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ENVIRONMENTAL SCIENCES DIVISION ANNUAL PROGRESS REPORT for Period Ending September 30, 1983

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Environmental Sciences Division Publication No. 2265

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ABSTRACT

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Research in the Aquatic Ecology Section during 1983 emphasized field predictions based on laboratory studies, biogeochemical cycling of nutrients, and ecosystem dynamics. A new multiyear study on the effects of acid rain on aluminum mobility and toxicity to stream ecosystems was initiated for the Electric Power Research Institute. Studies designed to increase our understanding of reservoirs and the relationships existing among reservoirs in linked systems continued.

The Earth Sciences Section initiated two new activities during 1983 that are characteristic of its strength in the disciplinary areas of soil chemistry, geohydrology, and geology. The first activity was the initiation of a program to develop in-depth information on the behavior of host geologic media during hydrofracture injection of grouted wastes, including geophysical, geohydrologic, and geochemical studies. The second activity included the installation of facilities in two small watersheds underlain by contrasting geologic units. These facilities will be used to investigate the role of macropores in subsurface transport. Both of these projects are expected to continue for several years.

The Environmental Analyses Section is organized around four themes: environmental assessment, environmental compliance, risk analysis, and regional studies. Assessment activities focused on geothermal, alcohol fuels, and nuclear fuel cycle technologies; and compliance analyses emphasized environmental regulations. Development and demonstration of ecological risk methods continued with emphasis on synfuels technologies; while regional analyses were directed primarily to acid deposition issues. Environmental technical support for the DOE hydroelectric program continued with major emphasis on examination of biological assumptions for specifying minimum instream flows.

The Terrestrial Ecology Section was involved in (1) basic and applied environmental research to support energy technology development and (2) gaining a better understanding of the structure and function of terrestrial ecosystems. Research highlighted in the report includes recent activities in ecosystem analysis, plant response to air pollutants, and elemental cycling studies. Acid rain activities have focused on crop research, while CO_2 research has been concerned with secondary effects on forest systems.

Emphasis in the Fossil Energy Program during 1983 focused on summarizing what has been learned concerning environmental effects of contaminants arising from direct coal liquefaction technologies. Four draft documents that identify remaining environmental issues were prepared.

Biomass Program production activities included biofuels program planning (including biomass conversion technologies), management of herbaceous and woody biomass production under intensive culture, and research on site productivity related to intensive forest management. Results from these activities are highlighted and include both ORNL staff and subcontractor contributions.

Three major activities were predominant in the Low-Level Waste Research and Development Program. (1) In support of the ORNL hydraulic fracturing facility, a benchmark network for precise leveling was installed, giving better resolution of the three-dimensional shape of the surface uplift pattern, which was measured as asymmetric with respect to the position of the injection well. (2) The distribution of radionuclide contaminants at the south edge of ORNL Solid Waste Storage Area 4 was characterized, indicating that "bathtubbing" of trenches is the major mechanism of

transport. (3) A chemical-treatment field demonstration injecting caustic soda and soda ash into a burial trench with a high inventory of ^{90}Sr brought about a dramatic lowering of ^{90}Sr concentrations in interstitial groundwater which has persisted for over two years.

Significant accomplishments of the DOE Low-Level Waste Management Program office during FY 1983 focused on program management and on preparation of the Corrective Measures Handbook. Program management functions included technical planning, resource allocation, program review, and coordination with other waste technology programs. In the area of technical planning, the following reviews of the status of technology were performed: (1) an update of a program position paper on modeling, (2) a position paper on greater-confinement disposal, (3) a paper on verification and validation factors for low-level waste disposal site models, (4) a comparison of geophysical characterization techniques, and (5) a summary of site-specific technology development activities supported by the Interim Waste Operations program.

In-house and external research in the DOE Global Carbon Cycle Program during the past year was primarily devoted to improving our understanding of the terrestrial component of the carbon cycle. The impact of terrestrial land-use change on the global carbon cycle was a major area of concern; results obtained from a variety of activities support an overall lowering of the magnitude of carbon fluxes to the atmosphere resulting from such changes. In addition, program staff organized and hosted the Sixth ORNL Life Sciences Symposium, entitled *The Global Carbon Cycle: Analysis of the Natural Cycle and Implications of Anthropogenic Alterations for the Next Century,* in Knoxville, Tennessee, October 31 through November 2, 1983. The symposium was attended by 180 scientists representing 10 countries.

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C. C. COUTANT

Fellow, American Association for the Advancement of Science.

D. L. DeANGELIS

Environmental Sciences Division Scientific Achievement Award for 1982.

R. J. LUXMOORE

Excellence in presentation award. Forest and Range Soils Division, Soil Science Society of America Annual Meeting, December 1982.

J. F. McBRAYER

Who's Who in the South and Southwest, 19th ed., Marquis Who's Who, Inc, Chicago.

R. V. O'NEILL

Fellow, American Association for the Advancement of Science.

T.-H. PENG

American Geophysical Union, "Editor's Citation for Excellence in Refereeing," for outstanding service to the authors and readers of *Geophysical Research Letters,* June 1, 1983.

H. H. SHUGART

Fellow, American Association for the Advancement of Science.

R. S. TURNER

Eugene P. Wigner Fellowship, Oak Ridge National Laboratory, June 1983.

R. I. VAN HOOK

Fellow, American Association for the Advancement of Science.

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Fellow, American Association for the Advancement of Science.

PART I. ENVIRONMENTAL SCIENCES DIVISION SECTIONS

1. AQUATIC ECOLOGY

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D. K. Whitmore
L. L. Wright

Introduction

The Aquatic Ecology Section is involved in basic and applied research that focuses on environmental problems and on gaining a better understanding of the structure and function of aquatic ecosystems. Four groups direct research in the areas of biogeochemical cycling of nutrients and contaminants, physiological ecology, ecotoxicology, and ecosystem dynamics. Interdisciplinary research is a basic guide of the section's research. In addition to working with staff from other sections of the Environmental Sciences Division (ESD), the Aquatic Ecology Section is performing ongoing

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collaborative research with six other divisions of Oak Ridge National Laboratory (ORNL) and with several outside organizations [e.g., Tennessee Valley Authority (TVA), The University of Tennessee, Tennessee Technological University, and the National Reservoir Research Program of the U.S. Fish and Wildlife Service (FWS)]. Research in the section for FY 1982 was funded by the National Science Foundation (NSF), 20%; U.S. Department of Energy (DOE), 45%; Electric Power Research Institute (EPRI), 15%; Nuclear Regulatory Commission (NRC), 10%; TVA, 8%; and Army Corps of Engineers (COE), 2%.

Streams, rivers, and reservoirs are the predominant aquatic ecosystems of the southern United States and serve as major focal points for our research. Vignettes of several research projects that we conducted during the past year will follow to provide the reader a summary cross-sectional view of our research efforts. The first five summaries describe our research in biogeochemical cycling—with the initial three discussing our ongoing effort with material spiraling in stream ecosystems and the latter two investigating the role of environmental variables (e.g., humic acids) on the bioavailability and fate of polycyclic aromatic hydrocarbons (PAHs) in fish. Our physiological ecology research is highlighted by two summaries—one describing the use of physiological processes in fish as indicators of ecosystem stress and the other discussing research related to the occurrence of Legionnaires' Disease bacteria and the environmental variables controlling their distribution. The translation of laboratory toxicity results to nature is a major emphasis of ecotoxicology in our current scientific society. A summary of our studies in this area and in the evaluation of multispecies algal bioassays provides a highlight of our ecotoxicology group. Ecosystem response to stress is the ultimate concern of our research. Summaries of our reservoir studies and river-reservoir contaminant transport modeling effort conclude this section of the annual report.

Ecosystem Dynamics

Aquatic research emphasizing ecosystem dynamics continues to be a major emphasis in the section. We describe two lines of whole-system-oriented studies that were emphasized during FY 1983. The summary from our reservoir studies highlights results focusing on spatial and temporal trends in nutrient availability for phytoplankton production along a headwater-to-mainstream reservoir series. The summary from our studies of the behavior of energy-related contaminants in river-reservoir systems discusses modifications of the Fates of Aromatics Model, which represents the working hypothesis that the fate of PAHs can be forecast from the chemical characteristics of PAHs.

Reservoir Studies (B. L. Kimmel, S. M. Adams, J. J. Elser, A. W. Groeger, and D. M. Soballe)

Man-made impoundments have become the predominant bodies of surface water throughout large portions of the United States during the past half-century. Reservoirs constructed primarily for flood control, navigation, and hydroelectric power generation now serve also as sources of cooling water for power plants, public and industrial water supply, and recreation, and as the recipients of municipal and industrial wastes. Despite their importance as multiple-use water resources, reservoirs are poorly understood ecologically; therefore, our ability to predict potential impacts of energy technologies on river-reservoir ecosystems is also poor. Primary goals of our DOE Office of Health and Environmental Research (OHER) supported reservoir studies are (1) to improve our understanding of reservoir ecosystems and their resilience to perturbation, (2) to provide basic information applicable to a variety of energy technologies, and thereby (3) to establish a sound scientific

basis for anticipating technology-induced impacts to reservoirs and river-reservoir environments. The following subsection highlights results from one of our subtasks which focuses on spatial and temporal trends in nutrients availability for phytoplankton production.

Dam construction associated with water and power development projects has converted rivers throughout the world into regulated series of man-made impoundments (i.e., river-reservoir systems). The effects of reservoir releases on downstream water temperature, flow regimes, water quality, and biota have received considerable research attention; however, little is known of the limnological and ecological gradients occurring within series of impoundments. We investigated patterns of nutrient availability for phytoplankton production in a headwater-to-mainstream series of three impoundments (Norris, Melton Hill, and Watts Bar reservoirs) located in eastern Tennessee. All three reservoirs have hypolimnetic discharges and are used for flood control, water supply, power generation, and recreation. The purposes of our study were (1) to determine whether phosphorus or nitrogen is the more limiting nutrient to phytoplankton production in these reservoirs, and (2) to evaluate longitudinal patterns of algal nutrient deficiency within individual impoundments and along the headwater-to-mainstream reservoir gradient.

We sampled uplake, midlake, and downlake stations in each of the three reservoirs on five occasions (June, July, August, October, and December) during 1982. A combination of nutrient analyses, nutrient enrichment bioassay experiments, and an enzymatic assay for algal alkaline phosphatase activity (APA) was used to evaluate the degree of nutrient availability and phytoplankton nutrient deficiency. Alkaline phosphatase is an enzyme synthesized in quantity by algae only when available inorganic phosphorus falls to low levels and the algae become phosphorus deficient.

Levels of soluble reactive phosphorus were usually <1.0 μg/L throughout the reservoir series during the growing season. Low phosphorus levels were accompanied by relatively high inorganic nitrogen concentrations, resulting in dissolved inorganic nitrogen:phosphorus ratios >30:1, the value that is usually considered to indicate potential phosphorus limitation in algae and that is well above the cellular composition ratio of 17:1 for phytoplankton growing at a maximum rate. Results of nutrient enrichment experiments also indicated potential phosphorus limitation of phytoplankton production. Significant (phosphorus < 0.01) stimulation of phytoplankton growth in phosphorus-enriched samples occurred in 73% of the experiments (Fig. 1.1), although the degree of response to enrichment was variable. A greater growth response often occurred when samples were enriched with both phosphorus and nitrogen rather than with phosphorus alone, suggesting that an increase in phosphorus availability could cause a rapid transition to nitrogen limitation.

Specific physiological indicators of nutrient deficiency (e.g., alkaline phosphatase activity) more realistically reflect in situ conditions by avoiding time-scale and methodological problems inherent in chemical analyses and nutrient enrichment bioassays. Although both nutrient analyses and enrichment experiments indicated that phosphorus was potentially limiting in the reservoir series throughout the study period (June–December), in situ phytoplankton phosphorus deficiency, as reflected by biomass-specific APA, revealed a different pattern (Fig. 1.1). APA levels increased during the summer, peaked in August in all three reservoirs, and then decreased again during the fall and winter as nutrient availability increased. During August, the period of pronounced algal phosphorus deficiency, significant ($P < 0.05$) longitudinal differences in APA occurred within individual reservoirs, with APA higher downlake than uplake, indicating increased phosphorus deficiency of the phytoplankton in downlake areas. Significant differences in APA among reservoirs were also observed; APA levels decreased downstream, indicating increased phosphorus availability and decreased algal phosphorus deficiency along the headwater-to-mainstream reservoir gradient.

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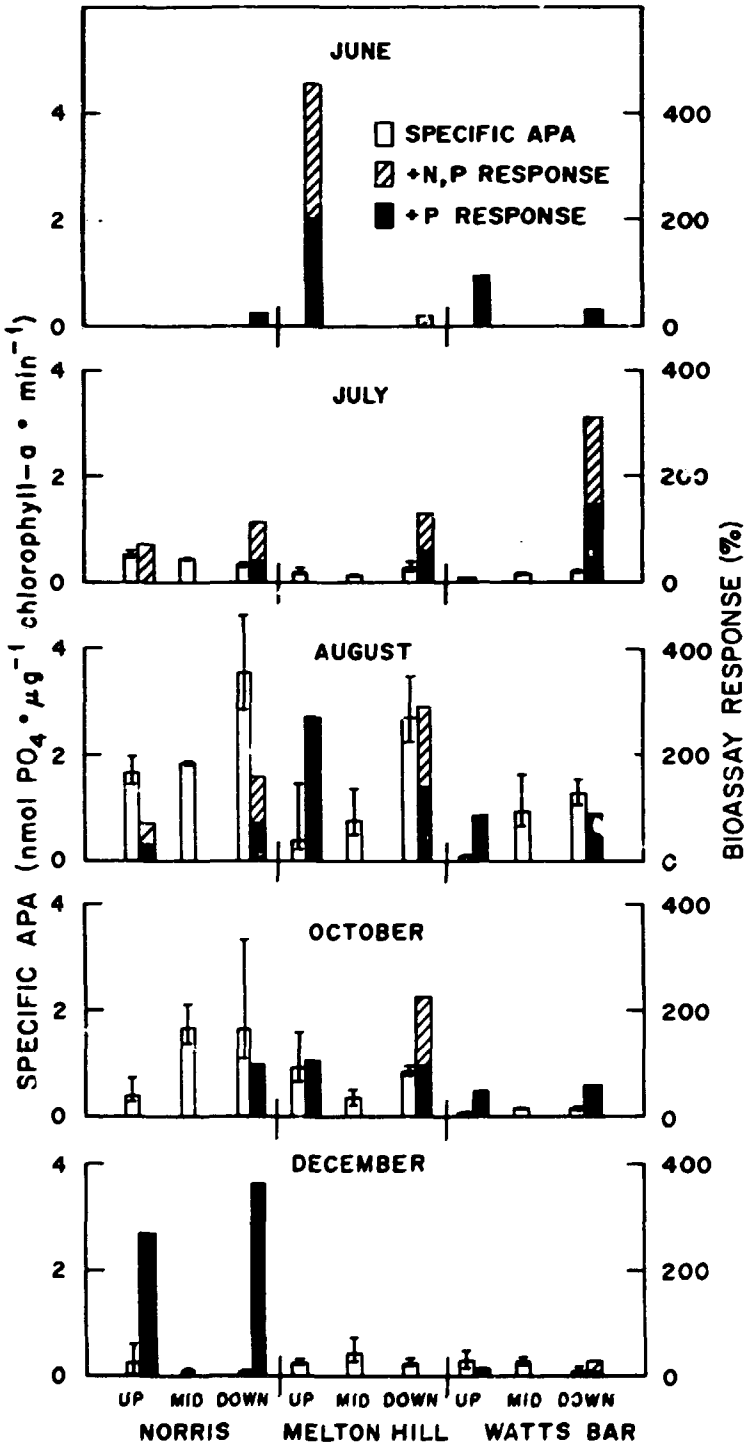

Fig. 1.1. Seasonal and longitudinal patterns of phytoplankton phosphorus deficiency in a headwater-to-mainstream series of three impoundments (Norris, Melton Hill, and Watts Bar reservoirs; eastern Tennessee; June–December 1982), as indicated by nutrient enrichment bioassay experiments and alkaline phosphatase activity (APA) assays. Enrichment bioassay responses are expressed as the percentage increase over enriched controls and represent the means of duplicated experiments. Algal growth responses to nitrogen enrichments were rare; therefore, those responses are not shown. Error bars indicate 95% confidence limits for biomass-specific APA levels.

These results and the redistribution of inorganic nitrogen in the three reservoirs observed during the study period indicated that, particularly during the growing season, hypolimnetic discharges from reservoirs upstream increased nutrient availability for phytoplankton production in downstream impoundments.

Our results suggest that reservoirs in series are linked ecologically by nutrient releases associated with upstream reservoir operations. A primary effect of a headwater storage impoundment (e.g., Norris Reservoir) is the temporal redistribution of the natural flow of water and nutrients downstream. Although reservoir basins are long-term nutrient sinks, in multiple-impoundment series nutrient releases from upstream impoundments influence the productivity of impoundments downstream and, particularly late in the growing season, likely result in a more efficient conversion of nutrients to algal biomass.

Modifications of the Fates of Aromatics Model (S. M. Bartell)

The fates of aromatics model (FOAM) represents the working hypothesis that the fate of PAHs in aquatic systems can be forecast from fundamental chemical characteristics of this homologous series of organic compounds. We have improved the food-web submodel to permit evaluation of the associated hypothesis that the effects of PAHs on biological production can likewise be forecast from basic PAH chemical characteristics.

Values of parameters that determine rates of growth of producer and consumer organisms in FOAM were revised with the aid of published data. Seasonal production dynamics of the food web now agree in magnitude and pattern with ranges of values commonly reported for freshwater systems. Realistic temporal production dynamics improve FOAM's capabilities for examining the effects of changing biomass on accumulation of PAHs by biological components of the system. The improvement also facilitates incorporation of toxic effects of PAHs on biological production. The resulting fates-and-effects model can be used to identify biomass distributions and PAH-loading regimes where toxic effects feed back on the pattern of PAH flux and the ultimate distribution within lotic and lentic ecosystems.

The submodel that calculates rates of PAH sorption to suspended and settled particulate matter was modified because of recently reported data. A kinetic model that considers rapid sorption and desorption of PAHs to particle surfaces and slower movement of sorbed PAHs into and out of particle interstices replaced the previous submodel that calculated PAH sorption rate as a fraction of an estimated maximum rate. The fraction was calculated as a function of the organic matter content of the sorbant. The new two-component submodel generates patterns of PAH sorption dynamics that are more consistent with reported values. Rate constants in the new submodel are also related to the organic matter content of the sorbant, but a maximum uptake rate does not have to be estimated. Previous analyses of FOAM indicated that the old maximum sorption rate contributed heavily to uncertainties associated with predicted concentrations of PAHs for sediments and biota in FOAM.

In previous analyses of the implications of parameter uncertainties on predicted concentrations of PAHs in system components, parameters were assumed to be normally or lognormally distributed. To obviate this assumption, nonparametric methods were used to define the parameter distributions solely in relation to underlying data. The first four moments of the data are calculated by repeated sampling from the data sets. Nonparametric analogs of the mean, variance, skew, and kurtosis define continuous Pearson distributions for FOAM parameters estimated from structure-activity correlations. These distributions can be sampled at random in continued analysis of FOAM

to test the sensitivity of previous conclusions on the normality assumptions. Results of the analysis will continue to direct FOAM modifications and refinement.

Biogeochemical Cycling

The theme of biogeochemical cycling unifies much of the ongoing research in the section. The first three summaries highlight our continuing activities on material spiraling in stream ecosystems which are developed around hypotheses concerning the annual pattern and mechanisms controlling phosphorus spiraling in small woodland streams. The last two summaries focus on newer initiatives involving the effect of environmental variables on the bioavailability and metabolic fate of polynuclear aromatic hydrocarbons in fish.

Material Spiraling in Stream Ecosystems (J. W. Elwood, L. A. Ferren, R. A. Minear, D. R. McKamey, P. J. Mulholland, J. D. Newbold, and R. E. Perkins)

During the past year, work in the NSF-sponsored project on Material Spiraling in Stream Ecosystems has centered on the (1) temporal patterns of phosphorus cycling resulting from microbial colonization and decomposition of leaves in streams, (2) effect of invertebrate leaf shredding on phosphorus cycling in streams, and (3) production and utilization of dissolved organic phosphorus compounds by microbes associated with stream substrates. These studies represent a continuation of our efforts to determine the annual pattern and mechanisms controlling phosphorus spiraling in small woodland streams.

During previous years we examined the influence of microorganisms associated with decomposing leaf detritus on phosphorus uptake in streams. As a continuation of this work we added about 400 g/m^2 of autumn-shed leaves to a once-through groundwater-fed darkened laboratory stream channel and made measurements of microbial activity (respiration, dehydrogenase activity, adenosine triphosphate content) and phosphorus uptake and turnover during a 50-d period. Although the channel was filled primarily with white oak (*Quercus alba*) leaves, a few dogwood (*Cornus florida*) and red maple (*Acer rubrum*) leaves were also placed in one section of the channel to determine whether there were species-specific differences in microbial succession and phosphorus uptake and turnover. To measure phosphorus uptake, carrier-free $^{32}PO_4$ was released for 1-h periods near the upstream end of the channel, and dissolved ^{32}P concentrations were measured at several locations downstream. Approximately 3 h following each $^{32}PO_4$ release, a few leaves of each species were assayed for ^{32}P activity, transferred to a second laboratory channel with identical leaf biomass and physical-chemical conditions, and periodically assayed for ^{32}P activity to determine phosphorus turnover rates.

Our results indicated that a regular pattern of microbial colonization of leaf detritus exists which greatly influences phosphorus cycling in streams. Uptake rates of PO_4 by microbes attached to leaves were initially very low (<0.2 ng P cm^{-2} h^{-1}), increased with time to peak at about 4 weeks for dogwood and red maple (38 and 28 ng P cm^{-2} h^{-1}, respectively) and 5 weeks for white oak (38 ng P cm^{-2} h^{-1}), and declined thereafter. Rates of phosphorus turnover exhibited a similar pattern but peaked at about 2 weeks—considerably earlier than phosphorus uptake. Among the indices of microbial activity measured, uptake of PO_4 was significantly correlated only with oxygen uptake ($r^2 = 0.71$, $P < 0.05$). Although the rate of PO_4 uptake by white oak leaves declined after week 5, net phosphorus accumulation continued until about week 7. The long-term phosphorus accumulation by leaves amounts to only 10–15% of the total uptake of PO_4 from the water by

leaves, however. Therefore most of the PO_4 uptake (85–90%) by microbes attached to leaves is recycled back to the water or removed by sloughing.

Uptake of PO_4 by the whole-stream ecosystem was less variable with time than by leaves alone, ranging from 20 to 80% of the input and peaking about 3 weeks after leaf addition. The lower variability of whole-stream PO_4 uptake and the earlier peak in uptake rate compared to leaves alone is probably the result of relatively high rates of abiotic PO_4 uptake by inorganic substrates in the early part of the study before the establishment of organic surface coatings on these substrates. In an earlier study, we found that abiotic adsorption to inorganic surfaces in the stream channels immediately after flow was begun could account for about 10–15% of the $^{32}PO_4$ added.

To determine the effect of leaf-shredding invertebrates on phosphorus cycling in streams, different densities of snails (*Goniobasis clavaeformis*) were collected from Walker Branch and were then added to three of four replicate cobble- and gravel-filled laboratory stream channels. The channels, which are fed by groundwater, were initially filled with autumn-shed white oak leaves (200 g/m^2) and were covered to prevent algal growth. The resulting snail densities in the four channels were 0.0, 0.8, 2.0, and 7.0 g/m^2, respectively. Tracer levels of carrier-free $^{32}PO_4$ were released to each channel for 1-h periods on five occasions over the 35-week study. Rates of uptake and turnover of ^{32}P, microbial abundance and respiration, and abundance of coarse particulate organic matter (CPOM), fine particulate organic matter (FPOM), aufwuchs, and seston were periodically measured.

Channels with snails had greater standing stocks of benthic FPOM (mostly snail feces) and seston concentrations and lower standing stocks of CPOM (leaf detritus) and aufwuchs compared to the channel with no snails. Although the amount of benthic organic matter (CPOM, FPOM, and aufwuchs) declined, with time, in all channels (initially 98% CPOM), the decrease was greatest in the channels with the medium and highest snail densities. Thirty weeks after snail addition, the channel with no snails was still dominated by CPOM (88% of total benthic organic matter), whereas the channel with the highest snail density was dominated by FPOM (85% of total benthic organic matter). Total numbers and mean size of bacteria associated with CPOM and FPOM were greatest in the channel with no snails, but respiration rates per unit cell were greater in the channels with snails, resulting in only small differences in total metabolic activity associated with CPOM and FPOM among channels.

