric modeling, but we expect to specify the scale of resolution which is practical in such analyses.

A long-range wind trajectory model written at the NOAA Air Resources Laboratory is in operation on the ORNL IBM-360 system. Figure 7.1 is an example of a line printer plot

Fig. 7.1. A 24-hr backward trajectory for the site located at 35° latitude and 84° longitude on October 2, 1974. The letters and numbers trace the wind's path, with the letters describing at what time it reached the site and the numbers indicating the location of the wind at 6-hr intervals.

produced by an early version of the trajectory program. The figure shows trajectories that reached the Oak Ridge area and the courses which they followed over the 24 hr prior to arrival. Using available data sets, we will examine the statistical distribution of such trajectories. This will allow us to model patterns of pollutant transport over long distances. The trajectory program also allows analysis of the converse, that is, the effects of pollutants of local origin on air quality in some other region. A very important associated problem which we are just beginning to discuss with diffusion meteorologists is that of the dispersion rate of toxicants at large distances from the source of emission. In testing predictions of the trajectory wind-rose model against measured ambient concentration, estimates of such dispersion rates will be needed.

A TEST APPLICATION OF A FOREST GROWTH MODEL

The FORET model, a stand-development simulator, that explicitly considers the birth, death, and growth of individual trees on a 1/12-ha forest stand (see pg. 57) is being

developed as a tool for determining effects of various pollutants on forest cover. Model applications for assessing pollutant effects on forests will consist of using known or expected changes on regeneration, growth, and mortality of trees to alter model parameters. The model can then project long-term potential effects of changes in land use or pollutant emissions on forests of the region.

The east Tennessee area offers a unique opportunity to test the validity of such a model in an "experimental" context. Because the chestnut blight of the early 1900s eliminated the chestnut (*Castanea dentata*) as a canopy tree species throughout the eastern United States, the functioning and structure of the forest has been altered. Thus, if one (1) parameterized a forest simulator based on data for the present forest without chestnut, (2) determined that the model satisfactorily simulated the dynamics of the east Tennessee forest such as they are known (the verification process), (3) made no changes in any part of the model except the addition of chestnut, and (4) tested whether the model adequately simulated the forests of east Tennessee as they occurred with chestnut (experimental testing - the first step in validation), then one could feel more certain of the model results, when developed in alternate contexts (e.g., perturbations other than the blight altering birth, growth, or death of selected species). Some of the staff are in the process of completing such a validation of the FORET model, and are currently documenting the historical forest of east Tennessee.

The model simulations have been run and an example is shown in Fig. 7.2. The initial survey of historical documentations of the east Tennessee forests and the independent

Fig. 7.2. The biomass of white oak and chestnut oak under historical conditions and present conditions. Figures show the means of 100 plots over 1000 years.

simulations of FORET with chestnut included are in qualitative agreement. Figure 7.2 shows the response of two species (mean response of 100 plots for 1000 years), White Oak (*Quercus alba*) and Chestnut Oak (*Q. prinus*), with and without chestnut as a viable species. Clearly, chestnut reduced the importance of both of these oaks in the historical forest, but this effect is not pronounced unless over 100 years of stand development is considered.

REGIONAL DISTRIBUTION OF MAMMAL AND BIRD SPECIES

The wildlife assessment effort within the Regional Analysis and Assessment project is directed toward delineating the geographical distribution of bird and mammal species within the 13-state southeastern region. The information being accumulated is designed to identify the distribution of species by state, by county, and by habitat (i.e., vegetation communities). All mammal species have been classified on a county basis, using distribution maps from various mammal guides and journal papers. The initial data compilation based on habitat factors has placed special emphasis on the 23-bird and 20-mammal species deemed rare, endangered, or threatened (Table 7.1). Concomitant with the

Table 7.1. Threatened, rare, or endangered species in the southeastern United States

<u>Birds</u>	
Brown pelican (<i>Pelicanus occidentalis</i>)	Pigeon hawk (<i>Falco columbarius</i>)
White-fronted goose (<i>Anser albifrons</i>)	Caracara (<i>Caracara cheriway</i>)
Roseate spoonbill (<i>Ajaia ajaja</i>)	Osprey (<i>Pandion haliaetus</i>)
Wood ibis (<i>Myctena americana</i>)	Burrowing owl (<i>Speotyto cunicularia</i>)
Great white heron (<i>Ardea occidentalis</i>)	Mangrove cuckoo (<i>Coccyzus minor</i>)
Sandhill crane (<i>Grus canadensis</i>)	Ivory-billed woodpecker (<i>Campephilus principalis</i>)
Snowy plover (<i>Charadrius alexandrinus</i>)	Red-cockaded woodpecker (<i>Dendrocoptes borealis</i>)
Everglade kite (<i>Rostrhamus sociabilis</i>)	Ipswich sparrow (<i>Passerculus princeps</i>)
Short-tailed hawk (<i>Buteo brachyurus</i>)	Dusky seaside sparrow (<i>Ammodramus nigrescens</i>)
Bald eagle (<i>Haliaeetus leucocephalus</i>)	Cape sable sparrow (<i>Ammodramus mirabilis</i>)
Peregrine (<i>Falco peregrinus</i>)	Black-whiskered vireo (<i>Vireo altiloquus</i>)
	Bachman's warbler (<i>Vermivora bachmanii</i>)
<u>Mammals</u>	
Gray bat (<i>Myotis grisescens</i>)	Sherman's fox squirrel (<i>Sciurus niger shermani</i>)
Indiana bat (<i>Myotis sodalis</i>)	Florida mouse (<i>Peromyscus floridanus</i>)
Mangrove fox squirrel (<i>Sciurus niger avicennia</i>)	Lower Keys cotton rat (<i>Sigmodon hispidus eximius</i>)
Goff's pocket gopher (<i>Geomys pinetis goffi</i>)	Florida black bear (<i>Ursus americanus floridanus</i>)
Cudjoe key rice rat (<i>Oryzomys</i>) - undescribed species	Everglades mink (<i>Mustelavision evergladenis</i>)
Pallid beach mouse (<i>Peromyscus polionotus decoloratus</i>)	Southeastern shrew (<i>Sorex longirostris</i>)
Key Largo cotton mouse (<i>Peromyscus gossypinus allapaticola</i>)	Round-tailed muskrat (<i>Neofiber alleni</i>)
Key Largo woodrat (<i>Neotoma floridana smalli</i>)	Red wolf (<i>Canis rufus</i>)
Florida panther (<i>Felis concolor coryi</i>)	Ozark big-eared bat (<i>Plecotus townsendii ingens</i>)
Key deer (<i>Odocoileus virginianus clavium</i>)	Virginia big-eared bat (<i>Plecotus townsendii virginianus</i>)

compiling of information to be stored within the data bank is the collection of macro-habitat values to be incorporated in models which quantify the changes in population structure resulting from habitat alteration. These data will allow us to examine the segregation of species within the principal vegetation communities of the southeast according to major physical and biological parameters by factor analysis and discriminant function analysis. Discriminant analysis can provide an integrated representation of bird

and mammal species across a spectrum of habitat variables. The ultimate aim of this program is to provide decision-making groups with the capability to consider how their management or development decisions may ultimately affect the natural structure of local or regional mammal and bird populations.

ENVIRONMENTAL EFFECTS OF COAL EXTRACTION IN APPALACHIA

The Environmental Sciences Division is currently examining the major regional environmental consequences of coal extraction throughout Appalachia. The objective is the development and application of assessment methodologies to address a variety of regional-scale environmental problems posed by past and projected future extraction of coal within the mined and potentially minable areas of the region. Three specific areas of concern are currently being addressed:

- (1) impacts on land-vegetation systems,
- (2) effects on water quality and quantity of disturbed watersheds, and
- (3) aesthetic impacts related to the visibility of surface mining to residential, recreational, and transportation centers in surrounding areas.

Because remote sensing was seen as a vital tool in addressing these problems at an appropriate scale, considerable effort has been directed toward developing and evaluating techniques for rectification and classification of Earth Resources Technology Satellite (ERTS) imagery. Major emphasis has been placed on reducing the data to a geodetic cell system with which computer-compatible data from other sources can be interfaced. Defense Mapping Agency (TOPOCOM) topography tapes and U.S. Census Bureau population tapes are being used in conjunction with ERTS imagery to locate surface mining activity relative to surrounding topography, vegetation, and population. Other pertinent data are being digitized manually to interface with this system. Analysis efforts have initially been concentrated on a 38,000-acre area in the New River basin near Oak Ridge. At the present time the following capabilities have been developed:

- (1) Correction, interpretation, and transformation of ERTS imagery to a form which accurately overlays 1:24,000 topographical maps. By using techniques of cluster, factor, and discriminate analysis, distinction currently can be made between six categories of land cover (three forest types, grassland, water, and disturbed land).
- (2) Geodetic location of disturbed areas within watershed basins.
- (3) Description of the disturbance within a topographical regime which considers such variables as position on slope, slope grade, and proximity to streams.
- (4) Relating known coal reserves to features of the adjoining landscape which are of economic and/or environmental concern.

This cell-based, computer-compatible system provides a unique capability for relating physical disturbances of the landscape to resultant alterations in environmental quality of the region. The ability to spatially describe surface mining activity relative to surrounding topography, streams, vegetation, and population provides major support for the regional environmental assessment objectives of this project.

As an inventory method this capability can be used to map the location and areal extent of mining activity for the region and to describe the relative severity of disturbance in subregional response units (i.e., drainage basins or individual watersheds). Impingement of mining activity on environmentally sensitive areas (i.e., unique habitats, limited ranges of wildlife, etc.), as well as impacts on productive agricultural or forest lands, can also be monitored.

As a tool in hydrologic studies, computer processing of several indices of mining activity and relevant watershed parameters is being used to develop a hydrologic model capable of describing the gross changes in water quality and streamflow that may be associated with coal mining activity. Water quality data have been collected from both disturbed and undisturbed watersheds throughout the region for use in quantifying the extent of mining-related changes in stream flow and water chemistry. Multiple regression techniques will be used to relate the magnitude of changes to indices of mining activity and natural features of the impacted watersheds. Many of the important parameters that will determine the level of hydrologic impact can now be determined by the previously described computer analysis techniques. Included among these are: size of watershed, amount of area disturbed, average slope, configuration of the disturbance, amount of overland water flow crossing the disturbed area, and the type and distribution of vegetation cover. While development of the model will provide a predictive capability for assessing future levels of impact associated with various intensities of coal extraction, general qualitative assessment can already be implemented with respect to sediment transport and flooding potential. Figures 7.3 and 7.4 demonstrate the use of our cell-based analytical system on the 38,000-acre test area in the New River Basin. Disturbed areas are first located within the surrounding topographical regime (Fig. 7.3) and then ranked in terms of potential hydrologic impact as related to two factors, steepness of slope and proximity to streams, which would increase the probability of an adverse effect (Fig. 7.4). This type of analysis can also be applied to potentially strippable areas to identify those which should be avoided to minimize adverse hydrologic impacts.

ORNL-DWG 75-13595

Fig. 7.3. Computer-generated display showing areas disturbed by surface mining (from ERTS) located within the surrounding topographical regime (from TOPOCOM).

AREA	100% IMPACT	75% IMPACT	50% IMPACT	25% IMPACT	TOTAL
AREA	10000	10000	10000	10000	40000
PERCENT	100	75	50	25	100
TOTAL	10000	7500	5000	2500	25000
AVERAGE HORIZONTAL DISTANCE FROM STREAM	1000	750	500	250	500
AVERAGE VERTICAL DISTANCE FROM STREAM	1000	750	500	250	500
DIFFERENCE IN ELEVATION OF THE CENTER CELL	1000	750	500	250	500
AREA	10000	7500	5000	2500	25000

ORNL DWG 75-13607

Fig. 7.4. Categorization of potential hydrologic impact of surface-mining activity based on slope steepness and proximity to streams.

The aesthetic impacts of strip mining have been approached from the standpoint of human visibility of the disturbed landscape. By partitioning the population into one-acre cells, an assessment has been made to determine the relative number of viewers that can see disturbed landscape in other cells within their view. The ability of a viewer to see a stripped area is calculated from a set of parameters which include elevation and slope aspect of the observer and the disturbed area, and the elevation of the landscape between the observer and mined site. Current research on the aesthetic impact project will relate the visibility of strip mines to roads, parks, streams, and other public-access installations. Utilization of these techniques will hopefully be utilized to assist in locating new stripping activity in areas where associated deterioration as aesthetic qualities is minimized and in giving priority to reclamation activities to speed improvement of areas previously impacted by mining.

During the course of the strip mine work to date the need has become obvious that mining activities and associated perturbations should be evaluated in relation to wildlife and wildlife habitat. There is a critical need to assess these impacts within a time frame that will permit immediate application of findings to speed recovery of lands previously disturbed and to ameliorate future adverse effects to areas that will be mined in the future. To pursue these problems and objectives a joint proposal was developed in cooperation with the TVA Division of Forestry, Fisheries, and Wildlife Development and submitted to the U.S. Department of Interior - Fish and Wildlife Service. The general objective of the proposed research, which is directly supportive of the overall project objectives, is to define wildlife potential of the region as affected by both past and present mining activity and to project future alterations in wildlife habitat, given various scenarios of mining and reclamation activity.

During the current year, the primary thrust of the overall project will be to extend current analytical capabilities and apply the techniques to three or four subregional areas in Appalachia. These subregions will represent a broad geographical range of mining activity, thus permitting a more thorough evaluation of our assessment methodologies and a more comprehensive analysis of environmental damages from mining for the entire region.

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51,699

8. Oak Ridge Environmental Research Park

J. T. Kitchings

L. K. Mann

J. D. Story

Establishment of certain federal lands as National Environmental Research Parks (NERP) has progressed as an outgrowth of the National Environmental Policy Act of 1970 and the Administration's Legacy of Parks programs. Two such parks were designated, one at the ERDA facilities at the Savannah River Plant near Aiken, South Carolina, and one at the site of the Idaho National Engineering Laboratory, Idaho Falls, Idaho. The major objectives of these programs were (1) to develop methods for the continuous and quantitative assessment of man's activities on the environment, (2) to develop models to predict the response of environmental components to proposed technological activities, and (3) to provide land-use plans which make preservation of representative regional natural areas compatible with human technological activities. This past year the Environmental Sciences Division began the development of the research and administrative foundations necessary to establish and operate such a research park on the ERDA Reservation at Oak Ridge.

The Oak Ridge Reservation is representative of the landscape and ecological systems which occur in the Appalachian region of the eastern United States. As such, it can play a unique role in assessing the significant environmental factors that determine the extent of environmental stress sustained through alteration of the landscape. The reservation contains a number of representative land and water ecosystems ranging from small southern coniferous forests to northern hardwood types and from small streams to man-made reservoir systems. Thus, the research park represents a place to conduct research and it can develop into a regional environmental reference center -- an ecological data pool which can serve this particular southeastern region of the United States.

Necessary to the achievement of a viable research park on the reservation is the assurance that research areas, industrial development, and the many varied activities associated with the existing Oak Ridge facilities can function compatibly. To attain this goal we have completed a land-use plan for the entire reservation. Documents describing the ecology and resources within the reservation's boundaries have also been completed. These documents contain discussions of land use, soils, vegetation types, drainages, geology, ecology, and natural resources.^{1,2}

Concomitantly, in compliance with the Federal statute³ that requires adequate protection for the resources on federal lands, natural areas and areas representative of the plant communities in the Appalachian region are being reserved as research reference areas (Fig. 8.1). Areas where unique plant or animal species occur are also being protected to ensure their continued propagation on the reservation. On three of the research reference areas (1, 5, and 8, Fig. 8.1), our approach in developing a series of permanent study plots was to look at each reference area as being "unique" in terms of surrounding forest types and as "representative" of certain types in the Appalachian region. This approach required us (1) to determine the structure of the community, (2) to relate the structural composition to environmental parameters (i.e., slope, moisture, etc.), and (3) to compare not only the community to the surrounding communities or buffer areas but to other natural areas on the reservation. To accomplish these goals we

Fig. 8.1. Forest communities which have been established as Research Reference Areas on the Oak Ridge Reservation.

employed the same techniques used by Grigal and Goldstein on Walker Branch.⁴ A 0% cruise was employed to establish a series of three concentric plots which were used to sample woody vegetation at each sampling point. All woody stems from 0.6 to 3.5 in. dbh were sampled within the 0.01-acre plot; all stems 3.5 to 9.5 in. dbh were sampled within the 0.1-acre plot; and all stems over 9.5 in. dbh were sampled within the 0.2-acre plot. In the future, a number of random 0.001-acre plots will be established within the 0.2-acre areas to determine composition and density of herbaceous species. The numerical classification techniques were applied to our data and resulted in establishing six major forest groups over the three areas that were sampled. The sample plots that comprise these larger forest groups will constitute core plots - areas which can be sampled over a long period of time to assist in the determination of (1) forest successional patterns, (2) potential changes in forest community that result from man's manipulation, and (3) potential changes in community structure that result from industrial effluents.

Research on the deer herd inhabiting the reservation was initiated in September 1974, through a contract with the University of Tennessee (UT) from the Environmental Sciences Division. Objectives of the project were to delineate the density and distribution of the deer population on the Oak Ridge Reservation. Preliminary data indicate that the deer population is still relatively low on the area, but due to recent land management practice (forestry activities) and recognizing the tremendous capabilities of the white-tailed deer in terms of herd growth (high biotic potential), increased numbers of vehicle/deer accidents will occur. Based on the information provided by the UT study, contact has been made with the Tennessee Department of Wildlife Resource to elicit their aid in establishing a management program for the deer herd.

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51,700

9. Forest Management

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The forest management program on the ERDA Oak Ridge Reservation has completed its eleventh year of operation (two management cycles). The forest is managed on a multiple-use, sustained-yield basis with two objectives: to maintain an ecological park for research studies and to provide high-quality timber products through intensive forest management and sound conservation practices. Due to the excellent natural study areas provided by the forest, research activities conducted by the Environmental Sciences Division have a high priority for use of the forest.

The regeneration program met all goals for FY-1975. A total of 291 acres in compartments 1, 7, and 10 and the ORGDP (K-25) buffer were cleared, cultivated, and planted. A more diversified mixture of species was planted in 1975 and included numerous fast-growing high-quality hardwood species. Table 9.1 lists species planted this year and compares survival rates with species planted in previous years. The 1974 plantings were in extremely rocky, dry ground and survival rates were lower. Low survival rates for tulip trees in 1975 were due to dry planting sites, unsettled soil after cultivation, and condition of planting stock. A portion of the area planted with eastern cottonwood is a replant of 1974 cottonwood areas.

Table 9.1. Planting summary for 1975 and comparison of survival rates

Species	Total No. of seedlings	Total No. of acres	Survival rate (%)			
			1975	1974	1973	1972
Loblolly pine, <i>Pinus taeda</i>	153,000	184	95	64	97	80
Tulip tree, <i>Liriodendron tulipifera</i>	42,000	56	69	—	83	88
Eastern cottonwood, <i>Populus deltoides</i>	11,000	17	89	8	—	—
Sweetgum, <i>Liquidambar styraciflua</i>	5,400	8	86	—	—	—
Black walnut, <i>Juglans nigra</i>	4,000	9	87	—	—	—
Sycamore, <i>Platanus occidentalis</i>	4,000	8	99	—	—	—
Green ash, <i>Fraxinus pennsylvanica</i>	3,000	6	98	—	—	—
River birch, <i>Betula nigra</i>	<u>2,000</u>	<u>3</u>	<u>84</u>	—	—	—
TOTALS	224,000	291	89 (av)			

Cultivation of the black walnut and eastern cottonwood to release these species from competing herbaceous vegetation will be continued for at least another year. Three treatments at one-month intervals were required this year to retard competition. Fertilization of the black walnut plantations with either compost or chemical fertilizer will commence after the third or fourth growing season.

The same species will be planted in 1976 acreage in compartment 10 where large areas have been cleared of shortleaf pine (*Pinus echinata*) due to southern pine beetle (*Dendroctonus frontalis*) infestations. No replanting has been scheduled for 1976 because seedling survival rates were high. Even though the tulip tree survival rate is below the 75% desirable level it will not be replanted, because considerable die-back and resprouting of this species has been observed this year. With adjacent seed sources and resprouting, the stand should be fully stocked within five years.

Site preparation for 1976 tree planting began on June 1 and proceeded on schedule. Over 250 acres were cleared and readied for harrowing. This phase of our operation was facilitated by an abundance of clear, dry summer weather, the assignment of a full-time equipment operator to the department, the operation of two bulldozers, and the acquisition of a KG clearing blade. The use of a KG blade alone decreased clearing time by nearly 50%. The site preparation techniques employed this season were (1) clearing, piling, burning, and harrowing and (2) chopping, burning, and harrowing.

The southern pine beetle was still at epidemic proportions during 1975. Forest management personnel completed a sketch map survey of the infestations in June. The survey revealed a total of 262 spots containing over 6300 red-topped and fading trees. The ratio of green infested trees to red tops and faders was 1:2. The average spot size was 24 trees, with 17 spots in the 50+ tree category. This survey indicated a somewhat lower infestation incidence than the December 1974 survey. With the help of the mechanized pulping crew, salvage of infested pine timber has proceeded at an accelerated pace. Pulpwood salvage removals during FY-1975 have averaged 349 cords per month for a total of 4199 cords. Another survey will be made in early winter to determine the success of the salvage and control efforts and to confirm whether or not the outbreak is on the decline.

The new inventory and type mapping system has received little attention this year due to the re-inventory of the continuous forest inventory (CFI) plots required for revision of the ERDA Reservation Management Plan. Completion of the re-inventory and a new CFI computer program were facilitated by the hiring of four summer forestry students to assist in this and other summer management activities. The summer student program is both educational for the student and instrumental in easing the tremendous work load created by new forest management objectives such as the new type-mapping and inventory (PPS) system and southern pine beetle epidemic.

Timber stand improvement for FY-1975 was limited to pruning the limbs from 25-year-old white pines (*Pinus strobus*) along 0.3 mile of Grubb Island Road. Limbs were cut from the first 16-ft log on dominant and codominant trees and the stand was marked for thinning. Firewood cutting by permit only was initiated behind hardwood logging operations this year; slash, cull and dead trees, and trees excessively damaged by logging were removed. This activity removed some cull trees left by the loggers and greatly improved the appearance of the logged areas along the roads. No chemical hardwood control was completed during FY-1975. Prescribed burning was confined solely to slash disposal behind pulpwood salvage operations for southern pine beetle control. Approximately 250 acres were piled and burned during the summer of 1975.

The ten-year timber sales contract with Longleaf Industries, Inc., completed its sixth year. A total of 8,016,265 bd ft of pine and hardwood sawtimber have been harvested to date. Eight pine and hardwood sawtimber sales totaling 1,976,054 bd ft were consummated with Longleaf during FY-1975. These sales netted revenues of \$37,350. Income from pulpwood salvage amounted to \$16,795, bringing the total FY-1975 revenue to \$54,145.

SI, 701

10. Environmental Behavior of Trace Contaminants

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The Environmental Behavior of Trace Contaminants Program includes research projects supported by the Energy Research and Development Administration, the Environmental Protection Agency, and the National Science Foundation (RANN). These research projects address the environmental behavior of trace contaminants through both laboratory microcosm and industrially contaminated field sites. In the microcosm research our objectives include the evaluation of size and complexity as these relate to system stability, and the determination of validity and realism of laboratory systems in accurately reflecting the environmental transport and transformation of arsenic in both aquatic and terrestrial environments. Our field research projects include evaluation of the transport and distribution of trace element emissions from coal-fired power plants, determination of the biogeochemical cycling of mercury in an east Tennessee river receiving chronic mercury input from a defunct chloro-alkali plant waste disposal area, evaluation of lead-smelter-emitted Cd, Pb, Zn, and Cu on a forested watershed in southeastern Missouri, and the application of the Unified Transport Model to both the coal-fired power plant and the lead smelter emissions in an effort to simulate the transport and distribution of trace elements in two similar forested watersheds.

MICROCOSM STUDIES OF TRACE CONTAMINANT TRANSPORT IN NATURAL ECOSYSTEMS

Evaluation of the fate and effect of toxic materials in the environment is essential for establishing guidelines for controlling releases of these materials from industrial sources. Special tools are required to accomplish these evaluations in order to provide reasonable predictions of the fate and effect of toxic substances released to the environment. Microcosms or model ecosystems are now receiving increased attention as one type of tool for studying the structural and functional responses of ecosystems to contaminant additions and for studying materials transport, distribution, and effects. These model ecosystems consist of the specific components of a natural environment that are considered to be important in the transport, distribution, and effect of a chemical substance that may be released to the environment.

During the past year, we initiated research designed to evaluate both aquatic and terrestrial microcosms as potential tools for estimating environmental transport and effects of toxic materials. The technical objectives include (1) evaluation of the relationships among microcosm size, complexity, and stability, (2) determination of the realism and validity of using microcosm results as a reflection of actual environmental behavior of trace contaminants, and (3) evaluation of microcosms as potential "screening tools" for trace toxic contaminants released from industrial sources.

Our first year's activities are centered around meeting the requirements set forth in Objective 1. We have chosen the littoral zone of reservoirs typical of those found in the southeastern United States as our aquatic microcosm, and an old-field system as our terrestrial microcosm. Laboratory systems have been designed to identify the processes that must be monitored to determine when these systems have reached a steady state, and how long the systems remain in this state after initial establishment. In the aquatic system, population densities, photosynthesis, community respiration, pH, conductivity, dissolved oxygen, and temperature are routinely monitored. Temperature, light, relative humidity, moisture content, CO_2 evolution, soil macronutrients, microbial and vegetative biomass, and ATP are being monitored in the terrestrial systems. In our terrestrial microcosm studies, we have duplicated the laboratory systems in the field to obtain comparison data on similar systems in both field and laboratory situations. For our initial experiments, arsenic in the form of As_2O_5 was chosen as the test substance for several reasons, including ease of detection of both stable and radioactive species, transformation of arsenic through numerous valence states which may affect its volatility, and availability of information concerning its environmental behavior and detection.

In our microcosm modeling activities, we are surveying the literature pertinent to concepts of ecosystem stability and complexity, especially as this applies to the adequacy of models for measuring microcosm stability and complexity. We are focusing on system level responses which will be analyzed with ecosystem feedback models and time series statistical methods. Through a knowledge of system level responses, and individual population responses within the systems, we will be able to develop stability indicators for microcosm systems and a predictive capability for extrapolating the results of our experiments for longer time periods and for comparison with results from field studies.

MERCURY TRANSPORT AND DISTRIBUTION IN THE NORTH FORK OF THE HOLSTON RIVER

The North Fork of the Holston River originates in southwest Virginia, flows southwest into Tennessee, and after confluence with the South Fork, forms the main Holston River. The Holston River was impounded in 1942 forming Cherokee Reservoir (Fig. 10.1). A chloro-alkali plant located on the North Fork Holston River at Saltville, Virginia (approximately 277 km upstream from Cherokee Dam) in the 1950s began using a mercury cathode in the electrolytic separation of sodium chloride. Salt wastes from the manufacturing process have been deposited in two waste disposal ponds of approximately 120 acres (49 ha) adjacent to the river. Mercury contamination in the North Fork was observed in 1970 and subsequent investigations have verified the extent of contamination.⁴ The chloro-alkali plant was closed down in 1972 due to the high cost of complying with existing water quality standards for chlorides, total dissolved solids, and mercury. Our observations indicate that the plant waste disposal ponds are a continuing source of mercury contamination in the North Fork.

The overall objective of our research on the Holston-Cherokee system is to understand the biogeochemical cycling and transport of mercury in this contaminated environment. Specific objectives include (1) determination of the distribution of mercury in water, sediments, and biota of the Holston-Cherokee system to provide insight into mechanisms of transport and bioaccumulation; (2) determination of the extent of continuing mercury input to the system; and (3) investigation of potential atmospheric emissions of mercury from existing waste disposal ponds of the chloro-alkali plant.

In August 1974 and 1975, fish and benthic invertebrates were collected at select stations on the Holston-Cherokee system. Water samples were collected in 1975 by standard methods at select stations; those to be analyzed for dissolved and particulate

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Fig. 10.1. Schematic of Holston-Cherokee system with detailed location of waste disposal ponds and sediment core stations in Cherokee Reservoir. GC = German Creek, PVC = Poor Valley Creek, GS = Galbraith Springs.

mercury were filtered ($0.45 \mu\text{m}$) within five minutes of collection, utilizing a filtration system developed at our Laboratory. Sediment samples in the North Fork Holston River were collected by hand in backwaters or by Ekman dredge, depending on water depth. Core samples in Cherokee Reservoir were collected with a modified Livingston corer and samples from the waste disposal ponds were manually taken in polycarbonate or aluminum tubes.

Geochemical Studies of Mercury

Table 10.1 summarizes relevant geochemical data collected during 1975. Stations are identified by river kilometer downstream from the reference point located at the abandoned chloro-alkali plant (see Fig. 10.1). The most striking patterns in the distribution of Hg in the system relate to the variations in bottom sediment Hg and total Hg in

Table 10.1. Distribution of mercury and other physical chemical parameters for the Holston-Cherokee System at select stations in 1975

Station ^a (river km)	pH	Specific conductance (μmhos/cm)	Chlorides (mg/l)	Dissolved organic carbon (mg/l)	Particulate organic carbon (mg/l)	Suspended solids (%)	Total Hg water (μg/l)	Dissolved Hg water (μg/l)	Hg on suspended particulates (μg/g dry wt)	Hg bed sediment (μg/g dry wt)	Date
-43.0	8.0	248	1.8	2.16	b	12.0	0.070	0.001	5.80	0.136	8/26
-14.0	8.3	253	4.2	1.62	b	11.2	0.025	c	2.30	0.118	8/26
-9.0	8.1	251	4.2	2.32	b	7.8	0.034	b	b	0.165	8/26
-2.7	8.1	258	5.2	1.94	b	5.2	0.015	b	b	0.114	8/27
-2.7	8.4	b	2.8	b	b	b	0.003	c	b	b	5/21
-2.7	8.0	246	2.7	3.15	0.58	16.8	0.006	c	0.36	b	7/29
-2.7	8.2	244	2.5	2.05	0.32	12.0	0.007	c	0.58	b	7/30
-2.7	8.1	266	2.5	3.31	0.56	12.4	0.008	c	0.65	b	7/31
3.1	8.2	5150	1490.0	2.71	b	11.2	0.210	0.056	13.70	18.50	8/26
3.1	8.7	448	156.0	b	b	8.9	0.093	0.047	5.30	b	5/21
3.1	8.1	1405	427.0	2.01	0.36	9.8	0.196	0.071	12.90	b	7/29
6.4	8.3	4000	1275.0	2.98	0.92	12.8	0.167	0.075	7.20	b	7/29
6.4	8.0	1280	358.0	3.60	0.30	12.4	0.185	0.050	10.90	b	7/30
6.4	8.1	5700	1848.0	3.05	1.22	14.8	0.193	0.074	5.00	b	7/31
9.7	8.2	1179	300.0	2.36	b	4.2	0.074	0.040	8.10	9.20	8/26
17.0	8.2	1173	300.0	2.12	b	3.0	0.058	0.028	10.00	6.20	8/26
21.0	8.4	1250	334.0	3.83	b	6.2	0.067	0.027	6.40	4.30	8/26
43.0	8.4	821	216.0	2.60	b	4.0	0.032	0.021	1.20	2.40	8/26
133.0	8.1	669	158.0	2.73	b	12.2	0.025	0.018	0.57	0.92	8/27
184.0	7.6	354	43.2	3.28	1.59	4.8	0.010	b	b	b	9/9
190.0	7.7	205	12.6	1.94	1.02	19.8	0.029	0.010	0.96	0.82	9/9
277.0	8.5	224	14.1	1.81	0.70	3.8	0.006	0.005	0.26	b	9/9
277.0	7.7	245	14.0	1.72	0.74	3.8	0.009	0.004	1.30	b	9/10
277.0	7.4	267	15.0	1.86	0.93	21.0	0.012	0.006	0.29	0.48	9/10
278.0	7.5	246	14.3	1.94	0.91	6.4	0.005	b	b	b	9/10

^aStations are river kilometers above (—) and below plant.^bNot measured.^cNot detected.

Fig. 10.2. Distribution of total mercury in Holston River water (unfiltered) and sediment (dry weight) above and below the chloro-alkali plant in 1975. Error bars = 1 S. D.

We have hypothesized that the main downstream transport of mercury from the source area in Virginia to Cherokee Reservoir occurs in the particulate phase. If this is indeed the case, one would expect to find elevated concentrations of Hg in fine sediments deposited where the flow of the Holston is slowed upon entering quiescent waters (e.g., John Sevier Detention Lake and Lake Cherokee). Fine-grained sediment inputs from other, presumably uncontaminated, tributaries such as Poor Valley Creek and German Creek should not show elevated mercury concentrations.

Although the Hg concentrations of the unfractionated sediment samples (Table 10.2) are quite similar and do not indicate any disproportionate effect of the Holston River on the Hg burden of the reservoir, the concentrations in the <44- μ fraction in sediments derived from the Holston River are elevated by a factor of 3 to 8 over the values for sediments derived from the other tributaries. Thus if the concentrations of mercury in similar size fractions, especially the easily transported sizes (<44 μ), are compared, it is apparent that significant differences exist. The similarity in Hg concentrations in the <44- μ sediment fraction at the Holston tributary station (Galbraith Springs) with the suspended sediments and fine bottom sediments collected at the river station 25 km upstream (station at river km 190) lends considerable support to the above hypothesis. However, to completely study the question of Hg accumulation in the Cherokee Reservoir system will require information on the historical variations in Hg concentrations of the <44- μ sediment fraction in various locations in the lake where such sediments are and have been accumulating.

Table 10.2. Mercury concentrations in size fractionated sediments from three tributaries of the Cherokee Reservoir

Location	Depth	% <44 μ	Σ % OM	<44 μ % OM	Hg (ppm)		
					Σ	<44 μ	>44 μ
German Creek ^a	0-5	40	2.7	7.4	0.146	0.290	0.050
	5-10	60	2.8	3.8	0.132	0.171	0.067
Galbraith Springs ^b	0-5	12	1.6	7.3	0.177	1.090	0.043
	5-10	12	1.1	7.4	0.152	0.890	0.052
Poor Valley Creek ^c	0-5	11	2.5	3.1	0.077	0.220	0.053
	5-10	50	3.5	5.1	0.111	0.135	0.061

^aStation GC in Fig. 10.1.^bStation GS in Fig. 10.1. located in the Holston R tributary.^cStation PVC in Fig. 10.1.

Mercury Distribution and Behavior in Fish and Benthos

The distribution of total mercury and percentage methylmercury in fish species and benthic invertebrate taxa collected in August 1974 from the Holston show mean total mercury levels well above the 0.5-ppm FDA guideline. The concentration of total mercury in rockbass and hogsucker 5.5 km above the plant approach or exceed 0.5 ppm, which was unexpected for this control area. It is possible that localized movement of these species to and from the contaminated area below the plant could explain these slightly elevated levels. Fish species collected in Cherokee Reservoir, in general, contain muscle mercury below 0.5 ppm.

Estimates of total mercury and percentage methylmercury in benthic invertebrate taxa collected in August 1974 on the North Fork are given in Table 10.3. Benthic invertebrates 3.1 km below the plant contain total mercury at about the same level (mean 1.550 ± 0.271 $\mu\text{g/g}$) as fish species. Total mercury in benthic invertebrates 5.5 km above and 21.0 and 133.0 km below the plant appears to be lower than that in fish species at these stations. Mean percentage methylmercury in benthic invertebrates at all stations was on the order of 50%, but considerable variability exists between taxa at any given station. The finding that ~50% of total mercury in benthic invertebrates is methylmercury suggests that fish species in this system may derive a significant proportion of their methylmercury burden through feeding on benthic invertebrates.

Rockbass are predators, feeding primarily on benthic invertebrates and smaller fish. Hogsuckers are bottom feeders and undoubtedly ingest benthic invertebrates as well as sediment. Shiners are predominately insectivorous, feeding on benthic invertebrates. The potential food web, consisting of rockbass-shiner-benthic invertebrate in the North Fork, enables a qualitative examination of food chain concentration of total mercury. At 3.1 km below the plant all trophic levels in this chain have approximately the same mercury levels, indicating mercury is not being magnified at the station most contaminated with mercury. Mercury contamination due to sediments in the gastrointestinal tract of invertebrates may, however, mask this phenomenon. At the stations 5.5 km above and 133.0 km below the plant it appears that mercury concentration does increase with trophic level for these three taxa. It is possible that under high mercury contamination, available mercury in water and sediments floods the system and trophic accumulation of mercury is masked by direct accumulation from water.

BIOLOGICAL EFFECTS AND DISTRIBUTION OF HEAVY METALS ON CROOKED CREEK WATERSHED

Crooked Creek Watershed (CCW) is an important focal point for environmental studies of heavy-metal effects on forested ecosystems. The watershed is a 466-ha area within the Clark National Forest of southeastern Missouri located 24 miles east of Salem, Missouri, in Iron County. This portion of Missouri, known as the "New Lead Belt," is the world's largest lead-producing region.

The watershed itself lies on the Springfield-Salem Plateau, an area characterized by hills alternating with steep valleys. Canopy vegetation is largely oak species (black oak, white oak, and northern red oak) with a smaller portion of shortleaf pine. A primary Pb smelter, operated by American Metals Climax (AMAX) and situated at the apex of the triangularly shaped watershed, has been in operation since 1968. Both smelter stack emissions and associated fugitive particulates are the main source of heavy-metal contamination on CCW.

The objectives of this study are (1) to elucidate the fate of smelter emissions deposited on a forest landscape and (2) to evaluate the effects of heavy metals on various ecosystem components of the watershed.

Fate of Heavy Metals

The greatest accumulation of heavy metals in biological components occurs in forest floor litter (Table 10.4). The litter layer is a primary receptor of airborne particulate emissions from the smelter. Particulates have accumulated because deposition has occurred much faster than dissolution of the particles. The presence of these particulates in the litter affects invertebrates and other litter-dwelling organisms.

Dissolved metals from the litter layer are free to leach through the litter and into the underlying soil. Metals are then assimilated by plant roots and translocated into aboveground vegetation. Our data indicate that Pb is especially mobile at 0.4 km from the smelter. Values of 334, 2400, 680, and 467 ppm Pb were measured in Al soil, oak roots, boles, and leaves, respectively (Table 10.4). The deposition of highly soluble Pb particulates on the forest floor and the low pH (5.5) of forest soil enhance the mobility of Pb in this system.

In general, biological components of the ecosystem are enriched with Cd, Cu, and Zn relative to Pb as distance from the smelter increases (Table 10.4). This may be partially due to Cd, Cu, and Zn being associated with smaller particulates, which are carried further from the stack, and the fact that fugitive Pb concentrate has been deposited at the 0.4-km site.

The quantity of Pb and Cd in spring foliage was estimated by applying the allometric equations for total foliage biomass developed for species on Walker Branch Watershed⁵ (Table 10.5). These values were compared with 01 litter concentrations measured on Crooked Creek Watershed. On the basis of this comparison, leaf uptake of Pb was negligible at the 0.4-km site, and accounted for only 1% of the total Pb content of 01 litter at the 2.0-km site. Particulate loading of Pb on the forest floor apparently overshadows the amount of Pb assimilated by the tree leaves. Foliar uptake of Cd accounted for 3.3 and 12.8% of total Cd content of litter at the 0.4- and 2.0-km sites, respectively. These results indicate that Cd is assimilated by trees more readily than Pb. Our results indicate that Cd is less tightly bound in soil, thus more is available for root uptake.

Effects of Heavy Metals

Ecosystem-level effects of smelter emissions on Crooked Creek Watershed documented in this work include: (1) accumulation of incompletely decomposed deciduous forest litter out to 2 km from the stack, (2) a disruption of microbial species and populations, (3) depressed macronutrient pools in 02 litter extending to 0.8 km and an accumulation between 1.2 and 2.0 km, (4) depression of amino sugar content and urease activity as a function

Table 10.3. Total mercury (Σ Hg) and percentage methylmercury (% MeHg) in axial muscle of fish species in Cherokee Reservoir, August 1974 (Σ Hg = μ g/g wet weight $\pm$ 2 S.E., % MeHg $\pm$ 2 S.E.)

Species	River kilometers below plant					
	190.0 km		238.0 km		277.0 km	
	Σ Hg	% MeHg	Σ Hg	% MeHg	Σ Hg	% MeHg
Largemouth bass (<i>Micropterus salmoides</i>)	0.34 $\pm$ 0.16 n = 12 Size 129.6 - 2072.7 g	92.5 $\pm$ 6.2 n = 10 Size 129.6 - 2072.7 g	0.11 $\pm$ 0.04 n = 20 Size 19.3 - 780.0 g	80.5 $\pm$ 9.5 n = 11 Size 19.3 - 780.0 g	0.19 $\pm$ 0.04 n = 16 Size 57.7 - 450.6 g	68.5 $\pm$ 8.7 n = 10 Size 57.7 - 450.6 g
Bluegill (<i>Lepomis macrochirus</i>)	0.32 $\pm$ 0.07 n = 20 Size 35.0 - 156.3 g	82.9 $\pm$ 13.5 n = 11 Size 35.0 - 156.3 g	0.13 $\pm$ 0.03 n = 20 Size 11.4 - 74.5 g	73.6 $\pm$ 11.7 n = 10 Size 11.4 - 74.5 g	0.15 $\pm$ 0.04 n = 20 Size 6.9 - 103.3 g	70.3 $\pm$ 12.2 n = 10 Size 6.9 - 103.3 g
Gizzard shad (<i>Dorosoma cepedianum</i>)	0.09 $\pm$ 0.02 n = 20 Size 2.1 - 284.0	77.3 $\pm$ 10.9 n = 11 Size 4.1 - 284.0 g	0.06 $\pm$ 0.01 n = 20 Size 2.4 - 133.8 g	61.7 $\pm$ 14.6 n = 10 Size 2.4 - 133.8 g	0.06 $\pm$ 0.005 n = 20 Size 18.0 - 174.0 g	70.1 $\pm$ 8.3 n = 10 Size 18.0 - 174.0 g
Threadfin shad (<i>Dorosoma petenense</i>)	0.05 $\pm$ 0.005 n = 20 Size 1.1 - 4.4 g	57.9 $\pm$ 6.8 n = 10 Size 1.3 - 4.4 g	0.03 $\pm$ 0.01 n = 20 Size 0.5 - 15.0 g	54.3 $\pm$ 13.6 n = 9 Size 0.9 - 2.0 g	0.05 $\pm$ 0.01 n = 20 Size 1.2 - 48.7 g	83.8 $\pm$ 5.9 n = 7 Size 10.3 - 48.7 g

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Table 10.4. Distribution of Pb, Cd, Zn, and Cu in six ecosystem components of Crooked Creek Watershed as a function of distance from the stack

Distance (km)	Forest-floor litter (g/m ²)				Al soil ^a (ppm)				Oak roots ^b (ppm)				Oak boles ^c (ppm)				Oak leaves ^d (ppm)			
	Pb	Cd	Zn	Cu	Pb	Cd	Zn	Cu	Pb	Cd	Zn	Cu	Pb	Cd	Zn	Cu	Pb	Cd	Zn	Cu
0.4	98	0.17	2.8	1.61	334	3.55	24	18	2400	46	48	6.0	680	3.9	30	13	467	3.9	47	10
0.8	28.5	0.07	1.0	0.48	156	1.81	20	10	2.6	1.0	40	9.0	-	-	-	-	-	-	-	-
1.2	13.1	0.04	0.6	0.23	95	0.91	10	3.2	3.6	1.2	33	15.2	-	-	-	-	-	-	-	-
2.0	7.7	0.02	0.4	0.15	-	-	-	-	<6.0	3.7	19	10.1	14	2.4	10	2.2	89	1.9	33	8.5
21 (control)	0.3	0.002	0.07	0.02	13.8	0.23	5.0	0.9	-	-	33	10.0	4.6	0.9	7	1.3	-	-	-	-

^a1.0 N HCl extraction.

^bBark was removed to eliminate surficial contamination.

^c1974-1970 dated growth ring increments pooled.

^dLeaf buds were contained in polyethylene bags prior to sampling to eliminate surficial contamination.

Table 10.5. Estimated and measured Pb and Cd content of litterfall on Crooked Creek Watershed

Site (km)	Estimated (kg/ha)		Measured (kg/ha)	
	Pb	Cd	Pb	Cd
0.4	1.51	0.02	324	0.62
2.0	0.33	0.01	26	0.07

of distance from the source, and (5) a depression in cation exchange capacity and pH of litter near the source (Table 10.6 and Fig. 10.3).

Large accumulations of O2 litter were measured on Crooked Creek Watershed out to 2.0 km from the smelter stack (Table 10.6). Litter of the O2 horizon at the 0.4-km site contained a greater mass of fragmented undecomposed leaf material than the control. This accumulation may result from the elimination of arthropod and fungal populations necessary for litter decomposition.⁶

Table 10.6. Effects of heavy metal contamination on O₂litter

Distance (km)	Litter biomass (g/m ²)	CEC ^a (meq/100g)	pH ^a	Ca pool ^a (g/m ²)	Mg pool ^a (g/m ²)	K pool ^a (g/m ²)	P pool ^a (g/m ²)
0.4	1780 ^b	21.1	4.0	6.5	0.98	0.83	0.92
0.8	1921 ^b	19.1	4.1	10.9	1.35	1.31	0.15
1.2	1748 ^b	34.9	5.5	22.9	1.64	1.38	0.25
2.0	1595 ^b	33.4	5.2	23.5	1.90	1.90	1.08
21 (control)	1008	40.3	5.5	18.5	1.09	0.96	0.80

^aSignificantly different from the control at the 95% level.

^bSeasonally pooled values (1974).

An analysis of litter for amino sugars was utilized to provide insight into the historical microbial and insect activity on the watershed. Amino sugars in litter primarily exist as chitin, which is resistant to degradation and is not synthesized by green plants. Thus, analysis of amino sugars is a specific test for the historical presence of decomposer organisms. The result of this test on Crooked Creek Watershed indicates a marked decrease in amino sugars out to 0.8 km from the stack (Fig. 10.3).

Urease enzyme activity in litter was measured to further indicate loss of biological activity on the watershed (Fig. 10.3). This test is more sensitive than the amino sugar assay, because the production of urease enzyme is adversely influenced by heavy-metal contamination. Laboratory experiments on uncontaminated litter showed that the addition of 10,000 ppm Pb or 800 ppm Zn caused only a 15% reduction in urease enzyme activity. Both metal concentrations and enzyme activity were much higher than those found on the watershed. Thus, we conclude that the observed loss of enzyme activity on the watershed is partially due to a depression of microbial activity and not a simple inhibition of the enzyme. A reduction of the enzyme activity was found to occur out to 2.0 km from the smelter, which was further than the observed effect on amino sugars. This may indicate that the 2.0-km site is currently being slightly affected by the heavy-metal emissions.

Fig. 10.3. Percent amino sugars and urease enzyme activity in litter as a function of distance from the smelter stack on Crooked Creek Watershed.

Populations of fungi and actinomycetes were assessed in Crooked Creek Watershed litter to further document effects on decomposition processes. Dilution plate counts of fungi on rose bengal agar showed no difference between sites on the watershed and the control. The population of actinomycetes, plated on chitin agar, was reduced 100-fold at the 0.4-km site compared to the control.

Coupled with the accumulation of forest floor litter and the depression of microbial processes is a disruption of macronutrient pools in O2 litter (Table 10.6).⁷ In general, a decrease in pools of macronutrients was found in litter out to 0.8 km from the smelter, and an increase out to 2.0 km, relative to the control (21 km). These results were accounted for by a combination of low macronutrient concentrations near the smelter (0.4 to 0.8 km) and an accumulation of litter biomass over the entire watershed.

The composition of O2 litter was altered within 0.8 km from the stack. The bulk of O2 biomass was found to be a heterogeneous mixture of coarsely to finely fragmented leaves and twigs with a small amount of humus underlying the leaves. This accounts for the lowered cation exchange capacity of litter within 0.8 km from the stack.

Evidence from this study indicates that heavy metals emitted from the smelter disrupt nutrient cycling mechanisms by initially depressing decomposer activity in litter. This leads to a buildup of forest floor litter; thus, nutrients required for forest production are bound in litter and are not readily available for plant uptake. The net effect is that new litter is deposited which contains increasingly smaller amounts of

nutrients. This deterioration of nutrient cycling may lead to a loss of forest productivity. We would expect productivity to be most depressed in trees which are not tolerant of heavy metals or a reduced supply of available nutrients.

We hypothesize that the area affected by the smelter is increasing in size due to the continual load of heavy-metal particulates on the watershed. The area 1.2 to 2.0 km from the stack could eventually be affected to the same degree as the existing area within 0.8 km from the stack. The evidence collected in a one-year study of Crooked Creek Watershed supports this hypothesis, but is not adequate to fully test it. Therefore, we recommend that the forest ecosystem on Crooked Creek Watershed be monitored periodically over several years to further assess ecosystem effects. We further suggest that an assessment of macronutrient cycling in an affected ecosystem is important as an indicator of environmental disruption.

TRACE ELEMENT APPLICATIONS OF THE UNIFIED TRANSPORT MODEL

One of the major activities within nonnuclear transport and effects studies during the past year has been the development and application of models for simulating trace element movement in the environment. The ultimate goal of this work is to predict the consequences of the release of trace contaminants to the environment. The initial step toward reaching that goal is a demonstrated capability to simulate heavy-metal transport through the environment. Such an ability is necessary to the development of sound environmental management policy. Two examples of our transport model applications are presented here to highlight the progress we have made with our trace contaminant transport simulation model studies.

The first example focuses on the movement of heavy metals in forest soils. It involves the application of SCEHM, a soil chemistry model for the exchange of heavy metals,⁸ which is used in conjunction with our detailed soil-plant-atmosphere water flow model.⁹ SCEHM was applied at a site 0.4 km from a lead mine and smelter complex at Crooked Creek Watershed in Missouri to simulate the transport of lead, cadmium, zinc, and copper through the forest soil system. The solubilities and distribution coefficients of the contaminants were experimentally determined using soils and materials obtained at the site. Assuming initial concentrations of the contaminants to be negligible and using depositions measured by the New Lead Belt Team,¹⁰ the six-year period since the smelter began operation was simulated. The results are shown in Table 10.7.

Table 10.7. Experimental and predicted amounts of exchangeable heavy metals in soils at Crooked Creek Watershed. Values represent conditions after six years of nearby mine and smelter operation.

Metal	Exchangeable amounts (ppm)			
	A1		A2	
	Experimental	Predicted by Scehm	Experimental	Predicted by Scehm
Lead	650.0	480.0	180.0	5.6
Cadmium	8.0	5.3	3.8	2.1
Zinc	56.0	53.0	28.0	27.0
Copper	13.0	40.0	5.5	7.8

The experimental and simulated concentrations of Zn and Cd in the A1 and A2 soil layers agree quite well. The simulated concentrations of Cu are high, because SCEHM does not differentiate between free and complexed cations. Copper complexes readily, and the complexed Cu will move through the soil faster than the model predicts, which accounts for the larger simulated values. The simulation of lead content was low, possibly because the lead is entering the soil as particles of insoluble PbS and thus is less mobile than predicted by the model. Overall, SCEHM can be used to simulate the movement of heavy metals through the soil system, with the best results obtained for metals that remain as free cations in the soil solution.

The second example of trace element transport simulation involves the discharge of Cd from Walker Branch Watershed, near Oak Ridge, Tennessee. In this example, the emphasis was placed on simulating heavy-metal export from a drainage basin, given the atmospheric deposition rates and the physical and chemical attributes of the watershed. The study period extended from June 1973 through August 1974.¹¹ Because the primary means for Cd export is via the hydrologic cycle, we have included a comparison of monthly observed and simulated streamflow values in Fig. 10.4. One may use this comparison to help interpret the results of the Cd transport simulations shown in Fig. 10.5.

The first point to be made is that the general agreement between simulated and observed cadmium export values is quite good, considering the fact that more than 96% of the Cd deposited on the watershed appears to be retained. There is a general tendency during fall and early winter to oversimulate flow, yet closely approximate Cd export (i.e., undersimulate concentration). In the late winter and spring months, the trend changes to underestimation of flow and overestimation of Cd export (i.e., oversimulation of concentration). Obviously the model and/or the data are not fully representative of actual conditions. One possibility is that the flows that were sampled are not representative of the full range of conditions that exist for the basin. More specifically, one would expect the highest concentrations of Cd to occur during major storm events. However, most of the past sampling did not include major runoff periods. Hence the model results suggest that our measurements may have misled us into underestimating Cd export, and that we must place strong emphasis on sampling major storm events for heavy-metal transport. Once that question has been resolved, we will be able to judge the transport model performance more confidently and initiate any needed refinements to the model structure. In the meantime, the unified transport model is a tool that can be used now. The foregoing examples are a general guide to the accuracy one may expect when simulating the transport of heavy metals in the environment.

ATMOSPHERIC INPUT OF TRACE ELEMENTS TO THE LANDSCAPE

There is mounting evidence¹² that many activities of man, particularly combustion of fossil fuels and industrial processing of metals and their ores, are responsible for elevated concentrations of many trace metals in the atmosphere and, therefore, potentially increased rates of transport to, and accumulation in, the landscape. Work of this project relates directly to quantification of atmospheric input, landscape cycling, and hydrologic output of selected trace metals for the 97.5-ha Walker Branch Watershed (WBW), which is influenced by emissions from three local fossil-fueled stream plants. Specifically, our research objective is to derive relationships between levels of selected trace metals in air, rain aerosols, soil, and rock and, by these data and the known atmospheric emissions, to differentiate between natural and anthropogenic origins.

Trace element concentrations in stream water from WBW have been paired with instantaneous stream flows for each sampling time. This pairing permits calculation of discharge-weighted mean concentrations for each trace element (dissolved and particulate) and determination of the representativeness of stream sampling. The six-month mass balance¹³ for selected trace metals on WBW has been improved by using more reliable concentrations of selected metals (e.g., Cd in rain input), obtained during the preceding year, and by recalculating the watershed output of these metals for the six-month period using discharge-weighted mean concentrations.

Fig. 10.4. Observed and simulated monthly streamflow at Walker Branch Watershed, June 1973 - August 1974.

Fig. 10.5. Observed and simulated monthly cadmium export in streamflow from Walker Branch Watershed, June 1973 - August 1974.

Wet Deposition

Weighted mean concentrations of selected trace metals in rain on WBW measured by GFAAS during the preceding year are given in Table 10.8 where they are compared with concentrations used by Andren et al.¹³ to calculate a six-month mass balance for WBW. Within the obvious limits set by the smaller number of observations during the current year, the agreement between these data is not unreasonable except for Cd and perhaps Cu. Although we cannot positively identify the reason for the discrepancies between these data sets, we speculate that differences in various procedures (e.g., length of time that rain samples remained in field, the condition with respect to corrosion of the metal surfaces of the Wong samplers, and analytical techniques employed) may have been responsible. Specific problems identified with the type of Wong collector we used were the large metal area available for precipitation "splash off" into the collector vessel and the air gap between the sliding lid and collection vessel, which may allow dry deposition to contaminate precipitation samples. Fortunately the bulk of the new data presented here was collected with both these problems relatively minimized (exposed metal surfaces, except the sensor head, were coated with epoxy paint and the sliding lid was modified to minimize air gap). New precipitation collectors (USAEC-type) that seal positively and that contain a minimum of contaminate metals in their construction are currently under construction for use on WBW.

Under the assumption that the cadmium concentrations in wet deposition as given in earlier reports¹³ were in error by a factor of ~ 7 due to contamination problems, we have recalculated the six-month wet deposition input of cadmium to WBW (by applying this factor to the previously reported values of 62.4 g/ha) as 8.9 g/ha. This correction represents a seven-fold decrease in the wet deposition of Cd and has significant consequences in the corrected six-month mass balance for this element presented in a later section.

Table 10.8. Precipitation weighted means of trace element concentrations in rain ($\mu\text{g/l}$) on Walker Branch Watershed (WBW)

Element	Rain gauge #1 (west subbasin)	Rain gauge #3 (east subbasin)	WBW ('75) ^a	WBW ^b	$\frac{\text{WBW}^b}{\text{WBW ('75)}}$
Cd	0.22	0.77	0.94	7.0	7.4
Cu	4.0	4.9	4.3	15.7	3.7
Cr	1.2	0.68	0.96	1.9	2.0
Pb	4.8	10.1	7.0	12.9	1.8
Mn	5.2	2.0	4.6	12.9	2.8
Zn	26.6	34.2	30.4	27.5	0.9
Hg	0.62	0.41	0.52	0.17	0.3

^a_n = 8(Cd, Cu, Cr, Zn), n = 4(Pb, Zn, Mn); period from February to August 1975.

^b_n = 12; period from January to June 1974. [A. W. Andren, S. E. Lindberg, and L. C. Bate, *Atmospheric input and geochemical cycling of selected trace elements in Walker Branch Watershed*, ORNL/NSF/EATC-13 (1975)].

Aerosol Chemistry

Aerosol research during the past year was concentrated in the areas of technique development and validation. The bulk of the aerosol chemistry data reported previously, and subsequently utilized in calculations of cycling budgets for WBW¹³ and in determinations of sources of aerosols, represented total samples collected using Hi-vol samplers. Because such samplers are suspected of contamination problems, we recently tested low-flow vacuum pumps (14 to 28 liter/min) in conjunction with all glass or all stainless steel membrane filter holders for collection of total aerosols (equivalent aerodynamic diameter of $>0.25 \mu\text{m}$) at three sites in the watershed. This has allowed for comparison of temporal, spatial, and intertechnique variability. In all cases samples were collected within 1 m of the ground and were protected from wetfall as well as from direct gravitational settling of large ($>10 \mu\text{m}$) particles.

Table 10.9 summarizes total aerosol concentrations of selected elements collected by various techniques as well as computed ranges based on steam plant emission data.

Table 10.9. Comparison of measured^a and calculated air concentrations of selected elements in Walker Branch Watershed

Element	Concentrations (ng/m ³)						Overlap
	Computed range	A	B	C	D	E	
Al	655 - 2800	823	655	714	709	725 (10)	Y
As	0.28 - 3.03	1.35	1.49	1.52	1.18	1.39 (14)	Y
Br	0.23 - 3.25	23	12.2	8.3	8.6	13.0 (52)	N
Cu	273 - 1668	472	174	92.8	109	212 (83)	Y ^b
Cd	0.03 - 0.54	4.1	<8	4.3	4.2	4.2 (2)	N
Cr	0.88 - 3.9	1.7	1.8	2.0	2.2	1.4 (23)	Y
Cu	0.50 - 3.25	8.2	<5	<9	<9	<8	?
Fe	683 - 4160	313	232	274	245	266 (14)	N
Hg	0.008 - 0.043	0.13	0.15	0.07	0.07	0.11 (36)	N
K	97 - 346	223	189	207	204	206 (7)	Y
Mn	2.14 - 10.6	14	7.2	14.0	11.8	11.8 (27)	Y ^b
Na	32 - 151	201	97.7	124	121	136 (33)	Y
Pb	0.31 - 7.6	90	-	-	-	90	N
Se	0.13 - 0.48	1.05	1.6	0.98	0.94	1.1 (27)	N
Ti	32 - 151	66	28	36	28	39.5 (46)	Y
U	1.8 - 7.15	3.6	3.7	2.4	2.3	3.0 (27)	Y
Zn	2.9 - 59	23.4	17.2	14.5	15.4	17.6 (23)	Y

^aMeasured values:

A - total sample, Hi Vol collector, west weir, July 1974 (Andren et al., 1975³⁹).

B - total sample, nuclepore filter collector, rain gauge #5, 2/14-2/21 1975.

C - total sample, nuclepore filter collector, between ram gauges #2 & 3 under canopy, 3/20-4/3 1975.

D - total sample, nuclepore filter collector, rain gauge #5, 3/20-4/3 1975.

E - mean and coefficient of variation (in parentheses) for values A-D.

^bAgreement is within $\pm 1 \sigma$ of $\bar{x}$.

Atmospheric Transport Model

In view of some uncertainty in the July 1974 data (e.g., problems associated with Hi-vol samplers, a limited number of samplers and collection sites, and the short duration of the sampling period), it is reassuring to observe the reasonably close agreement among samples A through D. Of special importance is the excellent agreement between the samples collected simultaneously at two sites, one beneath and one outside of the forest canopy (samples C and D). This indicates that, on a fairly long time scale (14 days), the air mass within the watershed was well mixed and that, during this time period, local soil and dust sources were minimized. This is important in the design of future experiments but will require further validation.

The last column of Table 10.9 compares the mean measured values with the concentration ranges attributed to emissions from the nearby steam plants. The elements which showed an enrichment in WBW air over that expected to be contributed from the steam plants are Br, Cd, Hg, Pb, and Se. Significantly, these are all elements associated with combustion processes and hence are generally found to be concentrated on the smallest sized particles which have the longest atmospheric residence times. Thus, it is plausible that these elements reflect the importance of long-range transport over local sources to the air mass on WBW. In our previous work,¹³ this suite of elements was calculated as being enriched in WBW aerosols.

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11. Nuclear Materials Transport

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Nuclear technology is one established and feasible method of achieving energy independence. Concomitantly, it is important that selected nuclear technologies (uranium, thorium, and plutonium fuel cycles) create minimal environmental impact and hazard to man. Research on the transport and environmental behavior of nuclear materials in terrestrial ecosystems provides information on biogeochemistry, cycling, and fate of fission products, activation products, and actinides in man's environment needed to assess the environmental acceptability of nuclear options. Specific objectives are (1) to investigate the biotic and abiotic processes responsible for the cycling, dispersion, and ultimate fate of radionuclides of nuclear fuel cycles; (2) to understand the environmental chemistry and long-term behavior of thorium, plutonium, americium, and curium; and (3) to determine food chain mechanisms of radionuclide transport in natural and agricultural ecosystems.

PLUTONIUM AND RELATED TRANSURANICS

Research continues to focus on the behavior of plutonium, americium, and curium in the biologically rich ecosystems of the eastern United States. Efforts are interrelated within three major themes: (1) fundamental studies of the environmental chemistry and plutonium kinetics in soil and sediment matrices, (2) plutonium cycling in a 30-year-old contaminated floodplain, and (3) plutonium behavior in freshwater environments.

Environmental Plutonium Chemistry

Substantial progress has been made in understanding the environmental chemistry of plutonium.

Reduction of Pu(IV) to Pu(III)

A reduction of potential environmental importance is the formation of Pu(III) from higher plutonium oxidation states, particularly Pu(IV). This reaction will occur, however, only under strong reducing conditions at environmental acidities. Both humic and fulvic acids were found to reduce Pu(IV). However, under aerobic conditions, the reaction apparently occurs below about pH 3. Under anaerobic conditions, the reduction will likely occur at higher pH. However, pH 6 should be an upper limit even under strongly reducing conditions. The environmental significance of reduction is that trivalent plutonium may be a more soluble species than tetravalent plutonium. Under anaerobic conditions, reduction might lead to significant changes in plutonium behavior. Research is continuing on this question.

Physiochemical Associations of Plutonium in Contaminated Soil

The long-term fate of transuranium elements in the environment will largely be governed by the physiochemical associations which exist in soils and sediments. The nature of the reaction products present on soil colloids is therefore of immense importance in formulating decisions about long-term fate. The plutonium isotopes in the floodplain soil appear to be present as monomeric species. This conclusion is derived from the observations that cold HNO_3 and HCl will extract a significant fraction of the total plutonium.⁵ Figure 11.1 demonstrates that there are plutonium species which transfer to a chelating resin (Ca-saturated) when soil and resin are equilibrated together over a 14-week period.⁶ The cation exchange resin does not accumulate plutonium, indicating that the species interact with the soil quite strongly. Sodium-saturated chelating resin also extracts plutonium at a faster rate due to soil dispersion; soil calcium is replaced by sodium. Humic acids are also extracted by the sodium-resin and 5% of the soil plutonium was found associated with the soluble humates, which accounted for 16% of the total soil carbon. This demonstrates, for the first time, the association of plutonium with soil organic matter in nature. Extraction with 0.1 M DTPA (pH 6.5) removed about 28% of the soil plutonium. This extractable fraction is similar to that associated with the resin and humic acids; consequently, the organically associated plutonium is about 30% of the total present in floodplain soil. The remaining plutonium is sorbed to other colloid surfaces. This is indicated by the fact that NaOCl (pH 9.5) removes 82% of the soil Pu.

Concentration of Transuranics in Vegetation of a 30-Year-Old Contaminated Floodplain

Additional determinations of plutonium in natural vegetation of the floodplain confirmed results reported last year on plutonium uptake by plants. Concentrations of plutonium ranged from 0.01 to 0.1 dpm/g, and concentration ratios $[(\text{Pu})_{\text{veg}}/(\text{Pu})_{\text{soil}}]$ did not exceed the highest value of 0.006 reported last year. Concentrations of plutonium in vegetation generally were proportional to soil concentrations; at soil concentrations less than 10 dpm, the concentrations in vegetation approached the limit of analytical detectability (approximately 0.01 dpm/g).

Garden vegetables (snapbeans, tomatoes) and field crops (soybeans, millet) were planted in cultivated plots (Fig. 11.2) at the W45/S300-W45/S300 location of the floodplain (note Fig. 12-1, last year's progress report⁵). Concentration of plutonium in soil at this location ranged from 150 to 250 dpm/g. Concentration of plutonium in snapbeans, millet, and soybeans are given in Table 11.1. For a limited number of determinations of harvested garden plants, the Pu ranged from nondetectable to a maximum of 0.57 dpm/g; most of the values ranged from 0.03 to 0.06 dpm/g. Concentration ratios ranged from 0.0002 to 0.003. The concentration ratios compare favorably with those determined for native plants of the floodplain ecosystem (0.0006 to 0.006). The slightly lower concentration values may be related to the short-term annual growth cycle of garden and field crops, but more data and research are required to confirm this hypothesis. Nonetheless, it appears that plants growing in this habitat exhibit uptake which is at least a factor of 10 greater than that observed from greenhouse culture experiments. The higher uptake characteristics are likely related to monomeric plutonium associated with organic substances described in a previous section of this report.

Charge Characteristics and Apparent Molecular Size of Transuranics in White Oak Lake Water

Transuranium elements are present in the soluble ($<0.45 \mu$) fraction of White Oak Lake (WOL) water at high enough concentrations to accurately describe certain physiochemical properties which may affect their residence times in natural waters. The total concentration of plutonium in unfiltered WOL water averaged about 0.7 dpm/liter with a $^{238}\text{Pu}/^{239}\text{Pu}$ activity ratio of about 0.7. Curium-244 concentrations are about 2.0 dpm/liter. Filtration through Millipore 0.45- μ filters yielded a soluble plutonium fraction of 0.09 ± 0.01 dpm/liter, which had a $^{238}\text{Pu}/^{239}\text{Pu}$ activity ratio of 3 ± 1 (S.E.). Curium was present in the soluble fraction at 1.1 dpm/liter. The high fraction of ^{238}Pu appears reasonable because seeps from burial ground 5 contain ^{238}Pu only.

The physiochemical behavior of the transuranics present in the soluble fraction was evaluated by passing separate 10-liter filtered samples through cation exchange (sodium form) and anion exchange resins. Additional samples were spiked with tracer ^{237}Pu at about $10^{-11} M$ concentration and the resin affinities were also evaluated. The plutonium-spiked WOL water was also passed through Amicon Ultrafilters. Table 11.2 illustrates the comparative behavior of indigenous plutonium and the ^{237}Pu spike. Both indigenous plutonium and the tracer sorb to exchange resins in the same manner. When the ^{237}Pu -spiked solution was passed through the hydrogen form of the cation exchange resin, the sorption increased from 17% to 84%. This behavior, along with the observation that there is plutonium which sorbs to both anion and cation resin (i.e., total sorption was well over 100%), indicates displacement of weak ligands imparting the net negative charge. When the WOL water was evaporated, peroxidized, made to the original volume, and then spiked, ^{237}Pu showed much more cationic behavior. This implies that the complex may be partially organic in nature. However, carbonate and hydroxide complexes cannot be excluded. Amicon filtration revealed that 100% of the ^{237}Pu passed through a nominal 10,000-mol-wt membrane and $44 \pm 12\%$ (95% C.I.) passed a nominal 500-mol-wt membrane, indicating that the soluble species are small molecules.

Fig. 11.1. Equilibration desorption of Pu from floodplain soil by cation and chelating resins.

Fig. 11.2. Crops and vegetables being harvested from garden plots for determining concentrations of plutonium and other transuranics. Plants are growing on a site contaminated by waste effluents for a 30-year period. Plant uptake of radionuclides is evaluated from these experiments to determine if long-term soil and ecological processes influence the availability of nuclear contaminants. Net and fence protect plants from disturbance by animals.

Distribution of ^{237}Pu in a Littoral Freshwater Microcosm

To gain insight into the expected behavior of transuranics entering aquatic ecosystems, microcosm studies can be used to define more precisely those components of the natural ecosystem which are functionally important in the potential transfer of such contaminants to man. Eleven microcuries of $^{237}\text{Pu}(\text{NO}_3)_4$ were released into an aquatic microcosm which had been allowed to stabilize for one year previous to experimentation. The microcosm contained field-collected sediment and a diverse biotic assemblage (Table 11.3).

The initial water concentration (at 30 min after spike administration) was 1590 ± 86 dpm/g (95% C.I.). Water concentration fell by three orders of magnitude during the first week and at the end of the second week had fallen below detection limits (10-ml sample). At 90 days post spike, the microcosm components were intensively sampled. The

Table 11.1. Concentration of plutonium^a in snapbeans, millet, and soybeans from cultivated plots of the contaminated floodplain

Species	Plant material	N	Concentration range (dpm/g)	Ratio ^b
Snapbeans	Leaf	2	0.42 to 0.57	0.003
	Stem	1	0.18	0.0009
	Bean ^c	4	T ^d to 0.04	0.0002
Millet	Leaf	7	0.03 to 0.05	0.0002
	Stem	1	D ^d to 0.05	---
	Inflorescence	4	D ^d to 0.05	0.0002
Soybeans	Leaf	2	0.04 to 0.06	0.0003
	Stem	1	T ^d	---

^aPrimarily ^{239,240}Pu; detectable quantity of ²³⁸Pu was observed when ^{239,240}Pu was greater than 0.05 dpm/g.

^bMaximum concentration ratio (Pu)_{veg}/(Pu)_{soil} based on 200 dpm/g in soil.

^cWhole bean.

^dAt low limits of detectability, the distinction is made between T, a detectable but nonquantifiable quantity, and D, nondetectable.

Table 11.2. Comparative behavior of plutonium and curium in White Oak Lake water

Transuranic nuclide	% removed by resin form		
	Anionic	Cationic	
		Na ⁺	H ⁺
^{238,239} Pu	100	14	--
²³⁷ Pu	100	17 ± 2	84
(After H ₂ O ₂)	59 ± 5	35 ± 5	
²⁴⁴ Cm	100	5	--

surface sediment concentration was 1630 ± 282 dpm/g based on five samples, each of which was a composite of 25 subsamples from different locations in the microcosm. The water concentration on day 90 was $1.8 \pm 0.9 \times 10^{-2}$ dpm/g. The resulting K_d (distribution coefficient) for sediment was 9.0×10^4 . Trophic transfer factors (TTF) which relate the concentration observed in biota to that in sediments, are presented in Table 11.3. The TTF values are expressed as a percent of the sediment concentration.