Total uptake of $^{32}PO_4$ increased, and consequently uptake length of PO_4 decreased, in all channels with time, the result of reductions in total benthic organic matter. However, PO_4 uptake length was shortest in the channel with no snails and generally increased with increasing snail density, this pattern being more pronounced with time.

The results of this study indicated that the dominant effects of snail leaf shredders were to (1) increase the processing rate of CPOM to FPOM, a portion of which is lost downstream as seston; (2) reduce the microbial biomass associated with all benthic organic materials; and (3) increase the metabolic activity of the microbial community per unit cell. Although these effects were positively related to snail density, the relationship was not linear since the greatest effect was between the channel with no snails and that with the lowest snail density. With regard to phosphorus uptake, the reduction of CPOM abundance due to snails outweighed any increase in specific microbial activity and resulted in reduced uptake and increased uptake length of phosphorus at all snail densities. However, by increasing the conversion of CPOM to FPOM, and thus increasing seston transport in natural streams, snails may increase phosphorus uptake and invertebrate productivity downstream where inputs of CPOM are lower.

A series of short-term experiments was conducted during the past year to investigate the importance of dissolved organic phosphorus (DOP) compounds in streams. Measurements of dissolved phosphorus in Walker Branch indicated that at least 50% is in an organic form. To determine the relative size distribution and rates of production of DOP by microbes associated with stream detritus, we conducted short-term incubations of ^{32}P-labeled CPOM and FPOM collected from Walker Branch and, using sephadex gel chromatography, fractionated the dissolved ^{32}P released according to molecular size. The relative rates of utilization of DOP were determined by incubating the dissolved ^{32}P released from labeled FPOM and CPOM in stirred batch reactors containing unlabeled substrates and monitoring the loss of the various size fractions of ^{32}P from water.

The results of these experiments indicated that low-molecular-weight phosphorus (LMWP) compounds (mol. wt < 250), which elute from sephadex G-25 at the same position as PO_4, and high-molecular-weight phosphorus (HMWP) compounds (mol. wt > 5000), which elute in the void volume, are the dominant forms of dissolved phosphorus released by microbes colonizing CPOM and FPOM. Rates of release of LMWP were about 10 × greater than were rates of HMWP release by CPOM. However, loss rates of the released LMWP in microcosms with CPOM were about 100 × greater than were loss rates of HWWP, resulting in a gradual buildup of HMWP in the water in the batch incubations.

Our results indicate a potential ecological significance for HMWP in streams. In stream reaches that do not receive inputs of PO_4 (via springs or inputs from terrestrial sources), HMWP should become an increasingly greater portion of the total dissolved phosphorus pool with distance downstream. Utilization of HMWP may support much of the primary and secondary production in these downstream reaches.

Effect of Environmental Variables on the Bioavailability and Metabolic Fate of Polynuclear Aromatic Hydrocarbons in Fish (J. F. McCarthy, C. P. Cirmo, D. K. Whitmore, B. D. Jimenez, and T. Barbee)

One of the unifying goals of DOE/OHER-sponsored research is an understanding of the long-term health and environmental response to exposure to energy-related chemicals. Within this context, it is important to identify the processes that transform and transport contaminants in the environment and how materials move through the food-chain pathways back to humans. We have been examining the effect of environmental variables of two aspects of this process: the availability of energy-related contaminants for uptake by aquatic organisms and the metabolic fate of contaminants that do enter the aquatic food chain.

Specifically, three environmental variables have been studied in this context: the presence of naturally occurring dissolved organic matter such as humic and fulvic materials, the availability of food, and seasonal changes in temperature. Polycyclic aromatic hydrocarbons were used as model contaminants because they are products of energy-related technologies that pose a potential health risk to man due to uptake via the food chain, and because their chemical properties are useful in development of structure-activity relationships that permit extrapolation to a wider spectrum of potential contaminants.

Complexation of contaminants with naturally occurring inorganic and organic compounds in the water often alters the behavior of the contaminant with respect to its transport, fate, and bioavailability in natural systems. This principle has been recognized with respect to speciation of potentially toxic metals such as copper.

The importance of speciation of contaminants has not yet been fully recognized in the study of organic contaminants that may enter the environment as a result of energy technologies. By means of equilibrium dialysis experiments, we have demonstrated an excellent correlation between the hydrophobicity of a PAH (as indicated by the octanol-water partition coefficient, K_{ow}), and its affinity for binding to dissolved humic material (DHM), which is measured as a partition coefficient, K_p.

The binding of PAHs to DHM has a dramatic effect on the bioavailability of those contaminants to fish and aquatic invertebrates. We have examined the effect of DHM on the bioaccumulation of naphthalene (NPH) and benzo(a)pyrene (BaP) in bluegill sunfish, and on the bioaccumulation of those PAHs, as well as of anthracene and benzanthracene, in the cladoceran, *Daphnia magna*. Results were analyzed by multicompartment models to determine the relative rates of uptake of PAH dissolved in the water versus that of PAH bound to DHM. In all cases, the rate coefficient describing the uptake of bound PAH was only 0–5% of that for dissolved PAH. A model was developed to describe the interaction of the binding affinity of a contaminant for DHM (K_p), the DHM concentration in the water, and the bioavailability of the contaminant. The results are illustrated in Fig. 1.2. The left edge of the figure describes the increased potential for bioaccumula-

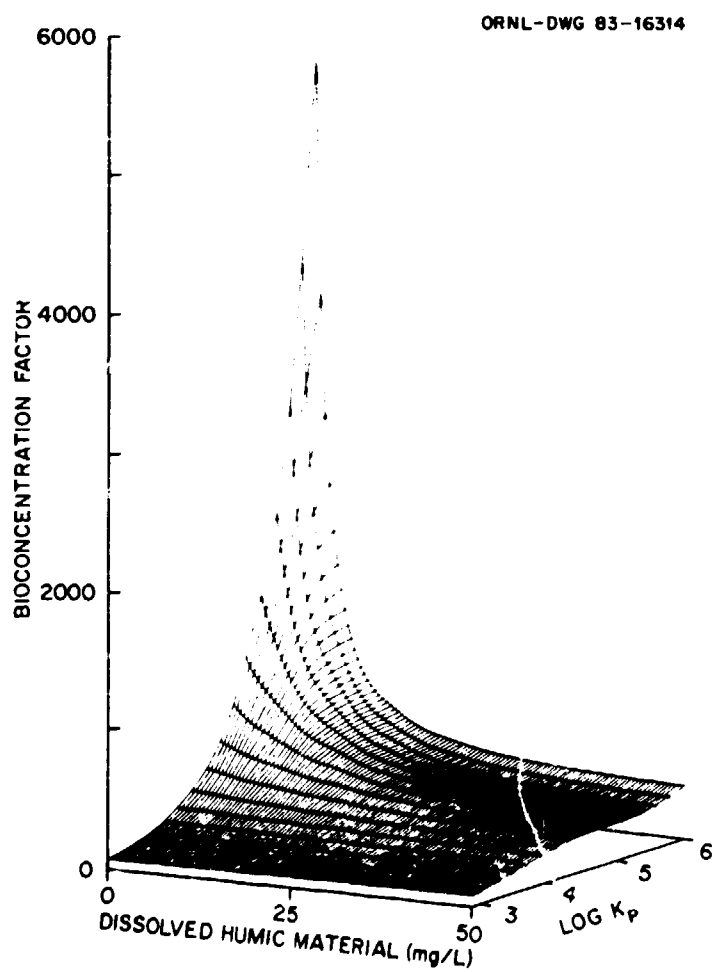

Fig. 1.2. Model of the interaction of the binding affinity (K_p) of a contaminant for dissolved humic material (DHM), the DHM concentration in the water, and the bioavailability of the contaminant.

tion of more hydrophobic PAHs in the absence of DHM. For less hydrophobic contaminants such as NPH (log K_p = 2.99, front edge of the figure), the bioconcentration factor is low in the absence of DHM, and the presence of increasing amounts of DHM has relatively little effect. However, for a very hydrophobic compound such as BaP (log K_p = 6.15, back edge of the figure), even a small amount of DHM binds a substantial fraction of the contaminant and results in a large decrease in bioaccumulation. Data from the experiments with bluegills and *Daphnia* agree very well with model predictions for all PAHs tested.

The high affinity for binding to DHM, and the resultant decrease in bioavailability could, therefore, mitigate the biological impact of those very hydrophobic contaminants having the greatest potential for bioaccumulation and transfer to man via food chains.

We have examined the uptake, metabolic transformations, binding to cellular constituents, storage, and excretion in bluegill of two PAHs (NPH) and (BaP) and the effect of two environmental variables (food availability and temperature) on these processes with respect to BaP. The two PAHs differ greatly in their susceptibility to metabolic transformation. Naphthalene taken up by fish remains as a parent compound, and only a small fraction of the total is transformed to polar excretion products or bound to cellular constituents. In contrast, BaP is very rapidly biotransformed. Within 4 to 8 h at 23°C, only 1% of the total BaP taken up by the fish remains as a parent compound; most of the BaP is bound to cellular constituents.

Biotransformation reverses the generally accepted relationship of a positive correlation between hydrophobicity of a contaminant and its potential for bioaccumulation, at least with respect to bioaccumulation of a parent compound. Although accumulation of the total (PAH + metabolites) is tenfold greater in bluegills exposed to BaP than to NPH, the bioconcentration of parent BaP is much less than that of parent NPH. Both food availability and temperature have significant effects on the rates of uptake, depuration, and metabolic transformation (both activation and detoxification) of BaP in bluegills. Feeding results in a small increase in the uptake of BaP but in large increases in the rates of detoxification and elimination of the PAH. The overall effect of feeding is to decrease the bioaccumulation of BaP in bluegills. Cold temperature (13 vs 23°C) resulted in decreased rates of uptake, metabolic transformation, and elimination of BaP.

Physiological Ecology

Energy production activities can affect physiological processes in aquatic organisms in a variety of ways. The broad research goals of the Physiological Ecology group are (1) to determine what physiological effects may result from energy production; (2) to develop reliable methods for detecting physiological effects in the field and the laboratory; and (3) to relate these effects to the growth and survival of organisms and the dynamics of populations. Two research projects are described below: an investigation of physiological indicators of stress in largemouth bass, and a study of environmental factors controlling the abundance of Legionnaires' Disease bacteria.

Physiological Indicators of Ecosystem Health (S. M. Adams, J. E. Breck, and U. Boruta)

Growth or production of fish is the ultimate expression of ecosystem health because this parameter integrates all the biotic and abiotic variables acting on an organism and reflects secondary impacts of chronic stress. Frequent estimates of growth throughout the year would be extremely helpful in the effective application of management and regulation strategies for ecosystems and in the understanding of predator prey interactions and trophic dynamics. The probability that changes

observed in growth could be related to man-induced perturbations and variations in prey availability or environmental conditions could be increased with frequent growth estimates.

Frequent growth estimates are costly or difficult to obtain for the purposes of many field investigations. Therefore, we have developed a cost-effective approach for estimating fish growth based on easily measured condition indices and physiological variables that are also relatively rapid response indicators to environmental conditions.

Regression models utilizing easily measured condition indices and physiological variables were developed for predicting monthly growth of I^+ and II^+ largemouth bass. The model that best fit observed growth in 1980 was used to predict growth in 1982. Conversely, the model that best fit observed growth in 1982 was used to predict growth in 1980. The liver-somatic index (LSI) and standard metabolism at surface and thermocline temperatures were the most significant parameters for predicting growth of I^+ and II^+ bass both years.

Determination of monthly growth using the liver-somatic index requires 50% fewer samples than the usual method of following changes in monthly mean weight. Fewer samples are required for the liver-somatic index to estimate growth than for the weight method, because the relatively large variance associated with the distribution of fish weights within an age class is reduced by normalizing these weights as a function of liver weight (the LSI) for each respective fish.

Because the LSI responds relatively rapidly to the level of energy intake and temperature (Fig. 1.3), this index can be used to estimate and to signal possible negative effects on fish before

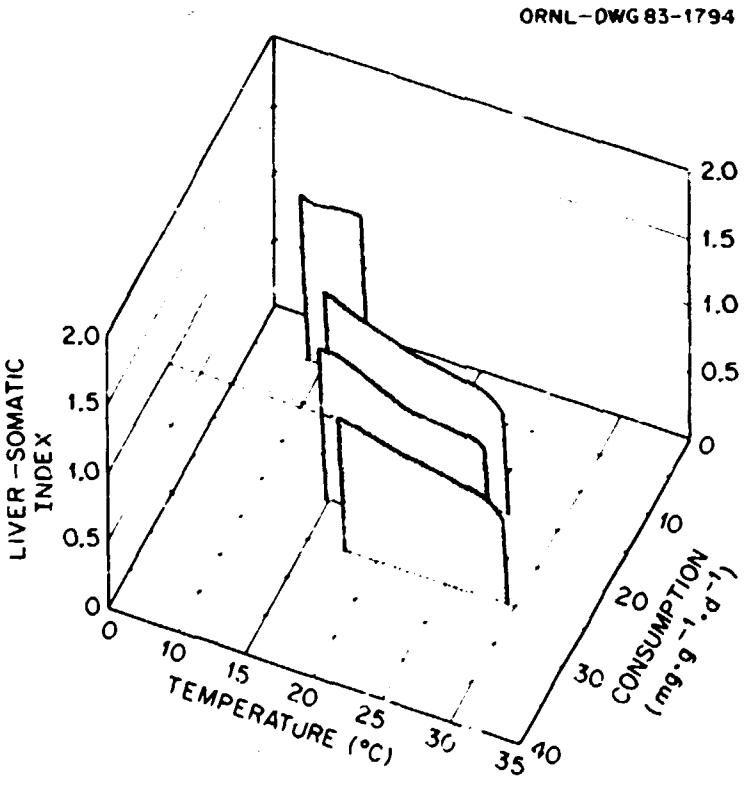

Fig. 1.3. Response of the liver-somatic index (LSI) in largemouth bass to various combinations of temperature and consumption during 1980 and 1982. For example, the LSI is 0.98 (dashed line) at a temperature of 18°C and a consumption rate of 25 mg g^{-1} d^{-1}. Shown are LSI value averages for I^+ and II^+ bass.

changes in growth can be observed. This approach could be a useful ecological and environmental management tool, because frequent cost-effective growth estimates could be used to identify the presence of ecological perturbations and to quantify their effect. The method may be particularly useful in cooler systems where metabolic demands are not extreme and for small fish where reproductive requirements are minimal.

Legionnaires' Disease Bacteria in Power-Plant Cooling Systems (S. W. Christensen, J. A. Solomon, and R. L. Tyndall)

Legionnaires' Disease (LD) initially attained notoriety after an outbreak in which a number of fatalities occurred in Philadelphia in 1976. The causative agent of LD (i.e., *Legionella pneumophila*) and other *Legionella* species are normal components of the aquatic microflora. Common-source outbreaks of LD have occurred in a pattern that suggests airborne spread of aerosol nuclei such as those generated by air-conditioning cooling towers. Indeed, studies of the source of infection of some LD outbreaks have occasionally implicated cooling towers associated with air-conditioning systems as the dispersal vehicles.

Our previous studies of electric power plants focused on the relationship between thermal discharges and the presence of *Legionella*. These studies confirmed that *Legionella* are a normal component of the aquatic microflora and consequently are commonly found in power-plant cooling waters. During 1983, research was conducted primarily in two areas: aerosol sampling of cooling tower discharges for the presence of *Legionella*, and identification of environmental parameters capable of controlling the abundance of *Legionella*. In addition, a study was begun of the association of *Legionella* with downtime procedures at power plants.

Sampling of cooling tower discharges for the presence of Legionnaires' Disease bacteria. Although extensive studies have been made of LD bacteria, little information was available on its discharge in the plumes of industrial cooling towers such as those of electric power plants. This is of importance because *Legionella* cannot infect until they are airborne and subsequently inhaled. To determine if and to what degree *Legionella* are discharged from large industrial cooling towers including those of electric power plants, the Nuclear Regulatory Commission sponsored an air-sampling study.

Air samples were taken at the point of discharge and at short distances downwind and upwind from six test towers. Water samples were also collected from the cooling-tower basins. In the laboratory, the samples were concentrated 500-fold by centrifugation and processed using direct fluorescent-antibody staining to determine the density of *Legionella*. Infectivity of selected samples was also determined by inoculation of guinea pigs and subsequent attempted isolation of the bacterium on agar. Concentrations of *Legionella* in air samples were then compared with those found in the basin water and related to meteorological conditions at the time of sampling.

The results showed that air discharged from the cooling towers contains minimal numbers of *Legionella*. The concentration of *Legionella* per 100 L of air generally ranged from less than one to several hundred, whereas the cooling tower water generally had *Legionella* concentrations 1×10^6 to 1×10^7 times that found in the air. Attempts to culture *Legionella* directly from air sample concentrates by plating on CYE agar were unsuccessful because the agar plates were quickly overgrown by bacteria other than *Legionella*. Similarly, intranasal inoculation of guinea pigs with air sample concentrates also resulted in infection of lung tissues with bacteria other than *Legionella*. During periods of high humidity and wind speed, *Legionella* were detected in a few downwind sam-

ples and one upwind sample. One site with extensive construction and excavation activity had higher *Legionella* concentrations in air samples as compared to other sites.

The limited data from this study, together with serologic and epidemiologic data from other studies, suggest that if there are problems relative to the association of *Legionella* with power plant cooling waters, they may be more germane to the area of industrial hygiene than to public health.

Identification of environmental parameters controlling the abundance of *Legionella*. For several years, EPRI has sponsored a research program on *Legionella* in power plant cooling systems. During Phase I of this project, a combined program of environmental and ecological sampling was carried out to characterize the ecological niche of *Legionella pneumophila*, the causative agent of LD. As a result of that study, it was concluded that more rigorous examination of individual environmental parameters would be possible by using an experimental approach than merely by sampling existing environments. Consequently, a laboratory program was begun that was aimed at the identification of environmental parameters controlling the abundance of *Legionella* in nature.

The assumption was made that factors likely to influence the growth of *Legionella* would fall into one of three categories: physical factors (e.g., growth temperature; cycling through repeated temperature shocks), water quality factors (e.g., nitrate, conductivity, pH), and associated biota (e.g., algae, protozoa, decaying macrophytes). A series of experiments was carried out to determine whether a given category was, in fact, capable of producing differential growth of natural populations of the bacterium.

Our results thus far indicate that different *Legionella* organisms (serogroups and species) respond differently to varying environmental conditions. For example, group A (a composite of four *L. pneumophila* serogroups) from one source showed a different response to increased temperature than did group C (a composite of four different *Legionella* species) from the same source. In fact, some *Legionella pneumophila* were able to survive exposure to 85°C for at least several hours. Some of the factors found influential in specific experiments included the growth temperature, water quality, and nitrate level.

We are currently trying to identify the specific serogroup or species responsible for each of these observed responses. In addition, we are attempting to replicate some of these experiments while broadening the range of spatial and temporal sources for the natural populations used in the experiments.

Ecotoxicology

As environmental toxicology grows more sophisticated in its ecological perspective, the disparity between prediction goals (i.e., consequences of pollution in natural ecosystems) and what can be readily measured (i.e., direct toxic effects on isolated organisms) becomes increasingly evident. Problems of pollution happen not in bioassay beakers but in intact ecosystems, where organisms are not isolated but, rather, are enmeshed in a complex web of interactions with other organisms and with the physical environment. These interactions greatly influence the impact of contaminants in natural environments, yet they are not predictable from laboratory bioassays alone. The major challenge for environmental toxicology in coming years is to find ways to translate laboratory data into predictions about nature. The Aquatic Ecology Section is addressing this issue through experimentation with test systems that incorporate competition, predation, and other ecological interactions; these systems range in complexity from two-species algal cultures to outdoor experimental ponds.

Research on toxicant effects on population interactions and ecosystem processes will continue as an important activity.

Laboratory-to-Nature Extrapolation: Comparison of Contaminant Effects in Bioassays, Microcosms, and Experimental Ponds (A. S. Bradshaw, P. J. Franco, J. M. Giddings, L. A. Hook, A. R. Johnson, J. L. Keller, M. T. Moore, and W. K. Roy)

A research program on the environmental behavior of complex organic mixtures (i.e., synthetic oils) provided the opportunity to investigate the relationship between bioassay results and toxicant effects in whole ecosystems. Representative oils were examined in a battery of single-species toxicity tests with algae, crustaceans, insects, snails, and fish, and the basic relationships between oil composition and toxicity were determined. Oils were then selected for experiments with whole ecosystems in the laboratory (microcosms) and the field (outdoor ponds). The objectives were (1) to observe the overall patterns of ecosystem response and to evaluate the importance of indirect effects caused by ecosystem interactions; (2) to compare microcosms with ponds and thereby to determine whether microcosms are valid surrogates for field studies; and (3) to compare contaminant effects in microcosms and ponds with results of laboratory bioassays and thereby to calibrate the bioassays with one type of aquatic ecosystem. We sought to determine whether bioassays underestimated, overestimated, or accurately indicated contaminant concentrations that caused direct toxic effects on organisms and ecosystem processes. Results from such comparisons will help in formulating an objective safety margin or application factor for translating bioassay data into estimates of environmentally acceptable levels of pollutants.

Sixteen microcosms and twelve ponds were used in these experiments. Both types of systems contained water, sediment, and a biotic community (dominated by the macrophyte *Elodea canadensis*) from a natural pond. The ecosystems were treated for 8 weeks with daily or weekly additions of a coal-derived oil over a range of exposure levels, and responses were monitored for several months beyond the treatment period. Variables measured included abundances of major ecosystem components (bacteria, phytoplankton, periphyton, macrophytes, zooplankton, insects, and fish), ecosystem metabolism (production and respiration), and water chemistry (pH, dissolved oxygen, alkalinity, and ammonium).

The effects of treatment on the microcosms were very similar to those observed in the ponds, indicating that microcosms could be economical surrogates for field studies for some purposes. A variety of direct and indirect effects were measured, ranging from small, transient changes at the lower exposure levels to near-total disruption of the systems at the highest exposure level. Cladoceran zooplankton populations and ecosystem metabolism were affected at the lowest input rates, but the effects disappeared before the end of the oiling period, and this exposure level (~3% of the 48-h LC_{50} for *Daphnia magna*) was considered safe for these ecosystems. At the next higher treatment level, effects on zooplankton and ecosystem metabolism were greater and persisted until the oiling ended; reproduction of mosquitofish (*Gambusia affinis*) in the ponds was also impaired. The ecosystems were increasingly dominated by opportunistic, stress-tolerant organisms such as rotifers and euglenophytes. The two highest treatment levels caused the extinction of many taxa and major changes in ecosystem function and water quality. The microcosms and ponds recovered from the second-highest treatment level, but the effects of the highest treatment persisted for at least a year after the oiling stopped.

Comparison of ecosystem responses with bioassay results (Fig. 1.4) revealed that the safe exposure level for the ecosystems was similar to the 28-d lowest observed effect concentration for reproduction by *Daphnia magna*. Both microcosms and ponds were seriously damaged at concentrations near acute bioassay LC_{50} values. Indirect effects occurred in ecosystems at all treatment levels, but they were most significant at intermediate levels; they were not a factor in determination of the safe concentration for the ecosystems.

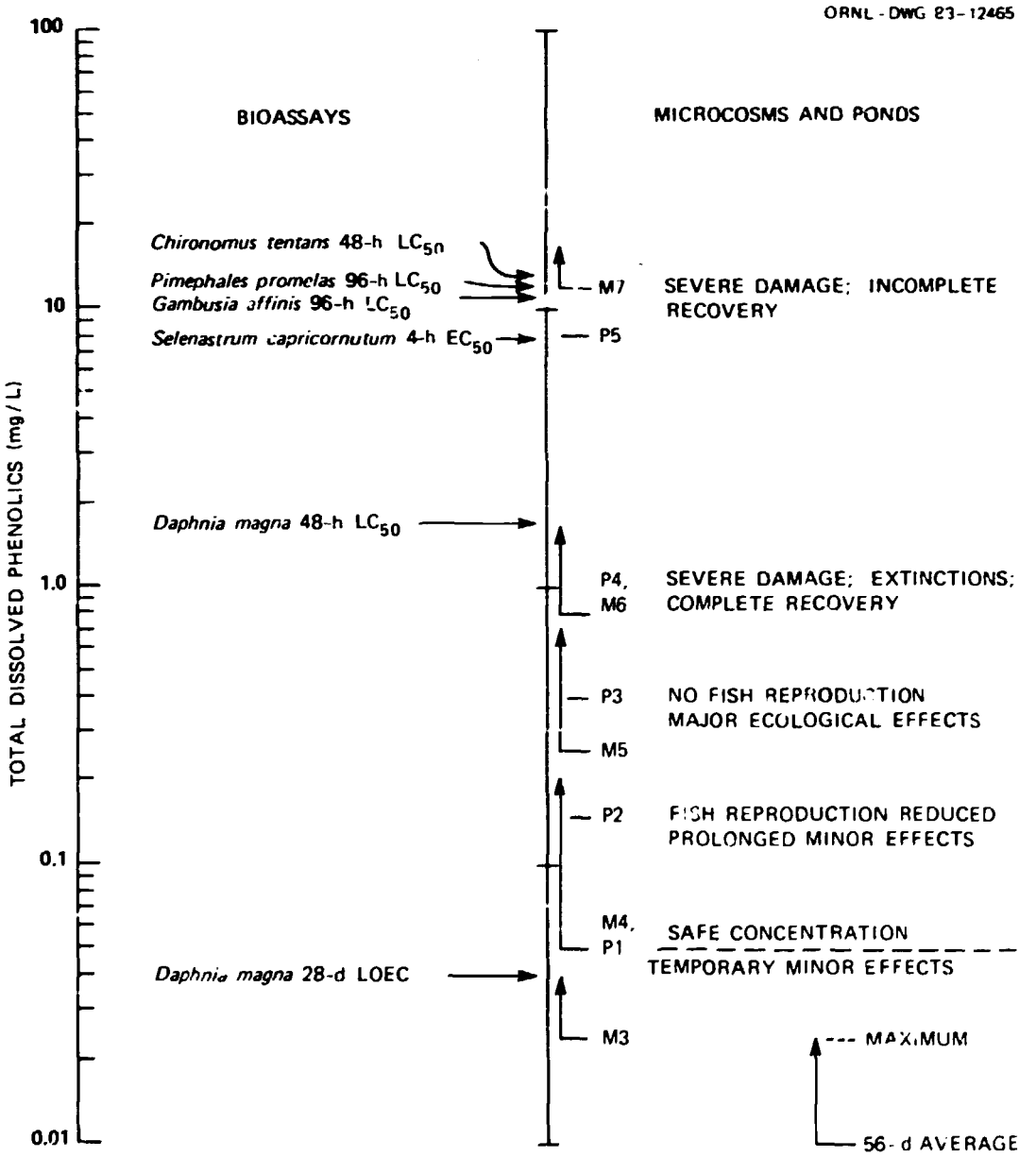

Fig. 1.4. Calibration of aquatic bioassays with results from microcosms and ponds. The vertical axis represents exposure concentrations of total dissolved phenols expressed as mg/L (logarithmic scale). To the left of the axis are bioassay results for the water-soluble fraction of a coal-derived oil (LOEC = lowest observed effect concentration). To the right are effects observed in microscoms (M3–M7) and ponds (P1–P5) treated with the same oil; short horizontal lines indicate 56-d average concentrations of dissolved phenols, and vertical arrows indicate maximum concentrations measured during the experiment.

Development of Multispecies Algal Bioassays (A. S. Badaruddin, B. G. Blaylock, and M. L. Frank)

Differential sensitivity to pollutants among algal species could result in contaminant-induced alteration of phytoplankton communities and interfere with normal successional patterns. It has been demonstrated that under certain conditions, mixed algal cultures are more sensitive to toxicants than pure cultures—that is, the relative abundances of two species in competition can be affected at toxicant concentrations that cause no measurable effects on either species when grown alone. The purpose of this study was to develop a multispecies, algal testing protocol for toxic substances.

The initial objective was to select algal species for testing in mixed species cultures. Eight species were cultured individually and in all possible two-species combinations. Daily growth rates were calculated for cultures in exponential growth phase. The hypothesis was that species that grow more slowly in mixed cultures than in pure cultures are under greater stress in mixed cultures and, therefore, should be more sensitive to the additional stress of a toxicant. On this basis, *Selenastrum capricornutum* and *Chlorella vulgaris* were selected for multispecies testing with Cu^{2+}.

Mixed cultures of *C. vulgaris* and *S. capricornutum* were exposed to five treatment levels of Cu^{2+}. Population growth of each species was determined by cell counts at various intervals for 264 h. Growth rates were estimated, and the percentage of growth inhibition for each species and for the total community was calculated for each treatment level. Contrary to the hypothesis, the percentage of growth inhibition of each species and of total algae was less in the mixed cultures than inhibition of each species in individual cultures. Species composition in the mixed cultures was altered only at the highest treatment level (0.5 mg Cu^{2+}/L), and this change was predictable from the differential sensitivity of the two species when grown alone.

Although these results did not support the hypothesis that multispecies algal cultures are more sensitive to toxicants than single-species cultures, this experiment involved only one toxicant and one species pair. Further development will include other toxicants and other species.

2. EARTH SCIENCES

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Introduction

Research conducted by staff members of the Earth Sciences Section (ESS) continues to be centered on developing information to understand and predict the impact of energy-related technologies on the geophysical environment. Progress is reported on ongoing projects as well as new initiatives.

New research initiated during the past year includes addressing the subsurface transport of energy-related environmental contaminants. This project includes the installation of research sites on the Walker Branch and Melton Branch watersheds to examine critical parameters controlling hydrogeologic transport in watersheds with different underlying geologic materials. Another new initiative is the development of geologic and geochemical data necessary to understand the behavior of the Oak Ridge National Laboratory (ORNL) hydrofracture facility. The information will serve

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as the basis for technology transfer in that it will provide the data necessary to site a hydrofracture facility at other facilities of the U.S. Department of Energy (DOE) or U.S. Department of Defense.

In addition to research activities centered within the ESS, staff members have been involved in consulting relating to operational activities at ORNL as well as serving as technical experts in environmental investigations of contaminant distribution at the Oak Ridge Y-12 facility. These activities include design and construction of engineered barriers to hydrologic transport of contaminants at the ORNL Solid Waste Storage Areas (SWSAs) for low-level radioactive waste, development of the hydrologic data base necessary for a new Central Waste Disposal Facility (CWDF), and the direction of studies aimed at determining the distribution of energy-related contaminants on the DOE–Oak Ridge site.

The ESS has experienced staff growth and will continue to grow during the next year. Expanded interaction with the Geology and Civil Engineering Departments at The University of Tennessee, including provision for graduate student research and joint staff appointments, will be an integral part of the projected growth.

Measurement of Radionuclides in Soils, Sediments, and Water

Radionuclide Distributions in Coastal Areas (C. R. Olsen, I. L. Larsen, and N. H. Cutshall)

Coastal regions historically have been sites for population growth, energy development, and commercial centers. As a result, a variety of contaminants are introduced into coastal environments (directly or indirectly) through the use of estuaries for waste disposal, for cooling purposes in electric power production, or as natural harbors. Adsorption on particulate matter is known to be the principal mechanism for removing many of these contaminants from coastal waters (Olsen et al. 1982). Accumulation and subsequent burial in sediments helps to isolate these contaminants from contact with epibenthic and pelagic biota (Cutshall et al. 1981). Unfortunately, however, quantitative measurements of the extent of removal and burial in any field system is extremely difficult because of the complex physical, chemical, and biological interactions that affect contaminant fate and their extreme variability with space and time. One of the tools available for studying these interactions is the distribution of radionuclides with a known source and history of input into the system.

The objective of this study is to measure the distribution of natural (^{234}Th, ^{228}Ra, ^{226}Ra, ^{210}Pb, and ^{7}Be) and anthropogenic (^{137}Cs, ^{134}Cs, ^{110m}Ag, ^{65}Zn, and ^{60}Co) radionuclides in water, suspended matter, and sediment samples to determine the rate, pattern, and extent of contaminant transport and accumulation in estuarine and coastal areas. Recently, we have developed techniques for measuring ^{210}Pb and ^{234}Th by nondestructive gamma-ray spectrometry (Cutshall et al. 1983), which enhances the number and rapidity of analyses, reduces the cost, and preserves samples for other analyses that require additional sample preparation.

Our approach involves cooperative efforts with other coastal zone scientists. Consequently, we conserve manpower and resources by avoiding ship and sampling costs and increase the significance of our results by combining them with the results of parallel biological, chemical, or sedimentological studies. We have shown that a strong covariance exists between radionuclide distributions and the distribution of a wide range of chemically reactive contaminants in the fine-grained sediments of several estuaries along the northeastern coastline of the United States—contaminants including polychlorinated biphenyls (PCBs), Kepone, DDT-DDE, petroleum hydrocarbons, and trace metals. In addition, we have used the distribution of ^{7}Be to delineate particle-pollutant sinks and to calcu-

late contaminant removal rates from the water column by settling particles. Half-removal times for ^{7}Be range from 4 to 8 d in the estuarine environment to 20 to 60 d in adjacent coastal waters during the period May to July 1981.

A sediment radionuclide inventory for the James estuary has recently been completed, and our results indicate that 30% of the ^{60}Co but only 15% of the ^{134}Cs released from the Surry reactor site has been retained in the estuary sediments; that about 40% of the ^{134}Cs and ^{60}Co sediment inventory is in areas that represent less than 5% of the total estuarine surface area. Depletion of the ^{134}Cs in downstream sediments forms a noticeable trend in the James River estuary, and we postulate that seawater cation competition and exchange is primarily responsible. We have initiated a study in conjunction with R. McLean (Maryland Power Plant Siting Committee) to determine the kinetics of radiocesium sorption-desorption and to identify the chemical forms, mechanisms, and rates affecting the fate of radionuclides in the Susquehanna–Chesapeake Bay System.

Finally, we have been examining the movement of continentally derived particulates into the deep sea via transport through submarine canyon systems. Sediments collected from beneath 1500–2000 m of water in Quinault Canyon contain ^{60}Co and ^{152}Eu, indicating that they are derived from the Columbia River. The presence of these radionuclides confirms that sediment from the Columbia River is transported to and deposited in Quinault Canyon on a time scale not more than a few years.

Calibration and Use of a Field Germanium Detector for Quantitative Measurement of Radionuclides in Soils (N. H. Cutshall and I. L. Larsen)

Direct measurement of radionuclides in field plots has numerous applications, particularly when portable, high-resolution detectors are used. Identification of radiation from radionuclide spills or from added tracers in the presence of background radiation caused by naturally occurring radionuclides is relatively easy with the use of current germanium detectors. These detectors are packaged in versatile, readily portable configurations that lend themselves well to field work. Quantitative analysis in the field, however, depends on development of accurate calibration procedures and standards.

A simple, empirical, curve-fitting approach has been used to develop quantitative calibration parameters for a portable intrinsic germanium detector used with a lead collimator and shield mounted on a tripod. The calibration procedure allows quantitative measurements to be made under certain commonly encountered field conditions. Calibration and field setup procedures for making quantitative measurements have been checked for accuracy and precision.

A lead collimator was constructed to limit the field of view of the detector. When situated 1 m above the ground surface, the collimator allows a circular field of approximately 40 cm diameter to be viewed by the entire detector and a field extending to 1.4 m diameter to be partially viewed, that is, exposed to a portion of the detector volume. For measurements of the 662-keV (0.107-pJ) gamma rays from ^{137}Cs, a 1-in.-thick (2.54-cm-thick) collimator has been found to provide the shielding necessary to reduce interference from sources outside the design field of view. A thicker shield is required for accurate measurement of higher-energy gamma rays such as those from ^{60}Co [1172 keV (0.188 pJ), 1332 keV (0.213 pJ)] or ^{40}K [1461 keV (0.234 pJ)].

Two models have been used in calibrating the detector for field use: (1) a uniform, surface-film model and (2) a homogeneous three-dimensional model. For the surface-film model, the calibration procedure involved measurement of radiation from standardized point sources placed at several

positions along a radius within the field of view. Then, for eleven energy values ranging from 87 to 1408 keV (0.014 to 0.227 pJ), the efficiency was computed as a function of radius. An empirical sigmoid function was then fitted to the resultant data for each of the separate energy values. After integration of the fitting function to cover the entire circular field of view, an efficiency for a uniformly distributed thin-film source was computed. Finally, the computed efficiency values were plotted against energy on a log-log figure. A straight line fitted to these points was used to interpolate surface-film efficiency values for each energy.

The three-dimensional model is based on the equation for radiation emission from an infinitely thick source. Calibration values were determined by multiplying the computed surface efficiency values by the appropriate output for each energy, and the resultant points were plotted on a log-log graph. A line fitted through these points was used to estimate volumetric concentrations in the soils beneath the detector.

Accuracy of the calibrated instrument has been checked by making measurements in zones contaminated by ^{137}Cs or ^{60}Co, which had already been well characterized. Results of the field measurements have been compared to determinations based on conventional sampling and laboratory analysis methods. The field measurements are accurate within the margin of uncertainty of the previous characterizations. Precision checks have been made by repeated measurements of contaminated areas. Results are reproducible within the estimated counting error, indicating that the procedure used for field setup does not contribute substantially to uncertainty in the results.

Nondestructive Low-Energy Photon Analysis of Environmental Samples (I. L. Larsen, N. H. Cutshall, and C. R. Olsen)

The analysis of radionuclides in soils and sediments that lack high-energy gamma emissions requires chemical leaching or dissolution, chemical purification, and subsequent alpha or beta counting. These methods, however, are time-consuming, require the attention of skilled technicians, and may produce uncertain or low yields requiring the addition of recovery tracers to ascertain yield. In some radiochemical separation schemes, incomplete purification may result in interferences during alpha analysis by other radionuclides.

Many of these radionuclides emit low-energy photons—either X rays or gamma rays—during alpha or beta decay. Attempts to quantitatively measure these photon emission rates, however, have had only limited success because of the uncertainty in photon attentuation due to variability in sample matrix composition. In such cases, standards must be fabricated in the same matrix to properly compensate for photon attenuation.

To avoid the need for chemical treatment and to alleviate the use of the addition of tracers, we have applied a technique for direct, nondestructive photon counting of environmental samples by measuring the self-absorption directly and applying an appropriate correction factor.

Examples and applications of the technique follow.

1. **^{210}Pb.** We have applied the direct counting, nondestructive self-absorption technique to sediment samples that were also analyzed by conventional methods utilizing chemical leaching or dissolution and purification, followed by either alpha or beta counting. Figure 2.1 illustrates the results of those comparisons. Virtually all values between 0 and 10 pCi/g fall along the line of equivalence. (1 pCi = 0.037 Bq.) Higher concentrations (1 to 50 pCi/g) of samples above the line of equivalence all represent determinations performed by one analyst using hot-acid leaching and may reflect either differences in calibration standards or incomplete ^{210}Pb removal during leaching. Compari-

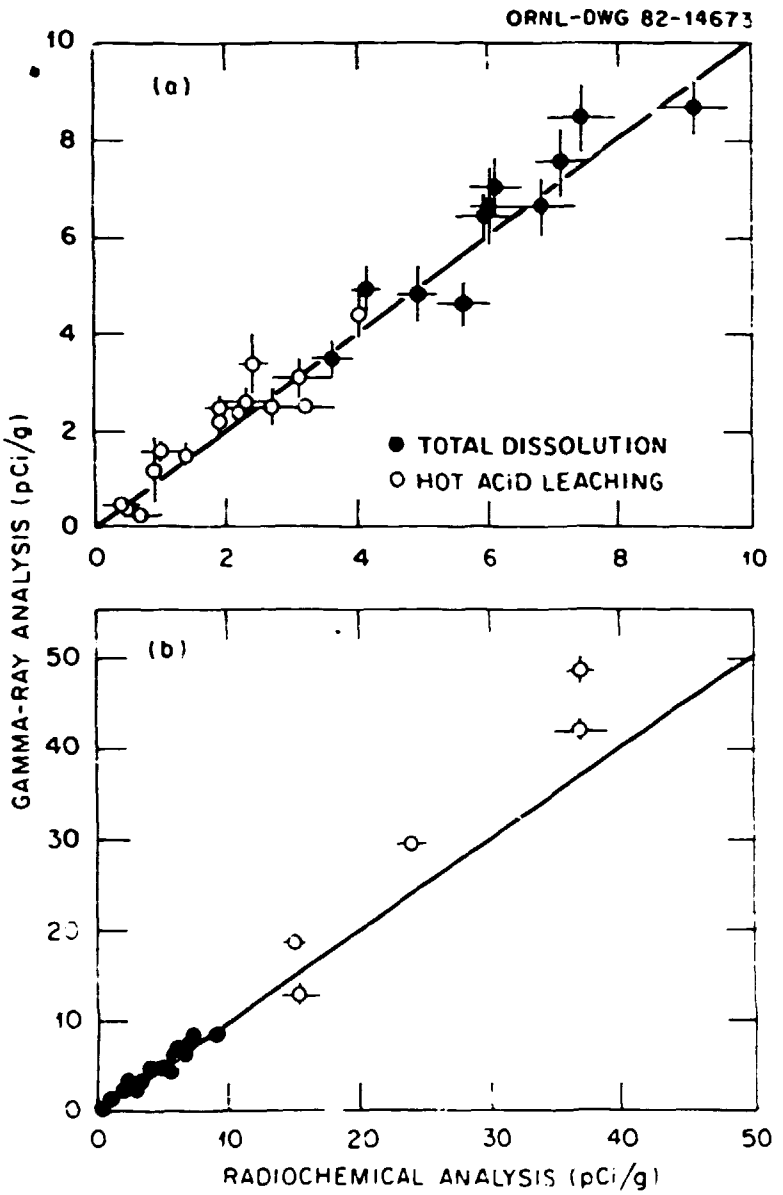

Fig. 2.1. Plots of results for ^{210}Pb analysis by gamma-ray counting vs radiochemical procedures. (a) Concentration range 0–10 pCi/g. (b) Concentration range 0–50 pCi/g. Error bars indicate 1σ counting errors. (1 pCi = 0.037 Bq.)

sons with standard reference materials (Table 2.1) indicate good accuracy for concentrations as high as 75 pCi/g using this technique.

2. ^{241}Am. The self-absorption correction technique was also applied to an intercomparison sample from the International Atomic Energy Agency consisting of marine sediment (SD-B-3). The value 192 ± 21 pCi/kg is in favorable agreement with analysis ranging from 142 to 194 pCi/kg performed by conventional alpha spectrometry methodology. (1 pCi = 0.037 Bq.)

3. ^{238}U. The technique was also applied to a soil sample from the U.S. Environmental Protection Agency (EPA)–Nuclear Regulatory Commission (NRC) submitted for analysis of ^{238}U by measuring the 63.3-keV (0.010-pJ) photon associated with the 24-d half-life daughter ^{234}Th. The

Table 2.1. Comparison of results of ^{210}Pb analysis with the expected value of certified reference materials

Material	Radionuclide	Certified value[a] (pCi/g)[b]	Determined value[a] ^{210}Pb (pCi/g)[b]
EPA/NBS mancos shale	^{226}Ra	1.55 ± 0.55	1.48 ± 0.06
EPA/NBS fly ash	^{226}Ra	3.51 ± 0.05	3.69 ± 0.15
NBL 76-B uranium ore	^{226}Ra	33.7 ± 0.3	32.1 ± 1.5
Canadian uranium ore DL-1	^{210}Pb	13.6 ± 0.4	14.1 ± 0.9
Canadian uranium ore BL-1	^{226}Ra	75.0 ± 2.0	75.4 ± 2.7
EPA/NRC intercomparison soil	^{210}Pb	5.2 ± 1.3	5.3 ± 0.2

[a]The number after ± is 1 standard deviation.
[b]1 pCi = 0.037 Bq.

measured value, 2.2 ± 0.2 pCi/g, was in excellent agreement with the expected value of 2.4 ± 0.3 pCi/g. (1 pCi = 0.037 Bq.)

Low-energy photons that accompany the decay of alpha or beta particles may be used to quantitize concentrations of certain desired radionuclides and may obviate the need for chemical dissolution, purification, and the addition of tracers to ascertain yield recoveries. The technique utilizing self-absorption correction methods is rapid, relatively simple, and provides accuracies comparable to conventional analytical separation techniques. Equipment procurement expenses can be compared to the equivalent labor costs involved in preparing approximately 300 samples for beta or alpha spectrometry.

Atmosphere-Canopy Interaction Studies: Dry Deposition of Particles to Inert and Vegetation Surfaces

S. E. Lindberg G. M. Lovett J. M. Coe

There are no widely accepted methods for routine measurement of dry deposition of polydisperse aerosols to forest canopies in complex terrain. Micrometeorological methods are strongly advocated, but they are not routinely applicable (Hicks et al. 1980). Carefully designed and positioned inert surfaces can yield useful estimates of particle deposition to natural surfaces and show several significant advantages: the actual measurement of fluxes, as opposed to the calculation of fluxes by micrometeorological methods; the simplicity of the method, which permits spatial replication and use as a routine monitoring procedure; the applicability of the method to a wide range of major and trace constituents of atmospheric particles; the ability to collect sufficient material for analysis of chemical speciation; and the ability to determine distribution of the deposited material within a canopy and thus estimate realistic surface concentrations. Research into the features of mass transfer of particles to plant canopies requires direct in-canopy sampling. Comparison of particle fluxes to inert surfaces and to canopy vegetation may provide information that will allow the "calibration" of surrogate surfaces.

We describe here data on dry deposition rates measured to inert surfaces and leaves during two experiments: the first in the forest canopy at Walker Branch Watershed (WBW) in eastern Tennessee and the second in a grass pasture in central Illinois.

The natural rate of dry deposition of particles containing SO_4^{2-}, NO_3^-, Ca^{2+}, and K^+ to flat inert surfaces and to living foliage was compared for eight experiments (Lindberg and Lovett 1983). The measurements were made in the upper canopy of a mature, mixed, oak and hickory stand at WBW during 1981–1982. Polycarbonate petri-dish deposition plates were situated at heights of 15 to 20 m, using a support providing automatic protection from precipitation. For generally dry periods of several days, plates were exposed adjacent to intact oak leaves, which were later extracted in the laboratory to determine surface accumulation of the above ions. Studies of dissolution kinetics were used to determine optimum extraction conditions for foliage. Results indicated good agreement between methods, yielding mean plate/leaf dry deposition ratios of 1.0 for SO_4^{2-}, 1.3 for K^+, 1.6 for Ca^{2+}, and 2.3 for NO_3^-. Although gas deposition complicates interpretation of SO_4^{2-} and NO_3^- ratios, the Ca^{2+} ratio may be useful for long-term calibration of surrogate surfaces for measurements of particle deposition in this canopy. Mean deposition velocities measured to inert plates ranged from 0.14 cm/s for SO_4^{2-} to 1.1 cm/s for Ca^{2+}.

Measurements of SO_4^{2-} and NO_3^- dry deposition were conducted in June 1982 as part of a dry-deposition intercomparison study in Champaign, Illinois, as a joint research project with Dr. Cliff Davidson of Carnegie-Mellon University (Davidson and Lindberg 1983). Data for Teflon plates without rims and polycarbonate petri dishes with 1-cm rims have been obtained and compared with data for Teflon sheets and polyethylene dustfall buckets used by other investigators. Results show that SO_4^{2-} deposition velocities for the plates are in the range 0.17 to 0.42 cm/s. Aerosol NO_3^- deposition velocities for the plates are in the range 0.76 to 1.8 cm/s, although these values may have been influenced by deposition of nitric acid vapor. Comparisons of SO_4^{2-} data for the four types of surrogate surfaces show deposition velocities that increase in the order Teflon sheets $\simeq$ Teflon plates < petri dishes < dustfall buckets. Differences in collector geometry as well as in surface material are responsible for these trends. Airborne size-distribution data obtained during the study show that much of the SO_4^{2-} mass is associated with particles of 0.5- to 1-μm aerodynamic diameter. However, using the size distributions as inputs to dry deposition models in the literature indicates that larger particles are responsible for most of the SO_4^{2-} mass deposition onto the surrogate surfaces. The calculated deposition velocities for natural grass surfaces are in reasonable agreement with measured deposition velocities onto the petri dishes.

Our results suggest that, under the conditions we have described, inertial impaction and sedimentation of supermicron airborne particles is more important than deposition of submicron material in influencing total SO_4^{2-} mass deposition onto surrogate surfaces—and possibly onto natural vegetation.

Nonnuclear Solid-Waste Technology

C. W. Francis

The leaching characteristics of various solid wastes have been evaluated to assess their weathering properties in shallow landfill environments. Research is centered around two tasks: (1) the development of a laboratory solid-waste extraction method to simulate codisposal of potentially hazardous wastes in municipal waste landfills and (2) short- and long-term leaching of solid wastes from the H-Coal process for coal liquefaction.