A materials balance for the microcosm (using a conservatively high biomass concentration of 1 kg/m^2 with the geometric mean of the observed plutonium concentrations in submerged plants) provides the following estimates: $1 \times 10^{-3}\%$ in the water, $4 \times 10^{-2}\%$

Table 11.3. Trophic transfer factors (TTF) for ^{237}Pu in biota of an aquatic microcosm

Common name	Genus	Structure	Sample size	TTF
Emergent plants				
Grass	<i>Panicum</i>	Spikes	11	≤ 0.11
		Stem and leaves	11	≤ 0.045
Cattail	<i>Typha</i>	Stem and leaves	1	≤ 0.029
		Stem and leaves	1	≤ 0.040
Watercress	<i>Nasturtium</i>	Stem and leaves	7	≤ 0.089
Submerged plants				
Algae	<i>Oedogonium</i>	Clumps	7	9.1
Moss	<i>Hygrohypnum</i>	Branches	60	27.0
Stonewort	<i>Chara</i>	Branches	75	0.19 ± 0.078^a
Pondweed	<i>Potamogeton</i>	Stem and leaves	30	2.5
Invertebrates				
Snails	<i>Physa</i>	Whole ^b	30	2.4 ± 0.46
		Whole ^b	30	1.5 ± 0.29
		Shells ^b	30	1.9 ± 0.59
		Carcasses ^b	30	1.2 ± 0.50
	<i>Gyraulus</i>	Whole ^b	63	6.4 ± 1.4
	<i>Goniobasis</i>	Whole	3	7.4
		Whole ^b	3	9.9
		Whole ^b	5	5.0
		Whole ^b	16	5.1
		Shells ^b	16	5.8
		Carcasses	16	3.5
Amphipod	<i>Hyalella</i>	Whole	130	3.6 ± 0.97
Vertebrate				
Goldfish	<i>Carassius</i>	Carcass-gut	4	0.47^b (0.16, < 0.54, < 0.60, 1.4)
		Gut ^c	4	30 (18-91)
		Whole ^c	4	2.3 (1.2-8.1)

^a95% C. I. (counting error). Not shown if less than 10%.^bAnimals held for 48 hr in uncontaminated spring water before sacrifice.^cGeometric means and ranges. Mean for carcasses is based on statistically significant values only.

in biota, and over 99.9% in sediments. If one multiplies the surface sediment concentration by the weight of sediments, the actual sedimentary plutonium pool is overestimated by approximately 60%. This indicated the presence of a concentration gradient even though the sediment depth was on the order of 2 cm and extensive mixing by burrowing organisms undoubtedly occurred.

Owing to the high affinity of sediments for ^{237}Pu and limited sample sizes, activity levels in some biotic samples were below detection limits (<1 pCi). However, these measurements are useful because they provide estimates of the upper limits of plutonium concentration. There is a striking difference between the concentrations in emergent plants sampled above the water line and in submerged plants. The much higher levels in submerged vegetation suggest strongly that surface adsorptive phenomena were dominant. Levels in emergent vegetation are comparable to those reported in terrestrial plant uptake studies.

ENVIRONMENTAL BEHAVIOR OF URANIUM AND THORIUM AS RELATED TO THE THORIUM FUEL CYCLE

The thorium fuel cycle uses naturally occurring ^{232}Th as a fertile material to produce fissionable ^{233}U . The neutron capture of ^{232}Th and beta emission of ^{233}Th and ^{233}Pa lead to the production of ^{233}U which is separated during reprocessing, then refabricated and recycled back to the reactor to compose approximately 37% of the fuel elements.⁷ Reactor technologies using this breeding process include the High-Temperature Gas Cooled Reactor (HTGR), the Light-Water Breeder Reactor (LWBR), and the Molten-Salt Breeder Reactor (MSBR). Several other uranium isotopes are also formed as a result of nuclear reactions in the core and are recycled with the ^{233}U . These include ^{232}U , ^{234}U , ^{235}U , and ^{236}U . These byproducts, particularly ^{232}U , significantly increase the radiological hazards of the recycled ^{233}U fuel.

Uranium-232 is produced in thorium-bred ^{233}U fuel by several interactions. These interactions are depicted in Fig. 11.3. Differences in the thorium fuel can result in ^{232}U concentrations at equilibrium recycle of 360 ppm to 1160 ppm.⁸ The ^{232}U decay chain is a member of the $4n$ or thorium series. In this decay chain there is no long-lived "stopping" nuclide such as exists in the ^{238}Pu , ^{239}Pu , ^{240}Pu , or ^{241}Pu chains.

Fig. 11.3. Production and decay scheme for long-lived uranium and thorium radioisotopes produced in the thorium fuel cycle.

A preliminary assessment of the potential radiological impact of ^{232}U and daughters in ^{233}U fuel indicates that the three particulate radionuclides of most concern from a radiological impact standpoint are ^{232}U , ^{228}Th , and ^{224}Ra . The buildup of ^{232}U and ^{233}U daughters in the environment could increase the potential dose commitment to the bone by a factor of approximately 7.5 over the dose commitment calculated soon after the material is released.⁹ The release of high specific-activity uranium or thorium isotopes to the environment and their entry into food chains leading to man therefore presents a potential long-term hazard which requires examination.

As a new project, two major efforts are under way. First, the existing literature on the behavior of uranium and thorium in the environment is being evaluated to determine the extent to which the consequences of uranium or thorium releases from this fuel cycle can be evaluated. Because uranium and thorium occur at parts-per-million concentrations in soils and sediments, released nuclides will undergo isotopic dilution with natural "pools" of elements in the biogeochemical cycle. The specific activity of these pools as well as the pool size will affect the ultimate assessment of the radiological hazard. For example, only 15% of the uranium and 40% of the thorium in a California terrace soil will isotopically exchange.¹⁰ This type of evidence indicates that not all of the natural uranium or thorium in soils is available to plants. The release of more soluble nuclides in the environment raises the question as to the real biologically available pool and therefore the exact fraction of soil or sediment radionuclide upon which to base transfer coefficients used for dose calculations.

The second major research task to be initiated in the current year involves the collection and processing of environmental samples to standardize analytical procedures and to determine if existing releases of enriched uranium at Oak Ridge facilities can be used as tracer simulants for determining environmental pools of biologically available uranium.

FISSION AND ACTIVATION PRODUCTS

The major objective in studying the transport of nuclear fission and activation products is to understand abiotic and biotic processes responsible for the dispersion and consequential fate of radionuclides in the environment. On-line operating light-water reactors that release fission products such as ^{137}Cs make it necessary to understand the behavior of the fission products in various ecosystems. Likewise, possible releases of activation products such as ^{60}Co at fuel recycling centers and ^3H and ^{14}C at future nuclear energy production facilities (e.g., HTGR and fusion reactors) require an analysis and assessment of the fate of the activation products in the environment. Thus, the variables responsible for the environmental transport of these radionuclides are being addressed by the radionuclide cycling group. At a number of field sites on the ERDA Oak Ridge Reservation, research has been conducted on the transport of ^3H , ^{60}Co , ^{14}C , and ^{137}Cs . In the laboratory, microcosms and zonal density-gradient techniques have been used to test suspected transport pathways and adsorption mechanisms of the various radionuclides.

Tritium-Contaminated Floodplain

Tritiated H_2O has been observed seeping from burial ground 5 onto a small forested floodplain immediately below the burial ground site. During the wet seasons, groundwater containing as much as 45 nCi/ml surfaces in the low-lying areas. Previous research has been confined largely to defining concentrations of ^3H in the soil water and in the free water of the vegetative cover growing in the area.

Almost no data are available on the cycling of bound ^3H (organically bound by fixation in photosynthesis) in ecosystems; consequently, current efforts have been directed at analyzing the bound ^3H in plant material and soil organic matter. The major objectives were to determine when tritiated H_2O first reached the floodplain and to evaluate the time required in forming various components of soil organic matter, using the dated, bound ^3H in soil organic matter.

Tree core samples from a tulip poplar (*Liriodendron tulipifera*) located at the lower part of the floodplain indicated one surge of tritiated H_2O moved through the area during 1966 (Fig. 11.4). The 3H concentration in the 1966 tree rings was almost 15 times greater than concentrations in 1965. Data on tritiated H_2O concentrations passing over White Oak Lake dam showed that four times more 3H passed over the dam in 1967 than in 1966, indicating a lag period before the surge was detected at the dam.

Fig. 11.4. Concentration of tritium in yearly growth rings of a tulip poplar (*Liriodendron tulipifera*) growing on a tritium contaminated floodplain.

Tree core data taken from three pine trees (*Pinus taeda*) located 8 m from the tulip poplar indicated that a large variation existed in bound 3H among yearly growth rings, depending mainly on location of the trees (Fig. 11.5). These data indicated that the largest 3H releases have occurred since 1969 and 1970. It is not clear why 3H concentrations in the trees varied so greatly for trees growing in such close proximity, although it appears that the topography of the area and pattern of underground water movement through the partially consolidated soil parent material may be responsible. Further tree core samples from larger trees located upslope and nearer burial ground 5 should clarify the pattern of 3H uptake as well as the tritiated groundwater movement from the burial site.

A sample site approximately 7 m from the tulip poplar was selected to study the concentration and distribution of organically bound 3H in litter and soil components. Recently deposited leaves from the tulip poplar and twigs from pine trees contained similar 3H concentrations (11 to 12 nCi/g). The older 01 litter contained approximately one-half the 3H concentration measured in the freshly fallen tulip poplar leaves and pine twigs, namely 6 nCi/g. The soil 3H concentrations rapidly decreased from the A1 (1.7 nCi/g) to the A2 (0.2 nCi/g) soil horizons.

Fig. 11.5. Concentration of ^3H in growth rings of three pines (*Pinus taeda*) growing on a ^3H -contaminated floodplain.

Detailed analyses of the ^3H in the various soil components (Table 11.4) showed that the ^3H concentration in the intact roots was greater than four times the concentration in any other soil component and represented approximately 17% of the total ^3H soil burden. In the <2.0-mm soil fractions, the organic debris, >50 μ in diameter with density <1.8 g/cm³ and 1.8 to 2.4 g/cm³, contained on the order of 5 to 8 nCi/g respectively and represented 52% of the total ^3H burden. The silt (approximate ^3H concentration, 0.7 nCi/g) contained 18% of the total soil ^3H burden. The remaining ^3H burden (13%) was associated with the clay (approximately 1 nCi/g), sand (<0.1 nCi/g), and soil aggregates and partially decomposed plant material >2-mm diameter (3.2 nCi/g).

The data showed that ^3H concentration in the soil components decreased with smaller particle size and increasing density of the unconsolidated soil organic matter (detritus of roots, leaves, etc.). Thus, the more weathered material containing the lower ^3H concentrations likely represents detritus from plant material formed before 1969 when titrated H_2O concentrations in the area were low as confirmed by tree ring measurements. Ratios of $^3\text{H}/\text{C}$ and $^3\text{H}/\text{H}$ in the soil organic matter components will be compared to similar ratios measured in the tree rings to date these soil organic matter components.

Table 11.4. Concentration and distribution of bound ^3H in soil aggregates from the A1 soil horizon of the ^3H contaminated floodplain below burial ground 5

	Aggregate size (mm diam.)			
	>2.0	2.0 - 0.8	0.8 - 0.6	<0.6
	(^3H in nCi/g)			
Soil aggregates and partially decomposed plant material	3.2			
Roots	36.5			
Organic debris >50 μm with density <1.8 g/cm ³		6.4	7.9	5.1
1.8 - 2.4 g/cm ³		4.0	4.4	2.4
Sand (>50 μm)		<0.1	<0.1	<0.1
Silt (50 - 2 μm)		0.7	0.7	0.8
Clay (<2 μm)		0.9	1.1	1.1
Weight (%)	6.7	28.7	7.8	55.8
^3H (nCi/g)	6.3	1.5	2.2	1.3
^3H burden (%)	24	25	11	40

Through the use of sequential solvent extractants (i.e., mild reagents) that remove fats, waxes, polysaccharides, hemicellulose, and cellulose, and strong reagents that extract highly unavailable biological forms such as lignin and humic acid, the biological availability of organically bound ^3H in soil may be estimated. From such extractions the relative age of each soil extraction may also be estimated, using the $^3\text{H}/\text{H}$ and $^3\text{H}/\text{C}$ ratios. Sequential solvent extraction removed nearly 80% of the ^3H from the <0.6-mm sieved soil (Table 11.5). The ^3H concentration of the humic acid (3.9 nCi/g) was considerably less than the ^3H concentration (8 nCi/g) in the ash-free (1.8 to 2.4 g/cm³) fraction, indicating a higher ^3H specific activity in the lesser decomposed soil organic matter fraction. Approximately 50% of the ^3H was extracted by the 6 *N* HCl (90°C for 2 hr), representing the hydrolysis of the hemicellulose and cellulose which is potentially biologically available in plant detritus.

Microcosms

Microcosm research indicated the chelation of cations released from decaying litter by organic decomposition products. This chelation mechanism allows for rapid and effective transport of cations from detritus to roots. Subsequent microcosm research of radioelement transport indicates considerable complexing (20 to 60%) of ^{60}Co and ^{54}Mn released from decomposing deciduous litters such as dogwood and tulip poplar, and virtually no complexing (<0.5%) when these elements are released from acid coniferous litter such as pine. Readily soluble monovalent Cs is not complexed with either broadleaf or coniferous leachates and any transport in soil is in the ionic form, as indicated by near quantitative recovery of ^{134}Cs from soil leachates on cation exchange columns.

Density-Gradient Large-Scale Zonal Centrifugation

The inception and development of density-gradient centrifugation of soils and sediments has provided a technique to more clearly understand the fate of radionuclides and trace contaminants in the environment.¹¹ For example, it has been used successfully in

Table 11.5. Sequential solvent extraction of bound ^3H from soil^a

	^3H concentration (nCi/g)	^3H distribution (%)
Soil extractants		
Benzene - methanol		2.6
0.5 <u>N</u> HCl		7.4
0.1 <u>M</u> NaP_2O_7		5.0
6 <u>N</u> HCl at 90°C for 2 hr		50.5
Chloroform - methanol		3.0
0.5 <u>N</u> NaOH		
Fulvic acid		4.6
Humic acid	3.9	8.3
Filtered debris from extracts		0.3
Residual	0.4	18.1
Original soil sample	1.3	

^aSoil sieved to <0.6 mm diam, A1 horizon.

determining the reaction sites in soils and sediments of the radionuclides ^{60}Co , ^{137}Cs , ^3H , ^{239}Pu , and the toxic element Cd.¹²⁻¹⁵. The large-scale rotor has allowed density separations of up to 15 g of material, while separations in swinging bucket rotors are limited to 250 mg per centrifuge tube.

By using a large-scale zonal rotor, sufficient quantities of various soil density fractions were obtained to determine statistically significant counting rates for soil samples where the initial concentrations of radionuclides were too low to be measured at statistically acceptable levels. For example, in a soil sample taken from the floodplain at the upper end of White Oak Lake, the <50- μm particle size fraction contained 0.45 ± 0.45 , 1.07 ± 0.2 , 0.31 ± 0.09 , and 3.83 ± 0.09 nCi/g of ^{106}Ru , ^{60}Co , ^{125}Sb , and ^{137}Cs , respectively. Density separations by a large-scale zonal rotor produced soil density fractions enriched in these radionuclides by factors of 3 to 30 (i.e., density fractions contained 7.39 ± 1.84 , 30.9 ± 0.4 , 3.55 ± 0.45 , and 9.59 ± 0.27 nCi/g of ^{106}Ru , ^{60}Co , ^{125}Sb , and ^{137}Cs , respectively). The high concentration of ^{106}Ru (7.36 ± 1.84 relative to 0.45 ± 0.45 nCi/g in the original sample) in the 1.78 g/cm^3 density fraction indicated part of the ^{106}Ru is adsorbed to soil organic matter. On the other hand, the distribution of ^{60}Co did not follow the soil organic matter distribution, indicating a poor association with soil organic matter.

Radiocesium Budget of a 30-Year-Old Contaminated Floodplain

Data on radiocesium concentration of soil and vegetation of a 30-year-old contaminated floodplain were presented in last year's progress report.¹⁶ This year the distribution and budget of ^{137}Cs have been determined for different components of the floodplain ecosystem.¹⁷ Radiocesium concentration data were developed for the major components of the ecosystem (Table 11.6); soil mass was determined from field measurements; biomass of vegetative components was determined from mensuration measurements and regression analysis;¹⁸ and budgets of ^{137}Cs in different compartments were calculated from average estimates of concentration and mass. The soil ^{137}Cs budget (120.6 Ci) for a $20,000\text{-m}^2$ area was based on a summation of profile increments (such as that given in Fig. 11.6) rather than the simple product of soil mass and average concentration.

Table 11.6. Mass, ^{137}Cs concentration, and ^{137}Cs budget for major soil and vegetation components of a contaminated floodplain^a

Component	Mass ^b (g)	^{137}Cs concentration (nCi/g)	^{137}Cs budget (Ci)
Soil	1.5×10^{10}	8.3×10^3	1.21×10^2
Roots	6.0×10^7	1.1×10^3	6.3×10^{-2}
Bole	1.6×10^8	4.0×10^1	6.6×10^{-3}
Branch	5.0×10^7	4.0×10^1	2.0×10^{-3}
Leaf	8.0×10^6	3.0×10^1	2.4×10^{-4}
Litter	1.2×10^7	1.8×10^1	2.2×10^{-4}
Ground cover	2.2×10^6	3.3×10^1	7.2×10^{-5}

^aData and evaluation based on a 2 ha area.

^bBiomass of root, bole, branch, and leaf components estimated from regression equations [W. F. Harris et al. pp. 41-64 in Young, Harold (Ed.). *IUFRO biomass studies. Mensuration, growth and yield*. Univ. Maine Press, Orono (1973)]; mass of soil, litter, and ground cover based on extrapolation from field collections.

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Fig. 11.6. Distribution of soil- ^{137}Cs in floodplain ecosystem. Highest concentrations were found at the base of 1944 retention pond dam and along White Oak Creek.

Results of ^{137}Cs distribution in different components showed vividly that the soil contained by far the greatest fraction (99.94%) of the ^{137}Cs deposited in the floodplain ecosystem (Table 11.6). Only 0.06% of the ^{137}Cs of the floodplain was present in the vegetative components. Previous results^{16,17} also showed that all the nuclide remained in the top 50 cm of the soil profile; none had been transported through the unconsolidated sediments. These observations confirmed the prediction of effective retention of radiocesium by soil, particularly by the illitic clay minerals of Oak Ridge area soils.¹⁹ After a finite period of 30 years, these results provided a significant validation of the important role played by soil minerals in the retention of radiocesium.

Roots contained the greatest fraction of ^{137}Cs found in vegetative components of the floodplain ecosystem. Eighty-seven percent of the radiocesium in vegetation was in roots. The average concentration of ^{137}Cs in roots was approximately 25 times higher than that in aboveground vegetation. However, the ^{137}Cs burden in roots was approximately 10 times greater than that in aboveground vegetation. These results suggested a root-to-top transfer coefficient of 0.1.

Approximately 0.06% of all ^{137}Cs present in the floodplain was measured in biotic components (below and aboveground combined). Based on the simplified assumption of near-equilibrium conditions after 30 years (uptake by biotic components is equivalent to losses), then the annual uptake coefficient (fractional transfer from soil to vegetation) for the ecosystem would be 0.0006 per 30 years or 0.00002 per year. A coefficient of 0.00002 would represent a maximum because the vegetative budget was not assimilated uniformly in one year [i.e., a substantial component of the biomass (roots, bole, branch) may have accumulated ^{137}Cs during the rapid growth phase]. An estimate of minimal annual uptake would be that represented by the leaf budget (3.15×10^{-4} Ci), 0.0003% or 0.000003 of total ^{137}Cs of the floodplain. Thus, from 0.00002 to 0.000003 would represent the range in uptake coefficients by the biotic components of the floodplain. A determination of radiocesium dynamics and internal cycling would be required to estimate more precisely the annual uptake coefficient.

Results on the distribution of ^{137}Cs in biotic and abiotic components of a 30-year-old contaminated floodplain confirmed that the nuclide remained in the soil pool; only a nominal fraction was transported annually to biotic components. Concentration ratios and uptake coefficients for the 30-year-old ecosystems are consistent with established relationships on radiocesium distribution in terrestrial environments.²⁰

Carbon-14 Global Cycling Assessment

Because of the anticipated release of ^{14}C from fusion and HTGR nuclear facilities, a thorough investigation of the present distribution of global ^{14}C from nuclear weapons testing is needed. In collaboration with the Thorium Utilization Program of the Chemical Technology Division, an analysis of the global distribution and cycling of ^{14}C was initiated. The first step in this investigation was to examine estimates of ^{14}C released into the atmosphere from nuclear tests. By 1962 a yield of 511 megatons had released approximately 2200 kg of ^{14}C into the atmosphere²¹ (Table 11.7). If it is assumed that a pre-1950 specific activity²² in the atmosphere was 1.41×10^{-12} g ^{14}C /g ^{12}C with a total of 68×10^{16} g ^{12}C currently in the atmosphere, then the natural (pre-1950) ^{14}C was ~ 958 kg. The calculated excess of ^{14}C (above 1950 natural levels) in the atmosphere was ~ 298 kg in 1962 and 670 kg by 1969, using data from Vogal and Marais.²³ Only $\sim 31\%$ (670/2178) of the ^{14}C released into the atmosphere between 1945 and 1969 from nuclear tests was still in the atmosphere in 1969. This is comparable to an estimate by Walton et al.²¹ of 30% of the excess ^{14}C remaining in the atmosphere by July 1968. Thus, the remaining 70% (1525 kg) must be in other reservoirs of the earth.

Only about 411 kg could be accounted for in other reservoirs (150 kg in the surface ocean and 261 kg in the biosphere) and the remaining 1114 kg was considered to be in the deep ocean.²¹ Thus, it was concluded that over 50% of the total excess ^{14}C released from nuclear tests had reached the deep ocean by 1969. If this estimate of deep ocean excess ^{14}C is too high, then previous estimates of ^{14}C retained in the terrestrial biosphere components (especially forests) would be too low according to calculations by simple difference.

Table 11.7. Carbon-14 yields to the atmosphere from nuclear testing between 1945 and 1969^a

Period	Air tests		Surface tests		Total	
	Yield (megaton)	¹⁴ C atoms x 10 ²⁷	Yield (megaton)	¹⁴ C atoms x 10 ²⁷	¹⁴ C atoms x 10 ²⁷	¹⁴ C (kg)
1945-51	0.19	0.038	0.57	0.057	0.095	2.21
1952-54	1.0	0.2	59.0	5.9	6.1	141.74
1955-56	11.0	2.2	17.0	1.7	3.9	90.62
1957-58	57.0	11.4	28.0	2.8	14.2	329.95
1959-60	Test moritorium					
1961	120.0	24.0			24.0	557.66
1962	217.0	43.4			43.4	1008.43
1967	3.0	0.6			0.6	13.94
1968	4.0	0.8			0.8	18.59
1969	<u>3.0</u>	<u>0.6</u>			<u>0.6</u>	<u>13.94</u>
Total	416.9	83.24	104.57	10.46	93.7	2177.5

^aData through 1962 are from A. Walton, et al., *J. Geophys. Res.* 75(15):3089-3098 (1970); data from 1967-1969 are from K. Telegadas, U.S. AEC HASL-243, pp. 13-15 (1971).

Using the best available estimates of carbon pool sizes and production rates of various terrestrial biosphere components²⁴ and specific activities of these components,²⁵⁻²⁸ the ¹⁴C concentrations in Danish cereals were $\sim 35\%$ above natural concentrations in 1962²⁷ thus raising the specific activity to about 1.84×10^{-12} g ¹⁴C/g ¹²C. Multiplying 1.84 times the organic carbon pool in agricultural crops gives 303 kg of ¹⁴C or 79 kg excess of ¹⁴C above the pre-1950 natural level of 224 kg.

Carbon-14 is accumulated in growth rings of trees with levels of ¹⁴C activity in a particular growth ring in apparent equilibrium with the levels of ¹⁴C in the atmosphere which existed during the time the ring was formed.^{25,28} Therefore, it is necessary to calculate the amount of ¹⁴C in forest and woody vegetation on a cumulative basis. The annual net primary production values for forest²⁴ were multiplied by ¹⁴C specific activities for each year and accumulated to obtain natural ¹²C and excess ¹⁴C pools (Table 11.8). The excess ¹⁴C in the terrestrial biosphere was calculated to be 356 kg and 747 kg in 1962 and 1969 respectively. These values are nearly 3 and 15 times higher than values given for the terrestrial biosphere^{21,22} for 1969 and 1962 respectively. If these revised estimates of excess ¹⁴C in the terrestrial biosphere are added to other world reservoir estimates,²¹ then more than 70% of the ¹⁴C released from nuclear tests through 1969 can be accounted for in reservoirs other than the deep oceans.

If careful consideration is given to high levels of ¹⁴C activity of the biota and soil in the immediate vicinity of nuclear test sites, the unaccounted excess ¹⁴C (which is typically placed in the deep ocean) may be even lower. For example, Koranda²⁹ reported relatively high concentrations of ¹⁴C in the biosphere and soil in the detonation environments in the Pacific Proving Grounds (where nuclear devices were tested from 1948 to 1958). On Runit Island, outer growth rings contained concentrations of ¹⁴C 78% above natural, leaves 125%, litter 204%, and soil 2920%. Thus, budgeting of ¹⁴C from any source must consider the ¹⁴C content in the immediate environment of the release before budgets from such releases on a global scale can be considered reliable. This assessment activity is continuing with evaluation of available analytical models of global carbon circulation.

Table 11.8. Carbon pools and production for the various components of the terrestrial biosphere^{a,b}

	Organic carbon pool (10 ⁹ metric tons)	NPP ^c (10 ⁹ metric tons/yr)	Natural ¹⁴ C pre-1950 (g x 10 ³)	Natural + excess ¹⁴ C (g x 10 ³)	
				1962	1969
Atmosphere	680		958	1256	1628
Terrestrial biosphere					
Forest and woodland	1012	36	1387	1468	1706
Agricultural	165	6	224	303	347
Other (grassland, desert, etc.)	<u>403</u>	<u>14</u>	<u>538</u>	<u>734</u>	<u>843</u>
Total terrestrial	1580	56	2149	2505	2896

^aFrom Massachusetts Institute of Technology, "Man's impact on the global environment, Assessment and recommendations for action, Ecological effects." IN *Study on Critical Environmental Problems*, MIT Press. Cambridge and London. pp. 113-166 (1970).

^bPre-1950 levels of ¹⁴C are based on specific activities taken from A. W. Fairhall and J. A. Young, in *Advances in Chemistry Series No. 95*, Amer. Chem. Soc. pp. 401-418 (1970); ¹⁴C amounts in 1962 and 1969 are based on specific activities calculated from data of J. C. Vogel and M. Marais. *Radiocarbon* 13(2): 378-394 (1971).

^cNPP - Net Primary Production.

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PART IV. ANALYSIS AND EVALUATION, AND DIVISION EXTENSION ACTIVITIES

12. Analysis and Evaluation

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NUMERIC DATA MANAGEMENT AND ANALYSIS

This project provides, both operationally and conceptually, many current ERDA projects with the tools for addressing the numeric data handling problems as an integral component of the total analysis and assessment. Numeric information support is a project within the Analysis and Assessment Program and provides numeric data handling support to ongoing research projects by obtaining and managing extant data as needed, by developing new data processing and analysis capabilities, and by coordinating the use of computer facilities, including remote batch job entry and interactive terminal access. Collaboration with the research staff within the Division and within ORNL is the key aspect of this project. Some of the current areas of our involvement include regional analysis, geocology, the U.S. International Biological Program Eastern Deciduous Forest Biome (U.S.IBP/EDFB), and, to a lesser extent, numerous other terrestrial and aquatic ERDA-sponsored research projects. Major accomplishments include implementation of and training in the use of the Statistical Analysis System¹, development of Numerical and Textual Information System,²⁻⁴ publication of a Division data processing guide,⁵ operation of a computer facility, and acquisition of computer equipment to meet data processing needs. Future goals are the expansion of computing capabilities, development of a computer graphics system for display of spatial data, and continued collaboration with researchers on data processing activities.

The specific objectives are: (a) to process data with the most cost-effective means available; (b) to implement the present computer hardware and software needs of Division staff and to plan for future needs; (c) to coordinate data processing activities within the confines of budget, manpower, and time; and (d) to store documented ecological data in a computer-accessible form.

These objectives are implemented through the data management scheme presented in Fig. 12.1. This scheme considers the flow of data from project conceptualization and data gathering through the various manipulation phases. Each section within the scheme represents an area of activity involving the computerization of some manual task, which often requires the guidance or control by data managers in the numeric support project. While this is the overall scheme, the following paragraphs describe specific tasks within the numeric information support project.

Fig. 12.1. Numeric data management scheme.

MAINTENANCE OF COMPUTERIZED DATA HANDLING SYSTEMS

The primary goal of this activity during the past year has been to document completely the systems and procedures for the Numerical and Textual Information System (NUTIS)-- the computerized data handling system used by this project. This documentation includes the complete description of the computer software portion, the systems manual,³ and documentation of the mechanics of how to input and code data.⁴ The revised and expanded Statistical Analysis System (SAS75)¹ was obtained from North Carolina State University and will replace the current SAS programs as our principal set of data manipulation and analysis routines.

Additional accomplishments within this activity included the standardization of units of measure, site identifiers, and dates within extant data sets gathered under the U.S.IBP/EDFB data banking effort. A computer routine was developed to replace the various missing value indicators within each data set with a standard indicator consisting of a blank field.

Occasionally research project personnel required that a computer program, obtained from another computer facility, be made operational on the main ORNL computers. This required reprogramming and the addition of computer system language instructions peculiar to this installation. This activity centered around modeling programs or small computer software packages for special purposes.

IDENTIFICATION, PROCUREMENT AND DOCUMENTATION OF EXTANT DATA

A number of data volumes were procured as required and requested by Division projects. These volumes included water quality and quantity data for the entire United States and ambient air quality and land-use data for the southeast United States. These data were supplied on magnetic tapes along with descriptive data formats. Most of these data required substantial amounts of time and labor to become familiar with the details of the tape attributes (e.g., labels and blocks of data per length of tape) and to separate out the inconsistencies between what was described on the data format and what was actually on the data volumes. A more complete documentation was then detailed for each of the volumes in order to facilitate later application and use. Subsequent extractions of portions of the data were performed by projects requiring the necessary data. Smaller data sets than those named above were procured and documented according to the stated needs of individual researchers. These smaller data sets served the same purpose as those above (i.e., that of providing estimates for processes or events in order to more completely describe a current ecosystem study).

COLLABORATION WITH OTHER RESEARCH PROJECTS

Current ERDA research projects require consultation on formatting, computerizing, and recording modes for data collection. This activity was necessary for efficient handling of data prior to analysis, and allowed review and suggestions to be made on the experimental design. By having a format and appropriate forms for computerizing the data, little time lag occurs between data collection and analysis. When data collection has preceded consulting activity, additional time is often required to reformat, recopy, and code the data prior to analysis.

DATA PROCESSING ASSISTANCE

Routine data analyses (e.g., means, standard deviations, plottings, and regressions), are required almost daily within the ERDA programs in the Division. We could not perform all of the analyses requested, but instead attempted to educate the researchers to do some of their own data processing. A series of concentrated short courses in data processing was held, concerned with basic computer job submission and statistical data processing using the Statistical Analysis System (SAS).¹ Subsequent discussions, as requested, were held for smaller groups of researchers with specific questions in an area of data processing.

In addition to short courses, further assistance was provided to project personnel by preparing a data processing guide.⁵ This guide details in "cookbook" form how to perform most of the routine data manipulations and computer job submissions to the ORNL main computers, using the Division computer facility or dial-up computer terminals.

DATA PROCESSING HARDWARE

In addition to systematizing data processing procedures and promoting the researcher's involvement in his own data processing, the planning for computer hardware needs of ERDA projects is a function of this project. To plan for current and future needs in the Division requires knowledge of present capabilities and future directions of the main ORNL computer facilities. With this kind of information and with a prediction of the direction and scope of ERDA research projects, we are developing an efficient and flexible Division computer facility (Fig. 12.2), and purchasing equipment for the main ORNL computer facilities. Additional data handling equipment (e.g., tapes and disks) is being added for local storage of data for retrieval or high-speed transmittal to the main computers. In addition this facility will be implemented with graphical display software for local data manipulation and display. Currently the Division facility is used primarily for remote entry of computer jobs to the main ORNL computers and for printing output on the computer printers located in the facility. This batch entry station increases by a factor of approximately four the number of computer jobs which can be processed daily by a user. Statistics on the average number of computer jobs processed per day and during the first year by month are given in Table 12.1. Note the large increase in

Fig. 12.2. Schematic diagram of the Environmental Sciences Division Remote Job Entry system showing the main station (Mod-comp II/25), peripherals, and general work flow.

Table 12.1. Monthly summary of remote batch station (RBS) workload from October 1974 through September 1975

Month	Jobs	Up days	Jobs/day
Oct. 1974	216	16	13.5
Nov.	559	19	29.4
Dec.	504	18	28.0
Jan. 1975	467	22	21.2
Feb.	591	20	29.6
Mar.	720	21	34.3
Apr.	833	22	37.9
May	1151	22	52.3
June	1150	21	54.8
July	479	15	32.0
Aug.	1141	18	63.4
Sept.	<u>768</u>	<u>15</u>	<u>50.5</u>
TOTAL	8579	229	(Av) 37.5

the number of jobs over last October when the facility was just being established. The main ORNL computer facilities were upgraded by our Division in the past year by the purchase of a swapping head disk (costing \$35,000) to be installed and used by all computer users.

Overseeing the operation of this facility is an integral part of the numeric support for ERDA research projects. Operations include input and output of computer jobs, maintenance of satellite computer software and hardware, and scheduling of hours of operation for the facility.

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13. Eastern Deciduous Forest Biome

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ANALYSIS AND MODELING

Stability and Connectance in Food Web Models

Investigations of nonlinearities in ecological systems achieved several interesting results during the past year. We examined the relationship between stability and connectance in large ecosystem models, a subject which has been the focus of much study and speculation throughout the history of mathematical ecology. Recent work⁴ has indicated that the stability of such models decreases with the connectance (or complexity) of the model. These findings contradict the intuitive reasoning of MacArthur and many others that stability should increase with complexity in an ecosystem.

We considered a food web model with ten species in three trophic levels. A Monte Carlo technique was employed to assign magnitudes of the connections among the species. The stability was examined for thousands of systems and it was shown that May's results⁴ do not apply to some important special cases. If the model is characterized by low assimilation efficiencies, a bias toward strong self-regulation at higher trophic levels, or a bias toward donor independence, the probability of stability can increase with connectance.

Global Stability of Populations with Age Structure

Models in which all members of a population, regardless of age, are lumped into one variable can be highly unrealistic in many cases. This is especially true for insects and other animals divided into larval and adult life stages, or otherwise strongly differentiated. For example, in teleost fish, the fry and adults are usually quite different in feeding habits and vulnerability to predation, as well as in fecundity. Numbers of teleost fish within age classes tend to fluctuate greatly from year to year; however, the population as a whole shows great "resiliency" in the sense used by Holling⁵ (i.e., the population is able to avoid fluctuations resulting in extinction).

We have investigated the resiliency of a set of nonlinear differential equations representing a population with age structure. The mathematical analog of resilience is "global stability." We used the so-called circle criterion to establish conditions under which this model is globally stable. Among the conclusions drawn is the implication that a system is more stable the more each age class regulates its own numbers. For example, a model of teleost fish is most stable when the numbers of fry are reduced by competition from or cannibalism by other fry.

Estimates of Predator-Prey Limit Cycles

One of the most intriguing types of behavior exhibited by predator-prey models is the occurrence of stable limit cycles. These cycles consist of regular fluctuations of predator and prey densities about an equilibrium value. If perturbed, the system will return to the same limit cycle trajectory. It is believed that many regular population fluctuations in nature are examples of limit cycles.⁴

In spite of the obvious importance of limit cycles in the study of ecosystem models, they are very difficult to analyze mathematically. In general, one must simulate the appropriate nonlinear differential equations on a computer to obtain the period and amplitude of the limit cycle. May⁴ has obtained these values analytically for a special case.

We considered a realistic assumption, that is, a large class of nonlinear predator-prey models with the characteristics that, as prey numbers decrease, predator feeding efficiency also decreases. For this important class of models we showed that the period and amplitude of the limit cycle can be estimated by methods of asymptotic analysis.

Global Stability of Food Web Models

One of the most difficult challenges facing mathematical ecologists involves the analysis of large, complicated ecological models. Large sets of coupled nonlinear differential equations are notoriously intractable. Nonetheless, if one is modest in one's demands, some general idea of the system's behavior can be extracted from such equations.

Of great importance in large ecosystem models is the concept of resiliency,⁵ or equivalently, global stability. We have presented general criteria which guarantee the global stability food web models, and have concluded that most realistic food web models should fit these criteria. In performing our analysis we considered the intersections of "zero isosurfaces" in N-dimensional species space. Figure 13.1 shows three such surfaces in three-dimensional species space, where x_1 , x_2 , and x_3 are autotroph, herbivore, and omnivore biomass densities, respectively.

Role of Consumers in Ecosystems

Recent work in theoretical ecology⁴ has tended to emphasize the destabilizing influence of consumer populations. Such analyses have stressed the direct effect of feeding on plant populations and the resultant reduction of photosynthetic capability. However, a large number of indirect effects due to consumer populations are also known and documented.⁶ The possible counterbalancing effects of beneficial side effects with the destabilizing direct feeding relationships have been examined in recent theoretical work.

One of the greatest advantages of mathematical models is their ability to rigorously establish a set of assumptions about a system and then objectively draw out the implications contained in these assumptions. This capability has always been a powerful inducement for the use of mathematical models, but as yet little theoretical work of this nature has been done in ecosystem analysis. In the present study we utilized the powerful analytical capabilities of simplified models to explore some hypotheses about the role of consumers in ecosystems. The purpose was to isolate particular interactions and examine the relative importance of direct and indirect effects.

In terrestrial decomposition subsystems, mesofauna feed directly on microfloral populations, tending to decrease remineralization. At the same time, the fauna comminutes

Fig. 13.1. Zero isoclines in population density state-space for a system of three species. The $K_1 = 0$, $K_2 = 0$ and $K_3 = 0$ isoclines are associated with the autotroph, heterotroph and omnivore, respectively. S_4 is the equilibrium point of the system.

the litter material, increasing surface area and therefore encouraging microfloral activity. By developing a simplified model of the processes involved we were able to investigate the contrasting influences of grazing and comminution. Simulations with the model demonstrated that the effects of comminution far outweighed the negative aspects of direct grazing. The percentage reduction in the time required to remineralize 50% of the initial substrate nutrient for grazing rates was between 0 and 0.6 (representing consumption of 60% of the available microflora per unit time), and comminution factors were between 1 and 30 (representing an increase of 30 times in the number of particles as litter passed through arthropod guts).

A similar analysis was performed for phytophagous insects which tend to move nutrients in excreta from the vegetation to the soil where they can be lost from the system by leaching. At the same time, the possibility exists that frass, composed of readily available carbohydrates and nutrients, permits increased microfloral activity and increased remineralization of recalcitrant nutrients in litter and soil. This would be analogous to the co-oxidative effects noted in aquatic ecosystems. By developing a simple model of these processes, it is possible to show that for some sets of parameter values, the co-oxidative process could well counterbalance the direct feeding effect and result in a greater availability of nutrients for plant growth.

These theoretical studies show that direct analysis of material transport through ecological systems may lead to erroneous conclusions about the functional role of consumer populations. In the instances examined, the indirect effects (not directly related to energy flow) may predominate and lead to advantages for ecosystem function in spite of destabilizing effects of direct feeding.

Heterotrophic Biomass in Ecosystems

Recent work⁷ indicated that ecosystems display interesting differences in their energy-capturing bases. Some systems possess a number of species, each with a different spectrum of responses to the environment, and each capable of rapid reproduction (e.g., phytoplankton communities). Other systems such as forests have large structural components to maintain the plants through unfavorable periods. However, the "phytoplankton" system permits rapid reproduction with potential exhaustion of a critical resource and subsequent depression of plant populations. If system stability involves constancy in spite of environmental changes, the need for explicit regulation of the autotrophic base would be more apparent in a pelagic system than in a forest. Therefore, it is not surprising that a larger biomass of consumer organisms is typically found in the aquatic ecosystem.

If the ecosystem is conceived as merely the chance coincidence of populations with overlapping environmental requirements, one might expect the heterotrophic standing crop to be proportional to net primary production. With a larger supply of available energy, one might expect more heterotrophs to be supported without disrupting the system. Data presently available on ecosystems do not seem to confirm this hypothesis.

On the other hand, if the ecosystem is conceived as an interacting system, then heterotrophs might be assigned a control function. If heterotrophs can operate to control the rate of energy production by consumption, this regulatory function should be more important in systems with a greater potential for rapid changes, that is, systems with greater "power" capacity as defined by Odum and Pinkerton.⁸ Thus, one would expect greater heterotrophic standing crop per unit autotroph as the production turnover time decreases, that is, as the system potential for rapid change increases. Figure 13.2

Fig. 13.2. Ratio of heterotroph to autotroph standing crop graphed against system turnover time (total living tissue/net primary production). The points on the graph represent six widely contrasting ecosystems: Tu - tundra, Tf - tropical forest, Df - deciduous forest, Sm - salt marsh, Cs - cold spring, and Po - pond.

indicates that the expected relationship exists. While such a simplistic relationship may not stand the test of more extensive data analysis, current evidence supports the hypothesis that heterotrophs play a rate regulation role in the ecosystem.⁹⁻¹⁴

Stable Volume Concept for Ecosystems

A primary motivation for the development of ecosystem theory is a desire to understand and predict the full range of ecosystem responses to perturbations; in particular, to locate the region around the current operating state within which the system will respond linearly. In other words, how far can the system be disturbed without causing an unstable response with the possibility of irreparable damage?

Figure 13.3 shows the stable volume for a tropical forest model developed from Odum and Pigeon.⁹ The graph illustrates parameter values for which the equilibrium conditions

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Fig. 13.3. Graph of the "stable volume" for the tropical forest ecosystem. The axes represent parameter values of Eq. 1, where a is litterfall and translocation, b is maximum grazing rate, and j is net primary production. The volume enclosed by the solid figure contains combinations of parameter values which do not change the state variables by more than 20% at equilibrium.

do not vary by more than 20%. The parameters represent net primary production (j), consumption by heterotrophs (b), and litterfall (a). Each of these parameters was set at the values derived from Odum and Pigeon⁹ and then increased by one-third and decreased two-thirds.

The figure shows a plane running at 45° from the "j-axis." All parameter combinations that result in no change in the equilibrium values of the state variables lie on this plane. Thus, a change in net primary production could be balanced by a change in heterotrophic feeding rate and cause a zero net change in the system. The stable volume tends to form along the diagonal of this plane, with unstable regions associated with high transfer from autotrophs to detritus combined with low productivity, and low values for litterfall combined with high productivity.

The significance of the figure is not that current models are capable of drawing realistic bounds on the stable volume; the significance lies in the potential to refine this type of analysis as ecosystem theory becomes better developed. Eventually one should be able to establish the regions around the current operating state of the ecosystem beyond which alterations must be regarded as intolerable.

Error Analysis of Ecological Models

In modeling ecological systems it is necessary to represent a large number of individual dynamic units (e.g., organisms or populations) by a small number of mathematical variables. This necessity introduces an intrinsic error because a single variable cannot duplicate exactly the behavior of a collection of individual units. This is particularly true when the units differ in their dynamic properties such as turnover time.

Because of the increasing importance of mathematical models in ecological research, we investigated the error in model predictions caused by the "lumping" process. We proceeded by setting up models for a pair of interacting populations and comparing its transient behavior with a single-variable model for the sum of the two populations. The coefficients for the lumped model are derived by assuming that the systems are identical at equilibrium, an assumption which is commonly found in the development of ecological models.

In the simplest case, the paired model is assumed to be linear and is compared to an "equivalent" single variable model. In this important case, it is possible to explicitly solve the models for their behavior at time t and arrive at an expression for the error:

$$E(t) = \frac{\Delta}{Z} \left[e^{\lambda_1 t} (fcV + fbc - UV - bU) + e^{\lambda_2 t} (bc + bU - fcV - fUV) - e^{\lambda_3 t} (Z + fZ) \right]$$

where

$$\Delta = \chi_1(0) - \chi_1(\infty)$$

$$f = \frac{\chi_2(0) - \chi_2(\infty)}{\Delta}$$

$$U = a + b + \lambda_2$$

$$V = c + d + \lambda_1$$

$$Z = bc - UV$$

$$\lambda_i = \frac{-S \pm \sqrt{S^2 - 4D}}{2}, \quad i = 1, 2$$

$$S = a + b + c + d$$

$$D = UV - bc$$

$$\lambda_3 = \frac{(I_1 + I_2)(ac + ad + bd)}{I_1(c + d + b) + I_2(a + b + c)}$$

and I_1 , a , b , c and d are the inputs and transfer coefficients for the paired model.

While this expression is extremely complex, it represents a general solution to the "lumping" error in linear models. Because it is a general solution it can be utilized to determine the error introduced by lumping any pair of units into a single variable. The expression can also be examined directly which reveals that no error results when the turnover times of the pair of units are identical. Thus it should be possible to lump pairs of populations with very similar rate processes without introducing significant error into model calculations.

LANDSCAPE PATTERNS - FOREST ISLAND INTERACTIONS

The objective of this study is to assess how forest stands function when they are relatively small in size, embedded in a matrix of nonforest land uses, and separated from each other by distances of tens to hundreds of meters. Emphasis is on how and to what extent these "forest islands" function interactively as a regional forest ecosystem under the impact of the relative isolation imposed by man. This is being addressed through a program of modeling and field surveys. It was begun in June 1975 as a coordinated effort of investigators at several universities and at Oak Ridge National Laboratory. The specific goals of the project and the relationships between the efforts of each investigator were defined at a conference at Rutgers University in April 1975. This overview describes the work that was done during summer 1975, and preliminary results are included to illustrate the project goals.

Project Overview

The project had its origin in studies which have shown aberrant trends of development in species composition of relict forest stands in Wisconsin^{15,16} and in the tropics¹⁷ as a result of their small size and isolation. To the extent that forest islands are analogous to the conditions envisioned in island biogeography, its conceptual base comes from such work as MacArthur and Wilson.¹⁸ Its thrust, however, is toward the issue of how to define objectives for managing landscape mosaics where natural vegetation occupies only a portion of the area, and establish criteria for meeting them, as was presented recently by Sullivan and Shaffer.¹⁹

Field surveys of the trees, lesser vegetation, and selected fauna of forest islands are being made in New Jersey and Wisconsin. These studies give an inter-regional comparison on the relation between the size and shape of forest islands and the number of species in their component biotic populations. Additionally, all forest islands in a 280-km² area north of Milwaukee, Wisconsin, (Fig. 13.4) are being surveyed to test several models developed to simulate the internal dynamics of forest islands and the dispersal of seeds from one forest island to another.

The ability to simulate how seed dispersal between forest islands affects their internal dynamics is a broad objective of this project. The forest stand dynamics model, FOREST,²⁰ is being revised and recalibrated so that it can be used to simulate internal stand dynamics under conditions of restricted seed availability. Revision of an air pollution dispersion model as a wind-borne seed dispersal model will account for levels of interaction between forest islands. Development of a model of seed dispersal by animals is also underway. The two seed dispersal models will be used to compute the extent to which forest islands can receive seeds from an exogenous seed source; FOREST will be used to simulate the development of forest islands under the computed conditions of seed availability and of disturbances that accompany forest utilization. Ultimately, a regional forest island ecosystem simulator will be developed so that a number of scenarios of forest island sizes, spacings, and disturbance patterns can be tested. This will lead to general statements of how landscapes can be managed to achieve specified ecologic and resource objectives.

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Fig. 13.4. Wisconsin study area and test site. Municipalities are shown in heavy stippling. The large municipality is the city of Milwaukee. Developed suburban zone around the city is shown in light stippling.

Surveys of Forest Islands

An understanding of how the species composition of the flora and fauna of a forest island is affected by its size, shape, proximity to other forest islands, and the character of surrounding land uses is a major goal. Forman and Elfstrom²¹ have studied the species composition of the flora of a number of wooded areas on the New Jersey Piedmont. This work was extended to the specific question of how the species composition of isodiametral

forest islands is related to their area. Surveys of thirty forest islands of mature vegetation that varied in size from 0.01 to 24 ha suggest that the number of species of trees and seed-eating birds stabilizes when their size reaches 2 ha (Fig. 13.5). By contrast, the number of insectivorous and predatory bird species was still increasing in the largest forest islands surveyed, and further increases are tentatively projected to 40 ha. Only forest edge bird species were present in 0.2-ha stands, while forest interior species began to appear at 0.8 ha. Litter decomposition rates, an index of decomposer populations, stabilized at 0.2 ha. It is clear that forest island size is a key landscape attribute that affects species diversity.

Fig. 13.5. Schematic diagram relating the integrity of various ecosystem components to forest size. Carnivores are the number of insectivorous and predatory bird species. Herbivores equals the number of seed-eating bird species. Producers equals the number of tree species. Litter decomposers equals leaf decomposition rate in litter bags. (Furnished by Richard Forman, Department of Botany, Rutgers University, October 1975.)

The relation between the length/width ratio of forest islands and their population structure is being studied in New Jersey. Twelve 2-ha stands having 1:1 to 36:1 length/width ratios and eight 7.5-ha stands with ratios from 1:1 to 7:1 have been selected. Three of the smaller and two of the larger stands are in the sample used for the size-population study. Only forest islands that have stable boundaries (as indicated by strong lateral branching of the edge trees) were chosen. On each forest island, trees were surveyed on ten 10 x 40-m randomly located plots, and a number of 5 x 10-m plots to assess edge effects. A reconnaissance of the entire stand was made for rare species not otherwise surveyed. Birds were surveyed by the Emlen method.²² Mushrooms were sampled in June by reconnaissance along transects. Sampling was done on all stands during a 3-day period after a precipitation event for this environmentally sensitive flora. These survey data will be analyzed and assessment of the impact of the surrounding non-forest landscape on species composition in New Jersey will be undertaken.

In Wisconsin, 43 wooded areas that range from 0.08 to 20.0 ha have been surveyed. The vegetation was sampled in four strata: (1) canopy, all trees > 10.2 cm dbh; (2) under-story trees 2.5-10.2 cm dbh; (3) shrubs 0.5-5.0 m tall; and (4) shrubs < 0.5 m tall and all herbaceous vegetation. The survey of shrubs and herbs will be completed during summer, 1976. The stratified random line strip technique²³ was used for the vegetation survey. Three bird surveys were made by a modified Emlen technique²² on transects 30 m apart on 20 of the 43 sites during July and August. The remaining sites will be surveyed during 1976, and the sites already surveyed will be revisited during the 1976 breeding and nesting season. Small mammals were surveyed using Sherman live traps. Traps were located on one transect across the width of the forest island, and another along its length for four consecutive days. Presence of larger mammals was noted by sign and observation. Trapping will be extended into 1976.

The 280-km² test area is a 29 x 9.7-km rectangle that extends north from Milwaukee. It is parallel to and 8 to 10 km from the shore of Lake Michigan (see Fig. 13.5) that has approximately 100 forest islands of varying sizes, shapes, tree species composition, and management histories, including 30 of the 43 already surveyed. The remaining stands will be surveyed by a combination of remote sensing and onsite surveys to assess tree species composition so that their stand history can be simulated with the seed dispersal models and FOREST.

FOREST -- A Forest Stand Simulator

FOREST²⁰ is being revised to model forest island dynamics. The first stage of this revision, reparameterization of the model so that it reflects the ecologic conditions in the northern hardwood stands located in the test area, was completed in August 1975.²⁴ Further revision is underway so that FOREST can accommodate exogenous seed supplies.

Additionally, the distribution of overstory seed producing trees is being studied in relation to the pattern of reproduction to assess the assumption in FOREST of ready accessibility of seedlings for ingrowth to larger size classes on large blocks of forest. Trees > 7.6 cm dbh were mapped on a 1.8-ha square plot, and trees 1.4 m tall to 7.6 cm dbh were sampled along strips. Reproduction 0.3 m to 1.4 m tall was mapped on a centrally located 0.6-ha plot. Germination and early seedling survival patterns as well as seed dispersal are implicit in the locations of reproduction of each species. The spatial bi-spectral analysis being applied to the field data will give insight into the spatial arrangement of reproduction relative to the overstory, but not the single process of seed dispersal.

Seed Dispersal Models

Seed dispersal from one forest island to another is a key ecologic process whose general relation to distance is readily described. It is also a multifaceted operation about which much has been written. The extent and utility of the extant information was assessed through two literature searches, one on wind-borne seed dispersal, the other on seed dispersal in which animals are the agents. Annotated bibliographies on each subject, with over 300 citations, have been completed and are being edited.

Seed dispersal models appropriate to inter-forest dispersal are being developed. A wind dispersal model that accounts for dispersal up to about 2 km from a seed source in various directions in response to a variety of meteorologic conditions was sought. The Atmospheric Transport Model²⁵ is being adapted to this new use by: (1) substituting a seed dispersal rate that reflects the timing of seed ripening and the effect of wind speed on seed release for the assumed constant source strength; and (2) adjusting the dispersion parameters for the relatively heavy seeds (compared to atmospheric pollutants) with their more rapid fall rates. The model will then accept wind rose data and data on seed fall rates for each tree species with wind-dispersed seeds to provide information on the relative numbers of seeds being dispersed to up to ten locations.

The model of seed dispersal by animals rests upon an assessment of how animal behavior leads to seed dispersal. Since the literature points to birds as a major agent of dispersal for the tree species (such as black cherry and the oaks) in the Wisconsin test area, the

first model will focus on this fauna. The literature review has provided general statements about distances over which birds transport seeds, although no appropriate model of this aspect of bird behavior was found. Our task is to draw upon information about animal behavior while designing a model that will give order-of-magnitude assessments of seeds available to forest islands at various distances from seed sources where the intervening nonforest landscape also may be a determinant of animal behavior.

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14. Environmental Information

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ECOLOGICAL SCIENCES INFORMATION CENTER

In support of ERDA's program of bioenvironmental research, the Ecological Sciences Information Center (ESIC) selects, abstracts, and indexes information from published documents. ESIC collaborates closely with ERDA scientists in the Environmental Sciences Division to compile computerized information files (or data bases) on the environmental effects of cooling electric generating stations and on radioecology. Information support is provided to the assessment of the impact of both nuclear and fossil energy fuel cycles. As part of this information support, an information overview⁴ entitled "Environmental, Health and Control Aspects of Coal Conversion" has been written in conjunction with the ORNL Environmental Resource Center.

The sources and interactions of radionuclides in the environment, pathways to man, and effects in man and experimental animals is a concern of ESIC. A computer-searchable data base resulted from literature references and abstracts originally assembled as the basis for a comprehensive literature review by C. W. Francis on the movement of radionuclides in soil and uptake by plants. Many of the 1400 references are related to the major fission products in radioactive fallout, strontium 90, and cesium 137, but nearly all fission products are included, as are a large number of biologically important activation products and various naturally occurring radionuclides. Transport of uranium and thorium in the environment as related to the thorium cycle is the subject of a data base, annotated bibliography, and critical review. ESIC has compiled a data base of more than 5000 references on the environmental aspects of uranium and the transuranics.

Another subject of concern to ESIC is that of the effects resulting from the cooling necessary for electric generating stations. A data base on the effects of temperature on aquatic organisms was initiated to review the 1971 literature, and it has grown to about

3500 references with the addition of the 1975 literature. Scope includes reviews, site studies, producers and consumers, distribution, temperature tolerance, tissue and organ responses, reproduction, growth, feeding, temperature and other stresses, activity, predator-prey relations, decomposers, diseases, and beneficial uses. Environmentalists are also concerned about the effects of power plant chlorination and as a result a data base was built on the chemistry and effects of chlorine in aquatic systems. To support research on a fish population model to predict the effects of power station operations on representative fish species, ESIC compiled a data base on the life history of striped bass. Annotated data bases on fish protection at intake structures, dams, and cooling towers are also available.

Other data bases compiled in collaboration with researchers in the Environmental Sciences Division include mathematical modeling as related to fish populations and the role of the ecologist in assessing environmental impact. An indexed and annotated data base is being compiled to assist in the assessment of global carbon cycling and its possible influence on weather. The journal *Ecology* was searched from 1956 through 1976 for articles pertaining to ecosystem analysis, either subprocesses or total systems, and an annotated and indexed data base was built. Personal collections of references to the fauna of Tennessee and the flora of Arizona are being input into computer-searchable files. The first 500 publications of the Environmental Sciences Division were abstracted, indexed, and stored in computer-searchable form.

EDFB INFORMATION CENTER

Marked improvement has occurred in the past year in the documentation of EDFB Memo Reports (67 to 83%), EDFB/IBP reports (56 to 79%), and open literature contributions (33 to 57%) (Table 14.1). The situation regarding EDFB data sets (Table 14.2) has changed minimally (51 to 54%) due principally to debugging problems in initiating and implementing NUTIS, the Numeric and Textual Information System. With the exception of data sets, for the first time complete documentation of EDFB publications exists for a given year. This is true for 1970 and 1971 and nearly so for 1972 (95% complete). Overall documentation increased from 50 to 70% during the past year. Hopefully, next year's effort will result in documentation of all available EDFB publications.

Issues 2-3 of Volume IV of ABSTRACTS reflect a number of improvements and changes made in the past year to more efficiently utilize page space and thereby increase the number of abstracts in each issue. Space utilization was improved primarily by program changes in the computerized publishing procedure, including more consistent and complete page filling in the text, three (as opposed to two) column format in the indices, and sequential printing of author, data, title, and publication (or data set) description/designation without field identifier. With these changes, increased numbers of abstracts (about 30%) are now being printed on approximately the same number or fewer pages.

There has also been an attempt to improve internal consistency within the ABSTRACTS data base, and a number of changes were initiated. The entire data base will be edited for consistency in the near future. For example, keywords are to be standardized with provision for addition of a few nonstandard terms. The standard keyword list will be revised annually to accommodate new terms. These are now being reviewed within EDFB. One change is use of CFB, DSB, EDFB, GRB, and TNB as acronyms for uniformly identifying the Coniferous Forest Biome, the Desert Biome, the Eastern Deciduous Forest Biome, the Grasslands Biome, and the Tundra Biome, respectively. These, along with U.S.IBP in conjunction with report designation, allow each abstract to "stand alone" for identification purposes. Merging with other data bases in the future will be facilitated if the need arises. The editor has requested feedback on proposed changes that will be implemented following discussion with editors from other biomes.

During the year, ABSTRACTS, U.S.IBP ECOSYSTEM ANALYSIS STUDIES, Vol. IV, No. 2 (56 pp., May 1975) was produced.

Other center activities included, but were not limited to, the following:

(1) Searches of bulk data bases (primarily BIOSIS and BIORESEARCH INDEX) on topics including vertebrate bioenergetics, vegetation corridors, nitrogen fixation, biophysics of

Table 14.1. Summary of documentation of EDFB reports, publications, and data sets in ABSTRACTS, USIBP Ecosystem Analysis Studies

Type of record	Publication, report, or data date	Total identified	Total documented in ABSTRACTS ^a	Percentage documented
Memo reports	1970	10	10	
	1971	139	139	
	1972	170	159	
	1973	95	35	
	1974	10	9	
	1975	2	2	
Subtotal		426	354	83
EDFB-IBP reports	1970	5	5	
	1971	11	11	
	1972	13	13	
	1973	10	8	
	1974	11	5	
	1975	3	0	
Subtotal		53	42	79
Contributions	1970	11	11	
	1971	16	16	
	1972	19	19	
	1973	67	45	
	1974	64	17	
	1975	12	0	
Subtotal		189	108	57
Data sets	1970	60	45	
	1971	62	29	
	1972	53	24	
	1973	15	5	
	1974	-	-	
	1975	-	-	
Subtotal		190	103	54
TOTAL		846	592	70

^a Through Vol. IV, No. 4.

Table 14.2. EDFB data sets - Status of documentation, storage, and availability

Site	Total anticipated	Total received	Total (%) documented in ABSTRACTS ^a	Total (%) on ORLOOK	Total stored	
					Mag tapes	Card decks
Coweeta	37	28	13 (35)	9 (24)	3	7
Lake George	27	18	15 (55)	11 (41)	1	3
Lake Wingra	103	49	24 (23)	23 (22)	14	23
Oak Ridge	88	68	37 (41)	33 (38)	18	30
Triangle	38	27	14 (37)	13 (24)	9	13
TOTAL	293	190	103 (35)	89 (30)	45	76

^a Through Vol. IV, No. 4.

nitrogen fixation, microbial conversion of mercury, coal fly ash, forest habitat/succession, invertebrate ecology, seed dispersal, paddlefish, biogeography, forest mineral cycling, *Canis latrans*, spider behavior, and isopod bioluminescence.

(2) U.S.IBP data base searches on ORLOOK included those on forest mineral cycling models, Tennessee IBP studies, biomonitoring programs, and Tundra Biome reports.

(3) Other frequent information requests were for current and back issues of ABSTRACTS and other EDFB documents. Occasional requests for information from other ORNL data bases were honored. Twenty to 30 requests each month are being received.

(4) Meeting attendance included:

(a) ERDA Workshop on Improved Exchanges of Data Bases and Models (DBER/ERDA, Germantown, Maryland, April 28-29, 1975). The workshop consisted of representatives of all ERDA national laboratories, presenting brief summaries of their capabilities and needs, with a statement of problems associated with exchange of informational data bases and implementation of models.

(b) ERDA Conference on Computer Support of Environmental Science and Analysis (MITS/ERDA, Albuquerque, New Mexico, July 9-11, 1975). Speakers on the conference program were ERDA staff or ERDA contractors who addressed such topics as computerization of data from air pollution, watersheds, environmental impact, energy, and cartographic studies. Prospective computer hardware and software capabilities were discussed in terms of resource sharing.

(c) BIOSTORET (MDQRL/EPA/Cincinnati by Dr. C. E. Weber at Environmental Sciences Division/ORNL, July 23, 1975). Development of BIOSTORET, a system for storing aquatic numerical data, was discussed in detail.

(d) ESD numerical data meeting (R. H. Strand at various times, Environmental Sciences Division/ORNL). Numerical data handling capabilities were described and discussed in a series of meetings.

(e) IACF (Information Analysis Center Forum), ORNL. Local information system developments are discussed at irregularly scheduled meetings, and selected common problems are solved by committees.

(f) ASIS (American Society for Information Sciences). Monthly meetings of the local chapter have speakers that describe current information system activities in the Oak Ridge area.

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15. Educational Activities

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W. F. Harris	

One of the major accomplishments during the past year was the development of a set of goals defining Division Policy in the broad field of education. The paragraphs which follow discuss the activities and accomplishments related to these goals.

Goal 1. *"Extention Function" -- To contribute regionally, nationally, and internationally to undergraduate, graduate, postdoctoral, and other continuing education. The Division collectively represents an impressive pool of human and mental resources. Within the broad research and development goals of the Laboratory, an ongoing contribution to education, particularly at the post-secondary level, is seen as a vital means of extending the influence of the Division. We are committed to conveying understanding, awareness, and skill in environmental science and management through the interpersonal mode of education. To this end we promote an ongoing program of internships, laboratory rotations, and other on-site learning experiences at the post-secondary level. In addition, the basic skills and interests of Division staff can be shared through in-house courses, University of Tennessee and ORAU-sponsored courses, and other arrangements.*

Given the large and highly competent staff of the Division -- one of the largest pools of environmental sciences manpower in the world -- we recognize our responsibility not only in specialized research and development but also in education and training in the field of environmental sciences. Additionally, we recognize that Division staff members and research programs benefit from working with students. Since staff-student interaction is on a virtually one-to-one basis, projects are very carefully designed and supervised, and many of the results produced contribute substantially to the advancement of scientific knowledge.

At the interface between the Graduate School of Biomedical Sciences, a University of Tennessee graduate program conducted in the ORNL Biology Division, and the Environmental Sciences Division, there is an emerging field of research of great importance. In recognition of the mounting importance of this field we have organized a special committee within the Division to work with a parallel committee in the Biology Division to develop guidelines and work to implement an interdisciplinary program. Two of the mechanisms used to date to foster interaction have been laboratory rotations by Biomedical students in Environmental Sciences Division laboratories and summer undergraduate trainees (sponsored by the Carnegie Foundation) in a Biology Division-administered program working on research projects in the Environmental Sciences Division.

Plans are being laid for joint seminars, basic interdisciplinary course offerings, dissertation research bridging the two fields, and other means of cooperation. Student participation during the past year has come from a variety of institutions and has involved several programs (Table 15.1.).

Table 15.1. Numbers of students in ESD programs, October 1, 1974 to September 30, 1975

Program	Number
ORAU Undergraduate Research Participants	10
SCUU (Southern College University Union)	6
Emory University	6
University of Tennessee (graduate)	10
University of Kentucky (graduate)	1

In addition to these, a number of students were supported on subcontract research for the Eastern Deciduous Forest Biome Program at various universities (Table 15.2.).

Table 15.2. Institutions and number of graduate students involved in the Eastern Deciduous Forest Biome program

Institution	Number
University of Georgia	2
Rensselaer Polytechnic Institute	4
University of Wisconsin, Madison	6
Case Western Reserve University	1
Duke University	1
Southern Illinois University	1
University of Wisconsin, Milwaukee	2
Rutgers University	2

Goal II. *"Internal Function" -- To promote continuing education of staff. Division staff are encouraged and enabled to participate in "life-long" learning. To this end, on-the-job training, in-house training and "refresher" courses, tuition reimbursement, job schedule adjustment, and other opportunities are provided. Continued professional competence is promoted through participation in national and regional meetings, workshops, and courses. A seminar program is conducted to help staff keep abreast of current research. The Division is committed to enabling each of its staff to develop to the fullest possible extent in accord with his or her interests*

and abilities. This is vital both to the satisfaction and continuing competence of staff members and to the continued high level functioning of the Division.

Table 15.3. lists the seminars sponsored by the Education Committee.

Table 15.3. Speakers, dates, and topics in the ESD seminar series during the past year

Date	Speaker and institution	Seminar title
Sept. 25, 1974	W. Porter, Univ. of Wisconsin	Heat Transfer Engineering as Applied to Animals and Their Environment.
Oct. 7	D. Force, California State Polytechnic University	The Development of Complexity and Stability in Ecosystems
Oct. 21	A. Kowalczewski, University of Connecticut	The Role of Aquatic Macrophytes in the Production of a Eutrophic Lake
Oct. 23	D. Edgington, Argonne National Laboratory	Natural and Artificial Radionuclides in Lake Michigan
Nov. 6	T. Zaret, University of Washington	A Predation Model of Lake Zooplankton Community Structure
Nov. 21	C. Turnbull, Virginia Commonwealth University	Civilized Man and Primitive Man: Their Views on the Environment
Dec. 4	E. Peele, ORNL, Energy Division	Nuclear Power Plants
Dec. 11	D. Bunting, University of Tennessee	Zooplankton: Entrainment and Thermal Effects
Dec. 18	J. Schindler, University of Georgia	Significance of Detrital Election Flux in Intermediary Metabolism of Soft Water Lakes
Jan. 8, 1975	W. Smith, Yale University	Root Exudation
Jan. 15	H. Allen, National Commission on Water Quality	Physiological-Ecological Studies of the Carbon Cycle in a Softwater New England Lake
Jan. 22	L. Harris, University of Florida	Game Management in East Africa
Jan. 29	J. Craig, El Paso Natural Gas Company	Environmental Considerations for Coal Gasification Facilities
Feb. 5	F. McCormick, University of Tennessee	An Overview of Ecology Programs at UT
Feb. 12	K. Z. Morgan, Georgia Institute of Technology	The Linear Hypothesis of Radiation Damage...Is it Conservative
Feb. 13	R. Forman, Rutgers University	Ecosystem Size: A Stress on the Forest Ecosystem
Feb. 19	J. Moore, University of Tennessee	Economic and Environmental Aspects of Strip-Mining

Table 15.3. (Continued)

Date	Speaker and institution	Seminar title
Feb. 26	B. J. Copeland, North Carolina State University	The Relationship of Stream Flow to Estuarine Productivity
Mar. 5	F. James, National Science Foundation	New Graphic Techniques and Multivariate Analysis of Complex Systems
Apr. 2	R. Darnell, Texas A & M University	The IBP Conservation of Ecosystems Program
Apr. 9	D. Heinle, University of Maryland	Energy Input: Outflow of a Saltwater Marsh
Apr. 16	W. Herrnkind, Florida State University	The Power of <i>In Situ</i> Marine Research Methods
Apr. 23	R. Bachman, Iowa State University	Land Runoff of Phosphorus and the Prediction of Algal Levels in the Lakes
Apr. 30	R. Wetzel, Michigan State University	Primary Production in Aquatic Systems
May 12	T. Webb, Brown University	Eleven Thousand Year History of the Vegetation of Northeastern North America
May 13	C. Roswell, University of Maryland	Lithomorphic Sequences in the Central Folded Appalachians
May 19	W. L. Lindsay, Colorado State University	Equilibrium Approach to Chemical Transformations in Soils
July 23	A. Peck, CSIRO, Australia	Interactions Between Land Use and Salt Cycling Through Australian Water Sheds
July 28	V. Adams, University of Tennessee	Time-Delay Effects in Host-Parasite Models
July 30	C. Weber, EPA, Cincinnati	Development and Implementation of BIOSTORET
Aug. 13	S. Bratton, National Park Service	Management Problems in the Great Smoky Mountains National Park: Wild Boar, Endangered Species, and Grassy Balds
Sept. 10	R. Jenkins, National Reservoir Research Program, Fayetteville, Arkansas	Estimating Fish Production and Harvest in Large Man-Made Lakes
Sept. 15	W. Leggett, McGill University	Migrations and Population Dynamics of American Shad in the Connecticut River
Sept. 13	R. Giles, Virginia Polytechnic Institute	Use of Large Scale Data Banks in Land Use Decision Systems

Goal III. *"Communication-Information Function" -- To promote communication to inform various audiences of Division programs, results, and applications. Uncommunicated research is useless. To insure that research results and potential applications are communicated effectively, efforts are made (a) to facilitate use of audio-visual media (including the development of self-communicating displays, films, and slide presentations), (b) to maintain high quality publication of results and to facilitate production of such publications through solicitation, assistance in writing, typing and editorial services, internal review, and financial support, and (c) to encourage and facilitate interpersonal communication of Division activities through outside speaking engagements, seminars, and tours. The Division is committed to promotion of a varied, high-quality, "open" communication-information function.*

During the past year we have mounted a substantial effort in development of audio-visual materials (display panels, poster session materials, slides, photographs, and other products) to better communicate Division programs. This has been undertaken in recognition of the need for such materials, especially in view of our plans to occupy a new Environmental Sciences Laboratory. We recognize the need to communicate effectively to a variety of publics, including, but not limited to, our scientific peers. Under the direction of the Audio-Visual Communications Committee (Figure 15.1.) two major displays have been developed, equipment needs have been clarified especially with respect to the new building, a brochure has been produced, and numerous audio-visual services have been provided to Division research staff. We are presently preparing materials for posters, multi-projector synchronized slide-sound presentations, and self-guiding displays on additional programs. In addition we are coordinating audio-visual services for Division staff, developing a program of instruction for staff in the field of oral presentation, and developing and testing a computer filing and retrieval system for photographs that appear to have general potential for application throughout ORNL.

The results of this activity, publication and presentation, are listed in the appendix to this volume.

Fig. 15.1. Environmental Sciences Division Audio-Visual Communications Committee.
 Left - right: E. G. Struxness, Scott D. Hicks, Joe Pardue, Sig Christensen,
 Helen Pfuderer, F. G. Goff, Ron K. McConathy.