A Laboratory Extraction Method to Simulate Codisposal (C. W. Francis, M. P. Maskarinec, O. M. Sealand, and M. S. Hendricks)

The objective of this research is to develop a laboratory extraction method for solid wastes that simulates concentrations of potentially hazardous inorganic and organic constituents in leachates resulting from codisposal with municipal wastes in landfills. The intent is to produce a scientific rationale and a data base that supports the use of such an extraction method for characterizing the potential hazards of known toxicants in leachates resulting from codisposal of solid waste in a landfill containing a ratio of approximately 95:5 of municipal and industrial waste, respectively. Two field lysimeters, each containing approximately 1.5×10^3 kg of assorted municipal wastes, were used to generate a municipal waste leachate (MWL) that in turn was used to leach four industrial wastes under anoxic simulated codisposal conditions. One of the wastes was predominantely organic in character, consisting of heavy ends and column bottoms from the production of trichloroethylene and perchloroethylene. Two wastes contained both inorganic and organic hazardous constituents: one was a paint-production sludge and the other was an admixture of American Petroleum Institute (API) separator sludge and petroleum refining incinerator ash. The fourth waste was from an electroplating wastewater treatment.

Leachates resulting from the four industrial wastes being leached with MWL were monitored for concentrations of inorganic and organic constituents over 79 d [to a liquid/solid ratio of MWL and industrial waste of approximately 20:1, similar to the liquid/solid ratio currently being used in the extraction procedure (EP) to determine toxicity under the Resource Conservation and Recovery Act (RCRA)]. Air-tight Tedlar bags were used to collect leachate, to avoid loss of volatile organic compounds, and to maintain an anoxic environment. Data from the field lysimeter test facility were used to identify concentrations of target constituents (those constituents in the leachates of the industrial wastes that were observed at concentrations statistically higher than those observed in the control leachates). This data base was used as a model to develop a laboratory extraction method to simulate the target concentrations.

To simulate the 25 target concentrations observed in the industrial-waste leachates from the lysimeter test facility, 32 different laboratory extraction methods were tested in duplicate. These extractions consisted of an upflow-column and rotary-batch procedure, using four media: (1) a 0.1 *M* sodium acetate, pH 5 buffer (concentration of acetate equivalent to the maximum allowed in the present EP); (2) carbonic acid; (3) deionized distilled water; and (4) municipal waste leachate from the field lysimeter test facility—all at liquid/solid waste ratios of 2.5, 5, 10, and 20. Concentrations of the 25 target chemicals were determined in the laboratory extractions of the respective wastes and compared to the target concentrations in the leachates of the lysimeter. The relative difference between the laboratory concentration and the target values were ranked and then statistically analyzed across all combinations of chemicals and wastes to best simulate target inorganic chemicals, target organic compounds, and both inorganic and organic target chemicals.

Target concentrations can be established using various criteria (e.g., maximum observed concentrations in leachates from the lysimeter and concentrations integrated over selected leaching intervals). Using maximum observed concentrations as target values, the best-ranked extraction method (procedure, medium, and liquid/solid ratio) for the sixteen inorganic and nine organic chemicals was upflow-column with MWL at a liquid/solid ratio of 5. This extraction method, however, was not statistically different ($P < 0.05$) from the next six ranked methods. The two poorest extraction methods were upflow-column and rotary-batch extractions using deionized distilled water

as the extracting medium at a liquid/solid ratio of 20:1. The best-ranked extraction method for simulating target concentrations, determined by integrating over leaching intervals of 8 to 20 liquid/solid ratios, was a rotary-batch extraction procedure using carbonic acid as the extraction medium.

Short- and Long-term Leaching of Solid Wastes from the H-Coal Liquefaction Process (C. W. Francis, M. P. Maskarinec, and L. K. Hyder)

Leaching tests were conducted on a variety of solid residues generated in the liquefaction, gasification, and wastewater treatment steps of the H-Coal liquefaction process. These residues included the vacuum bottoms generated in the liquefaction of coal and the filter cake produced in the wastewater treatment facility at the H-Coal liquefaction pilot plant at Catlettsburg, Kentucky. The other residues consisted of the ash and clarifier bottoms generated on gasification of the vacuum bottoms.

Leaching consisted of a short-term regulatory extraction test (the EP toxicity test used to classify wastes under the RCRA) and long-term (>65 d) continuous-flow column studies to assess potential contamination of ground and surface waters as a result of land disposal of these wastes. The short-term test indicated that none of the wastes would be considered hazardous by the toxicity criteria of RCRA. Long-term leaching studies revealed that peak concentrations of potentially toxic inorganic constituents are generally below concentration limits of the primary and secondary drinking water standards and became 2 to 10 times lower on leaching to liquid/waste ratios greater than 5. The pH of the leachates from the gasifer ashes (coarse and fine slag) and clarifier bottoms from gasification of the vacuum bottoms was neutral to mildly alkaline, indicating little oxidation of residual sulfur.

The results of these studies differed considerably from those of other studies of ashes produced in entrained-bed gasifiers. Rainfall runoff from vacuum-bottoms flaked residue monitored over an 8-month period was also neutral to alkaline in pH, contained very low concentrations of inorganic constituents, and showed no indication of the chemical characteristics common in runoff from storage piles of high-sulfur coals. Aquatic toxicity tests on the leachates of the gasifier residues and the vacuum-bottom flaked residues gave nontoxic results; however, short-term mutagenicity tests (by the Ames *Salmonella* procedure) on the aqueous extracts of the wastewater filter cake were positive. Leachates from the solid residues, other than those from the filter cake (which contained detectable quantities of polyaromatic hydrocarbons (PAHs) and other complex organic compounds—some of which are known to be toxic—appeared not to be a major environmental concern relative to potential contamination of ground or surface waters on disposal of these wastes in properly designed landfills.

Weathering of Pyrite and Pyrrhotite (R. R. Turner and L. K. Hyder)

Earlier studies (Strayer and Davis 1983) on solid wastes from coal gasification identified production of acid leachates by these wastes as a potential disposal issue. Acidity can greatly accelerate the dissolution of wastes and reduces the contaminant sorption capacity of soils and other geologic media. Production of sulfuric acid by these wastes has been linked to the presence of pyrrhotite and elemental sulfur in the wastes. Thus, the problem is somewhat analogous to acid mine drainage, except that pyrrhotite and elemental sulfur rather than pyrite are the chief sources of reduced sulfur in gasification wastes. Recent research has involved comparison of weathering rates

of pyrite and pyrrhotite to determine whether these minerals exhibit different capacities to yield acid. The sulfur in pyrite and pyrrhotite exhibited similar fractional oxidation rates (pyrite = 2.6 $\times 10^{-5}$ d^{-1}, pyrrhotite = 2.0 $\times 10^{-5}$ d^{-1}) but, as expected, on a per-unit-mass basis (mg kg^{-1} d^{-1}) pyrite (FeS_2) yielded about twice as much sulfate as pyrrhotite (FeS).

Current experiments are testing the hypothesis that the weathering of pyrrhotite is accelerated when mixed with a glassy iron phase containing ferric iron. Ferric iron is thought to play a major role in the weathering of pyrite (Stumm and Morgan 1981). In the production of acid mine drainage, ferric iron is derived from the oxidation of ferrous iron released from iron sulfides, whereas, in gasification ashes it may be derived both from the oxidation of iron sulfides and from the dissolution of glassy compounds containing ferric iron. If this model is correct, then iron sulfides in gasification ashes that contain glassy iron may be oxidized faster than they would be alone.

Subsurface Transport Research

B. P. Spalding

Subsurface disposal of energy-production-related wastes poses short- and long-term potential environmental impacts. In either case, hydrologic transport will be the primary vector bringing contaminants from their disposal points into contact with the biosphere. Techniques need to be developed to predict the temporal and spatial sequences of any contaminant transport and to assess the ecological consequences of that transport. Many wastes contain constituents that will perturb the chemical and hydrologic characteristics of the geologic media in which they are disposed. Present hydrologic models can be quite sophisticated in describing spatially fixed hydraulic characteristics, but they do not allow temporal variation in inherent hydrologic or chemical adsorption properties. Wastes are likely to perturb geologic media as they leach reactive constituents, a process by which contaminant transport rates may be altered by orders of magnitude. In addition, present hydrologic models often demand more information about the hydraulic properties of a site than can be provided by a reasonable number of field measurements. Coupled with regulatory pressure for predicting contaminant transport from future waste disposal sites, the logical consequence of such a state of model development will be that good. but complex disposal sites, which would be adequate for a variety of wastes, may be ignored because they cannot be addressed by current modeling techniques. Ostensibly simpler sites, therefore, will be selected because they can be modeled. Many good sites likely will be neglected because they seem to be complex; actually, almost all sites are complex hydrologically. Hydrologic transport via so-called "preferred pathways," "macropores," "fractures," or "faults" is probably the rule rather than the exception. Thus, hydrologically simple disposal sites that can be modeled may be very difficult to find.

Research has been designed to measure subsurface transport of model elements and waste constituents. The fundamental processes of their adsorption to geologic media are being determined and described mathematically to facilitate their incorporation into hydrologic models. In addition, finite-element hydrologic models are being adapted for compatibility with chemical equilibria models. The physical processes of hydrologic transport in watersheds are being quantified to make them mathematically tractable. Thus, contaminant and hydrologic transport will be measured from bench-scale equilibria, one-dimensional flow in soil and rock columns, and three-dimensional flow in the field.

The subsurface transport research is divided into two tasks: hydrogeochemical transport processes and hydrologic transport of buried trace elements in contrasting watersheds. The hydro-

geochemical transport processes task centers on the construction of models to describe contaminant transport in a hydrologically simple situation, that is, the laboratory elution column. Three soils are being investigated for As, Mn, Cd, and Ni adsorption as a function of pH and ionic strength; their behavior during column elution with leachate of changing pH and ionic strength will be observed. Modeling is being conducted using adsorption as an empirical function of pH and ionic strength determined from bench-scale equilibria. Analogous elutions and their simulations with model organic compounds are performed concomitantly; these include naphthalene, 2,4,6-trichlorophenol, and acridine. These studies on the sorption of organics investigate the relationship among sorption coefficients, hydrophobicity, and soil organic carbon content, including low and high organic carbon solids and polar organics. In addition, because the source of changing leachate pH and ionic strength is the reactivity of specific waste constituents, the weathering rates of pyrite, pyrrhotite, and elemental sulfur have been studied both as model and as typical energy-production waste constituents. Ultimately, the chemical adsorption of inorganic constituents will be determined by solubility equilibria. A current chemical equilibria model, GEOCHEM, will be coupled with finite-element hydrologic models. Given the chemical composition of a particular waste, the chemical composition of the host geologic medium, and a description of its hydrologic characteristics, it may be possible to address the potential for transport of various contaminants by such a coupled model.

The second task is the hydrologic transport of buried trace elements in contrasting watersheds. In this task, the transport of contaminants will be studied in a situation that is hydrologically very complex, that is, the field watershed. As a first step, hydrologic transport in two watersheds will be measured using groundwater and contaminant tracers. Minimally adsorbing tracers (e.g., tritium and/or Fe-ethylenediamine-dihydroxyphenylacetic acid) will be used for groundwater tracking. Contaminant tracers (e.g., radioisotopes of the above elements and one organic) will be buried at hydrologically active and inert regions of each watershed. Using their observed breakthrough patterns, hydraulic properties including dispersivity and effective porosity will be determined. Spatial distribution of hydrologic and chemical properties will be determined and profile scaled from one intensely characterized soil profile (or block) at each site. Field contaminant adsorption will also be determined from these soil blocks and compared with the equilibrium data obtained in the first task. The extent of water and contaminant transport due to preferred pathways or macropores will be quantified and compared with that expected for bulk transport. Models will be adapted or developed to address these differences. Included will be models of the whole watershed or major parts—Unified Transport Model—(UTM)—and those of many assembled discretized elements (GEOHYDROFLOW- codes). Shortcomings of the models will be identified as a stimulus for their further evolution. More importantly, the processes of transport along preferred pathways will be identified and quantified in the combined experimental and modeling studies. Such information, as well as the techniques developed for its acquisition, will be of a basic scientific interest.

Model Refinement (G. T. Yeh)

Model refinement includes two aspects: (1) development of computational algorithms to reduce central-processing-unit memory so that the model can be applied to large field problems and (2) proper formulation of sorption processes to reflect the effects of soil-buffering capacity on the chemistry of influents. The first aspect is achieved by the derivation of orthogonal weighting and orthogonal upstream weighting finite element schemes for flow and transport equations, respectively. The second aspect is achieved through the development of two sets of computer programs:

GEOHYDROFLOW/GEOHYDROTRAN and GEOHYDROFLOW/GEOHYDROCHEM. The GEOHYDROFLOW program simulates water flow and moisture movement in saturated-unsaturated porous media. GEOHYDROTRAN and GEOHYDROCHEM compute chemical distribution in space and time due to water advection, hydrodynamic dispersion and molecular diffusion, biological degradation, and chemical sorption. GEOHYDROTRAN uses the empirical distribution coefficient (K_d) concept to treat sorption processes with K_d being dependent on the pH and ionic strength of the influents, whereas GEOHYDROCHEM adopts appropriate theoretical chemical equilibrium models to treat sorption processes by considering soil sites as one of the master species.

The GEOHYDROFLOW model is being developed by incorporating an orthogonal weighting function into the FEMWATER computer model. The accuracy of GEOHYDROFLOW is being tested by comparing its simulations with an analytical solution and with those obtained with FEMWATER. GEOHYDROTRAN is being developed by modifying FEMWASTE. The modification involves the computation of two chemical species. First, the distribution of ionic strength as a function of space and time is calculated based on the conservation principle of total mass of all chemical species involved, with the assumption that total moles for all chemical species associated with a particular valence are chemically preserved. Second, the distribution of pH values is simulated based on the mass balance of hydrogen ions. When the ionic strength and pH value of influents are significantly different from those found in the soil, it is not surprising to find that many predictions by conventional K_d models fail because the buffering capacity of the soil has not been properly taken into account. With GEOHYDROTRAN, this buffering capacity is modeled with a K_d function of ionic strength and pH value.

Although GEOHYDROTRAN utilizes the K_d-function and titration curve, GEOHYDROCHEM models the distribution of various chemical species and their affinity to specific soil sites using known thermodynamic stability constants. This chemical equilibrium model will compute the participation of chemical species based on the principles of mass balance, mass action, electrical neutrality, electron conservation, and phase equilibria.

Testing of Models (C. W. Francis and M. S. Hendricks)

Adsorption of inorganic solutes on soils has been determined in terms of batch-type K_d measurements (4:1 liquid/soil ratios) over a pH range from 3 to 8 and ionic strength from 0.0025 to 0.125. The buffering capacity to acidic and alkaline solutions for each soil is determined. Breakthrough curves for the selected constituents from 2.54-cm-ID columns packed with soil are being compared to predicted breakthrough curves from GEOHYDROFLOW/GOEHYDROTRAN.

Three subsurface soils are being used to test GEOHYDROFLOW/GEOHYDROTRAN in laboratory columns. Two of the soils, Fullerton cherty silt loam and Apison silt loam, are soils from the DOE reservation at Oak Ridge and dominate in the Walker Branch and Melton Branch watersheds, respectively. The other subsurface soil is the Dormont silty clay loam, which was selected because it had been used in previous soil attenuation experiments.

Measurements of K_d values for cadmium and nickel have been determined for the three subsoils: Fullerton, Apison, and Dormont. Radiotracers were spiked to initial solutions containing 1 and 10 mg/L of cadmium and nickel, respectively. Three replicated measurements were made over a 5 × 5 pH/ionic strength matrix. The pH values were 3, 5, 6, 7, and 8, and the ionic strengths were 0.125, 0.063, 0.0125, 0.0063, and 0.0012 in sulfate-based solutions. Soil suspensions (4:1 liquid/soil

ratio) were adjusted to the desired pH level 24 h before equilibrating with the isotope of choice. Values for K_d have been determined at 24 and 48 h to assess equilibrium.

Research has been initiated in the determination of cadmium and nickel breakthrough curves through the three subsoils as influenced by influent solutions of varing ionic strength and pH. Presently, breakthrough curves have been obtained for cadmium (1 mg/L) and nickel (10 mg/L) in 0.125 ionic strength solutions at acidic, neutral, and alkaline conditions for the three subsoils.

Geologic Activities

The Earth Sciences Section was involved in a variety of geologic activities during the fiscal year. One of the major efforts was centered on the hydrofracture facility, a unique project used to dispose of intermediate-level nuclear wastes at ORNL by injection of the wastes mixed with cement in rock strata at 30.5 m (100 ft) below the surface. Geologic mapping of strata and structures was concentrated on the injection site and surrounding area to more fully understand the relationship between geologic characteristics and successful operation of the facility. During the latter half of the year, geologists in the section helped in the development and initiation of a monitoring program designed to give information about the physical impact that a waste injection has on the site. The program has resulted in quantification of the uplift and the amount of ground tilting experienced at the site. Geoscientists from Lawrence Berkeley Laboratory (LBL) are also working closely with ORNL personnel to install seismic geophones in the ground so that the acoustics produced by the propagating fracture can be tracked and the rate and direction of fracture formation can be measured.

A second topic of geologic research involved the delineation of the mechanism(s) by which metals are concentrated and retained in organic-rich fine-grained clastic rocks. The principal activity for FY 1983 was characterization of the petrology and geochemistry of metal-enriched portions of the Michigamme Formation. Metal enrichment patterns within the Michigamme Formation are related to the occurrence of quartz- and carbonate-rich iron formations. Such lithologies are interpreted to have formed by the venting of subsurface brines into the depositional basin during the accumulation of Michigamme Formation sediments. Study of mineral assemblages from the iron formations and associated metal-enriched shales can provide data to place constraints on the geochemistry of the subsurface brine that transported the metals and on the geochemistry of the depositional environment in which the metals were precipitated and immobilized. Samples of iron-formation and metal-enriched shale sequences have been obtained from the Michigamme Formation at five localities. Mineral assemblages and textural relationships have been determined by optical petrography for samples from two of the localities, and electron microprobe analysis of the assemblages is in progress. Research planned for FY 1984 involves the completion of petrographic and microprobe characterization of samples from all five localities. Theoretical calculations, based on observed mineral composition and assemblage data, can then be performed to characterize the geochemical nature of the depositional environment in which the metal-enriched shales formed.

During the year, the ORNL Geoscience Committee continued its activity, chaired by a geologist from the Earth Sciences Section. The purpose of the committee is to recommend to management areas of future geoscience development at ORNL. The committee reviewed various options and suggested that the broad areas of waste management, carbon cycling, and resource studies constitute the highest-priority developmental topics, building on existing strengths. A list of secondary research areas was also identified.

Over the last 4 years, the section has enjoyed a working relationship with the Department of Geological Sciences at The University of Tennessee. During the year, two candidates for master's degrees and two candidates for doctoral degrees were supported for their thesis research; two section geologists are members of the University staff. We also pursued ways to increase interaction with this University department and look forward to increased student support and joint appointments.

Geochemical Model Calculations Related to High-Level Waste Repositories (N. H. Cutshall)

The Nuclear Waste Act of 1982 provides a timetable for the licensing of a repository for high-level nuclear wastes. The NRC is responsible for issuing the repository license. Geochemical models and computer codes are likely to be used in the repository site-characterization process not only for simplification of groundwater data sets and to infer flow fields but, also, at least potentially, to forecast the behavior and mobility of radionuclides in the zone surrounding a repository. Because it is expected that repository performance assessment will rely to some degree on geochemical models, it is necessary that NRC be able to appreciate the value and limitations of model applications. A set of codes for geochemical calculations is being assembled and applied to confirmatory analyses of site conditions.

Efforts during the past year have been directed toward the Basalt Waste Isolation Project (BWIP) site: reviewing published BWIP efforts and evaluating the experimental uses of synthetic groundwaters for laboratory simulations of sorption and precipitation reactions.

BWIP methodology and information. Preliminary information suggested that BWIP site-performance assessment would rely on solubility limitations to provide geochemical controls on mobility of key radionuclide species. Many of the key radionuclides elements form sparingly soluble oxides or oxyhydroxides under normal groundwater conditions. Whereas the formation of poorly characterized amorphic phases or sorption and coprecipitation on mineral surfaces may keep the radionuclide concentrations even lower, so that the pure oxides would not actually form, the supposed upper limits to concentrations provided by the oxide phases are postulated to be sufficient for adequate retardation of radionuclides.

The rationale and approach for applying solubility controls and the estimated solubilities were described by Early et al. (1982). They developed and used the computer program EHPH to calculate solubilities of several elements under the BWIP groundwater conditions. EHPH makes no allowance for ionic strength and equates activities and concentrations on the grounds that ionic strengths are sufficiently low. Temperature and pH were fixed at 25°C and 9.5, respectively, and a range of Eh values was entered. A groundwater composition recommended by Jones (1982) was used as the solution medium, and thermodynamic constants from three compilations and one primary report were merged for the data base. Solubility limits for 16 elements (Ni, Se, Zr, Tc, Pd, Sn, Sb, Sm, Eu, Pb, Ra, Th, U, Np, Pu, and Am) were computed with respect to possible pure solid phases. Data for technetium and radium were said to be inadequate, and it was recommended that these elements be reconsidered with improved data. The authors concluded that oxides and hydrous oxides adequately controlled the solubility for most of the radionuclides considered. Soluble species were predicted as complexes either with hydroxide or with carbonate. Based on computer runs that omitted the most stable solid phase, the authors concluded that less-stable metastable phases could provide solubility control with only modest increases in concentration if kinetics for formation of the most stable compounds were slow. Selenium was indicated as the one element

among those treated for which solubility was substantially in doubt, and experimental work with selenium was recommended.

Deutsch, Jenne, and Krupka (1982a, 1982b) used the code WATEQ2 with the Columbia Plateau groundwater data from van Denburgh and Santos (1965), LaSala and Doty (1971), and Apps et al. (1979) to compute equilibrium speciation and mineral saturation indices. They found that many samples were near the saturation value with respect to calcite and concluded that equilibrium with calcite is probable for BWIP site groundwaters. They also suggested that calcite would, therefore, provide a control on groundwater calcium concentrations and on pH. Other solids that were near saturation included the zeolites wairikite and analcime and amorphic silica. Their model data bases did not include the zeolites commonly found at the Hanford site such as clinoptilolite (possibly heulandite). Analcime is often found at Hanford, although it is not abundant; wairikite is rarely reported. Dissolution of volcanic glass, abundant in the basalts, was suggested as the cause of amorphic silica saturation.

Deutsch, Jenne, and Krupka (op cit.) discussed iron chemistry and its implications as compared with system redox potentials. They noted that no solubility-limiting phase for ferrous iron had been identified. The absence of sulfide data from the analytical data, however, prevented consideration of sulfide minerals that could possibly be important. They note that if there is no control (i.e., removal) of ferrous iron, its concentration should increase downward along flow gradients, but that no such increases have been observed. This implies that there is either a yet unknown removal mechanism for ferrous iron or an oxidation and removal as ferric iron. Concentrations of ferric iron are not limited by the most abundant iron-bearing secondary mineral, nontronite. Amorphic ferric hydroxide is suggested as the probable iron-limiting solid based on the measured platinum electrode potentials (−0.05 to +0.15 V). Oversaturation with respect to amorphic ferric hydroxide is generally computed for those samples where platinum electrode measurements have been made.

Most of the analytical data available to Deutsch, Krupka, and Jenne are for samples from the upper 91 m (300 ft) of the basalt formations, and very few of the analyses are for samples from greater than 305-m (1000-ft) depths. Wells that penetrate the basalts to depths of the repository horizon have been unnecessary for irrigation; therefore, they have been rare. Furthermore, Apps et al. (1979) caution against dependence on reported groundwater compositions because of suspected contamination. For example, although they pumped 64,000 gallons of water from a packed-off section of well DC-2 to remove local contamination, samples drawn subsequently contained tritium at about 20% of the Columbia River levels. Apps et al. express skepticism about possible contamination of earlier well samples; they note that although they pumped packed sections at length and were able to obtain constant conductivity and temperature, indications normally taken to signify uncontaminated water, the water still contained diesel oil and "bacterial breakdown odor." The experience of Apps et al. is not uncommon in ground water sampling and analysis, and unquestioning reliance on analytical data—especially for trace constituents—seems inadvisable. Nonetheless, major constituents such as the alkali and alkaline earth metals and the principal anionic constituents are probably not greatly contaminated if reasonable precautions have been taken.

Groundwater composition calculations and results. The computer code PHREEQE (Parkhurst, Thorstenson, and Plummer 1980) was used with BWIP analytical data to determine equilibrium speciation and saturation indices for Hanford groundwaters. Results were substantially in agreement with those of Deutsch, Jenne, and Krupka (1982a, 1982b). Data for groundwaters from four deep wells (DC15, DC6, DB15 and DC14) were used. Apparent oversaturation with respect to calcite and fluorite was frequent, and all samples appeared to be oversaturated with respect to either

quartz or chalcedony and to goethite or hematite. Oversaturation with respect to crystalline silica phases is common and presumably reflects the ready dissolution of glass and the extremely slow reactions of dissolved silica and crystalline silica at low temperatures. Similarly, iron concentrations may be limited by formation of amorphic ferric hydroxide rather than the more stable iron oxide phases because of the unfavorable kinetics of the latter.

Three published recipes, GR-1 and GR-2 (Salter, Ames and McGarrah 1981) and GR-3 (Jones 1982) for experimental, synthetic solutions that simulate BWIP site groundwaters were also entered as starting compositions in the PHREEQE code. Saturation results were similar to those for computations made using analytical groundwater data. Apparent oversaturation with crystalline silica phases was found for all recipes. GR-1 is apparently undersaturated with calcite, whereas the other two are slightly oversaturated. For fluorite, GR-1 contains no fluoride and thus the solution is undersaturated; GR-2 appears slightly oversaturated, and GR-3 is substantially above saturation with respect to this mineral.

Discussion and conclusions. The computational results are essentially in agreement with earlier work related to the BWIP site. The conclusions that may be drawn from the results can be different, however. The general oversaturation with several common crystalline phases is not unique to the BWIP location and might, indeed, be expected. Volcanic glass, which forms during rapid quenching of molten silicate solutions, is considerably less stable than the crystalline phases or minerals for which computations have been made. Thus, the reactivity of glass with water leads to dissolution of several elements to levels considerably in excess of their saturation "limits" for equilibrium. Reaction rates for nucleation and precipitation of minerals can be extremely slow at the low temperatures of the undisturbed repository site. Consequently, the product solutions remain oversaturated with respect to crystalline silica, hydrous oxides of iron, and calcium fluoride for long time periods. For example, the fluoride concentrations appear to increase with increasing depths, even beyond the expected solubility limit of fluorite. Thus, although fluorite is a hypothetically limiting phase, it does not appear to be effective during time scales at least as great as the age of the groundwater at depth. Groundwater ages from the repository horizon are typically estimated at 10^4 years. Therefore, the groundwater solutions appear to remain out of equilibrium with respect to simple crystalline phases for time periods that are significantly long in terms of repository performance.

Slowness to attain equilibrium from the solution side may present a logical difficulty in assuring repository performance by way of solubility controls in both the near field and the far field for radionuclides whose limiting solid phases cannot be shown to come to equilibrium with groundwater solutions under repository conditions. It may be necessary to prepare the limiting phases themselves as a component of the waste form to take credit for the extremely low concentrations that may exist at equilibrium. It should be noted that irrespective of the fact that solution concentrations are found to exceed solubility limits, this occurs only where solutes are added under chemical conditions other than the final solution conditions or in a chemical form other than the limiting solid phases. Excess silica and excess fluoride in BWIP groundwaters appear to derive from reactions of unstable glass with groundwater (or perhaps from the mixing of different groundwaters), not from dissolution of crystalline silica or fluorite. The secondary mineral formation sequence at BWIP appears to have proceeded from clay (usually smectite) to clinoptilolite to silica polymorphs and clay (Benson and Teague 1979). Evidence for subsequent dissolution is restricted to clinoptilolite (Teague 1980). Thus, once quartz or opal or even the higher temperature polymorphs, cristobalite or tridymite, are formed, they are resistant to dissolution as predicted by solubility calculations. Presumably, the

introduction of fluorite into BWIP site groundwaters would result in a reduction of the existing fluoride and calcium levels.

Geophysical and Structural Characterization of Melton Valley (C. S. Haase)

During the first half of FY 1983, the primary activities centered on obtaining a complete geologic section of the Conasauga Group and the Rome Formation in Melton Valley. A borehole, collared in the Knox Group on Copper Ridge, was completed to a depth of 828.4 m (2718 ft). Core recovery was better than 99%, which is excellent. The complete core has been logged (Fig. 2.2) and

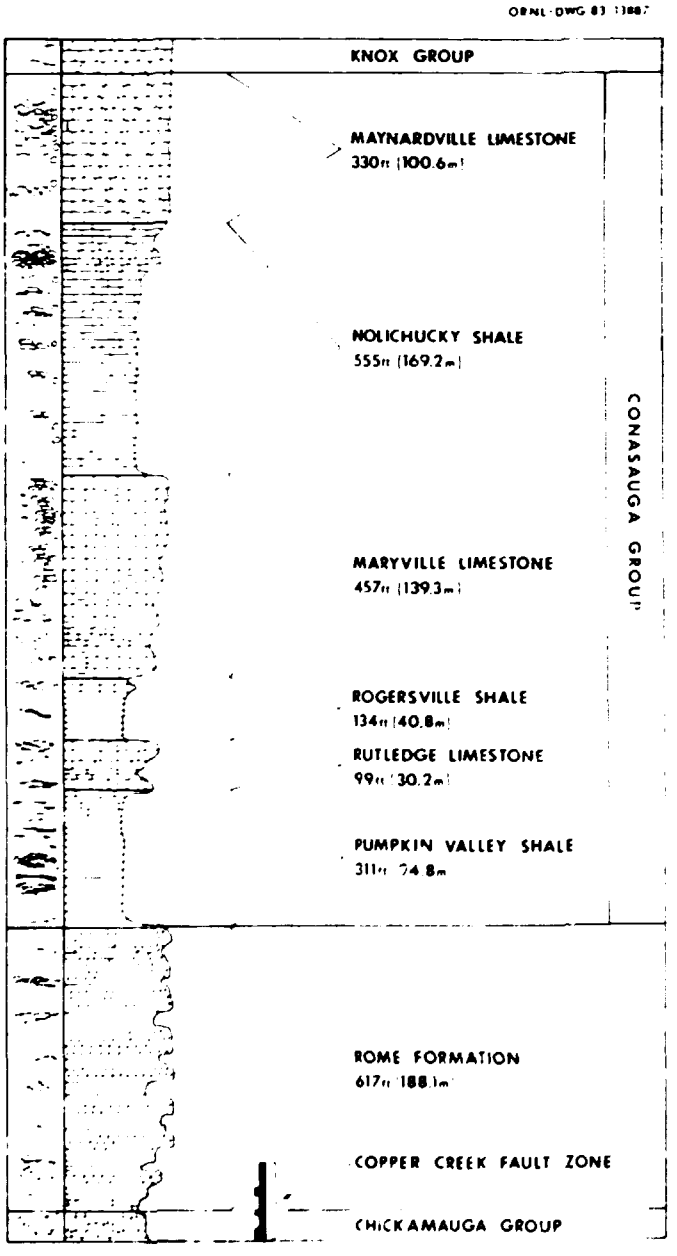

Fig. 2.2. Generalized lithologic log for borehole ORNL-Joy No. 2, illustrating the stratigraphy of the Conasauga Group and the Rome Formation in Melton Valley. Total depth of the borehole is 828.4 m (2718 ft).

photographed and is stored in the recently completed core-storage facility. A suite of geophysical logs has been obtained from the borehole by U.S. Geological Survey personnel. The logs obtained are caliper, gamma ray, neutron, temperature, acoustic velocity and waveform, and acoustic televiewer. Geophysical log response patterns from the borehole have been correlated with lithologic and rock-fabric data obtained from the core logging to provide the first complete, detailed description of the Conasauga-Rome stratigraphic interval at the ORNL site. Work is continuing with samples of the core; primary activities are petrographic characterization and measurement of porosity and permeabilities of the various constituent formations of the Conasauga Group. A report summarizing the stratigraphic and lithologic data obtained from the borehole is in preparation.

A literature search and analysis of data on the regional lithostratigraphy of the Conasauga Group throughout East Tennessee was completed. A draft manuscript ["Lithofacies and Paleogeography of the Conasauga Group (Middle and Late Cambrian) in the Valley and Ridge Province of East Tennessee"] was prepared. The manuscript is being submitted for open literature publication.

During the second half of FY 1983, the emphasis of this subtask was redirected toward support of the ORNL Hydraulic Fracturing Facility. The primary activity was implementation of a program to evaluate available techniques to monitor the extent and orientation of hydraulically induced fractures. Three techniques were identified for evaluation: measurement of the surface uplift caused by hydraulic fracturing by precise leveling; real-time measurement of the surface uplift pattern by a tiltmeter array; and measurement of microseismic signals from the propagating hydraulically induced fracture. Planning and design of the experiments proceeded in conjunction with personnel from LBL. All fabrication of on-site facilities necessary to implement the experiments has been completed. The benchmark network for the precise leveling was completed in June 1983, and the tiltmeter and microseismic experiments will be conducted during the planned October and November injections.

Data from the precise leveling activities have been obtained for the July and August 1983 hydrofracture injections. The design of the benchmark network provides better resolution of the three-dimensional shape of the surface uplift pattern than provided by previous networks installed at other ORNL hydraulic fracturing facilities. Uplift patterns measured are asymmetric with respect to the position of the injection well (see Fig. 2.3). Preliminary analysis of the uplift patterns suggests that the observed shape is consistent with a hydraulic fracture orientation that dips slightly to the southeast. This is not the only possible interpretation, however, and additional study and analysis are in progress. Results obtained thus far indicate that precise leveling measurement of surface uplift patterns caused by hydraulic fracturing will provide useful data about fracture orientation.

Waste Isolation Program

S. H. Stow

The Waste Isolation Program is supported through the Office of Crystalline Repository Development (OCRD) and the Office of Nuclear Waste Isolation (ONWI), managed by Battelle Memorial Institute at Columbus, Ohio. DOE plans to identify a second nuclear waste repository site in the late 1980s, and the research efforts of the program have been chiefly directed toward providing technical information that can be used in site identification.

Division personnel have concentrated on study of the crystalline (granitic) rocks of the southern Appalachians, generating geologic, hydrologic, and ecologic data. Geologic and hydrologic

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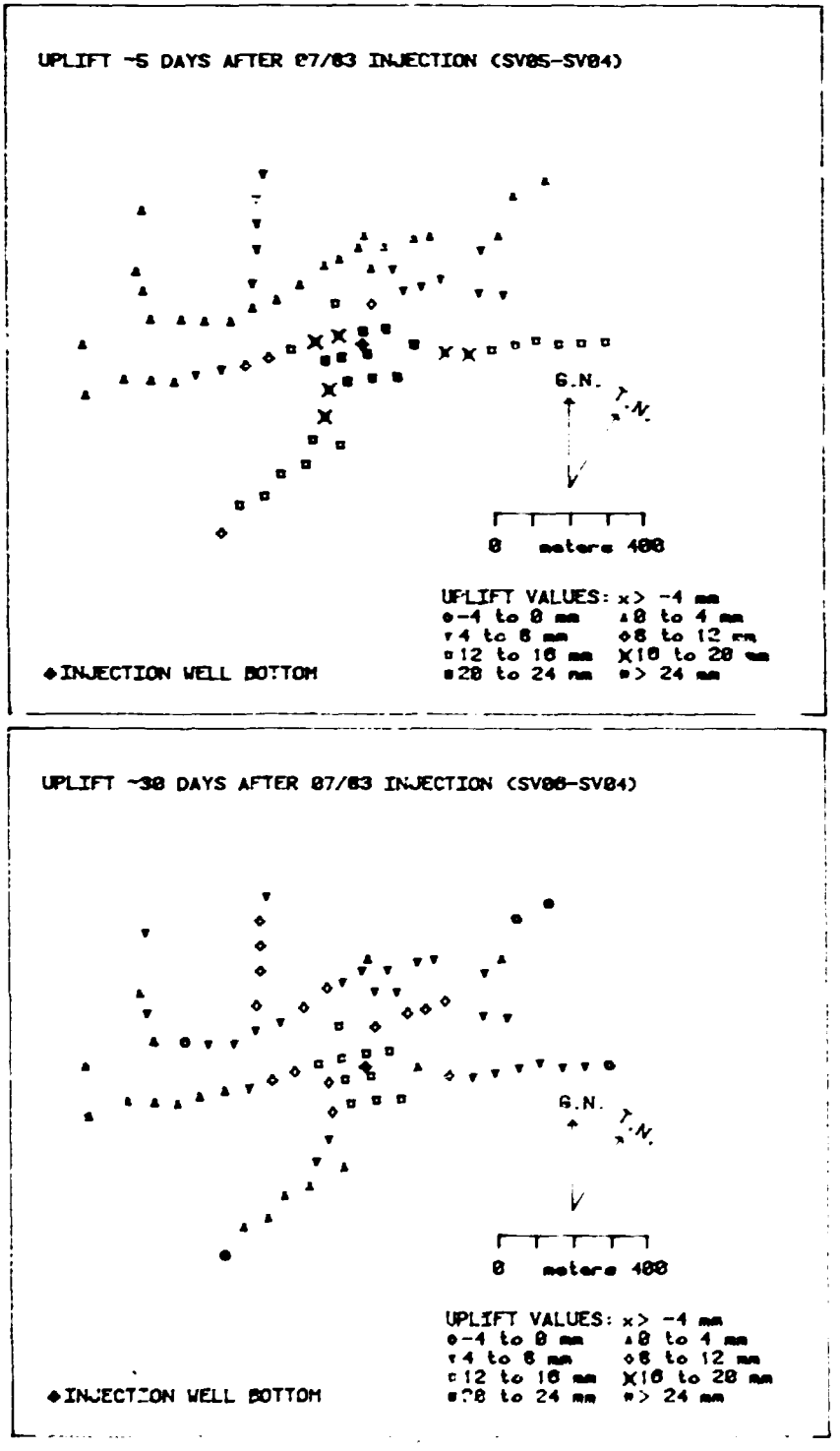

Fig. 2.3. Plan view of the benchmark network at the new ORNL Hydraulic Fracturing Facility, illustrating the uplift values measured 5 d after the July 1983 injection and again approximately one month later. Note that the initial uplift magnitudes are generally greater than those observed in the later survey. G.N. represents ORNL grid north and T.N. represents true north.

information were assessed for some 60 crystalline rock bodies in the states of Maryland, Virginia, North Carolina, South Carolina, and Georgia. Specifically, such aspects as rock type, hydrologic flow patterns, distribution of mineral resources, seismic potential, and erodibility were used to help screen candidate rock bodies for further investigation.

A regional environmental characterization of the Southeastern region was completed as part of DOE's National Waste Terminal Storage Program. The goal of this program is to develop permanent radioactive waste disposal capabilities in deep geologic formations. The study region consisted of portions of Maryland, Virginia, North Carolina, South Carolina, and Georgia. The report described and quantified variables for the southeastern region: demographic, socioeconomic, land use, natural resource, terrestrial and aquatic climatic, and physical. This report will provide information useful for the screening process, which will narrow the scope of future investigations.

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3. ENVIRONMENTAL ANALYSES

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Introduction

The Environmental Analyses Section (EAS) was established in 1983 to contribute ESD technical expertise to interdisciplinary environmental analysis and assessment activities of ORNL. The section is organized around 5 project areas (Environmental Evaluation and Assessment, Environmental Risk Analysis, Technology Applications, Regional Studies, and Resource Analysis and Statistical Support). The EAS continued cooperative efforts with the ORNL's Energy Division preparing environmental impact statements for uranium fuel cycle and hydroelectric projects. Summarized below are additional significant accomplishments for 1983.

Environmental Risk Analysis

L. W. Barnthouse

Environmental risk analysis may be defined as the process of identifying potential adverse effects of human activities on the environment and evaluating the probabilities and consequences of their occurrence. Consistent with this definition, the principal focus of activity of the Environmental Risk Analysis Group is quantification of (1) expected impacts and (2) uncertainties concerning expected impacts of energy-related environmental stresses. Since 1981, major effort has been devoted to evaluating environmental risks of three major classes of synthetic fuels technologies: direct coal liquefaction, indirect coal liquefaction, and oil shale extraction. This work is funded by the U.S. Environmental Protection Agency (EPA). An evaluation of the potential bioaccumulation

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of long-lived contaminants in fish populations of the Great Lakes, funded by the National Oceanographic and Atmospheric Administration's (NOAA) Great Lakes Environmental Research Laboratory, was initiated in early 1983.

During FY 1983, risk analyses were performed for atmospheric and aqueous effluents associated with commercial-scale designs for eight synthetic liquid fuels processes. Members of the group also contributed to the Department of Energy's (DOE's) Health and Environmental Effects Document for direct coal liquefaction.

Extrapolating Effects of Whole Effluents (G. W. Suter II and A. E. Rosen)

Although numerous environmental risk analysis methods have been developed to consider the effects of individual chemicals on fisheries, none of them address the total toxicity of a complex effluent. The need for such a method arises in the assessment of new industries for which an expected effluent can be described chemically but is not available for testing. The method must convert the toxicities of the component chemicals into a common unit and combine them into an estimate of whole-effluent toxicity.

Complex effluents such as those from a synfuels plant contain thousands of chemicals most of which have never been tested for their ichthyotoxicity or for the properties that determine environmental transport and fate. This difficulty is avoided by grouping the chemicals into 38 categories with similar chemical properties termed risk analysis units (RAUs). The toxicity of each RAU is represented by that of a member chemical for which toxicity data are available. Transport-related properties are similarly based on representative chemicals for which the needed data are available.

Acute lethality was chosen as the indicator of toxicity, because experimental evidence indicates that acute lethal effects on fish are generally concentration additive, whereas there is essentially no evidence concerning the joint toxic effects of chronic exposures. The upper 95th percentile of the predicted ambient concentration based on the distribution of flow volumes was used as an estimate of the acute exposure to each RAU. The chosen common response was the 96-h LC_{50} for largemouth bass (*Micropterus salmoides*). For each representative chemical, the LC_{50} for the tested species was extrapolated to the largemouth bass by using regression equations developed by Suter et al. (1983). These bass LC_{50}s were then divided into the acute exposure concentration to generate a quotient referred to as the toxic unit (TU). The TUs were then added to generate an indicator of total toxicity (STU), which corresponds to a fraction of an LC_{50}, assuming concentration additivity.

This analytical technique was applied to four direct coal liquefaction technologies. The resulting STU values were 0.17 for Exxon Donor Solvent, 0.078 for SRC-II, 0.18 for SRC-I, and 0.21 for H-Coal. The high STU for H Coal is due primarily to four RAUs with TU values between 0.01 and 0.1 that account for 94% of the STU: ammonia, phenols, aliphatic/alicyclic hydrocarbons, and aldehydes and ketones. The other three technologies have lower STU values, primarily because of fewer RAUs emitted in significant amounts rather than because of lower overall emission rates. For all technologies, ammonia is a major contributor to the total toxicity.

The STU values for these four technologies are low enough to suggest that massive fish mortality is unlikely; however, they are all well above the safety factor of 0.01 that is often applied to fish acute toxicity data. Therefore, the whole effluent might be expected to cause acute sublethal effects or lethal effects in the sensitive embryo and larval life stages. Such effects merit further consideration. The fact that the total effluent toxicity for these four categories is the sum of two to four RAUs with roughly similar toxicities indicates that combined effects need to be considered, but the

number of chemical categories involved is not unmanageably large. Further work can focus on the environmental chemistry and toxicity of these few chemical categories. In addition, attention needs to be focused on the nature of the combined effects of mixed chemicals in chronic exposures.

These results can be compared with results of tests for *Daphnia* acute lethality in diluted SRC and H-Coal effluent treated in bench-scale facilities (Bostick et al. 1982). The *Daphnia magna* 48-h LC_{50} for steam stripped and biooxidized SRC effluent (equivalent to the treatment assumed for our analysis but without phenol extraction) was 2.4% effluent. The *D. magna* LC_{50} for steam-stripped and solvent-extracted H-Coal effluent (roughly equivalent to our treatment) was 4.4% effluent. For comparison, our model generates an exposure in the first river reach equivalent to 0.4% effluent. Thus, our predicted exposure is approximately an order of magnitude lower than the acute toxic concentration to *Daphnia* of bench treated effluent. This result is consistent with the STU values presented above, which are approximately 0.1 of a largemouth bass LC_{50}.

Soil-Solution Concentration Calculation for Risk Analysis of Synfuels (C. F. Baes III)

Ground deposition of atmospheric pollutants released from synfuel plants poses potentially significant risks to both man and the environment. Risk assessment models typically calculate total ground deposition into the root zone, but not partitioning of the pollutant between solid and solution phases. Assessment of biological availability of soil chemicals is based on bulk concentration in the root zone, because soil-plant concentration factors have traditionally been determined through greenhouse pot studies. However, plant toxicity tests are usually conducted in solution culture; therefore, most assessment models of plant toxicity must employ the conservative assumption that all deposited material is dissolved to make use of experimental data. To provide a more realistic assessment of plant toxicity and also incorporate information from solution culture plant uptake studies into an assessment of root uptake pathways, we have developed an estimate of the soil solution concentration based on the soil-water distribution coefficient, or K.

Total ground deposition at a given location is estimated by integrating the ground-level deposition rate (estimated by a Gaussian plume model for short distances and by a trajectory model for long distances) over the lifetime of the synfuel facility. Losses resulting from degradation and leaching are approximated by first-order removal constants, and total deposition into the root zone is corrected for these removal processes. The soil solution concentration in the root zone is then estimated by assuming a linear relationship between solid and solution concentrations. The soil-water distribution coefficient is most often measured by mixing a chemical with soil and water and determining the concentration in each phase after equilibrium has been achieved. However, for the majority of synfuel effluents, structure-activity relationships are used to estimate K_d for the assessment model.

Because the distribution coefficient is in the denominator of the soil solution calculation, the estimated solution concentration could take on extremely high values with small values of K_d. To bound the calculation, a maximum soil solution concentration is estimated by dividing the total deposited and retained material by the total quantity of water in the root zone. The soil solution concentration used in the plant toxicity assessment is the lower of the two values estimated by the above methods.

In addition to providing for a better method of incorporating data from plant toxicity tests conducted in solution culture into the plant toxicity assessment model, the soil solution calculation provides an opportunity to use information on plant uptake of synfuel compounds obtained from solution culture experiments. Little information exists on plant uptake of synfuels. Of the few studies

conducted, most are based on uptake from solution culture rather than bulk soil. The soil solution concentration calculation allows for the use of both types of studies in the synfuels assessment model, and it reduces the model's dependence on poorly validated structure-activity relationships for estimating plant uptake.

Models for the Behavior and Fate of Long-Lived Contaminants in Fishes of the Great Lakes (J. E. Breck)

Understanding the behavior and fate of long-lived contaminants in aquatic ecosystems requires knowledge of the influence of contaminant concentrations in water and food on the concentrations in fishes. Of particular interest for this research project are the relative contributions of several contaminant pathways to fishes. Possible pathways are direct uptake from water and uptake, via the food chain, from bottom-dwelling and planktonic organisms. Because many persistent chemicals accumulate in the sediment, information is needed on the contribution of contaminants from bottom-dwelling organisms. Research done for NOAA has focused on the simulation of polychlorinated biphenyl (PCB) and dieldrin accumulation by the alewife. The alewife, a member of the herring family, feeds on both bottom-dwelling and planktonic organisms and, in turn, is the dominant prey of salmon and lake trout in Lake Michigan.

The approach taken in this research was to adapt previously developed models of fish growth to predict contaminant uptake and elimination by fish. These models incorporate information on the major physiological processes (consumption, respiration, egestion, excretion, and reproduction) that determine growth. The models also incorporate information on factors such as food quantity and quality, fish size, and water temperature that affect physiological processes. From observed fish growth and water temperature data, and with the physiological information in the model, estimates were made of the oxygen uptake and the food consumption rates that were required to produce the observed alewife growth. With these estimates of energy consumption, and with information on the percentage and energy value of each prey type in the diet and the contaminant concentration in each prey type, the amount of contaminant ingested was computed. The rate of contaminant uptake from the water was modeled as directly proportional to the rate of oxygen uptake and to the contaminant concentration in the water.

The simulated PCB concentrations were within the range of the observed PCB concentrations in Lake Michigan alewives (approximately 1 to 5 $\mu g/g$ as Aroclor 1254). About 50% of the alewife PCBs are estimated to have come directly from the water, with the other half coming from the food chain. According to the simulations, the bottom-dwelling invertebrate *Pontoporeia hoyi* contributes about 30% of the total alewife body burden of PCB. The PCB concentration in alewives is expected to increase with fish age, approximately doubling from the end of the first growing season to the end of the sixth.