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PART V. ENVIRONMENTAL ASSESSMENTS

16. Radiological Analyses and Applications

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For the past several years, our development of models for understanding and predicting radionuclide transport in the environment and our involvement in radiological assessments for NRC and ERDA have greatly extended our capabilities in this area of endeavor. This state-of-the-art methodology was used extensively this past year in the radiological sections of NEPA statements and other special assessments. The flexibility of the methodology for application to environmental assessments is seen in the large number of nuclear facilities and reactor concepts that were evaluated for radiological impacts. Our work included technical evaluations of fuel cycle facilities to support two breeder reactor concepts in addition to conventional light-water and gas-cooled reactors. For the second year, a special application of the methodology outside the nuclear power program involved assessments of potential radiation exposures to members of the public from the use of a variety of consumer products containing radionuclides. This work resulted in completion of the CONDOS methodology and computer code to assess potential radiological impacts from the manufacture, storage, distribution, use, and disposal of unlicensed consumer products.

Our involvement in different types of radiological assessments made it necessary to incorporate many new features into the methodology while still meeting our commitments in the NEPA and the "as low as practicable" activities. Our modeling philosophy continues to emphasize the construction of models which can be implemented with available data bases and which are reasonably easy to use in applied problems. Feedback between the methodology development and the applications work provides favorable conditions for meeting the programmatic needs of ERDA and NRC with realistic assessments.

Another important accomplishment this year involved the first application of our CUMEX nonnuclear environmental pollution index and methodology. An assessment was completed of cadmium releases from a commercial smelter. This application of CUMEX helped to lay the groundwork for other more comprehensive studies to be undertaken in the coming year.

The ESD Plowshare program, which had been active since 1967, was terminated at the end of the 1975 fiscal year. This move was necessary because of the drastic curtailment of ERDA's national Plowshare program. Much of the methodology developed for this program is being integrated into other ongoing projects, including the assessment of nonnuclear pollutants released to the environment.

CUEX PROJECT

Aquatic Pathway Modeling

A model identified with the code name AQUAMOD was developed to simulate radionuclide movement through aquatic pathways to man.⁴ The major objective of this model is to estimate the time-dependent intake by man of radionuclides released into an aquatic ecosystem. A secondary objective is to estimate the environmental buildup in accumulation sites of long-lived radionuclides released over extended time periods. The model as depicted in Fig. 16.1 consists of (1) basic components (receiving water, interstitial water, exchangeable sediments, and nonexchangeable sediments) that form the major abiotic accumulation

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Fig. 16.1. Block diagram of AQUAMOD (solid lines). Dashed lines associated with x_9 show the macrophyte accumulation site sometimes included. Aquatic food 3 includes a loss term $\lambda_{b,7}$ because the concentration factor and turnover time of the element in this compartment were known. Aquatic food 4 represents benthos for which sediment or interstitial water concentration factors were available.

sites for elements; (2) additional accumulation sites, such as macrophytes, that may be required in addition to the basic abiotic sites to account for the total element content of the system; and (3) every aquatic food harvested from the system. Modeled in this way, the time dependence of the radionuclide in the system is governed completely by the dynamics of the accumulation sites. The one-way couplings in some cases ignore transfer from aquatic food back to the accumulation sites even though this is known to occur. The high degree of system simplification is necessitated by data limitations. However, in many aquatic systems these simplifications may not preclude realistic simulations of time-dependent radionuclide concentrations in aquatic food compartments and accumulation sites

(at least in the short term). Model complexity for a particular radionuclide can be expanded as additional data become available. Modeling objectives are achieved within the extent and accuracy of existing data. The model is structured so that in the event of data limitations the predicted radionuclide intakes by man are more likely to be overestimated than underestimated. Basic data requirements of the model include: (1) elemental content and turnover rate of each accumulation site in the system; (2) concentration factors, turnover rates, and harvests of each edible aquatic food; and (3) physical transport parameters, such as turnover rate of the receiving water and transfer rate between this water and the bottom sediment. The aquatic system is assumed to be operating normally in equilibrium, and conservation of radioactivity is ensured. The addition of a radionuclide and its subsequent transfer through the system is viewed as a small perturbation which in no way affects the system. The predicted radionuclide content ($\mu\text{Ci/g}$) of an aquatic food compartment multiplied by man's consumption rate (g/day) for that food, yields an estimate of the daily radionuclide intake rate ($\mu\text{Ci/day}$) via that particular pathway.

AQUAMOD Simulation of ^{137}Cs Behavior in an Oligotrophic Lake

A constant-coefficient version of AQUAMOD⁴ was built for ^{137}Cs with as much detail and realism as was allowed by the available data base,⁵ and the dynamics of specific activity ($\mu\text{Ci } ^{137}\text{Cs/g}$ stable cesium) in components of a hypothetical oligotrophic lake following a pulse input of ^{137}Cs were simulated. Transfer coefficient values determined from the data base are given along their respective transfer arrows in Fig. 16.2. All organisms

Fig. 16.2. Specific activity model for ^{137}Cs movement in an oligotrophic lake. This model indicates the complexity that was achieved with AQUAMOD for selected radionuclides.

in the model except fishes are treated as single compartments. Fishes are treated as the sum of two coupled compartments, one fast and one slow. The fishes chosen to populate the hypothetical lake represent a broad spectrum of species types found in lakes, both in terms of feeding habits and rate constants. Rate constants for Fish 1 and the detritus-feeding fish were derived from studies of bluegills (*Lepomis macrochirus*)⁶ and carp (*Cyprinus carpio*),⁷ respectively, from White Oak Lake at ORNL. Fish 2 represents the top carnivore in the lake, a highly desirable game species likely to be eaten by man.

Time histories of ^{137}Cs specific activity in components of the hypothetical oligotrophic lake were predicted using the time history of ^{137}Cs concentration in lake water (140-day half-time) from the experimental work of Kolehmainen et al.,⁵ as a forcing function. A preliminary evaluation was made of the model and the transfer coefficients presented in Fig. 16.2 by comparing the predicted time histories of specific activity in biota in the hypothetical lake with the experimental measurements of Kolehmainen et al. Bioaccumulation factors were used to convert predicted specific activities into radionuclide concentrations to facilitate the comparisons. Comparison of the predicted ^{137}Cs concentrations of the hypothetical fishes with those of perch (*Perca fluviatilis*) captured in the experimental lake⁸ is shown in Fig. 16.3. The predicted concentrations of the fishes

Fig. 16.3. Comparison of predictions of ^{137}Cs concentration in the hypothetical fishes with field data obtained for perch by Kolehmainen et al. (1968).

form an envelope around the perch data because of the perch's feeding habits and rate constants. The perch, a predator of benthic invertebrates in the oligotrophic lake, has feeding habits which are, in terms of specific activity flow, nearly equivalent to those of Fish 1. The simulation agrees well with the experimental results considering the uncertainty of the estimated rate constants of the perch.

Data sets are being sought for additional validation of AQUAMOD, and thus for further support of the premise that reasonable parameters used in systems analysis equations provide realistic predictions of radionuclide transfer through the environment.

Development, Extensions, and Applications of the AIRDOS Computer Code

The AIRDOS computer code⁹ was revised into modular format during the past year to make it easier to apply the many options required for assessment work. The new structured version, which is not yet fully operational, will also make it possible to add new environmental models to the code with a minimum of reprogramming. The models used for external exposures have been refined to estimate external doses for each organ individually. This eliminates some excess conservatism in dose estimates. The aquatic pathway model, AQUAMOD, was prepared for inclusion as a subroutine in AIRDOS. A subroutine was written also to enable AIRDOS to treat multiple sources, and a finite plume model was developed to calculate gamma ray exposures from overhead plumes. We plan to use this model indirectly to generate fitting parameters for a simple, fast-running subroutine for AIRDOS.

AIRDOS was applied to a large variety of environmental analyses and impact statements during the past year. A large radionuclide data bank has been assembled as a result of carrying out these various assessments.

Internal Dosimetry Methodology

Several computer codes have been prepared to strengthen computing capabilities and facilitate the addition of radionuclides to the internal dosimetry data base. One code calculates the dose equivalent to each of 22 human organs per unit residence of a radionuclide in the organ; inputs to the code are the energies and intensities specific to the radionuclide for each radiation type. A second code, INDOS IV, estimates the doses accumulated by the lungs, GI tract, and other organs of man following the ingestion or inhalation of a radionuclide. The contributions of radioactive daughter products are calculated explicitly rather than being included in effective absorbed energy factors. The intake rates for the two exposure modes are input to INDOS IV as step functions of time. The models implemented are compatible with those of ICRP Publications 10¹⁰ and 10A.¹¹

As a first step toward incorporating more recent internal dosimetry models, a code of limited but useful capabilities has been prepared. This code NEWREM calculates inhalation and ingestion dose conversion factors (i.e., dose commitment per unit intake) for various organs; exposure is assumed to be acute. Models for the lungs and GI tract are derived from the ICRP Task Group Lung Model^{12,13} and the work of Dolphin and Eve,¹⁴ respectively.

Carbon-14 Assessment Methodology

Existing data and methods for estimating the dose to man resulting from the release of ¹⁴C to the environment as carbon dioxide have been reviewed. On the basis of recently published information^{15,16} new dose-rate factors relating the specific activity of ¹⁴C in tissue to the resulting dose rates to various organs have been computed. The method of dose estimation rests on the assumption that the ¹⁴C specific activity in man's tissues approaches a value which is an average of the steady-state specific activity in the air that he breathes and in the local atmosphere at each point of production of his dietary intakes; the average is weighted by uptake coefficients for inhalation and ingestion, and those terms corresponding to the latter exposure mode are weighted further according to the apportionment of the dietary intake of carbon among the various sources.

To give an indication of comparison of dose estimates based on these new factors and the metabolic models of ICRP Publication 2,¹⁷ Table 16.1 shows steady-state dose rates from natural ¹⁴C computed by both methods.

Table 16.1. Comparison of ^{14}C natural background doses from specific activity factors and ICRP-2 metabolic models^a

Organ	Total ^b dose rates at steady state (millirem/year)	
	Specific activity	ICRP-2 metabolic model ^c
Total body	1.3	0.47
Fat	3.6	2.0
Bone ^d	0.79	0.47

^aAssumed atmospheric specific activity = 6.1 pCi/g carbon.

^bIntake via inhalation and ingestion.

^cAssumptions: Dietary intake rate = 400 gC/day.
Breathing rate = 20 m³/day. Total carbon
concentration in air = 300 ppm CO₂ by volume.

^dRelative damage factor $n = 5$ omitted.

Compilation of Methodology for the Prediction of Environmental Transport of Radioactivity and Dose Estimation

The first draft of a report (ORNL-4992) which describes and summarizes the methodology employed by the Radiological Analyses and Assessments Group in preparing environmental radiological assessments has been extensively revised. Chapters on external and internal dose estimation were completely reorganized and rewritten, and some new tables were computed to enhance the usefulness of the document to readers who are without access to a computer. Many other tables were recomputed to reflect revisions and corrections in the data base. In order to conserve paper, several appendices were omitted, and much of the other material was compressed.

Documentation of Bioaccumulation Factors Important for Power Plants in the Nuclear Fuel Cycle

A report on "Bioaccumulation Factors for Radionuclides in Freshwater Biota" has been submitted for publication following an extensive technical review by members of the Environmental Sciences Division and the Radiological Assessments Branch of the U. S. Nuclear Regulatory Commission. The 220-page document provides a concise review of available information on bioaccumulation factors for tritium and the isotopes of cesium, strontium, iodine, manganese, and cobalt in major biotic components of freshwater environments. The document also provides a methodology for estimation of bioaccumulation factors. This methodology includes a derived equation which may be used to convert the bioaccumulation factors for stable isotopes to those for short-lived radionuclides when such factors for the latter may not be available. Simple models are presented that relate the bioaccumulation factors for a given radionuclide to the concentrations of stable elements and carrier elements in the water. These models are important because the wide variations in

bioaccumulation factors exhibited by a given organism in different bodies of water may be due to the differences in stable-element and carrier-element concentrations in the water. The effects of various factors including the physicochemical form of the radionuclide may result in deviations from the models and these factors are discussed. Bioaccumulation factor data are examined in the context of the models, and recommended bioaccumulation factor relations are given for each radionuclide in each biotic component studied. The recommended bioaccumulation factor relations are directly applicable to studies directed toward calculation of radiation dose to biota and man and the document itself provides an excellent reference for those involved in radiological hazards assessment for environmental impact statements.

ICRP Draft Report, "Principles and Methods for Use in Radiation
Protection Assessments Related to Planned and Unplanned
Releases of Radioactive Materials into the Environment"

A draft report has been prepared by a task group chaired by E. G. Struxness for Committee 4 of the International Commission on Radiological Protection (ICRP). The report includes the development of a systems analysis methodology for use in the context of radiation protection assessments and sample calculations to show how this methodology can be applied in practice. Two mathematical methods (concentration factor and systems analysis methods) are described which are useful in predicting the relationship between releases of radioactive material into the environment and the expected radiation dose or dose commitment to individuals and populations which could result therefrom. In both methods the expected dose to man is estimated from conceptualized environmental and food-chain compartment-kinetics. The report has been submitted to Committee 4 of the ICRP for final review and publication as another report in ICRP's regular series of publications.

CUMEX PROJECT

Demonstration of a Nonnuclear Assessment Methodology

Extensive work has been performed on the development of a methodology for assessment of nonradioactive pollutants. The nonnuclear methodology is designated by the acronym CUMEX and initial research efforts have concentrated on performance of a site-specific study to demonstrate the feasibility of this assessment methodology.

Initial efforts in the CUMEX project involved selection of a specific nonnuclear pollutant about which a sufficient amount of information was known to permit detailed study and of a specific site where significant amounts of the pollutant had been released. Cadmium was selected as the pollutant that would be used in the initial demonstration of the CUMEX concept, and an industrial smelting complex located near Helena, Montana was chosen as our site-specific application. The Helena Valley Area was the subject of a 1972 environmental study performed by the U. S. Environmental Protection Agency.¹⁸ From this EPA report we were able to obtain specific information on pollutant source terms, meteorological conditions, cadmium concentrations in soil and biota, and measures of cadmium intake by man.

Computer models were used to predict the environmental transport of cadmium from information on the atmospheric source terms and site-specific environmental data. The Atmospheric Transport Model (ATM),¹⁹ a submodel of the Unified Transport Model developed by members of the Ecology and Trace Contaminants Project at ORNL, was applied to the area surrounding Helena to predict the air concentrations and depositions of cadmium in the vicinity of the smelter. The atmospheric releases of cadmium and seasonal atmospheric stability data were taken from the EPA report while monthly rainfall and wind-rose data were obtained from the National Oceanic and Atmospheric Administration - Asheville meteorological report.^{20,21}

The ATM predicted total wet and dry deposition values and air concentrations for 48 receptor points uniformly spaced at distances of up to eight miles from the point of release. Average yearly cadmium deposition values predicted by the ATM one mile east of the smelter range from 0.7 mg/m²/month for a 1-μ particle to 3.5 mg/m²/month for a 10-μ

particle. Actual cadmium deposition values measured by the EPA within a radius of one mile from the smelter range from 1 to 4 mg/m²/month for particles of unspecified size. Measured data showed a deposition of from 0.1 to 1.0 mg/m²/month within 60 sq miles of the smelter. Simulated results ranged from 0.1 to 0.3 mg/m²/month for 1- to 10- μ particles at distances of eight miles east of the smelter. Measured cadmium air concentrations ranged from 0.6 to 10 μ g/100 m³ while predicted results ranged from 3 to 7 μ g/100 m³ for 1- to 20- μ particles one mile east of the smelter.

The amount of cadmium that subsequently reaches man through the terrestrial food chain was predicted through use of the terrestrial transport model TERMOD, a model originally created for use in our radiological assessment methodology.²² The terrestrial transport model was adapted to provide estimates of cadmium concentrations in man from consumption of specific items in the food chain. Application of the model to predict food chain concentrations in the Helena area yielded estimates of cadmium concentration which were then compared to data presented in the Helena document prepared by the EPA.

Modifications made in the radiological version of TERMOD included derivation of an expression for the uptake of cadmium by man from the subsurface soil pool and derivation of an expression for the uptake of cadmium from soil to pasture grass. The behavior of cadmium in the terrestrial food chain has been studied by following a pulse release of cadmium through the environment. Assuming a pulse release with a deposition of 15 μ g/m², we have examined the subsequent rate of intake by man and the percent intake via inhalation and consumption of milk, beef, or truck crops. Intake rates were calculated for a daily dietary intake of 2500 g and assumed cadmium environmental half-times of either 10 or 50 years in subsurface soil pool. Preliminary calculations involving a 10-year environmental half-time indicate that the total intake of cadmium by man is maximum at the time of release, 1 μ g/day, and decreases by a factor of 30 in the 100 days following release. Intake values decrease further with time and reach values of 3.5×10^{-4} μ g/day at 50 years post exposure. The intake from milk is maximum at 1.1×10^{-1} μ g/day on the second day after release, and the intake from beef is greatest 100 days after release at a value of 1.2×10^{-2} μ g/day.

Physiological models were adapted from research published by Friberg²³ to predict the uptake and retention of cadmium resulting from exposure to the various environmental pathways simulated by the ATM and TERMOD. The physiological models were used to calculate cadmium concentrations in critical organs as a function of magnitude and duration of cadmium exposure. Friberg has associated a concentration of 200 ppm wet weight cadmium in the kidney cortex with induced renal dysfunction in man.²³ Initial calculations indicate that this renal concentration could be attained in an individual exposed to an air concentration of 2 μ g cadmium/m³ for 50 years. This same critical level could be reached in an individual who ingests 200 μ g cadmium daily for 50 years. As a point of reference it must be mentioned that the nation's air contains an average concentration of 0.002 μ g cadmium/m³ and that the average American ingests from 130 to 162 μ g cadmium/day.

Questions concerning operational guidelines for existing facilities and assessment criteria for potential sites have been studied from the point of view of relating any prescribed tissue concentration limits to environmental levels (e.g., in air and soil) and the latter to the emission rate at the source. While we have stopped short of recommending specific limits at any of these stages, we have made and discussed comparisons of the Helena test case with legal limits, with documented health effects (e.g., correlation of kidney disease with concentrations in the kidney cortex), and with average exposures for the U. S. population. Methods for making such comparisons are useful to operators of polluting facilities, to officials for enforcement of existing standards, and to all individuals having responsibility for decisions related to siting new facilities.

PLOWSHARE PROJECT

Program Termination

The Plowshare project at this Laboratory was terminated at the end of FY 75 because of a sharp curtailment in the national program. A summary report²⁴ was prepared covering

the evaluations of radiological exposure from Plowshare applications during the period 1967-75. Much of the methodology developed initially in the Plowshare program is being refined and applied in other areas.

Estimated Radiation Doses from Tritiated Gasoline

Application of nuclear explosives to recovery of oil from oil shale, proposed by investigators at Lawrence Livermore Laboratory,²⁵ would result in incorporation of tritium in the resulting petroleum products. The last dose estimation study performed under the Plowshare program was an evaluation of doses that could be received if all the gasoline used in cars and trucks in the Denver metropolitan area contained 5 μ Ci of tritium per gallon. The tritium in the gasoline would be converted to HTO and released from automobile exhausts at ground level. Traffic counts at various locations in the area, together with a national average value of 12.16 mpg for gasoline consumption, were used to estimate tritium release rates in each of 400 4-km² areas into which the metropolitan area was divided. The AIRDOT computer code described in the previous progress report²⁶ was used with annual average meteorological data to calculate doses from the dispersed atmospheric radioactivity releases. The estimated highest potential dose to a continuously exposed (168 hr/week) individual is 0.006 millirem/year and the potential population dose to 1.06 million people living in the area is 2.3 man-rem/year. A report²⁷ describing this work has been released and a paper on the same subject will be presented at the November 1975 meeting of the American Nuclear Society in San Francisco.

RADIOLOGICAL ASSESSMENTS

Radiological Assessment Work for Environmental Impact Statements

This year we were involved in the preparation of ten environmental impact statements, four of which were major program statements issued by ERDA or NRC. Table 16.2 lists the documents, the sources requesting our work, and the kind of activities performed in the preparation of the documents. Several of these statements are still in the commenting period and our involvement will extend until all official comments have been given a response and final environmental statements (FES) have been issued by the responsible agencies. In addition, our participation will be required in subsequent hearings on environmental impacts and safety.

Consumer Products Containing Radionuclides

Work on the consumer products project was divided into three major efforts: (1) refinement of the CONDOS computer code; (2) preliminary assessments of the potential radiation doses to users of several radionuclide-containing products that are exempt from licensing requirements; and (3) preparation of environmental statements about products for which exemptions from licensing requirements are being sought. This work was supported by the Office of Standards Development, U. S. Nuclear Regulatory Commission (NRC).

Experience in the application of the CONDOS methodology²⁸ and changes in the requirements of the NRC have indicated that the original model of the life span of a product is satisfactory, but that modification and improvement of the first version of the computer code would be useful. Thus, the radionuclide data base now includes all radionuclides currently used in consumer products. New radionuclides may be added easily to the data base. Greater flexibility has been provided for selecting combinations of radionuclides and the relative activities of radionuclides in decay chains. Other modifications and improvements to the computer code include addition of the capability to estimate radiation doses to selected body organs, as well as to the total body; restatement of the dose equation models to accommodate the new flexibility in radionuclide selection; and revision of the output format for input data to permit easier verification of the data.

Table 16.2. Activities in radiological assessment for environmental impact statements

Document	Source	Activity		
		Radiological impact assessment	Methodology development	Response to comments
Oak Ridge Operations Three-Plant Study	General Manager, ORO	a	a	b
LMFBR Program EIS (WASH-1535)	ERDA	a	a	a
GESMO Program EIS (WASH-1327)	NRC	b	a	a
Expansion of U.S. Uranium Enrichment Capacity (ERDA-1543)	ERDA	a	a	a
Light-Water Breeder Reactor Program DES (ERDA-1541)	Bettis APL-ERDA	c	a	b
Oak Ridge Gas Centrifuge Enrichment Facility PDES	ERDA	a	a	b
Portsmouth Gaseous Diffusion Plant Expansion PDES	ERDA	a	a	b
Spark-Gap Irradiators that Contain Cobalt-60 DES	NRC	a	a	b
Personnel Neutron Dosimeters that Contain Natural Thorium DES	NRC	a	a	b
The Sale and Use of Metal Scrap Homogeneously Contaminated with Enriched Uranium Below a Specified Concentration	ERDA	a	a	c

a - Completed by us this year.

b - To be completed by us.

c - Completed by others.

Several radionuclide-containing products have been studied and preliminary assessments were made of the potential radiation doses to users of the products. Table 16.3 summarizes the results of the studies and assessments. Realistic exposure pathways were considered in these assessments, but conservative conditions of exposure (time of exposure, distance from product, etc.) were postulated. Therefore, the reported radiation doses should be regarded as upper limits of the potential doses.

Effort was supplied for the preparation of these environmental statements on three consumer products proposed for exemption: spark-gap irradiators containing ^{60}Co for use in oil-burner ignition systems (DES to be issued for comment); neutron dosimeters containing natural thorium radiators for measurement of personnel exposures to fast neutrons (PDES in review); and static eliminators and ion generators containing tritium, ^{147}Pm , or ^{85}Kr (in preparation).

Environmental Assessment of the Unrestricted Sale and Use of Scrap Metals Slightly Contaminated with Uranium

Large quantities (about 55,000 tons) of metal scrap (mostly iron, nickel, and aluminum) valued at about \$60 million will be generated by ERDA-sponsored facilities by 1981. This scrap has been in contact with, and is thus contaminated with, enriched uranium. At the present time, such material cannot be sold unless the buyer possesses a license to receive special nuclear material (enriched uranium).

Table 16.3. Summary of information and preliminary estimates of potential radiation doses to users of selected radionuclide-containing consumer products

Consumer product		Radionuclide		User	Estimated total-body dose, (millirem) ^c
Name	Number ^a	Name	Quantity ^b		
Circuit protectors	d	Co-60	0.28 μ Ci	Airline pilot ^e	9.4×10^{-2}
Counterweights	d	Nat U	28 kg	Airline steward ^e	0.32
Fire detectors	380×10^3	AM-241	2.0 μ Ci	Homeowner ^f	8.9×10^{-2}
Gas mantles	20×10^6	Nat Th	0.35 g	Camper ^f	5.5
Glassware	10×10^6	Nat U	1.5 g	Housewife ^f	0.38
Glow lamps	180×10^6	Kr-85	0.01 μ Ci	Housewife ^e	3.1×10^4
Welding rods	d	Nat Th	0.52 g	Welder ^f	13

^aEstimated numbers of units manufactured in 1974.

^bTypical quantity of radionuclide in one unit.

^cPotential average radiation dose equivalent to the total body from one year of product use.

^dNumber of products manufactured is unknown.

^eTypical user.

^fIntensive user.

Because of the quantity and value of the metal scrap and the impracticability of the licensing requirements, ERDA has requested the NRC to amend its rules and regulations to allow unrestricted sale and use of the scrap. An environmental assessment of the potential impacts of such an amendment was prepared by the National Lead Company of Ohio with the assistance of ORNL. This assessment was submitted to NRC by ERDA in support of its request.

Reclaimed metal scrap is commonly used as feed material by the primary metals industry and, thus, may be used in a wide variety of products. Several representative examples of products which could be manufactured from the contaminated scrap were selected for detailed assessment, viz., frying pans, coins, sheetmetal, and knee braces. The assessments considered transport of bulk quantities of scrap, product manufacture, and product distribution, use, and disposal. Potential impacts on man, on other biota, on the environment, on other manufactured products, and of unauthorized recovery of enriched uranium were assessed.

The assessment concluded that: (1) unauthorized recovery of sufficient enriched uranium to form a critical mass would be very difficult, if not impossible; (2) nonradiological impacts would likely be small and would not differ from those normally associated with the products considered; and (3) the radiological impacts would likely fall within normally accepted limits. Potential radiation dose equivalents to the total body of maximally exposed persons were estimated to be: 0.2 to 7.1×10^{-3} millirem/year to bulk transportation workers; 0.1 to 3.7×10^{-2} millirem/year to product manufacturers; 1.0×10^{-5} to 0.48 millirem/year to distributors; 4.0×10^{-7} to 0.80 millirem/year to users;

and 8.0×10^{-11} to 5×10^{-5} millirem/year to other members of the general public. Impacts on biota other than man and on the environment would likely be negligible, or no worse than the impacts on man.

Reactor Fuels Containing ^{232}U and Daughters

Assessment of the radiological impact of ^{232}U and daughters was expanded to include an evaluation of three principal areas. First, a study was conducted to compare the 50-year dose commitment from ^{232}U and daughters with the dose commitment from other radionuclides which would comprise the airborne releases from a high-temperature gas-cooled reactor (HTGR) fuel reprocessing plant. A hypothetical reprocessing plant was assumed using source terms and retention factors from the literature on other reprocessing facilities.

The second area reviewed the effect of increasing ^{232}U concentration in recycled fuel on dose commitment to bone resulting from inhalation of ^{233}U HTGR fuel. Finally, the study evaluated the impact of ^{232}U daughter buildup in the environment on dose commitment resulting from inhalation and ingestion of equal mass of HTGR fuel, liquid metal fast breeder reactor (LMFBR) fuel, and light-water reactor (LWR) fuel.

Table 16.4 lists in decreasing order of magnitude the annual dose commitment from particulates to the total body and bone. Dose commitments were calculated to give the maximum individual dose at 1.5 miles from a plant stack. The dose commitment from ^{232}U and daughters is combined because the only significant source of daughters is from the decay of ^{232}U . From these data it is concluded that current technology will provide acceptable containment of ^{232}U and particulate daughters. The study also showed that the noble gas ^{220}Rn must have a retention factor of approximately 10^3 to reduce the dose commitment to the total body from ^{220}Rn and daughters to less than the dose commitment to total body from other volatile radionuclides being released.

Table 16.4. Ranking of significant particulate radionuclides by annual dose commitment at 1.5 miles from a model HTGR fuel reprocessing plant

Total body		Bone	
Radionuclide	Dose commitment (millirem)	Radionuclide	Dose commitment (millirem)
Cs-134	1.4×10^0	Sr-90	9.8×10^0
Cs-137	9.3×10^{-1}	Cs-137	1.3×10^0
Sr-90	2.0×10^{-1}	Cs-134	1.2×10^0
U-232 + daughters	1.1×10^{-1}	Pu-238	9.0×10^{-1}
21 other radionuclides	2.9×10^{-1}	Cm-244	9.0×10^{-1}
		U-232 + daughters	6.0×10^{-1}
		19 other radionuclides	7.6×10^{-1}

Figure 16.4 shows the effect of increasing ^{232}U content in recycled ^{233}U HTGR fuel on dose commitment to bone for inhalation of 10^{-12}g of fuel. The lower curve is the dose commitment to bone from HTGR fuel at 90 days following separation. The upper curve is dose commitment to bone from HTGR fuel at 10 years following separation. Increasing the concentration of ^{232}U from 0 ppm to 1200 ppm causes the dose commitment to bone to increase by a factor of approximately 35 for 90-day-old fuel, and a factor of approximately 185 for fuel with ^{232}U and daughters at equilibrium.

Fig. 16.4. Effect of ^{232}U concentration on dose commitment to bone.

The impact of ^{232}U daughter buildup in the environment on dose commitment to bone is illustrated in Fig. 16.5, which is a comparison of the dose commitment resulting from

Fig. 16.5. Dose commitment to bone vs time for inhaled LMFBR plutonium, HTGR uranium, and LWR uranium.

inhalation of equal masses of LMFBR plutonium fuel, HTGR uranium fuel, and LWR uranium fuel. On an equal mass basis, LMFBR plutonium is approximately 500 times more hazardous to man than HTGR uranium, and 10^7 times more hazardous to man than LWR uranium fuel soon after release to the atmosphere. The figure also illustrates that the buildup of ^{232}U daughters in the environment for 10 years increases the dose commitment by a factor of approximately 7.5 over the dose commitment calculated at 10^{-1} years.

This study concluded that for the assumed controlled routine releases of ^{232}U and daughters to the environment, a significant radiological insult to man would not result. However, ^{232}U significantly increases the radiotoxicity of recycled ^{233}U HTGR fuel, and the effect of ^{232}U daughter buildup in the environment may require a more detailed investigation.

Nuclear Fuel Cycle Project

Studies on the environmental and radiological assessments of fuel cycle facilities continued during this year. The correlation of the radioactive waste treatment costs and the impact of waste effluents will be used by the Office of Standards Development of the

NRC in establishing "as low as practicable" guides in the design and siting of fuel cycling facilities. The studies on uranium milling, fabrication of uranium dioxide LWR fuel, fabrication of U-Pu oxide LWR fuel, and LWR fuel reprocessing have been issued as ORNL/TM reports.²⁹⁻³²

The draft statements for studies of the HTGR fuel fabrication and HTGR fuel reprocessing plants were completed during the year and are being circulated for comment. Work is continuing on the UF₆ conversion facility.

The methodology used to estimate the potential radiation doses to individuals and populations and to biota other than man was developed in the CUEX program. New computer codes such as AIRDOS³³ and the revised version of INREM³⁴ have been incorporated into the current methodology to improve estimates of individual and population doses.

In Table 16.5 comparative data for the maximum individual and population total-body doses and the major radionuclides contributing to the doses are presented for a Case 1 study (represents current technology) for four types of facilities.

Table 16.5. Annual dose to individual^a and population^b from airborne effluents of LWR fuel cycle facilities

Facility	Maximum total-body dose ^c (millirem)	Population total-body dose (man-rem)	Major radio-nuclides and % contribution to dose
Mill ^d	1.0E+2	2.7	²²⁶ Ra(93%), ²³⁰ Th(4%)
Fuel fabrication (mixed oxide)	8.6E-3	1.1E-2	²³⁸ Pu(57%), ²⁴¹ Pu(27%)
Fuel fabrication (UO ₂)	9.0E-1	1.1E0	²³⁴ U(77%), ²³⁵ U(10%)
Fuel reprocessing ^e	7.9E0	4.8E+2	³ H(43%), ¹³⁴ , ¹³⁷ Cs(21%) ⁸⁵ Kr(18%)

^aAt 0.5 mile from plant in prevailing wind direction.

^bBased on actual population out to 55 miles of the facility for a midwestern site except for the mill where a western site was used.

^cAssumes that all food is produced in area of exposure.

^dMill dose includes dose from tailings pile.

^eDoes not include dose from C-14. Doses are being revised.

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17. Ecological Analysis and Applications

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The EAAP staff participated in the analysis of environmental impacts associated with five major areas of endeavor: (1) applications for licensing nuclear power plants (Division of Reactor Licensing, U. S. Nuclear Regulatory Commission); (2) modular integrated utility systems (Department of Housing and Urban Development); (3) uranium enrichment capacity of the United States (U. S. Energy Research and Development Administration); (4) the analysis of the ERDA-Oak Ridge Operations; and (5) the Nuclear Energy Center Site survey (Nuclear Regulatory Commission). The ecological assessments were performed primarily by EAAP staff in cooperation with several research staff members. This activity represented an average of 2800 man-hours of effort per month. Following is an overview of the work performed in each of these areas.

Nuclear Power Plants. The staff was actively involved in the ecological assessments of 8 to 14 reactors at any given time during the year. These assessments dealt with a wide array of ecological systems, both terrestrial and aquatic, including estuarine and riverine, salt and freshwater marshes, and coastal and offshore marine systems. The thrust of each of these tasks was to prepare a scientifically and legally defensible ecological assessment and to further the state of the art of environmental impacts assessment. In this context, predictive tools are currently being developed such as a quantitative approach to alternate site analysis and to the effects of impingement and entrainment on fish populations.

Integrated Utility Systems. A generic assessment of the environmental impacts associated with the construction and operation of Modular Integrated Utility Systems was completed in 1975. This system integrates all or several of the utilities serving a community, including electric power generation, heating and cooling, potable and fire protection water supplies, and liquid and solid wastes handling and disposal. A site specific assessment and follow-on analyses are also expected sometime in the near future.

Uranium Enrichment Capacity. The staff participated in the preparation of an environmental statement concerned with the proposed expansion of the U.S. uranium enrichment capacity. This expansion included ten gas centrifuge plants, one gaseous diffusion plant and four rotor fabrication plants. The impacts associated with over seven hundred 1000-MWe LWRs to be supplied by the expansion were also considered. In addition, the staff

participated in the completion of draft environmental statements for two new uranium enrichment plants, one gas centrifuge plant, and one gaseous diffusion plant, to be constructed at specific sites. Each statement was a first-of-its-kind in environmental impact analyses.

Oak Ridge Operations. An extensive description and evaluation of the Oak Ridge Reservation and the impacts of the three ERDA installations were made. This nine volume report may form the basis of an environmental impact statement on the ERDA-Oak Ridge Operations.

Nuclear Energy Center Sites Survey. The NECSS was mandated by Congress as a part of the act reorganizing the former AEC into the NRC and ERDA. As a part of this large interdisciplinary study, the staff has assisted in the development of siting criteria and of an approach for comparing the environmental costs of nuclear energy centers with those of equivalent amounts of generating capacity sited in the currently used dispersed mode. As a test case, this type of analysis was carried out for a hypothetical site on Kentucky Lake in Tennessee.

In addition to these environmental impact assessments, the staff was engaged in technical study projects and technical specification work. The four technical projects are: (1) an evaluation of multiple-usage of closed-cycle cooling reservoirs; (2) determination of parameters and data for alternate site evaluation; (3) guidelines for siting large cooling towers and criteria for monitoring and evaluating effluents released to terrestrial environs; and (4) the influence of power plant intake design and siting on fish impingement in the southeastern United States. These study projects are essentially state-of-the-art studies. The technical specifications work involves the synthesis and analysis of the data produced as a result of the environmental monitoring programs required for nuclear power plants by the NRC. The objectives are to validate ecological impact predictions made in environmental statements, to develop models to predict entrainment and impingement, to develop recommendations on standardization in data analysis as well as monitoring and data collection, and to develop deterministic ecosystem models to be used as a management algorithm in impact analysis.

A more detailed summary of staff participation in three specific areas of investigation is presented in the following text as examples of the diversity of activities of the group.