Using the same bioenergetic parameters, diet data, and temperature history as for the PCB simulations—changing only the contaminant elimination rate—the simulated dieldrin concentration in alewives is within a factor of 2 of the observed. Because the elimination rate of dieldrin is faster than that of most PCBs, dieldrin concentration in alewives is predicted to be nearly independent of fish age. Direct uptake from the water is predicted to be responsible for nearly 60% of the body burden of dieldrin in alewives. Although the food chain pathway is thus somewhat less important for dieldrin than for PCB, the bottom-dwelling invertebrate *Pontoporeia hoyi* still contributes about 25% of the body burden of dieldrin.

Environmental Compliance Activities

R. M. Reed

A variety of environmental compliance activities have been supported by the Section during FY 1983. The staff has continued to assist the DOE Office of Environmental Compliance in preparing guidance manuals to assist DOE program and project personnel in complying with federal environmental laws and regulations. The compliance guide on the National Historic Preservation Act has been published, and that for the American Indian Religious Freedom Act has been completed and is in the final stages of DOE review. A revision to the guidance manual on the Endangered Species Act (incorporating changes mandated by the Endangered Species Act Amendments of 1982) and interpretive guidance on revised regulations were also prepared. Background papers were developed on the ocean dumping of low-level radioactive wastes and on a lawsuit under the National Environmental Policy Act related to offshore leasing of oil and gas reserves near the Channel Islands. The staff has provided DOE with review comments on a number of Environmental Impact Statements and other environmental documents.

Several staff members have served on an ORNL team assisting the DOE Office of Oil, Gas, Shale, and Coal Liquids in reviewing Environmental Monitoring Plan outlines on synfuel projects. These outlines are submitted by applicants requesting Synfuels Corporation funding. The ORNL team reviews the outlines to determine if they meet the monitoring requirements specified in the guidelines developed by the Synfuels Corporation and recommends modifications where the submitted outlines are inadequate. More than 20 outlines have been reviewed during the year.

The American Indian Religious Freedom Act (F. E. Sharples and M. S. Salk)

The First Amendment to the U.S. Constitution guarantees the inherent right of all Americans to freedom of religion, but the religious freedom of Native Americans (including American Indians, Eskimos, Aleuts, and native Hawaiians) has often been restricted. The American Indian Religious Freedom Act of 1978 (AIRFA) was, therefore, passed to acknowledge that infringement and to state clearly that federal laws passed for other purposes were not meant to restrict those rights. DOE is required by AIRFA to ensure that none of its actions interfere with the inherent right of native Americans to believe, express, and exercise their traditional religions. The *Guidance Manual for Department of Energy Compliance with the American Indian Religious Freedom Act* was prepared to provide guidance on implementing the policy established by the AIRFA. The manual contains specific information on (1) understanding the rights and concerns of native Americans, particularly with regard to federal energy projects; (2) accomplishing successful consultation with native Americans under AIRFA; and (3) integrating DOE implementation of AIRFA with the requirements of other environmental laws and regulations, particularly the National Environmental Policy Act. The five-step procedure developed by DOE for complying with the AIRFA is described.

Since many native American religious leaders are unwilling to discuss their religion with outsiders, consultation through intermediaries (e.g., tribal political leaders and/or private Indian organizations) is often needed to ensure that appropriate inputs are received from the religious leaders before DOE undertakes a project. Early consultation with potentially affected native American tribes and development of information on any sites of possible religious significance that may exist in the project area are essential to avoid delays in DOE project schedules. The guidance manual clearly indicates the type of information needed for DOE compliance with the AIRFA and outlines recommended procedures for determining and addressing native American religious concerns.

National Historic Preservation Act (F. E. Sharples and M. S. Salk)

The goal of historic preservation is to provide American citizens with an understanding and appreciation of their cultural origins and heritage. Historic preservation is directed towards fostering conditions under which our modern society and our prehistoric and historic resources can exist in productive harmony. Section 106 of the National Historic Preservation Act (NHPA) of 1966, as amended, requires federal agencies such as DOE to consider the effects of their activities on any historic property that is included in or is eligible for inclusion in the National Register of Historic Places. Section 110 of the NHPA provides additional guidance on agency responsibilities, particularly with regard to properties owned and controlled by federal agencies such as DOE.

The DOE is required to give the Advisory Council on Historic Preservation an opportunity to comment on the effects of DOE projects on historic properties. In conducting the process, DOE staff should seek professional advice and assistance from the State Historic Preservation Officer of the affected state, the National Park Service, the Advisory Council on Historic Preservation, and other professionals in appropriate fields of specialization.

The *Guidance Manual for Department of Energy Compliance with the National Historic Preservation Act* outlines the basic steps for DOE project staff to follow to meet the requirements of NHPA. It includes information on identifying and evaluating historic properties, determining the effects of a DOE action on a property, and consulting with the Advisory Council to define alternatives that would avoid or mitigate adverse effects. The means of coordinating these compliance activities with those required by the National Environmental Policy Act are discussed, and historic resources discovered during the construction period are considered.

Ocean Dumping of Low-Level Radioactive Waste (C. T. Hunsaker)

Ocean dumping is the seaward transport of land-generated wastes by ships, barges, platforms, or aircraft and the disposal of these wastes in the marine environment. Recent interest in dumping low-level radioactive waste (LLW) in the ocean as an option to land burial has arisen for several reasons: (1) possible economic advantage, (2) the U.S. Navy's need to dispose of decommissioned nuclear-powered submarines, (3) DOE's need to dispose of large amounts of slightly contaminated soils, and (4) state evaluations of waste disposal needs under the Low-Level Radioactive Waste Policy Act of 1980.

A literature review of ocean dumping of LLW evaluated U.S. laws, international agreements, experimental and monitoring data, and ongoing studies. An internal report to provide background information for use by DOE staff in reviewing environmental compliance activities on ocean dumping of these wastes was subsequently prepared.

Ocean dumping of LLW is allowed in waters of the United States and in international waters; a temporary moratorium, however, has been placed on such dumping. The Marine Protection, Research, and Sanctuaries Act is the major legislation governing transport, storage, and disposal of radioactive waste. The major international agreement on ocean dumping, which has been ratified by the United States, is the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter (London Dumping Convention). The Third United Nations Conference on the Law of the Sea reinforces previous international policy on ocean dumping and defines the geographic extent of a coastal country's rights and responsibilities. The United States ended ocean dumping of radioactive wastes in 1970, but other countries have continued such activities in the northeast Atlantic under international supervision.

Monitoring of former U.S. disposal sites has neither revealed significant effects on marine biota nor indicated a hazard to human health. These studies have shown that marine microorganisms and algae are less sensitive to ionizing radiation than animals. Teleost fish are the most sensitive aquatic organisms, showing adverse effects at chronic exposures of 1 rad (radiation dose absorbed)/d. At chronic levels of radiation, repair processes may be able to keep pace with injury, and density-dependent responses in organisms may have compensating effects for highly fecund species. Other monitoring activities have revealed no effects on marine organisms that could be attributed to routine discharges into the Irish Sea of on the order of 10^{13} Bq from the Windscale reprocessing plant in the United Kingdom.

If future ocean dumping is to be done safely, models of physical, chemical, and biological processes are the predictive tools that must be used to determine the fate and effect of ionizing radiation in the marine environment. Dosimetry models for marine organisms are adequate, but models of oceanic processes need to be improved. Human exposure models are dependent on the identification of all critical pathways from the deep ocean to man. Data from monitoring of present dumping sites and chronic-dose radiation studies on marine organisms are also needed. Although existing amounts of low-level radioactive waste in the ocean have not proven to be harmful, the ability to predict an oceanic carrying capacity needs to be perfected.

Regional Analysis

D. S. Shriner

Regional Analysis activities during this reporting period included (1) development of advanced integrated assessment methods for analysis of acidic precipitation policy options, (2) implementation of data coordination and data management activities for the Assessments and Policy Analysis Task Group of the National Acid Precipitation Assessment Program, and (3) development of methods for definition of biophysical regions influenced by operations of facilities of the United States Air Force.

These activities span a broad range of problems of regional and national scope, and provide ideal opportunities for continued development of the principle and concepts guiding regional analysis. Complex issues of a regional nature often require that temporal, spatial, and functional characteristics of geographic areas define the bounds of the region, depending on the definition of the individual problem. Major program sponsors during this reporting period included DOE (Office of Environmental Planning), EPA (Office of Research and Development), and the U.S. Air Force (Air Force Engineering and Services Center, Division of Environmental Planning, Protection, and Assessment). Highlights of two regional projects are presented in the following subsections.

Integrated Assessment Methods Development for Analysis of Acid Precipitation Issues (D. S. Shriner)

The acid deposition phenomenon and its potential effects on a broad range of receptors represent an unprecedented challenge for integration, synthesis, and assessment. Policy decisions affecting control technology will be made on the basis of benefit-cost analyses that must reflect the full benefits from the effects perspective. The need to assess the cost of nonaction, or the benefits of control options, will require the integration of data from a broad range of sources, time scales, and

spatial scales, frequently without a common denominator. Recognition of the complex mix of information required for such an assessment has led to the formation of an interdisciplinary team of atmospheric scientists, ecologists, economists, and policy analysts for the purpose of ensuring the effective integration of data and models from diverse sources for policy analysis. This team is coordinated through the National Laboratory Consortium (NLC). The NLC was established as a part of Title VII of the Energy Security Act of 1980, which established the National Acid Precipitation Assessment Program (NAPAP). Representatives from ORNL, Brookhaven National Laboratory (BNL), Argonne National Laboratory (ANL), and Pacific Northwest Laboratory (PNL) have been assigned to an Assessment Coordination Team (ACT). The conduct of the activities of this team is coordinated by ORNL. The ACT can mobilize special expertise from each laboratory in the several areas necessary for development of an integrated assessment methodology for acidic deposition, enabling the consortium to address in depth all aspects of an integrated assessment methodology.

Policy options in the form of control or mitigation scenarios can be imposed on the integration framework, with the opportunity to examine the potential consequences of the option at each step of the assessment process. Changes in emissions patterns can be evaluated as changes in deposition fields. Deposition fields, in turn, are linked to the geographic distribution of resources at risk. Dose-response relationships generated from field experimental data can be combined with resource inventories to provide estimates of change in resource inventory over relevant temporal and spatial scales. Integration of these modified resource inventories with economic models then provides primary input to the policy objectives of the assessment.

To accomplish this task, the ACT has drawn on its personnel who, for several years, have conducted research in all of the above-mentioned aspects of the acid precipitation problem to formulate a framework for integrated assessment. A series of working-group meetings served as the vehicle to expand, refine, and evaluate this framework and to develop an integrated assessment methodology. The first working group meeting consisted of individuals representing a broad understanding of acid deposition phenomena and assessment methodologies. This meeting developed a conceptual strategy and structural framework for all components of an integrated assessment methodology.

This structure was assembled by scientists already involved in relevant research and reflected their intimate experience with data needs, expected progress, and the form in which they expect to report results. Most importantly, the meeting allowed individual researchers the opportunity to better understand both the needs of other researchers and how each individual project fits into an overall assessment plan. The meeting also resulted in a set of detailed lists of data and models required by each generic category of analyses (e.g., atmospheric processes, deposition processes, impacts and effects, economics). The specifications for spatial and temporal scales of data and models were listed. This information set the stage for a second meeting to evaluate the proposed assessment framework.

The second working-group meeting refined the assessment methodology structure and evaluated it. Small task groups worked on specific components of the acid deposition phenomenon. One task group ensured that the pieces fit together. The initial assessment methodology was tested with the best data available. Where data were lacking, were of uncertain reliability, or had inappropriate temporal or spatial scales, our experts, in consultation with the research task groups, used their best judgment to select data sets to use in constructing and fitting the linkages of the methods strategy. A preliminary strategy for an integrated assessment methodology has been developed. It has been evaluated to demonstrate that it has the potential to lead to a usable assessment. This evaluation, of necessity, began with data from which the strategy was constructed. Independent

data were used where possible but, as in the method development, subjective data sets were also employed. The first-year objective was to evaluate the approach, not to produce an actual assessment.

The evaluation showed the Acid Deposition Assessment Staff (ADAS) of the National Acid Precipitation Assessment Program how this approach can be used to focus research to produce useful results, to determine which NAPAP components may fail or lag because of technical considerations (e.g., unavailable input data, unresolvable conflicts in spatial or temporal scales, unavailable models, etc.), to show which elements require redirection, and to determine what new programs are necessary to fill identified gaps in the current NAPAP research program.

The results of the methodology evaluation at the end of the first year defined the scope of the revisions and refinements to the method that will be incorporated during the second year. The framework, once successfully tested during the second and third years of the project, will be applied to the 1987 and 1989 NAPAP Integrated Assessments mandated by Congress in the legislation establishing the NAPAP.

Data Coordination and Data Base Administration for Acid Deposition Assessment (R. J. Olson)

To support integrated assessment, the Acid Deposition Assessment Staff (ADAS) of NAPAP has initiated a data coordination activity to help ensure the timely exchange of accurate, usable data between components of NAPAP and between NAPAP and other data sources. This effort provides an efficient mechanism to establish the necessary flow of data and to promote consistency of data. A data coordinator works with NAPAP task groups to identify data needs and priorities, locate data sources, develop data exchange conventions, and initiate and monitor data exchange activities. Those common data files needed by several projects are emphasized by the data coordination function to ensure consistency. Responsibility for this data coordination lies within the Regional Analysis group.

The formal mechanism for both describing data needs and listing available files consists of submitting a written description of either needs or available material. These and other sources (project descriptions, assessment frameworks, etc.) will be used to compile and update an inventory of data files for distribution to all task groups. The data coordination activity is not designed to completely substitute for individuals searching for and acquiring new data, but rather, the data coordinator is available to aid such searches and should be informed of new data as they are acquired.

Two levels of data coordination are being established. The first level defines the substantive contents of the needed and available data; these include variables to be measured, geographic and temporal coverage, minimum level of disaggregation, QA procedures, etc. The second level defines data access techniques and possible transfer formats.

The ADAS has the responsibility of determining what data are needed by the Assessments and Policy Analysis Task Group of NAPAP to carry out integrated assessments. These specifications are being developed as a cooperative effort between the ADAS staff and researchers responsible for the generation of the data. Focal points within each task group are responsible for identifying pertinent projects within their groups and establishing the dialogue between the principal investigators and the ADAS staff.

The second phase of data coordination activity is addressing the design and implementation of the data management support facilities needed to provide data access and to carry out integrated assessments. The design of the data management support facilities addresses the need to store, retrieve, analyze, and display data gathered by different projects at a common level of aggregation

and using the same spatial and temporal scales. By incorporating these activities within the framework of the data coordination activity, individual task groups have the option of sharing resources and expertise needed by, but not uniformly available within, task group research efforts.

An Acid Deposition Data Network (ADDNET) has been established at ORNL to serve as a repository for selected data files. This activity, in concert with the data coordination activities, will store, document, and provide access to data. Access will be either on-line to the ADDNET or by providing data tapes to individual users. Some data may be utilized by a single investigator and other data may undergo aggregation before utilization by others, but the need to centralize all data within NAPAP is not envisioned. Instead, selected data will be entered into the ADDNET, and data paths to other sources of data will be established.

This large data coordination activity for a major national program has developed from a direct need for (and recognition of the importance of) large-scale geographic data resources such as the ORNL Geoecology Data Base (GDB). The principles and concepts established in the pioneering phases of the GDB have served as a model for this new generation of geographic data management systems. The staff of the Environmental Sciences Division, operating in coordination with fellow scientists from the member laboratories of the NLC, have provided timely support to the NAPAP during a phase of planning and rapid program growth. Both the data coordination management and the integrated assessment activities are expected to involve continuing support from the various national laboratories throughout the course of the remainder of the 10-year NAPAP program.

Environmental Impact Assessments

J. F. McBrayer

Environmental impact assessment has been a major activity of the Environmental Sciences Division since passage of the National Environmental Policy Act in 1969. Our mission has been to evaluate the effects of construction and subsequent operation of facilities for mining and upgrading fuels, energy storage, electric power generation, energy distribution, and waste disposal, and to advance the science of impact assessment. The group recently was presented with a new opportunity with the first decommissioning of a licensed nuclear facility. The impacts of decommissioning the Edgemont uranium mill and mill tailings are described below (V. R. Tolbert and L. D. Voorhees). We also were able to reevaluate a group of geothermal energy projects for which we previously had assessed impacts. This provided us with the opportunity to confirm our predictions and to identify any discrepancies in impact occurrence or mitigation implementation (J. W. Webb, G. K. Eddleman, and A. W. Reed).

Decommissioning of a Uranium Mill (V. R. Tolbert and L. D. Voorhees)

Over the past 13 years, the staff of the Environmental Analyses Section has evaluated applications and written numerous environmental impact statements or appraisals for the U.S. Nuclear Regulatory Commission (NRC) for all aspects of the uranium fuel cycle. These projects have included analyses of uranium mines, mills, fuel fabrication facilities, and nuclear power plants. Because of the long time required for construction and the long operating lives of these facilities, usually more than 30 years, the environmental reports prepared by the applicant and the environmental statements prepared by the staff focus primarily on construction- and operation-related impacts with only a general treatment of decommissioning. At the inception of a project, this is a reasonable approach because of several factors. There is little information available and there is no

experience with decommissioning of nuclear-related facilities to ensure long-term containment and stability of the decommissioning site. Development of methods of containment and stabilization are still in their infancy. The relatively young age of the nuclear industry has minimized the need to seriously address decommissioning.

The decommissioning of the Edgemont Silverking Uranium Mill in South Dakota is the first decommissioning to occur as a major federal action under requirements set by NRC in the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978. The decommissioning of the Edgemont mill tailings and mill facilities, removal of contaminated soil beneath the tailings piles and ponds, and removal of windblown tailings will serve as a prototype for future decommissionings of the more than 20 inactive uranium processing facilities that will be decommissioned under the Uranium Mill Tailings Remedial Action Program, and for decommissioning of aged nuclear power facilities.

Several major environmental issues were identified in the evaluation of plans for decommissioning the Edgemont Uranium Mill. Removal of the tailings to an isolated location rather than stabilization at their present site was determined to be the best alternative for long-term isolation and stabilization of the tailings. This alternative, over the short term, may increase windborne and erosional transport of contaminated materials, but control measures for dust and runoff and use of the best-available technologies for excavation and removal of the tailings will minimize short-term effects during decommissioning. The Edgemont Uranium Mill is located along the junction of Cottonwood Creek and the Cheyenne River adjacent to the town of Edgemont, South Dakota. Removal of the tailings from their present site to an isolated location fulfills the requirements of UMTRCA to make every reasonable effort to provide for disposal in an environmentally safe manner which would minimize or prevent radon diffusion and exposure to the human population.

Removal of the uranium mill and tailings to an isolated area will, in the long term, also remove the source of groundwater and surface-water contamination in the vicinity of the mill site. The continued leaching and leakage of uranium products and heavy metals into groundwater beneath the site and transport of these materials and eroded tailings into the Cheyenne River have been a major problem associated with the mill site.

Decommissioning of the mill site will involve removal of contaminated materials on-site, as well as windblown tailings from an area east of the mill site, and from the Cottonwood community to the southeast of the mill site. The major terrestrial effects associated with the decommissioning were determined to be the continued airborne transport of contaminated materials, windborne transport during decommissioning, and the establishment of an adequate vegetation cover over the disposal area after the decommissioning to ensure minimization of erosion and long-term stabilization.

The Edgemont decommissioning involves removal of approximately 2.1×10^9 kg of tailings and an undetermined amount of contaminated soil from the Edgemont mill site to a 100-ha disposal area 3 km from the site. The disposal area will consist of an earthen dam constructed across the lower end of a natural watercourse with runoff being routed around the site via permanent channels constructed to minimize erosion. The tailings will be contained behind the dam both below and above present ground level and covered with sufficient material to minimize root or burrowing-animal penetration into the tailings. The cover over the disposal site is also designed to reduce gamma radiation to background levels and radon exhalation to about twice that of background.

The tailings disposal area will be reclaimed with topsoil and native vegetation following the decommissioning. Voorhees et al. (1983) report that in arid and semiarid regions soil covers on slopes greater than 3 to 5° are not likely to persist over the long term and that rock covers should

be used. Because of the semiarid nature of the region, revegetation success and erosion of the cover material are major areas where monitoring will provide valuable evaluations of ongoing decommissioning.

The Edgemont decommissioning will provide the opportunity for evaluation of the containment and stabilization methods used for long-term isolation of the tailings and equipment and long-term attenuation of ^{222}Ra. Radon-222, a decay product of ^{239}Th, which has a half-life of 80,000 years, is a known carcinogen. UMTRCA requires that every reasonable effort be made to stabilize and control the disposal of the tailings in an environmentally safe manner and in areas remote from human populations.

Monitoring of the disposal area to ensure its integrity will also provide the opportunity to evaluate the stability and isolation of partial above-ground storage of the uranium contaminated materials, the near-term stability of the bentonite clay cover material, and isolation of the contaminated material from groundwater beneath the disposal site. The decommissioning and associated monitoring program for the Edgemont mill site will provide experience and guidance that can be used to facilitate future decommissionings of inactive uranium mill sites, fuel fabrication facilities, and nuclear power plants.

Retrospective Examination of Geothermal Environmental Assessments (J. W. Webb, G. K. Eddlemon, and A. W. Reed)

In 1976, the U.S. Energy Research and Development Administration Division of Geothermal Energy [now the Geothermal and Hydropower Technologies Division (GHTD) in DOE] established a number of programs intended to encourage the exploration, development, and use of geothermal energy. The programs focused on (1) various forms of geothermal energy (hydrothermal, hot dry rock, and geopressured geothermal); (2) geothermal exploratory drilling, and (3) geothermal loan guaranties to assist commercial development. In conjunction with these programs and their associated projects, a series of programmatic and site- or area-specific environmental documents were prepared to ensure protection of the environment and to satisfy the requirements of the National Environmental Policy Act (NEPA). The documents were either prepared or reviewed by the technical staff at ORNL and represent more than 6 years of experience by GHTD and ORNL in dealing with environmental concerns related to geothermal energy.

Because of this experience, a need arose to synthesize and assess the NEPA environmental analyses (EAs) and the subsequently implemented monitoring and mitigation. Such an effort is essential to verify the effectiveness of NEPA actions and, to our knowledge, is the only such review of NEPA activities. It would also provide a comprehensive perspective on environmental concerns to assist in future programmatic planning and technology transfer to both the public and private sectors. The work was conducted in three phases. In Phase I, the existing environmental analyses were reviewed for predicted environmental impacts and recommended mitigation and monitoring. The documents covered projects located in seven western states, two south-central states, and the eastern piedmont and coastal plain region, providing broad representative geographical coverage of geothermal resources in the United States. Phase II entailed an update on the status of currently active, site-specific projects obtained by consultation with DOE staff in GHTD in Washington, D.C., in the DOE San Francisco Operations Office, and with managers for operating contractors of geopressure wells. In Phase III, 48 individuals in federal, state, and local government and in industry were contacted by telephone to determine actual impacts and mitigation measures for existing projects. Based on the results of the study, a summary outline of environmental concerns was also designed.

In general, environmental analyses of geothermal projects portrayed potential impacts as relatively benign in comparison with most other energy-producing technologies. Fewer impacts were predicted and, when present, their consequences were usually not expected to be serious. In many cases, impacts could be substantially mitigated by appropriate siting, design of facilities, and use of appropriate control technologies.

Among the potential impacts most frequently cited, and hence judged most likely to occur, were air pollution (particularly hydrogen sulfide), high noise levels, increased erosion and sedimentation, and use of land for geothermal development. Impacts with a moderate probability of occurrence included subsidence, water pollution and consumption, local increases in fogging or icing, and habitat disturbance. Impacts considered unlikely to occur included seismicity, well blowouts, and cultural and socioeconomic effects.

The severity of impacts, should they occur, was seen as high for hydrogen sulfide odor, water consumption, and sometimes for water pollution. The severity of seismicity, blowouts, and cultural or socioeconomic effects was generally highly situation-dependent and could not be easily predicted. The effects of blowouts, for example, would depend on brine chemistry, site and area ecology, and the magnitude and duration of the accident.

Mitigation measures were recommended for most of the impacts, including proper siting, good construction practices, sound plant design, and control technologies. Proper site selection could avoid or lessen disturbance of natural habitats, conflicts with cultural and archeological values, and the potential for water pollution. Proper siting could also lessen the severity of consequences for air pollution, noise, water pollution, and use of land. Good construction practices could minimize minor air pollution from equipment use and limit erosion and sedimentation. Plant and well-field design could limit land use (e.g., by clustering wells) and pollution probabilities (e.g., by use of sumps). Control technologies are available for reduction of air pollution (including hydrogen sulfide and cooling-tower drift), noise, and prevention of blowouts. The technology for reinjecting spent geothermal fluids, available from the oil and gas industry, was refined and applied to geothermal brines. Reinjection greatly lessened concern over waste disposal as a major impact, and reduced the probability and degree of subsidence.