ALTERNATE SITES EVALUATION

As part of the NEPA-mandated Environmental Impact Assessment of proposed nuclear power plants the NRC is required to evaluate alternatives to the proposed site. Site selection is a two-stage process and is presented as such in the environmental report and the subsequent environmental statement. First, the applicant searches for potentially usable sites within or near his service area. This process of reconnaissance-level selection is well described in numerous studies published in the open literature and, consequently, is treated thoroughly in Regulatory Guide 4.2. The second stage is the selection of the candidate site. This process has received relatively little attention and consequently, the Regulatory Guide 4.2 has been able to provide little guidance in this matter. As a result, the extent of the description of the alternative sites presented in the applicant's environmental report and the quality of the staff's assessment of the alternatives varies considerably.

This study is designed to produce a list of parameters and associated levels of detail that will make possible an independent alternate sites assessment by the staff at minimum cost to the applicant. In addition, a method for converting the data into a figure for the relative environmental cost of development will be produced.

The study was begun by preparing a list of the parameters that might be useful in comparing the alternate sites and a list of methods which have been used in siting decisions for steam electric plants (Fig. 17.1). The sources of the methods and parameters were the open literature and a collection of Sections 9.2 of environmental reports. The parameter list is being reviewed by the staff of ORNL Environmental Statements Project in order to verify the completeness of the list and the relative importance of the parameters.

Fig. 17.1. Analysis of parameters and procedures for alternate sites evaluation.

The parameters will be tested by using groups of existing nuclear plants which occur in a limited region as analogs of alternate sites. The testing will establish the suitability of the chosen methodology and indicate a minimum list of parameters and the level of detail necessary to discriminate between the sites. Finally, the cost of obtaining the data will be determined in order to ensure that an excessive burden is not placed on the applicant.

The results of this study will be used to prepare recommendations for changes in the NRC Regulatory Guide 4.2.

TECHNICAL SPECIFICATIONS PROJECT

Introduction

The licensing of nuclear power plants requires the preparation of environmental impact statements that include environmental monitoring requirements as part of the

technical specifications. These specifications, both radiological and nonradiological (ecological), are designed with the specific purpose of documenting potential impacts on the environment and ensuring that nuclear power plants are operated without causing environmental damage. In order to determine the adequacy and effectiveness of these monitoring programs, it is necessary to examine, analyze, and evaluate the monitoring data collected.

At present, the degree to which environmental technical specifications adequately address real ecological problems, and the degree to which monitoring data conform to the intent of technical specifications, are unknown. Considerable time, effort, and money are being spent by utilities to accumulate monitoring data, but little evaluation of the quality of the data has been made. The major objectives of this technical specifications program are: (1) to validate thermal and ecological impact predictions made in the final environmental statement, using monitoring data; (2) to evaluate the pre-construction environmental studies and operational monitoring programs for their adequacy; (3) to recommend standardization in monitoring, data collection, and data analysis; (4) to identify possible environmental impacts common to several power plants with similar hydrological and ecological profiles; and (5) to develop deterministic ecosystem models for use as a management algorithm in impact analysis.

In the initial phase of this study by the ORNL staff, ecological monitoring programs of eight nuclear power plants that have been operational for at least one year are being reviewed. These data are being evaluated according to the comprehensiveness of the sampling programs and the adequacy of the data for use in construction of entrainment and impingement models. After completion of review on eight plants, four will be selected for thorough analysis of the monitoring data. In-depth analyses will concentrate on: impingement of fish; entrainment of phytoplankton, zooplankton, and ichthyoplankton; effects of thermal effluents on the major aquatic trophic groups (i.e., phytoplankton, zooplankton, benthos, and fish); and effects of chemical effluents such as biocides and heavy metals on the ecosystem.

Preliminary evaluation of some ecological data is given by representative examples of methods of analysis that can be applied to each of the four major groups of biota. In addition, confirmatory assessments of the monitoring data are compared with the predictions made in the final environmental statements. Initial analyses have addressed objectives 1 and 2: validation of impact predictions and evaluation of monitoring programs presented in the final environmental statement.

Fish - Peach Bottom Power Plant

The final environmental statement for Peach Bottom predicted that a reduction in standing crop of several fish species might occur, due in part to cold shock kills, in the event of a reactor shutdown. An analysis of variance was performed to compare fish catch per unit effort at plume, periphery, and control stations for winter and summer months. Results of the analysis (Table 17.1) demonstrate that fish do not preferentially

Table 17.1. Summary of results and analysis of variance for the catch per unit effort of fish in the plume, periphery of the plume, and control areas during the colder and warmer months of the year

	Mean catch per unit effort			F-test
	Plume	Periphery	Control	
Cold months	14.3	11.8	15.8	0.37 ^a
Warm months	91.8	18.9	32.6	8.97 ^b

^a Not significant.

^b $P < 0.05$ confidence level.

congregate in the plume in winter months, thus greatly reducing the potential of cold shock kills of a magnitude to measurably affect fish standing crop. Trawl data show that during summer months, fish density was highest at plume stations. This preliminary analysis addresses objective 1; however, several more years of post-operational data should be reviewed.

Benthos - Peach Bottom Nuclear Power Station

The final environmental statement for Peach Bottom predicts that the thermal plume may have a detrimental effect on the benthic population found in the immediate vicinity of the thermal discharge, but not on the system as a whole. Preliminary analyses were performed by comparing benthic faunal similarity at six discharge stations, subject to the influence of the thermal plume, to four control stations during the pre-operational years (1968-1973) and the post-operational year (1974). A Trellis diagram (Fig. 17.2) was constructed for pre- and post-operation years, and a comparison of the diagrams suggests that faunal similarity among stations before operation of the plant was greater than for the post-operational year (1974). During 1974, greatest dissimilarities occurred between discharge areas of the plume as compared to all other stations. Only three stations during the pre-operational years displayed 70% or less benthic similarity; however, this number increased to nine stations in 1974. In addition to this localized effect, discharge of effluents into that portion of the river known as Conowingo Pond appears to have had some influence on the total benthic community structure because dissimilarity of the benthos increased during post-operational years. Whether this apparent shift in benthic community structure is deleterious or beneficial in terms of ecological impact to the pond is impossible to evaluate at this time. This analysis addresses objective 2 by showing that additional data are needed to separate natural yearly variations from those system perturbations due to power plant operation.

Fig. 17.2. Faunal similarity of benthos - Peach Bottom Power Station.

Phytoplankton - Oconee Power Plant

The Oconee final environmental statement predicted that localized shifts in phytoplankton species dominance might occur especially at the discharge. Phytoplankton

monitoring data, however, suggest there were no shifts in species dominance, but a reduction in phytoplankton density at the discharge during warmer months. This reduction in density is shown in Fig. 17.3. In general, densities at control stations were higher than those for discharge stations during 1974. Possibly, the combined effects of thermal effluents and elevated summer temperature caused a decline in primary productivity at discharge stations.

Fig. 17.3. Density of total phytoplankton at Oconee Power Station (July 1974 - June 1975).

Phytoplankton population monitoring should be continued to determine whether the reduction in cell density at the discharge is a natural phenomenon or is mediated by power plant operation.

Zooplankton - Oconee Nuclear Power Station

The final environmental statement for Oconee predicted a reduction in zooplankton density would occur in the thermal plume during summer months. Monitoring data on

zooplankton density confirm this prediction for the first post-operational year. Large natural fluctuations in zooplankton population occur from year to year; however, additional post-operation monitoring data must be evaluated.

Conclusion

Analysis of some of the environmental monitoring data presented above indicates that more post-operational data are needed in order to distinguish between natural variations of ecological parameters and perturbations due to nuclear power plant operation. Once natural variation and power plant variations can be separated, the objectives of the technical specification program can be addressed.

Completion of an in-depth analysis of the monitoring data will result in streamlining the technical specifications program by eliminating unnecessary sampling, by identifying common areas of major ecological concern that require more intensive study, and by developing predictive ecosystem models to eliminate the need for future ecological monitoring.

AQUATIC ANALYSIS

Often an unavoidable consequence of the operation of steam electric plants is the entrainment and impingement of organisms. These two phenomena usually have a great potential for adversely affecting the aquatic ecosystem. In areas of high ichthyoplankton densities, there may be substantial loss of reproductive products due to entrainment. Impingement has resulted in the loss of many fish and occasionally has forced a plant shut-down due to screen clogging. Therefore, it is desirable to identify and predict the magnitude of these problems before a plant is built in order to implement preventive measures. The following are examples of two predictive tools developed for the assessment of the impacts related to the Atlantic Generating Station (AGS) that can be used toward the accomplishment of this objective.

Entrainment Model

The ecological and economic effects of entrainment can be approximated by equating the entrained biomass of phytoplankton, zooplankton, and ichthyoplankton to potential fish production. This model also assumes that plankton are uniformly distributed in the water column and that no reentrainment occurs. In equating loss of phytoplankton biomass due to entrainment to potential fish production, the efficiency of conversion of phytoplankton production to fish production is assumed to be 0.0058. Harvey³ found that this ratio was representative for temperate marine fish populations feeding at several trophic levels. In equating entrained zooplankton losses to potential fish production, the conversion efficiency of zooplankton to fish production is assumed to be 0.017. Both Clarke,⁴ who investigated the food-chain dynamics of fish on the Georges Banks area, and Harvey³ found that this ratio of 0.017 is representative of fish feeding at several trophic levels (0.017 represents a fish feeding somewhere between the third and fourth trophic levels, i.e., mixed zooplankton diet).

In the conversion of entrained fish eggs and larvae to potential fish production, the natural mortality of eggs was conservatively assumed to be 90% (ref. 5) and the mortality of larvae and 0-1 age class fish was assumed to be 99.79% (refs. 6-10) and 30% (ref. 11), respectively.

The biomass of each plankton group entrained was extrapolated to the equivalent production of 0-1 age class fish by (1) multiplying the average plankton density during any one year by the total volume of water removed by the AGS during the year ($4.1 \times 10^9 \text{ m}^3$), (2) assuming that the average dry weight of a phytoplankton cell is $2.3 \times 10^{-7} \text{ mg}$, (3) assuming that the average dry weight of an individual zooplankter is 0.001 mg, and (4) applying the appropriate natural mortality and trophic level conversions described above.

Based on the average yearly densities of ichthyoplankton during 1973 and 1974 at the AGS site, the equivalent annual fish production loss due to entrainment ranged between 49,000 and 480,000 lb for loss of eggs and between 80,000 and 170,000 lb for loss of larvae (Table 17.2). Based on the average densities of phytoplankton and zooplankton during

Table 17.2. Yearly average densities of ichthyoplankton during 1973 and 1974, number entrained per year, number surviving to the end of the 0-1 age class, and potential entrainment of ichthyoplankton expressed as potential production of fish in 0-1 age class

Species	Average density of eggs (number per cubic meter)		Entrainment (number per year)		Number surviving to end of 0-1 age class		Weight at age 0-1 (lb)	Potential annual production lost (lb)	
	1973	1974	1973	1974	1973	1974		1973	1974
<u>Eggs</u>									
<i>Brevoortia tyrannus</i>	0.004	0.013	1.6 x 10 ⁷	5.33 x 10 ⁷	2,286	7,462	0.1	228	746
<i>Anchoa mitchilli</i>	10.0167	2.593	4.15 x 10 ¹⁰	1.06 x 10 ¹⁰	5.81 x 10 ⁶	1.48 x 10 ⁶	0.008	49,265	11,840
<i>Scomber scombrus</i>	3.75	0.067	1.53 x 10 ¹⁰	2.75 x 10 ⁸	2.14 x 10 ⁶	38,500	0.1	214,000	3,850
Others	3.41	0.547						211,507	32,870
Total (eggs)	17.188	3.22						475,000	49,306
<u>Larvae</u>									
<i>Brevoortia tyrannus</i>	0.0014	0.001	5.74 x 10 ⁶	4.1 x 10 ⁶	8,032	5,740	0.11	803	574
<i>Anchoa</i> sp.	0.074	0.0009	3.03 x 10 ⁸	3.69 x 10 ⁵	425,000	517	0.008	3,600	4.0
<i>Ammodytes</i> sp.	0.834	2.911	3.2 x 10 ⁹	1.19 x 10 ¹⁰	4,790,000	1.67 x 10 ⁷	0.009	42,159	150,000
<i>Scomber scombrus</i>	0.018	0.011	7.38 x 10 ⁷	4.1 x 10 ⁶	103,000	5,740	0.1	10,327	574
Others	0.04	0.216						23,460	16,248
Total (larvae)	0.967	3.11						80,349	167,400

1973 at the site, the equivalent annual amounts of fish production lost due to entrainment of these organisms were 12,000 and 6500 lb, respectively (Table 17.3). These figures do not represent actual numbers of pounds of fish killed, but represent the potential loss of fish, given that all plankton killed by entrainment do not cycle back into the food web; that is, they are lost from the system. If not entrained, on the average 0.14% of the fish larvae and 0.014% of the fish eggs killed would have survived to be one year old.

Table 17.3. Yearly average densities of phytoplankton and zooplankton, and potential entrainment of phytoplankton and zooplankton expressed as potential production of fish

	Phytoplankton	Zooplankton
Average density individuals per cubic meter	1.03×10^9	4.25×10^4
Entrainment individuals per year	4.24×10^{18}	1.74×10^{14}
Entrainment (lb/year) ²	2.14×10^{6a}	3.84×10^{5b}
Potential fish production (lb)	1.25×10^{4c}	6.53×10^3

^a Average dry weight of phytoplankton cell is 2.4×10^{-7} mg.
Average dry weight of zooplankton cell is 0.001 mg.

^b Constant pumping rate of AGS is 4.09×10^9 m³/year.

^c Food chain conversion of phytoplankton to potential fish production is 0.0058. Zooplankton to potential fish production is 0.017.

This model represents a predictive method that can be utilized in the assessment of environmental impacts due to entrainment of plankton. It does not, however, address the significance of these potential impacts to the aquatic ecosystem. However, if the total potential fish production loss in 1973 (due to entrainment of ichthyoplankton) of 555,000 lb (Table 17.2) is compared with the commercial fish landings of 179,000,000 lb in New Jersey during 1972, this loss represents a production amount equivalent to 0.3090% of the New Jersey commercial landings.

Potential economic loss of Atlantic mackerel due to entrainment of its eggs and larvae lies between 225,000 and 4400 lb/year; these values would represent 3 and 0.2%, respectively, of the U. S. east coast commercial landings of this species. However, the actual impact is not expected to be significant, because this species is commercially under-exploited, populations and spawning activities are not localized, and characteristics of their reproductive biology indicate that these populations are reproductively stable. The potential loss of anchovy and sand lance also appears large, but because of their small size as adults and relative economic unimportance, entrainment of large numbers of anchovy eggs and sand lance would have only a small effect on the productivity of the area and will not be of ecological or economic concern.

The use of this model in environmental impact assessment allows quantitative losses due to entrainment to be predicted; these losses, however, must be further evaluated in terms of significance to the aquatic organisms or ecosystem concerned.

Impingement Model

The unpredictable nature of the spatial and temporal distribution of fish in relationship to a small fixed geographical area (Atlantic Generation Station site) on the continental shelf makes a precise quantifiable prediction of impingement impossible. However, if it is assumed that the relative abundance of the species of fish sampled by

the applicant represents the actual relative abundance of the species present at the site, an index of a relative number of fish of each species likely to be impinged can be approximated. In order to develop this index, the susceptibility to impingement must be determined for each species. This was done by ranking each species from 0 to 1.0 in each of five categories - swim speed, schooling, thigmotropism, vertical distribution, and relative abundance.

The rank was ordered with reference to susceptibility to impingement so that 0 indicates negligibly low susceptibility to impingement and 1.0 indicates high susceptibility.

Swim speed criteria and the resulting ranking for the various species ranks were based on the mean sustained swimming speed (4.4 body lengths per second) of the families of fish found at the AGS site. A sustained swim speed of 4.4 body lengths per second will allow a fish 85 mm long to escape a 30.5-cm/sec (1-fps) flow, given that the fish is allowed 1 body length per second to escape. Lengths of species of fish not reported by the applicant were approximated by length-weight regression equations. The criteria for arriving at the values in the remaining categories (except for relative abundance which is self explanatory) are explained in Table 17.4. Each of the five categories was then weighted according to its relative importance as a contributing factor to impingement. The weighting coefficients were based on the staff's judgment of the causal factors of impingement at coastal power plants. An example of the ranking and weights of five representative species of fish found at the Atlantic Generating Station site is given in Table 17.5.

By multiplying the weights and ranks in each category together, an index of susceptibility to impingement for each species (ISI_i) was determined. This is expressed for species i as follows:

$$ISI_i = \prod_{j=1}^5 (w_{ij}X_{ij}) = (w_{i1}X_{i1})(w_{i2}X_{i2}) \dots (w_{i5}X_{i5}), \quad (1)$$

where ISI_i is the index of susceptibility to impingement for species i , j designates an attribute (category) that contributes to impingement (schooling, swim speed, etc.), w_{ij} is the weight (0.00-1.00) of attribute j relative to the other attributes in terms of contributing to the susceptibility to impingement, and X_{ij} denotes the relative degree (from 0.00 to 1.00) to which species i possesses attribute j . The percentage of fish of species i likely to be impinged RN_i , would be given by

$$RN_i = 100 \frac{ISI_i}{\sum_i ISI_i} . \quad (2)$$

As stated above, it is not possible to predict how many fish will be impinged. The RN_i value only predicts the proportion of species to be impinged. It must be emphasized here that several species of fish are periodically abundant at the AGS site but were difficult to collect. Therefore, their true abundance would not appear in the relative abundance category. As a result, at least one species, the Atlantic menhaden, might be impinged periodically in large numbers, but such occurrences are not reflected in the index. Adult bluefish and Atlantic mackerel were also not collected by the applicant but could also be periodically abundant. However, they swim rapidly enough so as not to be an impingement problem.

As with the entrainment model, this method has not been validated and at this stage of the model only predicts the proportion of species to be impinged. It does, however, represent a first attempt to quantify the type and magnitude of the problems related to impingement.

Table 17.4. Criteria for assigning ranks in four behavioral categories that may potentially contribute to impingement of fishes at the Atlantic Generating Station

Rank	Swim speed (based on body length)	Schooling		Thigmotropism	Vertical distribution
		Density	Seasonality		
1.0	75—100% of the fish collected are 85 mm or less or if x length is less than 85mm where percent of catch is not known	Dense schools, that is, menhaden or anchovies	Schools or aggregation all season	Utilizes reefs extensively; common and frequent sitings	Predominately midwater fishes
0.75	50—74% of the fish collected are 85 mm or less or if x length is 86—100 mm where percent of catch is not known	Loose schools	Schools or aggregation three seasons	Seasonal reef utilization	Surface; midwaters and surface; midwater and bottom; surface midwater and bottom fishes
0.50	10—49% of the fish collected are 85 mm or less or if x length is 101—150 mm where percent of catch is not known	Occasional aggregation	Schools or aggregation two seasons	Occasionally associated with reefs	Surface and bottom fishes
0.25	1—9% of fish collected are 85 mm or less or if x length is 151—200 mm where percent of catch is not known	Found together in a narrowly bounded habitat such as a reef	Schools or aggregation one season	Rarely associated with reefs	Bottom fishes
0	The x length is greater than 200 mm	No schooling or aggregation	No schooling or aggregation	Never associated with reefs	NA ^a

^a Not applicable.

Table 17.5. Determination of the relative impingeability of major fishes found in the vicinity of the Atlantic Generating Station^a

	Density	Schooling		Weighted proportionate rank (x) (0.3)	Thigmotropism	
		Seasonality	Rank (x)		Weighted proportionate rank	
					Rank	{Rank} (0.2)
Anchovy	1.0	0.75	0.88	0.263	0.25	0.05
Menhaden	1.0	0.75	0.88	0.263	0.25	0.05
Summer flounder	0.5	0.50	0.50	0.150	0.75	0.15
Red hake	0.5	0.75	0.63	0.188	0.75	0.15
Striped searobin	0.025	0.025	0.025	0.0075	0.25	0.05

Table 17.5 (continued)

	Vertical distribution		Swim speed		Relative abundance	Product of weighted rank	Index of relative number impinged
	Weighted proportionate rank		Weighted proportionate rank				
	Rank	(Rank) (0.1)	Rank	(Rank) (1.0)			
					Rank (1.0)	$\pi (W_{i,j} \cdot X_{i,j})$	(R·Ni)
Anchovy	0.75	0.075	1.0	1.0	0.488	4.81×10^{-4}	0.47
Menhaden	0.75	0.075	0.75	0.75	0.002	1.47×10^{-5}	0.0014
Summer flounder	0.50	0.075	0.25	0.25	0.0018	1.83×10^{-5}	0.0018
Red hake	1.0	0.075	0.5	0.50	0.198	2.79×10^{-4}	0.27
Striped searobin	0.75	0.075	0.01	0.025	0.006	4.22×10^{-9}	0.0000041

^a In practice, a value of zero was not assigned to any species for any category. Each species to some extent is susceptible to impingement and the value of zero in any rank would result in an index of susceptibility of zero.

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18. Waste Management Analyses and Applications

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Land use for waste management and disposal has been practiced extensively in the nuclear industry. To prevent and mitigate adverse effects of this utilization of our resource, research on the geohydrologic characteristics of the formations and on the waste solutions is essential. An active program is being pursued in the waste disposal area of White Oak Drainage Basin of ORNL. In addition to the radioactive elements of nuclear waste, nonradioactive nitrates pose a particular problem in some of the nuclear processes. The studies reported in this section utilize soil microbes to decompose the nitrate; the particular emphasis is on engineering feasibility and parametric relationship for optimum decomposition.

Of increasing concern in the nuclear industry is the increasing generation and utilization of plutonium and its potential hazard in the environment. Its release in the environment is associated with bomb testing, fuel reprocessing, and processes related to fuel fabrication. Plutonium from these sources may behave differently in the environment, and understanding of its characteristics and properties will be invaluable in utilizing this valuable resource. Studies related to plutonium characterization from several contaminated sites are described in this section.

RADIONUCLIDE MOVEMENT FROM ORNL BURIAL GROUNDS

To reduce the transport of radionuclides from burial ground 4, engineering solutions have been recommended and are being implemented. A surface water diversion system to reduce infiltration of runoff in the burial ground has been implemented. Studies are being conducted on the utilization of bentonite-shale mix on the surface of burial grounds to form an impermeable seal. Tests are being conducted using plastic seals above several waste trenches in burial ground 5 to evaluate the effectiveness of near-surface sealing in preventing water from infiltrating into the trenches.

The ground-water discharge of ^{90}Sr from burial ground 4 ranges from 1 to 2 Ci annually and is directly related to annual precipitation with higher discharges occurring during wet years.³ Therefore, engineering methods designed to reduce ^{90}Sr discharge from the area must reduce the amount of groundwater that percolates through the buried waste. The groundwater moving through the waste originates from (1) infiltration of surface runoff from the basin above the burial ground and (2) infiltration of precipitation that

falls on the burial ground surface (Fig. 18.1). The increased infiltration rate on the burial ground from both (1) and (2) results from increased permeability caused by surface disturbance during burial operations. To mitigate the discharge, the following actions are being taken:

Fig. 18.1. Burial ground 4 and its associated drainage basin. The dashed line is the perimeter of the drainage basin which is divided into basins 1 and 2.

(1) Reducing infiltration of surface runoff: To reduce the infiltration of surface runoff, a surface water diversion system was proposed and implemented. This system consists of a paved interceptor ditch along the north side of Lagoon Road which collects the surface runoff; the runoff is then transferred across the burial ground by means of three paved conductor ditches (Fig. 18.2). Because this system has only been in operation for a short time, no data are available on its effectiveness.

(2) Reducing infiltration of precipitation: A second part of the engineering solution entails decreasing the amount of infiltration of precipitation through the burial ground surface itself. The surface seal must reduce infiltration and must not create a potential problem of surface runoff from the area. It must also have a long life and require little maintenance. A near-surface seal of natural materials (bentonite mixed with Conasauga shale), placed at a depth of about 2 ft, has been proposed. Bentonite was selected because it is subject to little change from weathering and will not require periodic resealing. The impermeable membrane formed by the compacted bentonite-shale mixture will reduce the infiltration of precipitation, and a 2-ft overburden which will reduce erosion will allow the growth of vegetation.

Tests on bentonite-shale mixtures show that a mixture with 5% bentonite yields good results under laboratory conditions. However, from tests conducted to date, it is felt that the final design of the mixture will contain approximately 10% bentonite. The increased bentonite is necessary because of less efficient mixing and compaction under field conditions.

Fig. 18.2. Surface runoff diversion system at burial ground 4.

In order to evaluate the effectiveness of near-surface sealing in preventing water from infiltrating, a field test in burial ground 5 was proposed and is currently under construction. Prior to sealing and during the wet winter months, water infiltrated into the trenches in burial ground 5, percolated downward to the less permeable trench bottoms (undisturbed shale), and flowed downslope and accumulated at the lower end of the trenches. After periods of sufficient rainfall (usually in the early spring) enough water accumulated to overflow the trenches and form surface seeps. These seeps are contaminated from leaching of the waste. The radionuclide concentrations from a seep associated with trench 83 are shown in Table 18.1.

In burial ground 5, three waste trenches (105, 83, and 72) were sealed with an impermeable plastic membrane placed at a depth of about 2 ft. Polyvinyl chloride was selected for the membrane because the design of the bentonite-shale mixture was not completed. The three trenches sealed in burial ground 5 are approximately 575 ft long, 15 ft deep, 10 ft wide, and lie parallel to each other in an area approximately 60 ft wide. The long axes of the trenches are parallel to the land slope, and an elevation difference of approximately 50 ft exists between the upper and lower end of the trenches.

The plastic seal in this case serves a double function. Not only does it serve as a field experiment (its original purpose), but also it eliminates the contaminated surface seeps. Because monitoring wells in and around the sealed trenches have not yet been installed, no data are available to evaluate the effectiveness of the seal.

Research on the transport of radionuclides from seepage trench 7 has continued along two lines, one related to the development and validation of the SOGMOD model and the other related to the geochemistry of the radionuclide transport.

The material transport portion of the SOGMOD model has been partially validated by comparison with an analytical solution of the simplified transport equation. The documentation of this portion of the model has been completed.⁴ Development of the coefficients necessary for validation of the complete SOGMOD model^{4,5} by simulation of ⁶⁰Co movement from seepage trench 7 is still underway.

Table 18.1. Concentration of radionuclides in seep water from trench 83 in burial ground 5 (dpm/ml)

	Radionuclide				
	^{90}Sr	^3H	^{125}Sb	^{244}Cm	^{238}Pu
Concentration	3.1×10^4	1.2×10^5	24.7	0.7	0.07

Geochemical studies of trench 7 are primarily focused on the transport of ^{60}Co which is the primary radionuclide in a seep below this trench. Because preliminary data suggested that organic complexing of ^{60}Co was responsible for its movement, dialysis membrane and chromatographic techniques are being utilized to better characterize the organic association of ^{60}Co . Data obtained to date using Sephadex gel G-10 show that the organics in the seep solution exhibit two distinct peaks corresponding to molecular weights above and below 700. In addition, the bulk of the ^{60}Co appears to be associated with the < 700-mol.-wt fraction.

BIOLOGICAL DENITRIFICATION OF HIGH NITRATE WASTES

Biologic denitrification studies have been directed to evaluating effective packing material and optimum flow rates for maximizing denitrification in tapered columnar units. Cooperative research between the Environmental Sciences Division of ORNL and the Y-12 plant has shown that biological denitrification is a feasible method of removing nitrates from high-nitrate wastewater produced at uranium refining and fabrication facilities.⁶⁻⁸ In fact, a full-scale denitrification plant is scheduled to be operational at Y-12 in July 1976. The engineering design of this plant is that of a continuous-flow stirred reactor because of the high concentrations of calcium and aluminum in the nitrate wastewater. Columnar packed beds are not acceptable for wastes that contain appreciable calcium and aluminum, as they soon become clogged by the formation of CaCO_3 and $\text{Al}(\text{OH})_3$.

On the other hand, columnar packed beds appear to be more favorable at UO_2 fuel fabrication plants that use the ammonium diuranate process in their UO_2 recycle system than at continuous-flow stirred reactors because the columnar units retain a larger biomass of denitrifying bacteria and the nitrate wastes are predominately NH_4NO_3 and HNO_3 . The most successful unit tested was a tapered columnar unit containing anthracite coal (effective particle diameter size between 2 and 3 mm). The density (approximately 1500 kg/m^3) of the anthracite coal makes this packing more effective than sand because, when used in a tapered column, the unit takes on many properties of a fluidized bed and the resulting denitrification rates are much higher than in similar-sized sand packing.

Maximum denitrification obtained in the tapered columnar unit was 1.4 g $\text{NO}_3/\text{m}^3/\text{sec}$ where 1 m^3 is the original volume of the packing. This is equivalent to reducing a nitrate stream of 10 kg NO_3/m^3 to less than 1 g NO_3/m^3 at a flow rate of 4.5 cm^3/sec , using 32.5 dm^3 of anthracite coal packing (Fig. 18.3). The difference between influent (295°K) and effluent temperature (307°K) was 12 K°. Calculations based on the heat generated by oxidation of the CH_3OH consumed was nearly twice that reflected by the increase in influent temperature. While a portion of the energy was retained in the form of microbial growth, the remainder was lost as heat to the surrounding environment. Thus, for a large unit (one capable of denitrifying 5 metric tons of nitrate a day) the heat loss will be less, and it appears some type of cooling will be necessary for such large commercial units.

Fig. 18.3. Schematic of the tapered columnar denitrification system.

PLUTONIUM IN CONTAMINATED ENVIRONMENTS

Plutonium characterization in soils and sediments from several different locations in the United States is being conducted. Samples from the Nevada Test Site (NTS), Oak Ridge National Laboratory (ORNL), and Mound Laboratory (ML) in Ohio have been studied. Whereas the NTS soil plutonium was found primarily in the coarse silt fraction (53 to 20- μ diameter), the plutonium in the ORNL and ML samples was concentrated in the clay size fraction (less than 2- μ diameter).

To understand the behavior and fate of plutonium, studies of contaminated sites are essential. Because many diverse factors and processes are operative at the different sites, precise definition of reaction mechanisms is difficult. Nevertheless, information on the characteristics of the plutonium as it exists in the matrix is valuable for assessing the potential hazard. To date samples have been obtained from four sites; these include the Nevada Test Site (NTS), Oak Ridge National Laboratory (ORNL), Mound Laboratory (ML) in Ohio, and Rocky Flats Plant (RFP) in Colorado. At each of these sites, comprehensive ecological investigations are being conducted by multi-disciplined groups; the results summarized in this report are part of these efforts.

Plutonium Distribution in Soil Particle Sizes

Total plutonium was determined in nine unvegetated surface soil samples (0 to 5 cm) from Area 13 in the Nevada Test Site (NTS); these samples were taken along a north-south transect, thus providing information on the concentration of plutonium as a function of distance from the point of detonation (GZ). Particle size segregation was performed on seven samples and the plutonium determined for each particle size. The coarse silt fraction (53 to 20- μ diameter) contained the highest percentage of plutonium in the soil (about 65%). These and other relationships found for the nine samples representing a north-south transect have been reported.⁹

In addition to the nine samples, two samples which were within 4 ft of each other were also analyzed. One sample was taken in the bare soil area which represents 90 to 95% of the total area in Area 13; the other was taken beneath a desert shrub. The latter occurs as a sandy mound, indicating accumulation of wind-borne particles. Also included for further studies were samples taken from a core in the canal near Mound Laboratory (ML) and from the surface of a floodplain which served as a temporary waste retention pond at the Oak Ridge National Laboratory (ORNL).

The samples were size segregated without any special dispersive treatment but with 5 min of ultrasonic treatment to induce dispersion. Results of the analysis are summarized in Table 18.2. Note that the ultrasonic treatment resulted in higher contribution of plutonium by the clay fraction. In the NTS samples marked A13 - 1A (bare soil) and A13 - 1B (vegetated soil) the major contributor to the activity is the coarse silt fraction; this is similar to the findings for the other samples taken in Area 13.

In the ML and ORNL samples the highest contribution to the total activity is by the clay fraction. The effect of ultrasonic treatment in breaking up aggregates is especially noticeable in the ML samples. Since the sample from the core of ML represents the 43- to 47-cm depth, the sediment appears to have been sufficiently consolidated to form relatively stable aggregates. In the ORNL sample, 32% of the activity is contributed by the coarse silt fraction; it is suspected that the 5-min ultrasonic treatment was insufficient to completely disaggregate the particles. These results, in part, explain the nitric acid solubility and citric acid solubility of the plutonium in the samples which were reported previously.¹⁰

Table 18.2. Plutonium contribution (%) by particle size without (A) and with (B) ultrasonic treatment

Size range (μ m)	NTS		NTS		ML		ORNL
	A13 - 1A		A13 - 1B		8C - 43-47		IRB - 1
	A	B	A	B	A	B	B*
2000 - 840	0.5	0.3	0	0.1	---	---	---
840 - 250	1.5	0.2	1.5	0.1	3.9	---	---
250 - 125	1.4	0.3	0.9	0.2	1.8	---	---
125 - 53	26.7	8.3	14.9	5.9	5.6	---	---
53 - 20	44.4	50.9	75.1	73.2	24.8	6.4	19.3
20 - 5	22.0	32.7	6.3	14.9	29.8	12.3	32.0
5 - 2	2.6	4.5	0.8	4.2	16.9	11.8	8.8
< 2	1.0	2.9	0.4	1.5	17.1	69.5	39.9
	100.1	100.1	100.1	99.9	99.9	100.0	100.0

*The A series of ORNL sample was not analyzed.

Mineral Association of Plutonium

Particle size segregation of the NTS samples has shown that the plutonium is associated with the coarse silt-size particles; in the ML sample, the plutonium was found primarily in the clay size particles. To further investigate the nature of the plutonium, these high plutonium fractions were subjected to density gradient segregation. This technique separates minerals according to their specific gravity.

The fractions obtained after density segregation are listed in the first column of Table 18.3. The bulk of the particles in the NTS samples show specific gravities ranging from 2.5 to 2.7 g/cm³. The interesting finding is in the distribution of the plutonium. In the bare soil (A13 - 1A), the plutonium is concentrated mainly in the "heavy" fraction (greater than 2.9 g/cm³) with approximately 75% in the 11% weight fraction. On the other hand, under the vegetation, the "heavy" fraction contributed less than 10% of the activity, with nearly the same weight of particles. The plutonium under the vegetation is associated primarily with the 2.5 to 2.7 g/cm³ fraction (80 to 90%).

Table 18.3. Plutonium distribution of coarse silt fraction of NTS samples and the clay fraction of ML sample

Density range ₃ (g/cm ³)	Nonvegetated soil (A13 - 1A)		Vegetated soil (A13 - 1B)		8C - 43-47	
	Weight (%)	Activity* (%)	Weight (%)	Activity* (%)	Weight (%)	Activity* (%)
< 1.8	0.3	1-3	1.0	0-1	5.9	16
1.8-1.9	---	---	---	---	8.5	6
2.0-2.2	2.1	1-2	0.7	0-1	---	--
2.2-2.3	6.2	1-2	5.0	0-1	7.9	6
2.3-2.4	9.8	3-4	7.8	2-3	64.9	70
2.4-2.5	17.2	4-5	6.5	0-2	---	--
2.5-2.7	45.0	5-15	61.5	89-95	---	--
> 2.9	11.1	60-85	8.9	1-10	4.5	2
	91.7		91.4		91.7	

* Numbers refer to range in values for duplicate analysis.

These findings suggest that the bulk of the plutonium in the bare soil occurs as discrete particles, presumably plutonium oxide or hydroxide. On the other hand, the plutonium under the shrubbery is different from that found in the bare soil. One possible explanation for the difference may be that the plutonium deposited under the shrubbery is "smeared" on the surface of silicate particles which were originally in the bare soil. Further speculation is premature at this time, especially because only one sample has been analyzed thus far. More samples have been obtained and are in the process of investigation.

The plutonium in the ML clay sample occurs in the 2.3 to 2.4 g/cm³ fraction. This fraction is also the highest weight fraction, which suggests close association of the plutonium with the soil particles. The occurrence of about 16% of the activity in the less than 1.8 g/cm³ fraction suggests association of the plutonium with organic matter of the sediment. Until hydrolyzed plutonium, corresponding to clay size particles, is investigated in density gradient media, the nature of the plutonium in the ML sample cannot be defined. Studies are being planned to investigate the role of hydrous oxides as well as that of reference minerals in sorbing plutonium from solutions.

The implications of the findings of size associations, acid and citrate solubilities, and mineral associations of plutonium to plant uptake and resuspension by wind have been considered and will be published.

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R. K. Schreiber

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D. S. Shriner

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H. H. Shugart

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H. H. Shugart, R. A. Goldstein, R. V. O'Neill, and J. B. Mankin

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F. H. Sweeton

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F. H. Sweeton and C. J. Barton

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L. W. Swift, W. T. Swank, J. B. Mankin, R. J. Luxmoore, and R. A. Goldstein

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T. Tamura

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"Environmental effects of chromium and zinc in cooling-water drift." pp. 408-426. In *Cooling Tower Environment, 1974* (S. Hanna and J. Pell, eds.). AEC Symposium Series. CONF-740302. 1975.

J. E. Till

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P. Van Voris and R. C. Dahlman

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W. Van Winkle

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H. A. Vanderploeg, D. C. Parzyck, W. H. Wilcox, J. R. Kercher, and S. V. Kaye

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A. P. Watson, R. I. Van Hook, and D. E. Reichle

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"Increased life span and decreased body weight in hamsters exposed to cigarette smoke." *Arch. Environ. Health* (in press).

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J. P. Witherspoon

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J. F. McCormick, J. C. Beatley, P. G. Murphy, T. P. O'Farrell, W. S. Osburn, Jr., T. D. Rudolph, F. B. Turner, and J. P. Witherspoon

"Natural terrestrial ecosystems." pp. 65-80. In *Long-Term Worldwide Effects of Multiple Nuclear Weapons Detonations.* National Academy of Science, National Research Council. 1975.

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J. P. Witherspoon and D. C. Parzyck

"Population exposure estimates as derived from an environmental assessment of LWR fuel cycle facilities, Part II: Long-term population dose following cessation of plant operations." pp. 199-206. In *Population Exposures: Proc., Eighth Midyear Topical Symposium of the Health Physics Society* (J. C. Hart, R. H. Ritchie, and B. S. Varnadore, eds.). ERDA Symposium Series. CONF-741018. 1974.

M. Witkamp

"Transfer of mineral elements in terrestrial and aquatic microcosms." *Int. J. Environ. Stud.* (in press).

M. Witkamp and B. S. Ausmus

"Processes in decomposition and nutrient transfer in forest systems." In *The Role of Aquatic and Terrestrial Organisms in Decomposition Processes* (J. M. Anderson and A. Macfadyen, eds.). Blackwell Scientific Publications, Oxford (in press).

D. A. Wolfe, G. W. Thayer, and S. M. Adams

"Manganese, iron, zinc and copper in an eelgrass (*Zostera marina*) community." In *Proc., 4th National Symposium on Radioecology* (C. E. Cushing, ed.), May 12-14, 1975, Corvallis, Oregon (in press).

W. R. Wolters and C. C. Coutant

"The effect of cold shock on the vulnerability of young bluegill (*Lepomis macrochirus*) to predation." In *Proc., Second Thermal Ecology Symposium, April 2-5, 1975, Augusta, Georgia* (in press).

T. M. Zaret and J. S. Suffern

"Vertical migration in zooplankton as a predator avoidance strategy." *Limnol. Oceanogr.* (in press).

Presentations

S. M. Adams

"Eelgrass fish communities: A functional analysis," American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

A. Andren and S. Lindberg

"Atmospheric input and geochemical cycling of trace elements in Walker Branch Watershed - I. Atmospheric input," American Society of Limnology and Oceanography Meeting, Halifax, Nova Scotia, June 1975.

B. S. Ausmus

"The ATP assay, what good is it?" EPA-NERL Laboratories, Corvallis, Oregon, June 1975.

C. J. Barton (F. H. Sweeton and C. J. Barton)

"Studies of the hypothetical use of tritiated gasoline in the Denver metropolitan areas," Denver Air Pollution Symposium, Denver, Colorado, March 1975.

C. J. Barton, R. E. Moore, and P. S. Rohwer

"Philosophy and methodology of assessment of doses to populations from combustion products of plowshare natural gas," Eighth Midyear Topical Symposium of the Health Physics Society, Knoxville, Tennessee, October 1974.

B. G. Blaylock

"Dose estimation and prediction of radiation effects on aquatic biota resulting from radioactive releases from the nuclear fuel cycle," International Symposium on Radiological Impacts of Releases from Nuclear Facilities in Aquatic Environments, Otaniemi, Finland, July 1975.

"Long-term studies on the effects of radiation on natural populations of *Gambusia affinis*," Tech Aqua Seminar Series, Tennessee Technological University, Cookeville, July 1975.

"Effects of radiation on aquatic organisms in White Oak Lake," Oak Ridge Associated Universities Special Training Division Course, Oak Ridge, Tennessee, July 1975.

W. J. Boegly, Jr.

"Multi-use trenches," Workshop on Utility Location and Coordination, American Public Works Association, Memphis, Tennessee, May 1975.

"Solid and liquid waste handling in small communities," University of Tennessee, School of Civil Engineering, Knoxville, Tennessee, October 1975.

"Common trenching - State of the art," 54th Annual Meeting of the Transportation Research Board, Washington, D. C., January 1975.

E. A. Bondietti

"Plutonium (IV) and thorium (IV) adsorption to soil colloids," American Society of Agronomy Meeting, Chicago, Illinois, November 1974.

"Radionuclides in soils," Oak Ridge Associated Universities Course on Ecology, Oak Ridge, Tennessee, July 1975.

E. A. Bondietti and D. R. Jackson

"Chemical and biological behavior of Pd and Cd in a smelter-contaminated forest soil," American Society of Agronomy Meeting, Knoxville, Tennessee, August 1975.

E. A. Bondietti, D. R. Jackson, and F. H. Sweeton

"Pb/Cd ratios in soils and plants: Chemical behavior of Pb and Cd in a smelter-contaminated forest," International Conference on Heavy Metals in the Environment, Toronto, Canada, October 1975.

D. M. Bradburn

"Forest management of ERDA reservation," Forest Management Class, University of Tennessee, Knoxville, Tennessee, April 1975.

R. L. Burgess

"Rural migration and changes in the productivity of regional ecosystems," American Association for the Advancement of Science meetings, New York, January 1975.

"Ecological research and international environmental programs," Invited lecture, University of Wisconsin, Milwaukee, Milwaukee, November 1974.

"Cartographic history of the eastern deciduous forest biome," symposium on "The Regionalization and Mapping of Vegetation Cover," XII International Botanical Congress, Leningrad, U.S.S.R., July 1975.

"Life Science for Physical Scientists," two lectures for ORNL in-house course, March - May 1975.

"Overview of ORNL environmental programs," to delegation from Middle Tennessee State University, ORNL Central Auditorium, April 1975.

"World environmental problems and the role of ORNL," luncheon speech to World Press Institute, ORNL, February 1975.

"Environmental problems: An ecologists point of view," Oak Ridge Associated Universities Summer course, July 1975.

S. W. Christensen

"Defining and determining the significance of impacts: Concepts and methods," Workshop on the Biological Significance of Environmental Impacts, Ann Arbor, Michigan, June 1975.

S. W. Christensen, W. Van Winkle, and P. C. Cota

"Effect of Summit Power Station on striped bass populations," Testimony presented to the U. S. Nuclear Regulatory Commission in the Matter of Summit Power Station, Units 1 & 2, Delmarva Power and Light Co. and Philadelphia Electric Company, March 1975.

C. C. Coutant

"Effects of power plants on aquatic organisms," Great Lakes Colleges Association Science Seminar, ORNL, October 1974.

"ORNL thermal effects program," IAEA Workshop on Power Plant Effects, ORNL, November 1974.

"Thermal effects studies at ORNL," Operations Division, ORNL, November 1974.

"Status of studies regarding entrainment and entrapment of aquatic organisms - An overview," Atomic Industrial Forum Conference on Water Quality Considerations for Steam-Electric Power Plants, Phoenix, Arizona, January 1975.

"Responses of bass to natural and artificial temperature regimes," National Symposium on the Biology and Management of the Centrarchid Bases, Tulsa, Oklahoma, February 1975.

"Representative and important species concept," Symposium on Integrity of Water, Washington, D. C., March 1975.

"Thermal effects of fish," Fish Ecology Class, Tennessee Technological University, Cookeville, May 1975.

"Sublethal thermal effects on fish," Tech Aqua Biological Field Station, Tennessee Technological University, Cookeville, July 1975.

C. C. Coutant (continued)

"Thermal pollution - Biological aspects," Panel on Electric Power, Commission on Natural Resources, National Research Council, Washington, D. C., July 1975.

"Thermal Effects," Oak Ridge Associated Universities Summer Institutes on Applied Ecology and Energy Sources for the Future (combined), Oak Ridge, Tennessee, July 1975.

"Telemetry studies with fish at Hanford and ORNL," Symposium on Telemetry, American Fisheries Society Meeting, Las Vegas, Nevada, September 1975.

"Impact of power plants on aquatic systems: A social perspective," Advisory Workshop on Impact of Power Plants on Aquatic Systems, Electric Power Research Institute, Asilomar Conference Grounds, Pacific Grove, California, September - October 1975.

C. C. Coutant and D. K. Cox

"Further studies of cold shock effects on susceptibility of young channel catfish to predation," Second Thermal Ecology Symposium, Augusta, Georgia, April 1975.

"Growth rates of subadult largemouth bass, 24-35.5°C," Second Thermal Ecology Symposium, Augusta, Georgia, April 1975.

D. K. Cox and C. C. Coutant

"Acute cold shock resistance of gizzard shad, *Dorosoma cepedianum*," Second Thermal Ecology Symposium, Augusta, Georgia, April 1975.

"Growth temperature response of striped bass, *Morone saxatilis*," Second Thermal Ecology Symposium, Augusta, Georgia, April 1975.

R. B. Craig

"The predatory response of loggerhead shrikes," American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

P. A. Cunningham

"The effects of mercury on the American oyster, *Crassostrea virginica*," Environmental Sciences Division, ORNL, July 1975.

R. C. Dahlman

"Cycling of cesium-137 in soil and vegetation of a floodplain 30 years after initial contamination," 4th National Symposium on Radioecology, Corvallis, Oregon, May 1975.

"Plutonium distribution in vegetation and soil of a 30-year-old contaminated floodplain," 4th National Symposium on Radioecology, Corvallis, Oregon, May 1975.

S. Draggan

"Microbial ecology," University of Tennessee Graduate Ecology Program, Knoxville, April 1975.

"Models in ecology," and "Microcosms as models of natural ecosystems," Biology Department, Tennessee State University, Nashville, September 1975.

"Assessment of the microcosm as a tool for estimation of environmental transport of toxic materials," American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

J. O. Duguid

"Use of finite element models for environmental problems," lecture series presented at ORNL, October - November 1974.

J. O. Duguid and E. G. Struxness

"Significant hydrologic problems in the nuclear fuel cycle," Geological Society of America Meeting, Miami Beach, Florida, 1974.

L. L. Dye

"Thermal tolerance of the adult Asiatic clam *Corbicula manilensis*," Second Thermal Ecology Symposium, Augusta, Georgia, April 1975.

N. T. Edwards

"Seasonality of nutrient cycling in a southern *Liriodendron* forest," American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

J. W. Elwood

"Environmental tritium," Oak Ridge Associated Universities Special Training Division course on Applied Ecology, Oak Ridge, Tennessee, July 1975.

L. D. Eyman

"Plutonium-237: Its production and use as a gamma tracer in research on plutonium kinetics in an aquatic consumer," International Conference on Environmental Toxicology, Rochester, New York, June 1975.

C. W. Francis

"Density gradient separations of soils with a large-scale zonal rotor," Department of Soil Science and Engineering Geology, University of Agriculture and Field Engineering, Vienna, Austria, August 1975.

"Anaerobic columnar denitrification of high-nitrate wastewater," Conference on Nitrogen as a Water Pollutant, Copenhagen, Denmark, August 1975.

R. H. Gardner

"Biomass allocation and productivity relations of forests," Leningrad, U.S.S.R., July 1975.

"Examination of relationships between parameters of ecosystem compartment models," American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

"Ecosystem models and their statistical reliability," Biology Department, The College of William and Mary, Williamsburg, Virginia, March 1975.

C. W. Gehrs

"The role of an ecologist in a hyper-developing society," Biology and Chemistry Departments, Hope College, Holland, Michigan, December 1974; Eckerd College, St. Petersburg, Florida, February 1975; and Department of Marine Sciences, University of South Florida, St. Petersburg, Florida, February 1975.

"Chlorine-containing stable organics: Their occurrence in and effects upon aquatic environments," IAEA Workshop participants - Cooperative on power plant effects, Oak Ridge, Tennessee, November 1974; and Biology and Chemistry Departments, Hope College, Holland, Michigan, December 1974.

C. W. Gehrs (continued)

"Chlorine compounds in aquatic environments," Department of Biology, Tennessee Technological University, Cookeville, November 1974; Oak Ridge Associated Universities Summer Institute on Applied Ecology, Oak Ridge, Tennessee, July 1975; and Oak Ridge Associated Universities Summer Institute on the Hazards Related to Electrical Energy Production, Oak Ridge, Tennessee, August 1975.

"Evaluating the dynamics of zooplankton populations," Ecology class, Hope College, Holland, Michigan, December 1974.

"A quantitative approach for analyzing copepod populations," Tech Aqua Seminar Series, Tennessee Technological University, Cookeville, July 1975.

T. Grizzard

"Seasonal nutrient dynamics of foliage and litterfall on Walker Branch Watershed, a deciduous forest ecosystem," Botany Department, University of Tennessee, Knoxville, July 1975.

"Seasonal nutrient dynamics of litterfall components," Agronomy Society of America Meeting, Knoxville, Tennessee, August 1975.

"Ecology and Pollution," Jefferson Jr. High School, Oak Ridge, Tennessee, May 1975.

"Ecology," Oak Ridge High School Biology Students, Oak Ridge, Tennessee, May 1975.

W. F. Harris

"The environmental fate of SO_2 and trace elements," American Coal Association Symposium, Louisville, Kentucky, October 1975.

"The significance of root production and turnover to short grass prairie and deciduous forest ecosystem function," American Association for the Advancement of Science Meeting, New York, January 1975.

"Ecosystem analysis," Botany Department, University of Tennessee, Knoxville, April 1975.

G. S. Henderson

"Comparison of cation and nitrogen budgets for Appalachian and Cascade Mountain watersheds," American Association for the Advancement of Science Meeting, New York, January 1975.

S. G. Hildebrand

"Bioaccumulation of mercury by fish and benthic invertebrates in the Holston River-Cherokee reservoir system," Joint Conference on Water Quality in the North Fork Holston River, Saltville, Virginia, May 1975.

S. G. Hildebrand and H. Zittel

"Supplemental testimony on the impact of chlorine discharges on aquatic biota of the Allen's Creek cooling lake," U. S. Nuclear Regulatory Commission - Atomic Safety and Licensing Board Environmental Hearings, Wallis, Texas, March 1975.

J. W. Huckabee

"Mercury in moss," University of Rochester Medical School, Rochester, New York, January 1975.

"Mercury in the environment," Oak Ridge Associated Universities Applied Ecology Course, Oak Ridge, Tennessee, July 1975.

"Mercury in the environment," Oak Ridge Associated Universities Summer Institute on Biological Considerations of Environmental Pollutants, Oak Ridge, Tennessee, August 1975.

D. D. Huff

"Studies of the contributions of nonpoint terrestrial sources to mineral water quality," Joint Workshop of the National Research Council and The Institute of Ecology on Methods of Ecosystems Analysis, Austin, Texas, December 1974.

"The unified transport model," Symposium on Water Quality and Ecosystems Modeling, sponsored by the Corps of Engineers at the Waterways Experiment Station, Vicksburg, Mississippi, January 1975.

"A watershed transport model user workshop," for ORNL and U.S.D.A. Forest Service Staff from North Carolina, New Hampshire, and Arkansas, ORNL, December 9-13, 1974.

"The adequacy and reliability of a model that simulates deciduous forest water relations," American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

W. C. Johnson

Approximately 25 lectures, including "The vegetation of America," "Land-use and forest succession in North-Central Georgia," and "Organizational structure and research program of the Environmental Sciences Division, ORNL," in Dushanbe, Baku, Tbilisi, Leningrad, Petrozovodsk, Tallinn, Novosibirsk, Moscow, and Pushchino, U.S.S.R., March - August 1975.

"Russian travelogue," Environmental Sciences Division, ORNL, September 1975.

W. C. Johnson, D. M. Sharpe, B. S. Ausmus, and Kermit Cromack

"The influence of anthropogenic factors on regional decomposition of forest litter," XII International Botanical Congress, Leningrad, U.S.S.R., July 1975.

R. L. Jolley

"Chlorine-containing organic constituents in chlorinated effluents from sewage treatment plants," Conference of the Water Pollution Control Federation, Denver, Colorado, October 1974.

"Application of high-resolution liquid chromatography to the analysis of dissolved organics in natural and processed waters," Meeting on the Practice of Chromatography, American Society for Testing and Materials, Philadelphia, Pennsylvania, October 1974.

"Determination of dissolved organic constituents in sewage effluents and natural waters," Department of Civil Engineering, University of Tennessee, Knoxville, October 1974.

"Chlorination effects on organic constituents in natural and process waters," Oak Ridge Associated Universities Traveling Lecture Program, Grambling State University, Grambling, Louisiana, April 1975.

"Soluble organic constituents in sewage treatment plant effluents as determined by a multicomponent analytical technique," American Chemical Society Meeting, Philadelphia, Pennsylvania, April 1975.

"Chlorination effects on organic constituents in natural and process waters," Eckerd College, St. Petersburg, Florida, April 1975.

"Chlorination of cooling water: A source of environmentally significant chlorine-containing organic compounds," 4th National Symposium on Radioecology, Corvallis, Oregon, May 1975.

"Analysis of soluble organic constituents in natural and process waters by high-pressure liquid chromatography," Annual Conference on Trace Substances in Environmental Health, Columbia, Missouri, June 1975.

S. V. Kaye

"Distribution and movement of radionuclides through the environment," Oak Ridge Associated Universities Special Institute on Nuclear Power Safety, August 1975.

"Food chain models related to human exposure," ERDA Analysis and Assessment Workshop, Argonne National Laboratory, Argonne, Illinois, May 1975.

M. J. Kelly, R. B. McLean, and S. W. Christensen

"Supplemental testimony of NRC staff on chlorine discharge." Testimony before the Atomic Safety Licensing Board in the Matter of Summit Power Station, Units 1 and 2, Delmarva Power and Light Co., and Philadelphia Electric Co., USAEC Docket Nos. 50-450 and 50-451, March 1975.

G. G. Killough

"Some mathematical models used in radiation dose calculations," Tennessee Academy of Science Meeting, Memphis, Tennessee, November 1974.

J. T. Kitchings

"ERDA Oak Ridge Environmental Research Park," Tennessee Nature Conservancy Workshop on Natural Areas, Cheekwood Gardens, Nashville, Tennessee, July 1975.

J. T. Kitchings, D. DiGregorio, and P. Van Voris

"A review of the ecological parameters of radionuclide turnover in vertebrate food chains," 4th National Symposium on Radioecology, Corvallis, Oregon, May 1975.

R. L. Kroodsmas

"Potential effects of whole-tree harvesting on bird populations of Appalachian Mountain hardwood forests," Logging Residues Conference, Morgantown, West Virginia, June 1975.

"Bird communities in pine plantations," Ecological Society of America Meeting, Corvallis, Oregon, August 1975.

S. Lindberg and A. Andren

"Atmospheric input and geochemical cycling of trace elements in Walker Branch Watershed. II. Cycling and output mechanisms," American Society of Limnology and Oceanography Meeting, Halifax, Nova Scotia, June 1975.

S. Lindberg, A. Andren, R. Raridon, and W. Fulkerson

"Input and output of trace elements at Walker Branch Watershed - Relation to coal-fired steam plants," Annual Research Triangle Park Conference on "Heavy Metals in the Environment," University of North Carolina, Chapel Hill, May 1975.

R. J. Luxmoore, D. D. Huff, R. K. McConathy, and B. E. Dinger

"Soil-plant water relations of tulip poplar forest on podsolized soil," American Society of Agronomy Meeting, Chicago, Illinois, November 1974.

J. S. Mattice

"Thermal effects of energy generation," Oak Ridge Associated Universities, Oak Ridge, Tennessee, December 1974.

"Environmental effects of power plants," Oak Ridge Associated Universities, Oak Ridge, Tennessee, March 1975.

J. S. Mattice (continued)

"Biological effects of thermal pollution," Oak Ridge Associated Universities, Oak Ridge, Tennessee, August 1975.

"Effect of temperature on growth, mortality, reproduction and production of adult *Lymnaea obsoleta* Say (Mollusca:Gastropoda)," Second Thermal Ecology Symposium, Augusta, Georgia, April 1975.

S. B. McLaughlin

"Effects of acid rain and SO₂ on terrestrial and aquatic ecosystems," Annual Chemists and Meteorologists Workshop, Ft. Lauderdale, Florida, January 1975.

"A programmable exposure system for kinetic dose-response studies with air pollutants," Air Pollution Workshop, Muscle Shoals, Alabama, April 1975.

"ORNL studies on surface mining activity in the new river basin," USGS Collaborative Conference on "Hydrologic Data Collection Activities in the New River Basin," Nashville, Tennessee, September 1975.

R. B. McLean

"A marine benthic faunal 'habitat web': A behavioral study," American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

R. E. Moore

"The effect of deposition velocities on estimates of environmental transport and population doses," Eighth Midyear Topical Symposium of the Health Physics Society, Knoxville, Tennessee, October 1974.

"The AIRDOT area source computer code," Denver Air Pollution Field Study Symposium, Denver, Colorado, March 1975.

F. R. O'Donnell, F. H. Clark, O. W. Burke, L. R. McKay, A. N. Tse, and R. F. Barker

"CONDOS - A model and computer code to estimate population and individual radiation doses to man from the distribution, use, and disposal of consumer products that contain radioactive materials," Eighth Midyear Topical Symposium of the Health Physics Society, Knoxville, Tennessee, October 1974.

R. V. O'Neill

"Importance of validation in ecosystem analysis," Symposium on the Future of Systems Ecology, Logan, Utah, February 1975.

"Prediction and validation of ecosystem models," San Diego State University, San Diego, California, April 1975.

"Heterotrophic dynamics in ecosystems," Symposium on the Role of Consumers in Ecosystems, Athens, Georgia, November 1974.

"Techniques in ecosystem modeling," Caracas, Venezuela, November 1974.

D. C. Parzyck

"The nuclear and nonnuclear assessment methodologies developed in the ORNL Environmental Sciences Division," Bionucleonics Department and the School of Pharmacy, Purdue University, West Lafayette, Indiana, September 1974.

"The research efforts of the Environmental Sciences Division radiological analyses and applications project," University of Tennessee Systems Ecology Group, Environmental Sciences Division, ORNL, December 1974.

"The carcinogenicity of coal conversion products," Summer Study Program, Carson Newman College, Jefferson City, Tennessee, July 1975.

M. R. Patterson, J. K. Munro, and R. J. Luxmoore

"Simulation of lead transport on the Crooked Creek Watershed," Conference on Trace Substances on Environmental Health, Columbia, Missouri, June 1975.

D. E. Reichle

"Control technologies for removal of sulfur during coal combustion," Annual Chemist and Meteorologists Workshop, Ft. Lauderdale, Florida, January 1975.

"Mineral cycles on hardwood and pine watersheds at Coweeta," XII International Botanical Congress, Leningrad, U.S.S.R., July 1975.

"National program statement for U.S. Man and the Biosphere Project II," National Academy of Sciences, Environmental Studies Board, Washington, D. C., October 1975.

"The implications of energy flow studies on human populations for the field of ecology," Workshop on Energy Flow in Non-Industrial Societies, Social Science Research Council, New York, February 1974.

P. S. Rohwer

"Estimation and evaluation of the radiation dose we will receive from our nuclear power reactors," Grambling State University, Grambling, Louisiana, and Southwestern University, Georgetown, Texas, February 1975.

"Radiation dose from nuclear power reactors," Oak Ridge Associated Universities Summer Institute on Biological Considerations of Environmental Pollutants, Oak Ridge, Tennessee, August 1975.

P. S. Rohwer (C. J. Barton, R. E. Moore, P. S. Rohwer, and S. V. Kaye)

"Calculational techniques for estimating population doses from radioactivity in natural gas from nuclearly stimulated wells," Fourth IAEA Technical Committee Meeting on Peaceful Nuclear Explosions, Vienna, Austria, January 1975.

P. S. Rohwer, C. J. Barton, and R. E. Moore

"Large-scale nuclear gas stimulation: Population doses estimated in the environmental assessment of carbon-14 releases," Eighth Midyear Topical Symposium of the Health Physics Society, Knoxville, Tennessee, October 1974.

P. S. Rohwer, S. V. Kaye, and E. G. Struxness

"CUEX methodology for assessing radiological impacts in the context of ICRP," Fourth U.S.-U.S.S.R. Bilateral Technical Discussion on Plowshare, and Fourth IAEA Technical Committee Meeting on Peaceful Nuclear Explosions, Vienna, Austria, January 1975.

P. S. Rohwer and W. H. Wilcox

"Radiological aspects of environmental tritium," Health Physics Society Meeting, Buffalo, New York, July 1975.

M. S. Salk

"Effects of selected pesticides on the growth of ten isolates of soil algae," Environmental Sciences Division, ORNL, April 1975.

D. S. Shriner

"Effects of simulated rain acidified with sulfuric acid on host-parasite interactions," First International Symposium on Acid Precipitation and the Forest Ecosystem, Columbus, Ohio, May 1975.

D. S. Shriner (continued)

"Effects of simulated rain acidified with sulfuric acid on nodulation of leguminous plants by *Rhizobium* sp." American Rhizobium Conference, Raleigh, North Carolina, August 1975.

H. H. Shugart, D. E. Reichle, N. T. Edwards, and J. R. Kercher

"Controlability of calcium cycles in temperate deciduous forests," American Association for the Advancement of Science, New York, January 1975.

E. G. Struxness

"Environmental impact statements," Oak Ridge Associated Universities Summer Institute on Energy Sources for the Future, Oak Ridge, Tennessee, August 1974.

"Environmental impact statements," Eighth Midyear Topical Symposium of the Health Physics Society, Knoxville, Tennessee, October 1974.

"Environmental impact statements," Oak Ridge Associated Universities Workshop on Nuclear Power and the Energy Crisis, Oak Ridge, Tennessee, November 1974.

"Significant hydrogeologic problems in the light-water reactor fuel cycle," Geological Society of America Meeting, Miami Beach, Florida, November 1974.

"Environmental impact statements," Oak Ridge Associated Universities Workshop on Nuclear Power and the Energy Crisis, Oak Ridge, Tennessee, December 1974.

"Environmental impact statements," Oak Ridge Associated Universities, State Radiological Health personnel, Oak Ridge, Tennessee, May 1975.

"Environmental impact analysis," Council on Environmental Quality, ORNL, June 1975.

"The environmental impact statement," Oak Ridge Associated Universities Workshop on Nuclear Power and the Energy Crisis, Oak Ridge, Tennessee, September 1975.

J. S. Suffern

"The relationship between human consciousness and the environmental crisis," Springfield College, Springfield, Massachusetts, December 1974.

"Nuclear energy centers - A preliminary report," Environmental Sciences Division, ORNL, March 1975.

"Analytical problems associated with nuclear energy centers," Mathematics Research Department, Y-12 Plant, Oak Ridge, Tennessee, September 1975.

F. S. Sweeton and T. Tamura

"Adsorption of Cd^{2+} from Ca^{2+} solutions by clay minerals," American Society of Agronomy Meeting, Knoxville, Tennessee, August 1975.

T. Tamura

"Characterization of plutonium in surface soils from Area 13 of the Nevada Test Site," Plutonium Information Meeting, Las Vegas, Nevada, October 1974.

"Analytical problems associated with environmental plutonium analysis," Chemistry Department, Tennessee Technological University, Cookeville, February 1975.

"Plutonium in surface soils of Area 13: A progress report," Plutonium Information Meeting, Las Vegas, Nevada, May 1975.

"Plutonium behavior in environmental systems," ORNL Research Committee, ORNL, June 1975.

F. G. Taylor

"Transport, deposition, and accumulation of chromium from cooling tower drift," Seventh National Air Pollution Workshop, Joseph Wheeler State Park Resort, Rogersville, Alabama, April 1975.

"Distribution of chromium in vegetation and small mammals adjacent to cooling towers," 4th National Symposium on Radioecology, Corvallis, Oregon, May 1975.

"Use of phenology in primary productivity studies," Graduate class in ecology, Tennessee Technological University, Cookeville, May 1975.

J. E. Till

"Health Physics training at the Barnwell Nuclear Fuel Plant," Health Physics Society Meeting, Buffalo, New York, July 1975.

"Health Physics Training," Poster Display at Health Physics Society Meeting, Buffalo, New York, July 1975.

"Significance of ^{232}U in recycled HTGR fuel," ORNL Managers, ORNL, March 1975.

R. R. Turner

"Water renewal time as a factor in nutrient cycling in a north Florida impoundment," American Society of Limnology and Oceanography Meeting, Halifax, Nova Scotia, June 1975.

"The effects of land use on nutrient and suspended solids budgets for three north Florida watersheds," American Society of Limnology and Oceanography Meeting, Halifax, Nova Scotia, June 1975.

W. Van Winkle

"Physical and biological effects of cooling systems and thermal discharges from nuclear power stations," IAEA Research Coordination Meeting, ORNL, November 1974.

"The application of computers in an assessment of the environmental impact of power plants on an aquatic ecosystem," ERDA-Wide Conference on Computer Support of Environmental Science and Analysis, Albuquerque, New Mexico, July 1975.

"Impact assessment, Indian Point, and striped bass," Oak Ridge Associated Universities Special Training Division Course on Applied Ecology, Oak Ridge, Tennessee, July 1975.

"The six-year cycle in Atlantic Coast striped bass populations: Fact or fancy," American Fisheries Society Meeting, Las Vegas, Nevada, September 1975.

J. P. Witherspoon

"Population doses from operating LWR fuel cycle facilities," Eighth Midyear Topical Symposium of the Health Physics Society, Knoxville, Tennessee, October 1974.

"Radiation in perspective," and "Impacts of nuclear power stations," Hopkinsville Community College, Hopkinsville, Kentucky, March 1975.

"Environmental impacts of nuclear power plants," Sam Rayburn Public Affairs Symposium, East Texas State University, Commerce, Texas, April 1975.

"Radiation in perspectives: Radiological impacts of the nuclear fuel cycle," Catawba College, Salisbury, North Carolina, April 1975.

"Environmental behavior of radionuclides and dose assessments," Oak Ridge Associated Universities Radiation Accident Management Course, Oak Ridge, Tennessee, May 1975.

"Radiological impacts of nuclear fuel cycle facilities," Carson Newman College, Jefferson City, Tennessee, June 1975.

M. Witkamp

"Processes in decomposition and nutrient transfer in forest ecosystems," British Ecological Society Decomposition Symposium, Coleraine, Northern Ireland, April 1975.

"Transfer of mineral elements in terrestrial and aquatic microcosms," American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

Theses

V. D. Adams

Analysis of the time delay in a host-parasite model, M.S., University of Tennessee, Knoxville, 1975.

E. A. Bardill

The effects of acute ionizing radiation on selected life stages of the calanoid copepod Diaptomus clavipes Schacht, M.S., University of Tennessee, Knoxville, 1975.

R. M. Cushman

Production dynamics of Alloperla mediana Banks (Plecoptera:Chloroperlidae) and Diplectrona modesta Banks (Trichoptera:Hydropsychidae) in Walker Branch, Tennessee, M.S., University of Tennessee, Knoxville, 1975.

R. D. Dueser

Structural niches in a forest floor small mammal community, Ph.D., University of Michigan, Ann Arbor, 1974.

T. Grizzard

Seasonal nutrient dynamics of foliage and litterfall on Walker Branch Watershed, a deciduous forest ecosystem, M.S., University of Tennessee, Knoxville, 1975.

D. C. West

Forest population structure in the southeastern United States, Ph.D., University of Tennessee, Knoxville, 1974.

Professional Activities

S. M. Adams

Participant - Preparation of the Draft Environmental Statement related to the manufacture of floating nuclear power plants, Docket No. STN50-437, April 1975, Atlantic Generating Station Environmental Statement; AIBS Meeting, Corvallis, Oregon, August 1975; and Workshop on the Biological Significance of Environmental Impact, University of Michigan, Ann Arbor, June 1975.

S. I. Auerbach

Member - Life Sciences Nominating-Screening Panel for 1975 Ernest Orlando Lawrence Memorial Award; Board of Editors, *Radiation Research*; Board on Energy Studies of the National Academy of Sciences, National Research Council; ERDA Traineeship Selection Panel; Adjunct Research Professor, University of Tennessee, Knoxville, Tennessee, Department of Ecology; Special Committee on Biological Water Quality of the Ohio River Valley Water Sanitation Commission.

S. I. Auerbach (continued)

Chairman - Committee on Energy and the Environment of the National Academy of Sciences-National Research Council Board on Energy Studies; Steering Committee for Analytical Studies for the EPA (National Academy of Sciences-NRC); and Ecology Session, Engineering Foundation Conference, New England College, Henniker, New Hampshire, August 1975.

B. S. Ausmus

Research advisor - Emory University undergraduate research participant and Oak Ridge Associated Universities undergraduate research participant, 1975.

Member - Women's Resource Task Force, Oak Ridge National Laboratory.

Participant - Conferences with E. A. Paul, D. Parkinson, and M. Witkamp, University of Calgary, Alberta, Canada, February 1975; with J. M. Anderson, University of Exeter, U.K., Oak Ridge, July 1975; with members of EPA-NERL staff, Corvallis, Oregon, June 1975; and with Oregon State University forestry and fisheries personnel, June 1975.

J. P. Baker

Participant - Preparation of report on the environmental effects of ERDA operations at Oak Ridge; and preparation of the ERDA environmental impact statement on the Expansion of U. S. Uranium Enrichment Capacity (WASH-1543) and site-specific statements on gas centrifuge and gaseous diffusion uranium enrichment facilities.

B. G. Blaylock

Major professor - Graduate thesis committee, E. A. Bardill (M.S.), University of Tennessee, Knoxville.

Member - Knox County Council on Environmental Quality.

Technical Reviewer - *Proceedings of Second Thermal Effects Symposium*.

Participant - Union Carbide Management System Training Program, November 20, 1974 - April 4, 1975.

W. J. Boegly, Jr.

Chairman - State of Tennessee's Board of Reclamation Review and "Waste Utilization Working Group," *U. S. National Energy R & D Plan* (ERDA).

Member - Committee on Utilities (A1A03), Transportation Research Board, National Academy of Sciences, and National Academy of Engineering.

Quality assurance coordinator - Environmental Sciences Division, ORNL.

Advisory member - Committee on Dual Distribution Systems, American Water Works Association.

Associate professor of civil engineering (Environmental Engineering) - University of Tennessee, Knoxville.

Participant - Preparation of environmental impact statement on MIUS (generic statement).

E. A. Bondietti

Session chairman - Symposium on Long-Lived Radionuclides in Soil-Plant Systems, American Society of Agronomy Meeting, Knoxville, Tennessee, August 1975.

D. M. Bradburn

Vice-chairman - East Tennessee Chapter of Society of American Foresters, 1975.

Member - Environmental Sciences Division Landscape Committee, ORNL.

Participant - Field trip of East Tennessee Chapter of Society of American Foresters to ERDA Reservation, April 1975.