Two general conclusions emerged from the Phase III survey of environmental impacts of existing DOE geothermal projects: confirmation of the generally minor nature of impacts; and demonstration of the importance of environmental analyses, early environmental planning, and the comprehensive use of mitigation measures.

The only detected impacts that were not anticipated to some degree in the project EAs were the use of four drill sites, instead of the one planned, and the drawdown of area wells at Boise, Idaho. The only detected discrepancies between recommended and implemented mitigation that may have caused problems involved inadequate attention to storage pit liners at a well in Louisiana; other discrepancies either proved insignificant or adequate substitutes were found. In general, the EAs appeared suitably conservative and reasonably accurate in assessing the nature and severity of impacts.

The survey revealed a number of mitigation measures that have been implemented at projects, with consequent reductions in environmental impacts. Frequently encountered areas for mitigation included noise reduction, cooling-tower drift eliminators, groundwater and surface-water monitoring, seismicity and subsidence monitoring, fugitive dust reduction, erosion and sedimentation reduction, blowout prevention, and spill and waste retention. The importance of these and other methods to maintaining the relatively benign nature of geothermal energy cannot be overemphasized.

Two provisos must accompany the above conclusions. First, a limited number of projects, with short or no operating history, were available for verification. Second, many impacts such as the probability and effects of blowouts involve substantial unknowns and were predicted in a generic manner. It is clear, however, that early analysis of environmental problems, although uncertain, and subsequent planning for appropriate mitigation or monitoring, can contribute substantially to avoidance of environmental degradation. Moreover, as geothermal development proceeds, consideration of the cumulative impacts of additional projects will become increasingly critical.

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4. TERRESTRIAL ECOLOGY

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Introduction

The Terrestrial Ecology Section is involved in basic and applied environmental research to support energy technology development and in gaining a better understanding of the structure and function of terrestrial ecosystems. The Section is organized around three basic areas of research: ecosystem dynamics, physiological ecology, and biogeochemical cycling. Major emphasis is on advancing ecosystem theory, particularly in forest systems; evaluating the ecological effects of air pollution on agricultural and natural systems; and evaluating site-specific and global cycles of major nutrient elements. Staff members are assigned to major division programs (biomass and carbon cycling) and to other research divisions at Oak Ridge National Laboratory (ORNL), and we make use of other division staff members in terrestrial activities. Our basic research program is designed to ensure continued development of expertise in disciplinary areas of terrestrial ecology. We are currently interacting with numerous outside institutions including the Tennessee Valley Authority (TVA), universities, sister national laboratories, and the National Park Service (NPS) within the U.S. Department of the Interior. Research is supported by the U.S. Department of Energy (DOE), 6%; the National Science Foundation (NSF), 21%; the Electric Power Research Institute (EPRI), 7%; and the Environmental Protection Agency (EPA), 11%. Activities also include subcontracting approximately 15% of our total research budget to universities. In the following paragraphs, we

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highlight recent activities in ecosystem analysis, plant response to air pollutants, and elemental cycling studies.

Research activities in ecosystem analysis continue to address development of mechanistic explanations for ecosystem behavior through the use of aggregation of component behavior into higher-level dynamics and examination of hierarchy theory. Additional studies in this area are concerned with evaluating relationships between animal abundance patterns and successional dynamics of forest landscape. The Oak Ridge National Environmental Research Park (NERP) serves as a unique resource for field testing these theoretical constructs in system ecology and is currently being used to a greater extent as an educational facility for regional institutions.

Air pollution studies continue to focus on acid rain and the interactions among major oxidants and environmental factors. Considerable effort deals with evaluation of the underlying physiological mechanisms that govern plant response to stress. Current field studies are concerned with determining crop response to acid rain with and without exposure to ambient air oxidants. In other work, influences of temperature and humidity are being evaluated in terms of plant response to SO_2 and O_3. In a new initiative, tree rings collected from the Great Smoky Mountains National Park are being analyzed for trace element content, including Al, Cd, Cu, and Zn, in an attempt to evaluate air pollution input to forest systems from industrial sources.

Biogeochemical cycling activities encompass ion mobility in soils, food chain transport of radionuclides in both laboratory and field experiments, and evaluation of forest response to increase CO_2 concentrations in the atmosphere. Ion mobility in soils under the influence of acidic precipitation suggests that natural sources of acidity are of the same order of magnitude as those from atmospheric deposition, and the latter may have little effect on overall soil acidity in East Tennessee forest soils. Technetium as ^{95m}Tc is being studied intensively in food chain studies involving small mammals and fescue-goat-milk systems. Increased CO_2 in the atmosphere leading to a warming of global temperature may have significant secondary effects on forest systems. Current studies are considering the magnitude of possible vegetation shifts in both spatial scale and species composition.

Advances in Ecosystem Theory

R. V. O'Neill R. H. Gardner

For a decade, researchers have sought mechanistic explanations by dividing ecosystems into components that are then investigated in detail. However, the attempt to reassemble ecosystem dynamics from these process studies has met with limited success. This problem has motivated two lines of research: the search for methods to aggregate component behavior into higher-level dynamics and an examination of "hierarchy theory" as a potential new paradigm for ecosystem analysis.

Aggregation studies have examined the errors introduced when several components are lumped into a single state variable. For mass-balance models, only two conditions permit aggregation without error. Components can be lumped if their environmental losses (e.g., respiration or migration) are characterized by identical linear functions. Under the second condition, the components must maintain constant proportionality throughout their transient behavior.

The theoretical results are applicable to nonlinear models of considerable complexity but are of marginal interest to field ecologists. Therefore, we developed a set of criteria that could be applied when the underlying model is unknown. The approach was to examine 40 alternative models and to state conclusions that were valid, no matter what the underlying dynamics. The studies indicated that error can often be minimized even though stringent theoretical conditions are violated. Thus,

except for serial components (e.g., members of the same food chain), components can ordinarily be aggregated with <10% error, even if the turnover rates differ by a factor of 3.

When measurement errors are considered, the criteria depend on the ability to measure parameters. In aquatic ecosystems, changes in water chemistry can sometimes be used to estimate total productivity more accurately than one can estimate productivity of the individual phytoplankton populations. In such cases, an aggregated model may have less error than its disaggregated version.

Explorations into hierarchy theory have involved new paradigms for examining ecosystems. When the system is viewed from other hierarchical perspectives, new insights can result. For example, on small time-space scales, populations may appear as relatively stable systems that resist or react to changes in the environment. Attention focuses on the negative feedback controls that permit the system to return to its previous state following perturbation. At the global scale, the environment appears as constantly changing, and the biotic system is seen to move continuously to new states appropriate to the changed condition. The system does not appear to be finely tuned by internal negative feedbacks and seems more like a set of positive feedbacks, prevented from rapid change by boundary conditions or constraints.

This new perspective permits one to clarify the problem of saltatorial evolution. Under current theory, greatly increased mutation rates or radical environmental changes are required to explain rapid evolution of higher taxonomic forms. However, if the system is a positive feedback system held in check by a system of constraints, then saltatorial evolution is easily explained. At the point of rapid change, some biological or environmental constraint is broken. Then accumulated genotypic potential can be expressed, and rapid expansion occurs until some new constraint is reached.

The fossil record contains many examples that fit this scenario. For example, a small biochemical change permitted the diatoms to develop a silicon shell that freed them from the constraint of predation and resulted in a spectacular radiation. The radiation continued until dissolved silica became depleted. At this point a new constraint was met and the radiation slowed dramatically. Thus, the new perspective permits a simple explanation of a phenomenon that was problematic under current ecological theory.

Other explorations in hierarchy theory considered methods for explaining phenomena at one hierarchical level (e.g., ecosystem) by mechanisms observed at another level (e.g., population). The approach requires that the phenomenon be observable at both levels by a change in the temporal or spatial extent of the observation set without changing observation criteria. Thus, one can relate the death of individuals to the death rate of a population by observing deaths over a sufficiently long time. On the other hand, a criterion for ecosystem stability (e.g., constant productivity over time) may be quite different from a criterion for population stability (e.g., relatively constant numbers over time). With such a change of criteria, there may be little possibility of explaining phenomena on one level by changes in another level.

Consequences of Habitat Selection for Mosaic Elements on Animal Communities

H. H. Shugart S. W. Seagle

Recent work supported by the NSF Systems Ecology Project inspects the relationships between animal abundance patterns and the successional dynamics of landscapes. The response of an animal population to a dynamically changing vegetative mosaic is strongly related to the rate of increase of the animal population with respect to both the rate of change and the frequency of disturbance of the landscape mosaic. If these landscape dynamics are slow with respect to the dynamics of the

population, then the animal population response is mostly manifested in the birth and death rates of the population. In this case, factors such as the availability of resources or space in suitable habitat are relatively constant factors, and the traditional modeling approaches of population dynamics (namely, autonomous nonlinear differential equations) can be used to project the expected population response. When the population processes are relatively fast relative to the population dynamics, one would analogously expect the population dynamics to be dominated by the dynamics of the landscape processes. It is this latter case that will be treated here.

In a landscape that behaves as a shifting mosaic of habitats, apparently several important relationships in community ecology, in particular, the species-area curve, can arise as a consequence of relatively simple models. A Markov model was used to simulate the patch dynamics of vegetation of islands of different sizes. Ten habitat types were recognized in this Markov model. The transition probabilities were calculated as the reciprocal of the successional time between these habitat types. The resultant 10 by 10 matrix was implemented as a first-order Markov process. For each patch on a simulated island, the age of the patch was classified as a given habitat type. The landscape area of the island was assumed to be the number of patches in a particular simulation. For each simulation, the starting conditions were the number of patches in proportion to the equilibrium implied by the underlying Markov matrix. At equilibrium, the landscape simulated by the model has all habitat types represented to some degree due to the inclusion of these disturbances.

To simulate the colonization of these island landscapes by animals, a pool of 150 hypothetical species was generated from uniform statistical distributions of different species-level attributes. These characteristics included:

1. The range of habitats utilized by each species.
2. The range of habitat ages utilized by each species.
3. The intrinsic rate of increase of each species.
4. The number of habitat patches needed to support an individual of a given species.
5. For cases in which a species competed with another, the species-specific efficiency of utilizing patches that overlapped in their potential occupancy (due to 1 and 2, above) with other species was used to determine the competition coefficient.

When this model was applied to cases with or without competition among the animals for landscapes of different sizes, a species-area curve with an appropriate shape relative to similar curves found in nature was obtained. Further, there was no difference in the basic shapes of the curves of the competition and the no-competition cases. It was considered appropriate to compare the results of the model with other mathematical attributes of species abundance curves drawn from islands of different sizes.

The model, $S = cA^z$, where S is the number of species, A is the area of an island, and c and z are model parameters, has been used to describe the relationship between the size and the diversity of an island. There is considerable debate on the interpretability of the parameter z, but its value has consistently been reported from empirical studies to be in the range of 0.20 to 0.35. Values computed for the species-area curve with the ORNL model are 0.284 and are in the center of this range.

National Environmental Research Park Study Center

P. D. Parr J. T. Kitchings J. D. Story

The Oak Ridge National Environmental Research Park (NERP) is comprised of 5500 ha of federally owned land. The NERP was established under the policy of the DOE to provide protected

land areas for research and education in the environmental sciences and to demonstrate the environmental compatibility of energy technology developments.

In the past, the opportunity for research on the NERP had been limited mainly to university scientists and students. With the NERP Study Center, however, the full potential of the research park as a public demonstration area, as outlined in the NERP charter, is beginning to be realized for other age groups. The array of ecological and environmental programs undertaken by the laboratory scientific staff, and the variety of ecological systems contained within the NERP area, provide an excellent opportunity to contribute to the environmental education of young people in the surrounding school systems.

The NERP Study Center program will provide outdoor experiences that can complement classroom presentations. The Study Center's activities will be geared to accommodate elementary, junior, and high school students. A variety of topics will be available and will require a 1- or 2-d field activity period. The proposed programs will emphasize a "hands-on" approach to learning about ecological relationships (i.e., food chains, habitat needs, nutrient cycles). Working with introductory ecology text provided by the NERP for background information, the teachers will lay the groundwork for field learning activities that will then serve as an extension of the classroom lessons.

Four study units have been prepared: resource allocation (niche) in a small mammal community, faunal and floral succession in fallen logs, environmental factors affecting plant distribution, and ecology of streams.

After actually experiencing the techniques and theory used in understanding ecological relationships, the students will have a better grasp of the problems and will have acquired the tools to apply to environmental problem-solving as it affects their everyday activities.

Physiological Responses of Soybeans to Simulated Acid Rain and Gaseous Air Pollutants

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R. J. Luxmoore A. E. Hunley
D. S. Shriner

Field experiments on the effects of acid rain on agronomic plants at several locations in the eastern United States have yielded inconsistent results. To understand those results and to predict from them the responses of crop plants under different climatic and edaphic conditions, a physiological basis of the rain-vegetation interaction must be established. In greenhouse and field experiments sponsored by EPRI, we have attempted to describe the physiological responses of soybeans (*Glycine max* cv. Davis) exposed to a combination of simulated acid rain and gaseous air pollutants.

Greenhouse-grown soybean plants were exposed continuously (644 h) to charcoal-filtered or polluted air (0.1 ppm SO_2 plus 0.05 ppm O_3) in fumigation chambers. Twice each week for 3 weeks, plants were removed from the chambers and exposed to 1.1 cm of simulated rain with pH 3.4, 4.2, or 5.0. Rain simulants contained ionic species typical of rain in the eastern United States plus H_2SO_4 and HNO_3 in a 1.5:1 molar ratio.

Daily photosynthetic rates were calculated from fumigation chamber influx and efflux concentrations, air flow rate, and estimated leaf area. After 3 weeks, foliar chlorophyll content was measured; following this, shoots were excised and acetylene reduction rates (an assay for biological nitrogen fixation) of intact root systems were measured. Leaf area and dry weights of roots, shoots, and abscised leaves were determined.

There were no visible symptoms of air pollution injury, and possible acid rain injury at pH 3.4 comprised <1% of leaf area. Exposure to SO_2 and O_3 inhibited photosynthesis, chlorophyll content, acetylene reduction, and vegetative growth. Reduced shoot growth in plants exposed to gaseous pollutants was due primarily to 34% greater leaf abscission in these plants. Acetylene reduction rates were 24% lower in fumigated plants.

There was no evidence of an inhibitory effect of acid rain on physiological processes in soybeans, in agreement with our previous growth analysis study. When there were effects of rain chemistry, growth and process rates were greatest at pH 3.4. Shoot growth and chlorophyll content were significantly greater at pH 3.4 than at higher pH. The acetylene reduction rate in fumigated plants was greatest at pH 3.4 but was not affected by pH in unfumigated plants. There was also a strong enhancement of photosynthesis in fumigated plants during the first 2 weeks of exposure to pH 3.4 rain. Rain effects on photosynthesis in unfumigated plants were small.

Greenhouse and controlled-environment experiments on acid rain can help us understand mechanisms of response and aid in the interpretation of yield responses of plants in the field. Ultimately, however, physiological responses must be demonstrated in the field. We measured the acetylene reduction rate of excised soybean nodules as a possible indicator of physiological changes in field-grown soybeans exposed to simulated acid rain and ambient gaseous pollutants.

Davis soybeans were grown at the acid precipitation field experimental facility on the Oak Ridge Reservation. Plots in open-top chambers received ambient (polluted) air or charcoal-filtered air. During natural rain events, covers were automatically moved to exclude ambient rain from the plots, and an equivalent volume of simulated rain of pH 3.2, 4.2, or 5.2 was provided. Acetylene reduction assays were conducted after plants had begun to form pods. Three plants from each plot were excavated and nodules were removed for the assay, which was done in 50-mL test tubes with 0.1-atm acetylene. Results were expressed as nmoles ethylene produced per milligram dry nodule per hour.

Acetylene reduction rates were 10% lower in ambient air than in charcoal-filtered air, indicating an inhibitory effect of gaseous air pollutants, as in the greenhouse study. There was also a significant effect of rain chemistry, and the response was bimodal. The acetylene reduction rate was lower at pH 4.2 (the approximate pH of ambient rain in Oak Ridge) than at pH 5.2 or 3.2. Such a bimodal response, which has been observed before as a response of plants to acid rain, suggests that nitrogenase activity may be differentially affected by components of the rain solution.

These results do not necessarily indicate a change in the nitrogen economy of the soybeans, because whole-plant nitrogen fixation is also related to nodule number. The acetylene reduction rate is, however, directly related to nitrogenase activity, which is dependent on plant metabolism and should reflect differences in photosynthesis or carbon allocation, for example. Hence, these results may serve as a physiological indicator of a response to rain chemistry in field-grown soybeans. More data will be required to explain fully the response and to evaluate its importance to plant growth and productivity.

Influence of Environmental Factors on Plant Response to Atmospheric Pollutants

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S. B. McLaughlin W. J. Selvidge

The environment can significantly influence the interaction between atmospheric gaseous pollutants and terrestrial vegetation. As edaphic and climatic conditions vary spatially or temporally, both the rate of pollutant uptake by foliage and the susceptibility of the plant's metabolism to toxic

pollutant derivatives change. Consequently, the effect on plant productivity of atmospheric pollutants will differ among regions of the country. Initial studies have demonstrated that both relative humidity and air temperature are climatic factors that significantly influence plant response to SO_2 and O_3. It is important to establish the applicability of these results to a range of vegetation types and other trace pollutant gases.

The influence of a 7°C range of air temperature (28 to 35°C) on plant response to SO_2 was investigated in both herbaceous (corn, *Zea mays)* and woody (tulip poplar, *Liriodendron tulipifera*; and green ash, *Frazinus pennsylvanica*) species, which were selected because of their dissimilar growth habits (annual/perennial), carbon metabolism (C_3/C_4 assimilation), and temperature tolerance range. The indices of plant response were changes in net photosynthesis and whole-plant water-use efficiency. The physiological basis of differences in plant response, either as a function of temperature or plant species, was evaluated through the determination of SO_2 uptake by foliage. The most consistent effect of raising the air temperature from 20 to 35°C during exposure to SO_2 was to increase foliar sulfur content in all species by 20 to 50%. The mechanism underlying this temperature-dependent response in pollutant uptake was a change in both stomatal and internal (i.e., residual) resistance to SO_2 diffusion. Even though pollutant uptake increased with temperature in all three species, the extent of injury did not necessarily follow the same pattern. Exposure to SO_2 at the higher temperature resulted in a greater decline in photosynthesis and water-use efficiency in both woody species, but less injury was recorded in *Z. mays*. Thus, the pattern of SO_2-induced injury as a function of temperature was not consistent among all species. The variability among plant species in their temperature-dependent response to SO_2 indicates that estimates of pollutant effects cannot assume greater injury at higher temperatures.

In *Phaseolus vulgaris* exposed to SO_2, an increase in relative humidity from 35 to 70% resulted in a two- to threefold increase in pollutant uptake and substantially more inhibition of photosynthesis. The comparability of these results for other trace pollutant gases was investigated in *Glycine max* (soybean) using two humidity regimes (40 vs 75%). Plants were exposed to 250 $\mu mol/m^3$ of carbonyl sulfide, (COS), H_2S, or SO_2 for 6 h/d for 2 d, during which net photosynthesis was monitored. After the 2-d exposure to SO_2, the net reduction in photosynthesis resulting from SO_2 exposure at high humidity (1116 mg CO_2 m^{-2} h^{-1}) was nearly 7 times more than the reduction in comparably exposed plants at low humidity (164 mg CO_2 m^{-2} h^{-1}). Thus, the pattern of enhanced injury from SO_2 at high humidity in *G. max* is similar to that observed in *P. vulgaris*. For the remaining two trace gases, the reduction in photosynthesis at high humidity exceeded that at low humidity by more than 40% (Table 4.1). Thus, the modifying role of relative humidity in

Table 4.1. Mean reduction in net photosynthetic rates (control treatment) of *G. max* exposed to each gas individually for two consecutive days at either high (70%) or low (40%) humidity

Relative humidity regime (%)	Reduction in photosynthetic rate (mg CO_2 m^{-2} h^{-1})		
	COS[a]	H_2S	SO_2
40	220	349	164
70	315	510	1114

[a]Carbonyl sulfide.

governing plant response to SO_2 is confirmed in a second species, and the pattern is consistent for at least two other trace pollutant gases.

Multielemental Analysis of Tree Rings as an Indicator of Historical Exposure to Air Pollutants

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In addition to providing data on historical growth rates of forest trees, tree rings may also serve as chronicles of historical exposure of trees to air pollutants. Concentrations of lead, cadmium, and other metal in tree rings have been related to contamination of the environment by smelters and other industrial point sources of pollution. In addition, line sources such as traffic corridors have produced patterns of lead accumulation in tree rings that can be related to the historical levels of traffic activity. The possibility of using chemical analysis of tree rings to reconstruct a historical sequence of exposure of forests to a variety of fossil-fuel-derived trace elements is intriguing, because it may supply evidence of patterns of historical change that conventional, recently initiated air quality monitoring networks cannot provide. Such information is essential in ongoing efforts to determine temporal and spatial relationships between forest growth and atmospheric pollution. During the past 2 years, a series of studies has been initiated to develop and test protocols for chemical analysis of tree rings for detecting trends in regional scale environmental pollution. The specific objectives of these studies were to (1) examine the elemental composition of tree rings exposed to local and regional anthropogenic pollution sources, and determine whether changes from increased coal combustion in East Tennessee could be observed in temporal patterns of trace metals in tree rings; (2) determine when such increases began; (3) identify which metals are suitable indicators of changes in air pollution; (4) ascertain whether temporal patterns are reflective of local or regional source terms or influences of postdepositional processes such as across-ring translocation; and (5) determine levels of accumulation of potentially toxic trace elements in physiologically active tissues such as the cambium and phloem.

Most of the work to date has concentrated on shortleaf pine, because this species shows both sharply decreasing growth rates during the past 20 to 25 years in East Tennessee and strong patterns of change in several trace elements over this period. Tissues were collected from the stem using a 12-mm increment corer followed by measurement and separation of successive 5-year growth segments. Analysis was by inductively coupled plasma emission spectroscopy of 0.1 N HNO_3 solutions containing ashed tissue segments.

Results to date have shown steadily increasing concentrations of Al, Cd, Cu, Fe, Mn, Mo, Ti, and Zn in shortleaf pine growth rings over the past 20 to 25 years. In part, these increasing concentrations have resulted from recent declines in tree growth rate, but when corrected for variations in growth rate, annual accumulations of many of these metals in xylem tissue have increased in recent years. The largest concentration increases with time were observed in rings from trees downwind of the 1200-MW(e) generating Kingston steam plant, which burns 4×10^9 kg coal per year. Trace metal concentrations in cambial tissues were as high as ten times those in the most recently formed xylem, and concentrations of Al, Cd, Mn, and Zn are near levels that have been associated with toxic effects when found in aboveground tissues of herbaceous plants. In trees sampled in the Great Smoky Mountains National Park (GSMNP), there was a period of suppressed growth between 1863 and 1912. During this period and 88 km upwind, smelting of iron and copper sulfide ores was occurring at the Copper Basin (Copperhill) near Ducktown, Tennessee. Associated with this smelt-

ing were large uncontrolled releases of SO_2 that contributed to the destruction of all vegetation within approximately 20 km of the Copper Basin. In addition to the patterns of growth suppression, there was an increase in iron accumulation observed in the GSMNP trees. This increase in iron (Fig. 4.1) corresponds remarkably well to the initiation of smelting operations in 1854, maximum uncontrolled SO_2 emissions in 1895, and the reduction in SO_2 emissions mandated by the U.S. Supreme Court in 1908. This historical pattern and the widespread occurrence of similar patterns of growth suppression and increased iron concentrations in tree rings since the late 1950s provide strong inferential evidence of tree response to atmospheric deposition. Additionally, the recent increases of trace metals other than iron in tree rings (not observed during the Copperhill era in the GSMNP trees) may reflect increased environmental availability from emissions of these metals from fossil fuel combustion and other sources. Both increased deposition to foliage and soil, as well as acid-rain-induced mobilization of available soil pools, are considered as possible sources of these increased tissue levels.