R. L. Burgess

Review editor - *Ecology*.

Member - Board of Editors, Council, Committee on Ethics and Professionalism, and Awards Committee, Ecological Society of America; Curriculum Committee, University of Tennessee Graduate Program in Ecology; Steering Committee, "Life Science for Physical Scientists," ORNL in-house course; ORNL Information Systems Advisory Committee; Liason Committee, ESD-Oak Ridge Graduate School of Biomedical Sciences; ESD Education Committee; ESD Social Committee.

Chairman - Environmental Sciences Division Landscape Committee.

Deputy Director - Eastern Deciduous Forest Biome, US/IBP.

Participant - First International Congress of Ecology, The Hague, Netherlands, September 1974; IBP Primary Production Workshop, Jädraås, Sweden, June 1975; XIIth International Botanical Congress, Leningrad, U.S.S.R., July 1975; National Wetlands Classification and Inventory Workshop, University of Maryland, College Park, July 1975; ESA Council Meeting, Oak Ridge, February 1975; ESA Council Meeting, Corvallis, Oregon, August 1975; Committee on Ecosystem Studies, The Institute of Ecology, Corvallis, Oregon, August 1975; National Science Foundation Program Review, Oak Ridge, May 1975; and Council on Environmental Quality Meeting, Oak Ridge, June 1975.

S. W. Christensen

Participant - Preparation of the aquatic ecology sections of the Final Environmental Statements, Fulton Generating Station Units 1 and 2 and Indian Point Unit No. 3; Cornwall (Storm King Pumped-Storage Project) Working Meeting, Washington, D. C., September 30 - October 1, 1974; Summit Power Station Working Meeting, Wilmington, Delaware, December 6, 1974; ASLB Hearings on Summit Power Station, Wilmington, Delaware, April 21-25, 1975; Oak Ridge Associated Universities Training Course on Use of Radionuclides in Research, Oak Ridge, Tennessee, April 28 - May 2, 1975; Workshop on the Biological Significance of Environmental Impacts, Ann Arbor, Michigan, June 4-6, 1975; NRC Meeting to draft a "Request for Proposal" relating to a survey of available models for use in assessing environmental impacts, Bethesda, Maryland, June 20, 1975; and Meeting of The Institute of Ecology's Water Ecosystem Committee, Washington, D. C., September 12, 1975.

C. C. Coutant

Member - National Advisory Council, Electric Power Research Institute; Research Advisory Committee, Lake Sangchris Study, Illinois Natural History Survey; Research Committee, Water Pollution Control Federation; Thermal Effluents Subcommittee, The Institute of Ecology; Subcommittee on Environmental Standards, American National Standards Institute; and Pollution Committee, Southern Division American Fisheries Society.

Research advisor - MIT Practice School in Chemical Engineering, ORNL.

Recruiter - Oak Ridge National Laboratory Ph.D. Recruiting Program, Cornell University.

C. C. Coutant (continued)

Participant - Union Carbide Management System Training Program; AEC/EPA Workshop on Coordination of Research and Monitoring Plans, Falls Church, Virginia, January 1975; Atomic Industrial Forum working meeting on Data Coordination for Utilities Conducting Ecological Field Studies Related to §316(A) of PL 92-500; and Aspen Seminar on Alternative National Strategies for Energy Development, Aspen Institute and Electric Power Research Institute, Aspen, Colorado, August 1975.

Advisor - Ministry of Natural Resources, Government of Ontario regarding power plant siting.

Research advisor - Graduate thesis committee, R. Yates (M.S.), University of Tennessee, Knoxville.

Technical Reviewer - *Transactions of the American Fisheries Society*, *Health Physics*, *Journal of the Fisheries Research Board Canada*, *Science*, *Estuarine and Coastal Marine Science*, *Chesapeake Science*, and *Journal of the Water Pollution Control Federation*.

Chairman - Advisory Workshop on Impact of Power Plants on Aquatic Systems, Electric Power Research Institute, Pacific Grove, California, September - October 1975.

Proposal reviewer - National Science Foundation, USAEC/ERDA.

Associate editor - *Underwater Telemetry Newsletter*.

D. K. Cox

Technical reviewer - *Health Physics* and the *Proceedings of the Second Thermal Ecology Symposium*.

Participant - Tours of Aquatic Ecology Laboratory, approximately 2 tours/week with a total impact of approximately 74 people/month.

R. B. Craig

Participant - Preparation of Offshore Power Systems Generic Environmental Statement, PDES, March 1975; Atlantic Generating Station Environmental Statement, DES, November 1975; Expansion of U. S. Uranium Enrichment Capacity Generic Environmental Statement, PDES, June 1975; Oak Ridge Gas Centrifuge Uranium Enrichment Plant Environmental Statement, PDES, September 1975; Portsmouth Gaseous Diffusion Plant Extension Environmental Statement, PDES, September 1975; Workshop on the Biological Significance of Environmental Impact, University of Michigan, Ann Arbor, June 1975; Workshop on the Management of Environmental Protection Projects, Drexel University, Philadelphia, Pennsylvania, August 1975; and American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

P. A. Cunningham

Participant - Preparation of generic study of technical specifications for nuclear power plants and Atlantic Estuarine Research Society Meeting, Morehead City, North Carolina, October 1974.

Technical reviewer - *Science*.

R. C. Dahlman

Section Chairman - 4th National Symposium on Radioecology, Corvallis, Oregon, May 1975.

Participant - Ecology-Meteorology Workshop, University of Michigan Biological Station, Pellston, June 1975.

Member - Site review team of the Idaho Nuclear Engineering Laboratory ecological studies and information meeting, Health Services Laboratory, ERDA Operations, Idaho Falls, Idaho.

R. C. Dahlman (continued)

Technical reviewer - *Health Physics*, 4th National Symposium on Radioecology; Mineral Cycling Symposium; and Proposals for National Science Foundation and ERDA Division of Biomedical and Environmental Research.

Committee member - Graduate Student University Tennessee Ecology Program.

D. L. DeAngelis

Chapter editor - Woodlands Synthesis volumes, International Biological Program.

K. R. Dixon

Participant - Plant-Soil-Water-Atmosphere Interfaces Workshop, University of Missouri, St. Louis, October 1974.

S. Draggan

Organizer - Symposium on Role of Microcosms in Ecological Research, American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

Chairman - Contributed papers session on Microcosm and Experimental Ecology Research, American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

Participant - Gulf Breeze Microcosm Workshop, Gulf Breeze, Florida, September 1975.

J. O. Duguid

Member - Association of Engineering Geologists; and American Nuclear Society Standards Committee (Working Group 2.9 to set guidelines for determining ground-water hydrology for power reactor sites).

L. L. Dye

Participant - North American Benthological Society Meeting, Springfield, Illinois, March 1975.

G. K. Eddlemon

Participant - Preparation of aquatic ecology sections of Preliminary Draft Environmental Statements for Sterling Power Project and Greene County Nuclear Power Plant; Draft Environmental Statement and supplemental testimony for Wolf Creek Generating Station, Draft and Final Environmental Statements for South Texas Projects Units 1 and 2; and ASLB Construction permit hearings for South Texas Project Units 1 and 2, April 1975.

N. T. Edwards

Participant - Oak Ridge Associated Universities Special Training Course on Use of Radionuclides in Research, April - May 1975.

J. W. Elwood

Participant - Workshop session on Environmental Behavior of Tritium, Symposium on Tritium Technology Related to Fusion Reactor Systems, Mound Laboratory, October 1974; and Oak Ridge Associated Universities Special Training Course on Use of Radionuclides in Research, April - May 1975.

Member - Executive Committee, North American Benthological Society.

Judge - Southern Appalachian Science Fair, University of Tennessee, Knoxville, April 1975.

Technical reviewer - *Health Physics*, *Journal of the Fisheries Research Board of Canada*, *Transactions of the American Fisheries Society*, and 4th National Radioecology Symposium.

W. R. Emanuel

Participant - Short Course on Hierarchical Approach in the Planning, Operation and Management of Water Resources Systems, Case Western Reserve University, Cleveland, Ohio, May 1975.

L. D. Eyman

Participant - Oak Ridge Associated Universities Special Training Division Course on Use of Radionuclides in Ecological Research, Oak Ridge, Tennessee, April - May 1975.

Technical reviewer - *Health Physics*, *Transactions of the American Fisheries Society*, *4th National Radioecology Symposium*, and *Mineral Cycling Symposium*.

C. W. Francis

Technical reviewer - *Science*, *Health Physics*, *4th National Symposium on Radioecology*, *Journal of Environmental Quality*, *Journal of Agriculture and Food Chemistry*, *Nuclear Science and Engineering*, and *Applied and Environmental Microbiology*.

R. H. Gardner

Research advisor - Emory University student, 1975.

Participant - Workshop, IBP-PT Woodland Working Party on Primary Production, Jädraås, Sweden, June 1975.

Technical reviewer - *Ecology*.

Member - IBP Woodland Data Set Management Committee.

C. W. Gehrs

Lecturer - University of Tennessee, and Oak Ridge Graduate School of Biomedical Sciences.

Research advisor - Don Creasia, Biomedical Graduate Program student, 1975.

Technical reviewer - *Science*, *Mineral Cycling Symposium*, *Second Thermal Ecology Symposium*, and *4th National Radioecology Symposium*.

Participant - Sloan-Kettering Institute Workshop on the Health Effects of Coal and Oil Shale Mining, Conversion, and Utilization, January 1975; and Coal Conversion DBER BPP Workshop, Coordination of Coal Conversion Aspects, June 1975.

Coordinator - Preparation and production of the ORNL proposal on Biomedical and Environmental Research for Support and Evaluation of Coal Conversion Technology; and Organization, preparation, and production of the draft DBER BPP in Coal Conversion.

Organizer - Workshop on Coal Conversion Balanced Program Plan, May 1975.

J. S. Griffith

Research advisor - R. Yates, (M.S.), University of Tennessee student, 1975.

Technical reviewer - *Transactions of the American Fisheries Society*.

W. F. Harris

Member - ORNL Proposal Review Committee; ESD Education Committee; and Executive Committee, Eastern Deciduous Forest Biome, Analysis of Ecosystems Program, US-IBP.

W. F. Harris (continued)

Participant - ERDA-DBER Workshop on Ecologist and Meteorologist, Pellston, Michigan, June 1975; ERDA-DBER Workshop on Regional Analytical Studies Programs, Chicago, May 1975.

ORNL representative - Southern Forest Environment Research Council, Virginia Polytechnic Institute, July - August 1975.

Technical reviewer - *Health Physics*, *Radiation Botany*, and *American Midland Naturalist*.

G. S. Henderson

Technical reviewer - *Forestry Chronicle*, *Soil Science Society of America Proceedings*, *Forest Science*, and *Canadian Journal of Forestry Research*.

S. E. Herbes

Participant - Workshop on Coal Conversion Balanced Program Plan, May 1975.

S. G. Hildebrand

Advisor - Institute of Ecology Water Ecosystems Committee assisting the National Commission on Water Quality in the assessment of achieving or not achieving water quality goals set forth in the Federal Water Pollution Control Act Amendments of 1972.

Participant - NRC Directorate of Licensing at ASLB Hearings for Allen's Creek Nuclear Power Station, Wallis, Texas, March 1975; and Oak Ridge Associated Universities Special Training Division Course on Use of Radionuclides in Research, April - May 1975.

Research advisor - R. M. Cushman (M.S.), Graduate Program, University of Tennessee, Knoxville.

G. S. Hill

Participant - Preparation of the draft report for developing the "as low as practicable" guides for the HTGR fuel reprocessing plant and the HTGR fuel fabrication and refabrication plants; Preparation of the environmental assessment of the radiological impact of the Oak Ridge Operations facilities, the Portsmouth Gaseous Diffusion Plant and addition, a gaseous centrifuge plant, and a gaseous centrifuge plant combined with a gaseous diffusion plant; and Preparation of a draft report of the consumer product environmental impact statement for static eliminators and ion generators containing radioactive materials.

D. D. Huff

Member - Committee on Water Quality of the American Geophysical Union, March 1975.

Major professor - L. R. Massie (Ph.D.), University of Wisconsin, Madison.

Participant - Short course on Hierarchical Approach in the Planning, Operation, and Management of Water Resources Systems, Case Western Reserve University, Cleveland, Ohio, May 1975; Development of a workshop report for the NRC/TIE Joint Panel on Ecosystem Analysis for submission to the National Commission on Water Quality; and Pilot course on Developing Technical Writing Skills, ORNL.

J. R. Hyndman

Participant - Workshop on the Biological Significance of Environmental Impacts, Ann Arbor, Michigan, June 1975; and Nuclear Energy Center Siting Survey for U.S. NRC report to Congress on feasibility of nuclear energy center concept.

D. R. Jackson

Participant - Workshop on Heavy Metals in Plants and Soils, University of Illinois, Urbana; and Workshop on Modeling Soil Chemical Processes (with Marvin Shaffer and Connie Begovich), Denver, Colorado.

W. C. Johnson

Exchange scientist - Soviet Union, March 15 to August 24, 1975, sponsored by U. S. and U.S.S.R. Academies of Science.

Technical reviewer - *The American Naturalist*; and proposals for *National Science Foundation and the Energy Research and Development Administration*.

Participant - Soviet IBP Synthesis Symposium, Leningrad, U.S.S.R., December 1974.

Chairman - Contributed paper session "Productivity of Terrestrial Communities," XII International Botanical Congress, Leningrad, U.S.S.R., July 1975.

S. V. Kaye

Member - ORNL Awards Program Committee.

Participant - Selection of university applications for ERDA fellowships in nuclear engineering, public health, and health physics; Union Carbide management training program; and ERDA analysis and assessment workshop, Argonne National Laboratory, May 1975.

Technical reviewer - *Nuclear Safety and Health Physics*.

G. G. Killough

Participant - Preparation of a supplement for the draft Proposed Final Environmental Statement for the LMFBR: *Section III D: Radioactive Waste Management and Radiological Assessment of Carbon-14 Releases from the LMFBR Fuel Cycle*; Preparation of the Preliminary Draft Environmental Analysis, Oak Ridge Operations (Three-Plant Study).

Technical reviewer - Draft ICRP Publication 10X: *Report of Committee 4 on Evaluation of Radiation Doses to Body Tissues from Internal Contamination due to Occupational Exposure*; and Appendix A of *Principles and Methods for Use in Radiation Protection Assessments Related to Planned and Unplanned Releases of Radioactive Materials into the Environment, A Report of Committee 4 of the ICRP*.

J. T. Kitchings

Participant - Symposium on Management of Forest and Range Habitat for Non-Game Birds, Tucson, Arizona, May 1975; and Workshop on Natural Area Inventories, The Nature Conservancy, Nashville, Tennessee, July 1975.

Coordinator - Activities related to terrestrial input to environmental assessment of ERDA's Oak Ridge Operations.

R. L. Kroodsmma

Participant - Preparation of terrestrial ecology and land-use evaluations for NRC Draft and Final Environmental Statements for Perkins Nuclear Station Units 1, 2, and 3, and Cherokee Nuclear Station Units 1, 2, and 3, the Draft Environmental Statement for North Coast Nuclear Plant No. 1; Preparation of an Environmental Assessment for the Molten Salt Breeder Reactor Fuel Reprocessing Engineering Center; ASLB hearings concerning environmental impacts of the Seabrook Nuclear Station Units 1 and 2; Logging Residue Conference, Morgantown, West Virginia, June 1975; and American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975.

R. J. Luxmoore

Participant - Workshop on Plant Growth and Uptake of Trace Contaminants, sponsored by NSF/RANN, St. Louis, Missouri, October 1974; Hydrologic Transport Model User Workshop, sponsored by the EDFB, Oak Ridge, Tennessee, December 1974; American Society of Agronomy Meeting, Knoxville, Tennessee, August 1975; Oak Ridge Associated Universities Isotope Methods Course, Oak Ridge, Tennessee, April 1975; and Southern Regional Soil-Water Work Group, Gainesville, Florida, April 1975.

Member - Tours Committee of American Society of Agronomy, Sponsored tour of the Society to ORNL, August 1975.

Supervisor of trainee students - J. M. Godwin (winter 1974) and Jean M. Bahr (summer 1975).

J. S. Mattice

Editor - *Corbicula Newsletter*.

Participant - International Atomic Energy Agency research co-ordination meeting on the Physical and Biological Effects on the Environment of Cooling Systems and Thermal Discharges at Nuclear Power Plants, Oak Ridge, Tennessee, November 1974; EPA/NRC Working Conference on Standardizing Biological Data Requirements for the Memorandum of Understanding, Falls Church, Virginia, January 1975; Second Thermal Ecology Symposium, Augusta, Georgia, April 1975; EPA meeting to consider location of Seabrook Nuclear Power Station intake, Narragansett, Rhode Island, April 1975; Workshop on the Biological Significance of Biological Impacts, Ann Arbor, Michigan, June 1975; and Preparation of the environmental impact statements of Seabrook and Douglas Point Power Stations.

S. B. McLaughlin

Discussion leader - Session on Atmospheric Problems of Sulfur, Seventh Annual Air Pollution Workshop, Muscle Shoals, Alabama, April 1975.

Participant - Meeting of Council for Surface Mining and Reclamation Research, Blacksburg, Virginia, May 1975.

R. B. McLean

Participant - Preparation of the Preliminary Draft Environmental Statement for the Atlantic Generating Station, the Preliminary Environmental Statement for the Offshore Power Systems, and the Final Environmental Statement for Jamesport; Supplemental testimony of NRC staff on chlorine discharge before the ASLB in the matter of Summit Power Station, Units 1 & 2, Delmarva Power and Light Co. and Philadelphia Electric Co., March 1975; and Workshop on An Evaluation of Multi-Purpose Offshore Industrial-Port Island: Major Research Problems and Promising Research Approaches, College of Marine Studies, University of Delaware, May 1975.

R. E. Moore

Participant - Evaluation of radiological accidents for the environmental report of ERDA operations in Oak Ridge, Tennessee; Preparation of environmental impact statements for Gas Centrifuge Process, 1985 K-25 Study, and ERDA operations in Portsmouth, Ohio; and Preliminary studies for Nuclear Energy Centers Site Survey.

Consultant - Bettis-Westinghouse on atmospheric dispersion and environmental dose estimation.

F. R. O'Donnell

Participant - Preparation of environmental statements on consumer products that contain radioactive materials (spark-gap irradiators that contain Co-60 and personnel neutron dosimeters that contain thorium); USNRC Regulatory Guide - Preparation of an Environmental Report in Support of a Petition for Rule Making - Exemption from Regulatory Requirements for Use of a Radionuclide-Containing Product; ERDA environmental impact assessment concerning Proposed Rulemaking - Exemption from Licensing Requirements for the Sale and Use of Metal Scrap Homogeneously Contaminated with Enriched Uranium Below a Specified Concentration; and Environmental analysis of ERDA operations in Oak Ridge, Tennessee.

Consultant - Preparation of U. S. Department of Housing and Urban Development Draft Environmental Statement on Modular Integrated Utility Systems (MIUS) Technology.

R. J. Olson

Participant - Conference on Energy Related Modeling and Data Base Management, Brookhaven, New York, May 1975; ERDA-Wide Conference on Computer Support of Environmental Science and Analysis, Albuquerque, New Mexico, July 1975; and Workshop on Coal Conversion Balanced Program Plan, May 1975.

R. V. O'Neill

Participant - Advanced Systems Ecology Course, University of Tennessee, Knoxville, 1975; UNESCO course on Systems Ecology, Caracas, Venezuela, November 1974; and TIE workshop on Ecosystem Processes and Organic Contaminants, Monterey, California, June 1975.

Technical reviewer - *Ecology and Science*.

B. R. Parkhurst

Participant - Preparation of the Draft and Final Environmental Statements for the Cherokee Nuclear Station Units 1, 2, and 3; and the Perkins Nuclear Station Units 1, 2, and 3; and the Draft Environmental Statements for the North Coast Nuclear Plant No. 1, and the Montague Nuclear Power Station Units 1 and 2; Workshop on Application of Biostatistical Methods to Nonradiological Environmental Impact Assessment, Bethesda, Maryland, October 1974; and Workshop on the Biological Significance of Environmental Impact, University of Michigan, Ann Arbor, June 1975.

D. C. Parzyck

Member - Health Physics Society National Committee on Public Information, July 1975 - July 1978; and Screening Committee for AEC Fellowship University Programs, December 1974.

Participant - Workshop on Coal and Oil Shale Health Effects, University of Cincinnati, January 1975; ERDA/National Laboratories Workshop on the Environmental Effects of Energy, Rockefeller University, September 1975; Oak Ridge Associated Universities training program in preparation for the American Board of Health Physics certificate examination, July 1975; and Oak Ridge Associated Universities training program in preparation for the American Board of Health Physics certification examination, March - May 1975.

D. E. Reichle

Lecturer - Graduate Program in Ecology, University of Tennessee.

Consulting Environmental Editor - Springer-Verlag, Inc.

Co-Project Manager - Experimental Ecological Reserves Project, The Institute of Ecology.

American Editor - *Pedobiologia*.

D. E. Reichle (continued)

Member - Associateship Selection Panel, National Academy of Sciences, 1975-1976; Panel on Environmental Monitoring, National Academy of Sciences, 1975; U.S. MAB National Committee, U.S. State Department, 1975; Science Research Advisory Committee, National Science Foundation, 1973-1974; Council Ecological Society of America; Environmental Studies Board, National Academy of Sciences, 1975; and U.S. Committee for SCOPE, 1975.

Chairman - U. S. MAB Directorate Project 2.

A. F. Robinson

Participant - Preparation of terrestrial and land-use section of Draft Environmental Statements for Wolf Creek Generating Station, South Texas Project, Sterling Power Project, Portsmouth Gaseous Diffusion Plant expansion, and Oak Ridge Gas Centrifuge Uranium Enrichment Statement; and Transmission line study on effects of corridors on small mammals and bird populations.

P. S. Rohwer

Lecturer - Oak Ridge Associated Universities Traveling Lecture Program.

Participant - Fourth U.S.-U.S.S.R. Bilateral Technical Discussion on Plowshare, Vienna, Austria, January 1975; and Fourth IAEA Technical Committee Meeting on Peaceful Nuclear Explosions, Vienna, Austria, January 1975.

M. S. Salk

Participant - Preparation of Final Environmental Statements for Wolf Creek Generating Station and Sterling Power Project, and Preliminary Draft Environmental Analyses for Green County Nuclear Power Plant and Oak Ridge Operations.

R. K. Schreiber

Participant - Statistical Analysis System Workshop, ORNL, May 1975; Oak Ridge Associated Universities Special Training Division Course on Use of Radionuclides in Research, April - May 1975; Role of Consumers in Ecosystem Symposium, Athens, Georgia, October 1974; American Institute of Biological Sciences Meeting, Corvallis, Oregon, August 1975; and Inter-agency meetings (Tennessee Valley Authority, Council of Environmental Quality, and U.S. Bureau of Sport Fisheries and Wildlife).

Member - Environmental Sciences Division Seminar Committee, ORNL; American Society of Mammalogists Bibliography Committee, 1974-1975.

Supervisor - Oak Ridge Associated Universities summer trainee, summer 1975.

D. S. Shriner

Participant - First International Workshop on Acid Rain and the Forest Ecosystem, Columbus, Ohio, May 1975; Seventh National Air Pollution Workshop, Muscle Shoales, Alabama, April 1975; and First ERDA Ecology-Meteorology Workshop, Pellston, Michigan, June 1975.

H. H. Shugart

Technical reviewer - *Ecology*, *American Naturalist*, *Science*, *The Wilson Bulletin*, and *Forest Science*.

Grant peer reviewer - NSF and ERDA, U.S. Forest Service.

Lecturer - Department of Botany, University of Tennessee.

Participant - TIE (The Institute of Ecology) Workshop on Energy Flow in Non-Industrial Societies, Transient Events in Natural Ecosystems.

G. R. Southworth

Participant - Oak Ridge Associated Universities Special Training Session on the Use of Radionuclides in Research, April - May 1975.

R. H. Strand

Member - Steering committee for data exchange and data banking, sponsored by The Institute of Ecology; and Long-range planning committee for automatic data processing equipment needs within ORNL.

Coordinator and lecturer - Annual Environmental Sciences Division short course on the Use of the Statistical Analysis System (SAS) in Environmental Data Processing.

Participant - Conference on Computer Support of Environmental Science and Analysis, Albuquerque, New Mexico, July 1975; and Data Exchange Committee meeting which discussed *Data Banking for National Needs - The Present and Future*, Tucson, Arizona, November 1974.

E. G. Struxness

Member - Committee 4 of International Commission on Radiological Protection.

Chairman - Committee 4 Task Group on Principles and Methods for Use in Radiation Protection Assessments Related to Releases of Radioactive Materials into the Environment, International Commission on Radiological Protection; and Session on Environmental Considerations, International Conference on Radiation Effects and Tritium Technology for Fusion Reactors, Gatlinburg, Tennessee, October 1975.

Co-Chairman - Steering Committee on Radiological and Environmental Aspects of Fusion Power, Oak Ridge National Laboratory, 1975.

Recipient - The American Nuclear Society 1975 Special Award for Waste Disposal and/or Management.

J. S. Suffern

Participant - Preparation of the Draft Environmental Statement related to the Jamesport Nuclear Power Plant and Montague Generating Station; Workshop on Biological Significance of Environmental Impacts, Ann Arbor, Michigan, June 1975; and Nuclear Energy Center Siting Survey (as Ecological Team Leader) for U.S. NRC report to Congress on feasibility of nuclear energy center concept.

G. W. Suter

Participant - Preparation of the Preliminary Draft Environmental Statement for the Atlantic Generating Statement; Energy Research and Development Administration agency comments on two coal-fired electric steam plants, Four Corners and Kaiparowits; and Determination of parameters and data for alternate site evaluation.

T. Tamura

Member - Committee on Educational Assistance (mineralogy), American Society of Agronomy; and Technical planning group of Nevada Applied Ecology Group, Nevada Operations Office, Las Vegas.

Consultant - Advanced Environmental Research Division of National Science Foundation.

Team member - Balanced Program Planning of ERDA representing geothermal energy development, June 1975.

Participant - Geothermal Environmental Workshop sponsored by National Science Foundation, Asilomar, California, November 1974.

F. G. Taylor

Participant - Preparation of environmental impact statements for Offshore Power Systems, Floating Nuclear Power Plants, and generic statement.

Technical reviewer - Enterprise Radiation Project, U. S. Forest Service.

Review board member - First Symposium on the Central Deciduous Forest, U. S. Forest Service and University of Illinois, Carbondale.

Instructor - Adult education program, Oak Ridge School System.

J. E. Till

Member - Health Physics Society Education and Training Committee.

Participant - Preparation of section on radiological impact of routine and accidental releases of radioactivity, Oak Ridge Operations environmental impact statement.

R. I. Van Hook

Participant - NAS/NRC Subcommittee on the Geochemical Environment in Relation to Health and Disease Workshop in Capon Springs, West Virginia, October 1974; TIE Ecosystem Processes and Organic Contaminants Workshop, June 1975; and EPA Substitute Chemicals Program Workshop, July 1975.

Discussion leader - Council of Environmental Quality Workshop on Ecological Data Base Development, November 1974.

W. Van Winkle

Participant - 1975 Northeast Fish and Wildlife Conference (Symposium on Fisheries and Energy Production, in particular), New Haven, Connecticut, February 1975; Meeting organized by EPA Region II relative to EPA's 316 permit status and technical requirements for adjudicatory hearings on the Hudson River power plants, New York City, April - May 1975; Workshop on the Biological Significance of Environmental Impacts, Ann Arbor, Michigan, June 1975; and Preparation of a "Request for Proposal" relating to a survey of available models for use in assessing environmental impacts, NRC Environmental Specialists Branch, Bethesda, Maryland, June 1975.

D. C. West

Participant - Nuclear Energy Center Siting Survey for U.S. NRC report to Congress on feasibility of nuclear energy center concept.

J. P. Witherspoon

Member - Graduate faculty, University of Tennessee, Knoxville; Steering Committee, TVA Region, Year 2000 Study; and Environmental Quality Advisory Board, Oak Ridge.

Lecturer - American Institute of Biological Sciences Visiting Lecturer Program in Radiation Biology.

Participant - Energy Symposium, East Texas State University, April 1975; National Academy of Science Workshop on Extraction of Uranium-Health Effects, March 1975; and Preparation of environmental impact statements for Oak Ridge Sites, Gaseous Centrifuge Program, Uranium Enrichment Program (ERDA-1543), Oak Ridge Gas Centrifuge Uranium Enrichment Facility, and Portsmouth Gaseous Diffusion Plant Expansion.

Participant and co-author - National Academy of Science/National Research Council Study on Long-term Effects of Nuclear War, January 1975.

Environmental Sciences Division Publications

Publications for which reprints are available are listed by number on the enclosed tear out sheets. Reprints may be obtained by circling the desired numbers and mailing the sheet to:

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Oak Ridge, Tennessee 37830

All "ORNL" and "EDFB" publications listed are published by Oak Ridge National Laboratory, Oak Ridge, Tennessee. All ERDA (and AEC) Symposium Series reports, designated "CONF," are published by the Technical Information Center, Oak Ridge, Tennessee.

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3. HOWDEN, H. F., and S. I. AUERBACH. 1958. Some effects of gamma radiation on *Trogoderma sternale* Jayne. *Annu. Entomol. Soc. Amer.* 51(1):48-51.
4. LACKEY, J. B. 1958. The suspended microbiota of the Clinch River and adjacent waters, in relation to radioactivity in the summer of 1956. ORNL-2410. 35 pp.
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7. WILLIAMS, L. G., and H. D. SWANSON. 1958. Concentration of cesium-137 by algae. *Science* 127(3291):187-88.
8. AUERBACH, S. I., D. A. CROSSLEY, JR., and M. D. ENGELMAN. 1957. Effects of gamma radiation on collembola population growth. *Science* 126(3274):614.
9. AUERBACH, S. I., and D. A. CROSSLEY, JR. 1958. Strontium-90 and cesium-137 uptake by vegetation under natural conditions, pp. 494-499 in *Proc. 2nd Int. Conf. Peaceful Uses At. Energy*, vol. 18, Geneva. Pergamon Press, London.
10. DAVIS, R. J., V. L. SHELDON, and S. I. AUERBACH. 1956. Lethal effects of gamma radiation upon segments of a natural microbial population. *J. Bacteriol.* 72(4):505-10.
11. GRAHAM, E. R. 1958. Uptake of waste Sr-90 and Cs-137 by soil and vegetation. *Soil Sci.* 86(2):91-97.
12. HOWELL, J. C. 1958. Long-range ecological study of the Oak Ridge area: I. observations on the summer birds in Melton Valley. ORNL-CF-58-6-14. 35 pp.
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14. AUERBACH, S. I., and D. A. CROSSLEY, JR. 1960. A sampling device for soil microarthropods. *Acarologia* 2(3):280-87.
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16. ROHDE, C. J. 1959. Studies on the biologies of two mite species, predator and prey, including some effects of gamma radiation on selected developmental stages. *Ecology* 40(4):572-79.
17. AUERBACH, S. I., et al. 1957. Ecological research. In *Health Phys. Div. Annu. Progr. Rep. July 31, 1957*. ORNL-2384:10-39.
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22. CROSSLEY, D. A., JR., and M. E. PRYOR. 1960. The uptake and elimination of cesium-137 by a grasshopper - *Romalea microptera* *Health Phys* 4 16-20
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24. COTTRELL, W. D. 1960. Radioactivity in silt of the Clinch and Tennessee Rivers ORNL-2847 47 pp
25. SCHURR, J. M., and W. N. STAMPER. 1962. A model for the accumulation of strontium and calcium by recently molted crayfish (*Cambarus longulus longirostris* Ort.). *Limnol Oceanogr* 7(4):474-77
26. OLSON, J. S., et al. 1960. Distribution of radioactive isotopes in plants, insects and soils *Nucl Saf* 1(3) 2-9
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40. KAYE, S. V., and P. B. DUNAWAY. 1962. Bioaccumulation of radioactive isotopes by herbivorous small mammals *Health Phys* 7 205-17.
41. CROSSLEY, D. A., JR., and M. P. HOGLUND. 1962. A litter-bag method for the study of microarthropods inhabiting leaf litters. *Ecology* 43(3) 571-73
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44. OLSON, J. S. 1961. Ecological sampling and meteorological calculation of fallout on forests near Oak Ridge ORNL-3181. 57 pp
45. DUNAWAY, P. B., and S. V. KAYE. 1963. Effects of ionizing radiation on mammal populations on the White Oak Lake bed, pp. 333-38 in Schultz, V., and A. W. Klement (eds.). *Proc First Natl Symp on Radioecology* Reinhold Publ. Co., New York and AIBS, Washington, D.C.
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58. AUERBACH, S. I., et al. 1961. White Oak Lake bed studies. In *Health Phys. Div. Annu. Progr. Rep. July 31, 1961*. ORNL-3189:81-105.
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OMITTED NUMBERS ARE OUT OF STOCK

Circle numbers desired:

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1	74	145	202	259	313	365	423	481	543	595	647	689	732	775
2	75	146	203	261	314	366	424	482	544	599	648	690	733	776
3	76	147	204	264	315	368	425	483	546	600	649	691	734	777
7	77	150	207	266	316	369	426	484	547	601	650	692	735	778
13	78	151	208	267	317	370	427	486	548	603	651	693	736	779
14	79	154	209	268	318	371	430	487	549	604	652	694	737	780
18	82	155	211	269	319	373	432	490	550	605	653	695	738	781
20	83	156	212	270	321	375	433	492	551	606	654	696	739	782
21	84	158	213	271	322	377	434	493	552	607	655	697	740	783
22	85	159	214	272	323	378	435	496	553	608	656	698	741	784
25	87	160	215	273	324	381	436	501	554	609	657	699	742	785
27	90	162	216	274	325	382	437	502	555	610	658	701	743	786
28	91	163	217	275	327	384	438	503	556	611	659	702	744	787
30	92	164	218	276	329	385	439	504	558	612	660	703	745	788
31	93	165	219	277	330	386	440	505	559	613	661	704	746	789
33	94	166	220	278	331	387	442	506	560	615	662	705	747	790
34	95	167	222	279	333	388	443	507	561	618	663	706	748	791
35	98	168	223	280	334	389	444	509	562	619	664	707	749	792
37	99	169	224	282	335	391	445	511	563	621	665	708	750	793
39	100	173	225	283	336	392	446	514	564	623	666	709	751	794
40	103	174	226	284	337	394	447	515	566	624	667	710	752	797
41	104	175	229	285	339	396	448	516	567	625	668	711	753	798
42	107	176	230	287	340	398	449	517	568	626	669	712	754	799
45	114	178	231	288	341	400	450	518	569	627	670	713	755	800
46	115	179	232	289	342	401	451	520	571	628	671	714	757	
48	116	180	233	290	343	402	456	521	572	629	672	715	758	
49	117	181	234	291	344	403	459	523	574	630	673	716	759	
50	118	182	235	292	345	404	460	526	576	631	674	717	760	
52	119	184	236	293	346	405	463	527	577	632	675	718	761	
54	121	185	237	296	347	407	464	528	578	633	676	719	762	
55	124	186	240	297	348	408	465	531	579	634	677	720	763	
56	127	187	241	298	349	409	467	532	580	635	678	721	764	
59	128	190	242	299	351	410	468	533	582	636	679	722	765	
63	130	191	243	301	354	411	469	534	583	637	680	723	766	
64	131	193	244	303	355	412	471	535	584	638	681	724	767	
65	132	194	245	304	357	413	472	536	585	639	682	725	768	
66	133	195	248	305	358	414	473	537	588	640	683	726	769	
67	134	196	249	306	360	415	474	538	590	641	684	727	770	
69	139	197	250	307	361	416	475	539	591	642	685	728	771	
71	140	198	251	308	362	417	476	540	592	644	686	729	772	
72	141	199	252	309	363	419	477	541	593	645	687	730	773	
73	143	200	257	310	364	420	478	542	594	646	688	731	774	

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