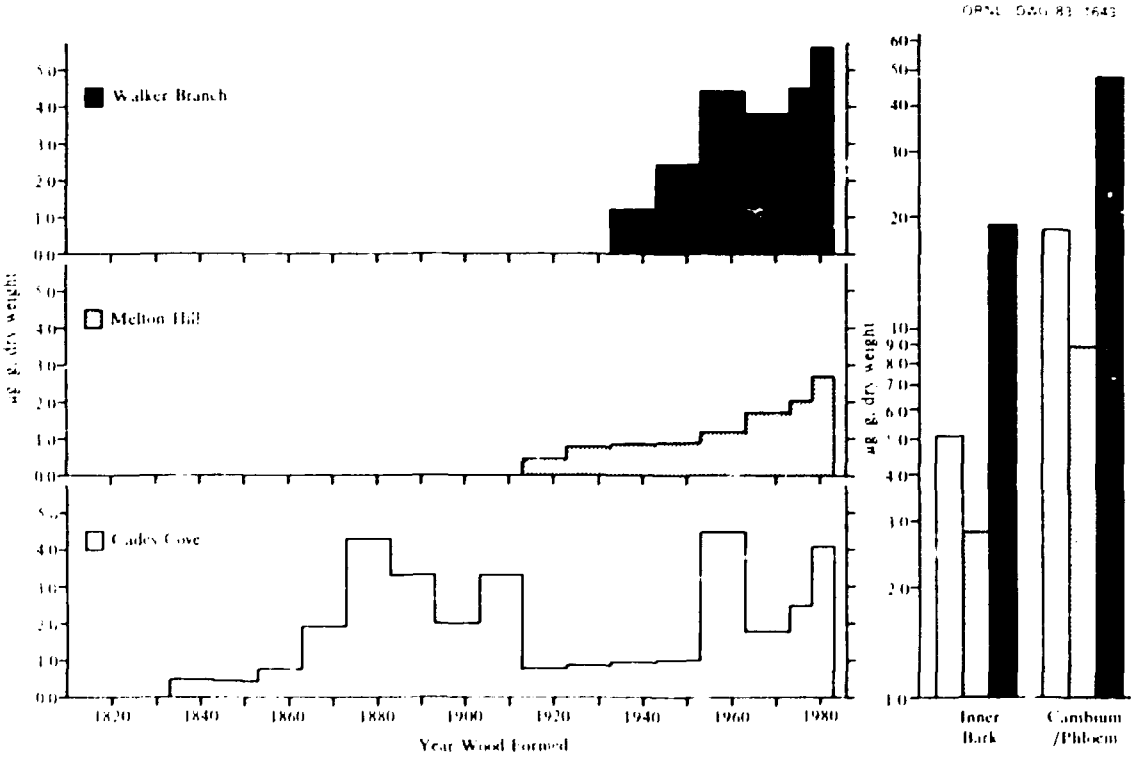

Fig. 4.1. Concentrations of iron in tree rings (xylem) of differing ages, inner bark, and cambium plus phloem tissues. Data are averages of samples from five shortleaf pine trees at each of three sites.

Sources of Acidity in East Tennessee Forest Soils

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In humid climates, several natural pedogenic processes act to decrease soil pH and base saturation and to increase exchangeable and nonexchangeable soil acidity. Amounts of acidity involved, however, are not well quantified, especially in forest soils. Studies funded by EPRI at Walker Branch and Camp Branch watersheds in eastern Tennessee have evaluated the relative magnitude

of two ecosystem sources of acidity—carbonic acid leaching and ion accumulation in woody biomass—in relation to H^+ from acid deposition. Although all atmospheric-derived acidity is not anthropogenic, quantification of atmospheric and ecosystem sources of H^+ will help evaluate the influence of acid deposition on soil acidity.

In 1981–82, annual atmospheric deposition of H^+, estimated from pH and volume measurements of bulk precipitation, averaged 0.49 to 0.77 kmol/ha. Hydrogen from annual uptake and accumulation of excess base cations $[(Ca^{2+} + Mg^{2+} + K^+) - (H_2PO_4^- + SO_4^{2-})]$ in aboveground wood of five forest stands, studied by the International Biological Program, ranged from 0.33 to 1.24 kmol/ha. Annual fluxes of H^+ from carbonic acid leaching plus ion accumulation in aboveground wood were therefore equal to or greater than (up to 2.7 times) the H^+ deposition in bulk precipitation.

In the Walker Branch and Camp Branch watersheds, fluxes of H^+ from ecosystem sources appear to be at least the same magnitude and, in some cases, much greater than those from the atmosphere; therefore, we conclude that while acid deposition has a significant effect on soil leaching rates, it has a relatively small influence on soil acidity at these sites. This is due to the large soil buffering capacity, even in the face of increased leaching. Furthermore, it was noted that base cations in short supply (i.e., calcium at Walker Branch) were conserved despite accelerated leaching by acid deposition, whereas more abundant cations (i.e., magnesium) were preferentially leached. Although there is evidence for similar soils being acidified by extremely high rates of acid deposition (e.g., Udults at Copper Basin, Tennessee), acid fluxes estimated in the present studies are considered to be representative of those in much of the southeastern deciduous forest that currently receives acid precipitation. Calculations of soil buffering capacity suggest that there are few sites in this region at which acid deposition will acidify soils, especially to the extent that soil chemistry and plant growth are affected adversely.

Radionuclides In the Environment

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Metabolism of ^{95m}Tc in Plants and Rats

A cooperative research project was undertaken with the Unité de Physiologie Vegetale at the Université Catholique de Louvain-la-Neuve, Belgium, and the Radiobiologies Department of the CEN/SCK Nuclear Center in Mol, Belgium, on the chemical form of ^{95m}Tc in plants and the metabolism of plant-incorporated ^{95m}Tc to rats. Technetium in corn leaves was studied using a chemical extraction scheme to selectively remove particular components of the plant tissue. Most of the technetium (60%) was extractable from corn leaves with ethanol and weak mineral acids, indicating that a major portion of the radionuclide was present in soluble forms. The remainder was in bound forms associated with proteins and polysaccharides of the plant cell walls. Differential centrifugation studies showed that 50% of the technetium in corn leaves was present in soluble forms in the cell cytosol. Approximately one-half of the technetium in the cytosol chromatographed on Sephadex-G 25 in a manner similar to TcO_4^-, but it was impossible to distinguish, without further work, if this was ^{95m}Tc present as pertechnetate or as complexes with small organic molecules.

The feeding experiments involved a comparison of the tissue distribution and retention of ^{95m}Tc fed to rats in three different forms: (1) biologically incorporated in corn leaves via root uptake of TcO_4^-, (2) incorporated with brown algae via exposure to TcO_4^- contaminated seawater, and (3) TcO_4^- mixed into a standard laboratory ration. The highest concentrations of technetium were found in the thyroids, hair, kidneys, and liver. Technetium was rapidly excreted from all tissues except thyroids and hair. The cumulative urine:fecal excretion ratios during 1 week after the various treatments were as follows: intraveneous injection, 1.9; ^{95m}Tc mixed with standard ration, 1.0; and ^{95m}Tc incorporated in corn or algae, 0.1. Thus, there was a marked reduction in the urinary excretion of injected technetium when the radionuclide was incorporated into plants used as food. The reduced gastrointestinal absorption of technetium following its incorporation into plants was supported by an analysis of the percent of the administered dose found in the rat thyroid gland, liver, kidneys, and blood.

Pasture-to-Milk Transfer of ^{95m}Tc and ^{131}I

Both ^{95m}Tc and ^{131}I were simultaneously sprayed on 4000 m^2 of pasture dominated by fescue and other grasses. Eleven dairy goats, about 6 months into lactation, were allowed to graze on the pasture for 17 days. Each goat was milked by hand and fed 500 kg of 15% dairy feed. The time course of ^{95m}Tc and ^{131}I in the milk of the three goats measured to date was dramatically different. Radioiodine reached a maximum in milk after 2 to 3 d, then declined. One week after the start of grazing, ^{131}I levels in milk (corrected for radiodecay) had not dropped below the concentrations found after 1 d of grazing. The ^{95m}Tc was found in milk as at day 1. This dramatic difference in technetium and iodine behavior might be explained by immobilization reactions occurring in the pasture over time, since ^{131}I:^{95m}Tc ratios on vegetation did not change over the measurement period. The vegetation-to-milk transfer factors are still being evaluated, but it appears that 1 week after grazing started, for example, ^{95m}Tc was being assimilated into milk only to the extent of 1/600 that of ^{131}I. Radiological assessment models generally have assumed that technetium behaves like iodine in mammalian systems. Stall feeding studies in which animals are administered controlled dosages of isotopes such as technetium would not have yielded the same perspective as this grazing experiment.

Deposition of Submicron Aerosols to Vegetation

Natural submicron atmospheric aerosols, which originate from condensation reactions, also contain natural radionuclides. These radionuclides (^{7}Be, ^{210}Pb, ^{212}Pb, ^{214}Pb, etc.) also originate by gas-to-particle conversion reactions and undergo attachment to the ambient aerosol.

In the past year, measurement techniques have been refined to evaluate air-to-vegetation transfer rates of ^{214}Pb and ^{212}Pb. These daughters of radon isotopes appear useful in evaluating dry period submicron aerosol flux to natural surfaces, particularly vegetation, because they allow direct measurements of deposition rates. This approach will enable (1) species comparisons, (2) canopy comparisons, (3) climate comparisons, and (4) atmospheric stability comparisons as they relate to the deposition rates of submicron particles on complex vegetation canopies.

In addition to the short-lived radon daughters, ^{7}Be deposition to fescue has been examined. Beryllium-7 is a cosmogenic radionuclide with a relatively constant air concentration, at least compared to point source pollutants. Therefore, variations in ^{7}Be concentrations on vegetation are

largely the result of natural processes and not point-source heterogeniety. Figure 4.2 illustrates the relationships between total ^7Be flux, precipitation concentration, and fescue concentration for the period July 1982 through June 1983. During vigorous growth periods (September, October, April, May, and June), fescue concentrations are low relative to precipitation concentrations and/or flux. During slow growth periods (July, August, winter) the opposite occurs, suggesting that growth dilution is an important factor in explaining overall air-vegetation relationships. Because of its long half-life (53.3 d), the measured ^7Be on vegetation is largely from wet deposition. These results can also be evaluated in terms of air-to-vegetation transfer ratios and compared to predictions made using assessment models. Those comparisons are in progress.

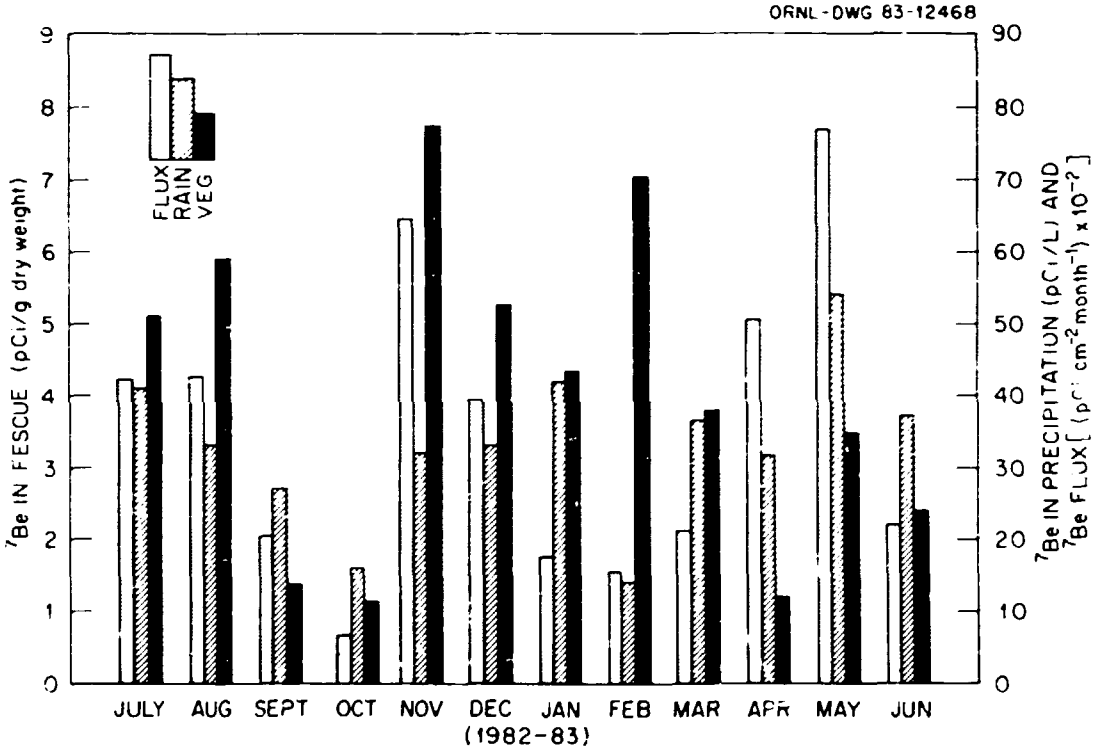

Fig. 4.2. Concentrations of cosmogenic ^7Be on 0800 Area fescue in relationship to ground area flux and precipitation concentration. (1 pCi = 0.037 Bq.)

Changes in Forest Community Biomass Projected from CO_2-Induced Warming

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Climate changes associated with increasing concentrations of atmospheric CO_2 may generate many secondary effects, including shifts in carbon storage in terrestrial vegetation. Forests are the primary vegetation type in which carbon is stored for long periods. Will it become a carbon sink, thereby reducing CO_2 effects, or a carbon source, enhancing CO_2 effects? The question is not easily answered. Forest ecosystems consist of time- and space-variable subsystems that affect one another. Long-term projections with normal empirical techniques are therefore unlikely to be accurate.

For several years, Terrestrial Section staff members have studied conceptual and applied problems with several forms of a computer simulation model that mimics the interacting, nonlinear sub-

systems that comprise forest ecosystems (e.g., Shugart and West 1977, Solomon et al. 1981). Recent model modifications allow accurate forest simulations over broad geographic regions. The model was applied to project forest responses to climate changes induced by enhanced atmospheric CO_2 concentrations. Simulations were run at 21 sites in eastern North America (32–64° N latitude, 67–97° W longitude).

Simulations began with bare soil plots under modern climate (1941–70) and continued for 400 years, followed by linear interpolation of climate means from 400 years to a CO_2 doubling at 500 years, and to a CO_2 quadrupling at 700 years, after which climate was stable to 1000 years. The climate change scenario is from Mitchell (1983) (also Mitchell and Lupton 1983); however, it reflects generally agreed-upon estimates of CO_2-induced climate change, which are that warming is greatest at high latitudes (e.g., for 2 × CO_2, +4°C at 59° N, +2°C at 32° N), greater warming occurs in winter than in summer (e.g., for 2 × CO_2, +2.5°C in summer, +5°C in winter, at 50° N), and precipitation changes are associated with intensification of midlatitude pressure gradients.

All 72 tree species simulated were available continuously. Direct fertilization of vegetation by CO_2 was assumed to be negligible. All simulations used a mesic silt-loam soil of generous water capacity to minimize effects of the poorly understood precipitation deficits in global circulation models.

Simulation results contain many implications for understanding future dynamics of carbon storage in forests. The central issue of carbon source and sink properties of forests is addressed in Fig. 4.3. By the time simulated doubling of CO_2 occurs (Fig. 4.3, left), the northern portion of the

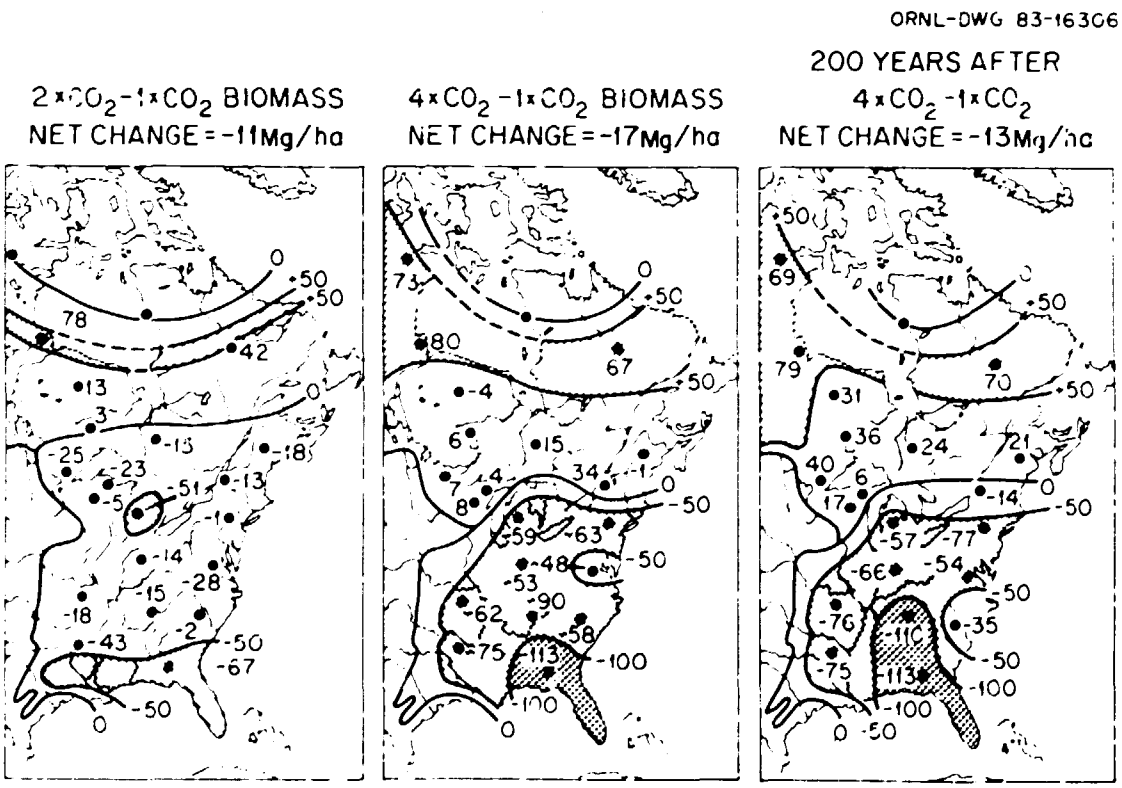

Fig. 4.3. Differences between modern aboveground biomass simulated at 21 sites in eastern North America and future biomass simulated under climate induced by a CO_2 doubling, by a CO_2 quadrupling, and by 200 years of climate that stabilized after a CO_2 quadrupling.

subcontinent has become a carbon sink and the southern portion a carbon source, with carbon balance achieved at about 50° N latitude. The modern prairie-forest border constitutes an implied western limit to carbon losses.

The strongest carbon sinks, at the 2 × CO_2 point in the simulations (Fig. 4.3, left), are found along the northern boreal forest border where forest invades tundra. The greatest carbon sources are in the deep south where forests are currently under water and temperature stress. Overall, the sites simulated are carbon sources, losing about 10% of pre-CO_2 biomass.

By the time CO_2 quadrupled (Fig. 4.3, center), total carbon further declined an average of about 6% more per site. The strong northern carbon sinks and southern carbon sources intensified and increased in areal cover. Meanwhile, the carbon-balance line migrated southward by about 5° of latitude (about 500 km).

Some 200 years after climate change ceased at the 4 × CO_2 level (Fig. 4.3, right), carbon storage dynamics continued to change. Carbon sources intensified further in the southeast, and the high-density northern carbon sinks expanded southwestward. Although the carbon-balance line appears to have undergone little geographic change, carbon storage, averaged across the 21 sites, increased about 4% during the 200-year period after climate stabilized. The continuation of significant changes in carbon storage dynamics, long after climate stabilization, is a property of the global carbon cycle previously considered only in relation to the atmosphere-ocean interface.

The foregoing simulation results provide initial estimates of future, aboveground carbon storage dynamics in forests that result from climate change. Still untreated are the issues of direct CO_2 effects on forest growth, the dynamics of more massive belowground carbon reservoirs, and the important influence on carbon storage of climate change rates, forest-tree migration capabilities, and the direct control of forest destruction and growth by man's use of the land.

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PART II. ENVIRONMENTAL SCIENCES DIVISION PROGRAMS

5. FOSSIL ENERGY PROGRAM

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Introduction

The objective of the Fossil Energy Technology Environmental Program at Oak Ridge National Laboratory is to accumulate and preserve environmental, health, and safety data generated under work sponsored by the U.S. Department of Energy's Offices of Fossil Energy and Energy Research and by the Environmental Protection Agency and others, which are highly relevant to an emerging synthetic fuels industry. The Environmental Sciences Division is supporting the ORNL program by preparing a set of critical reviews of the data and pertinent literature on the research and development activities associated with environmental transport, fate, and effects of the products of and the effluents and emissions from direct coal liquefaction technologies.

Direct coal liquefaction is a developing technology for which detailed environmental studies have been limited, and more complete information is needed for compliance with various federal statutes. Critical reviews of the literature on environmental transport, fate, and effects of direct coal liquefaction products, wastewaters, and atmospheric emissions, with emphasis on the SRC-I and SRC-II, H-Coal, and Exxon Donor Solvent processes, were done to assess the status of research that had been accomplished and to serve as a basis for planning future research programs. The reviews are organized around the following topics: (1) the initial issues that were believed to be important for the assessment of the transport, fate, and effects of direct coal liquefaction products, effluents, and emissions; (2) the research done to address these issues; (3) the initial issues that have been resolved by this research; and (4) additional research needs.

Products

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Studies on the environmental transport, fate, and effects of coal oils have been made primarily with products from the SRC-II and H-Coal processes. Results of toxicity tests and simulation modeling with these materials suggest that accidental releases of coal-derived middle distillates into large rivers may not cause direct mortality to aquatic organisms. Release into standing waters, however, could be more detrimental to aquatic ecosystems, depending on the volume of oil released and the size of the water body. There is little information on the long-term effects on aquatic organisms of releases of heavy distillates, but hydrotreatment can reduce the hazards associated with accidental releases of synfuel products.

The available information on the characterization of synfuel products and their ecological fate and effects remains inadequate for an accurate analysis of the environmental concerns associated with the future use of synfuels in the United States. There is also insufficient information on the

ecological fate and effects of petroleum products that synfuels will partially or completely replace. Continued research is needed, therefore, on coal oils, as well as petroleum, to resolve initial issues and also new issues that have arisen from the research efforts.

Wastewaters

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Although there are uncertainties associated with the final design of coal conversion plants (e.g., whether there will be effluent discharges) and with the data base, the results of research studies suggest that coal conversion effluents could adversely affect aquatic ecosystems. Of the many trace organic and inorganic contaminants that can be present in coal conversion wastewaters, the most important as causes of potential ecological hazards are phenols, polycyclic aromatic hydrocarbons (PAHs), and trace metals such as Hg, As, Pb, Ni, Cu, Zn, Fe, Be, and Cl. Other trace metals and inorganic compounds such as NH_3, H_2S, HCN, and sulfates are unlikely to cause highly toxic releases.

Unfortunately, there are many gaps in the research data on the interactions, transport, and fate of wastewater constituents. For example, the researchers have not all used the same methods, experimental organisms, and experimental design. Continued research is needed in these areas to resolve the issues and to provide the data necessary for risk assessment of coal conversion wastewaters.

Atmospheric Emissions

L. L. Sigal

The initial issues related to the environmental effects of atmospheric emissions from commercial-scale coal liquefaction facilities are largely unresolved, because such facilities do not exist in the United States. However, estimates of emissions have been calculated based on pilot plants and related industries. Effects due to emissions of the criteria pollutants are not expected, because they must be controlled within regulated levels. Research to date related to initial concerns about noncriteria pollutants suggests that CO_2 and low-molecular-weight hydrocarbon gases (except for ethylene) are probably not a problem. Uncertainties continue to exist for the effects of the sulfur-containing gases (other than SO_2), the PAHs and their associated nitrogen analogs, trace metals sorbed on particulates, and potential emissions of mercury for which the materials balance is incomplete.

Environmental effects of atmospheric emissions will vary depending on ambient biotic and abiotic conditions at coal liquefaction facility sites. Unknown factors contributing to potential impacts of atmospheric emissions include the types and rates of emissions and their environmental transport, transformation, interactions, and fate. At present, the ability to predict the risk from atmospheric emissions on terrestrial ecosystems is hampered by a lack of information. In particular, dose-response data are needed for food-chain models and ecological risk assessment methods.

6. BIOMASS PRODUCTION PROGRAMS

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Introduction

Over the past year, Environmental Sciences Division (ESD) efforts in biomass production have increased significantly. Areas of activity include biofuels program planning (which includes biomass conversion technologies), herbaceous biomass production, woody biomass production under intensive culture, and site productivity concerns related to intensive forest management activities. ESD manages three research programs for the Biomass Energy Technology (BET) Division of the U.S. Department of Energy (DOE): the Herbaceous Energy Crops (HEC) program, which is just getting started; the Short-Rotation Woody Crops (SRWC) program, which was initiated in 1978; and the Environment and Analysis (EA) program, with components of research initiated in 1979. Biofuels Program Planning (BPP) was recently initiated in ESD, with coordination involving the Chemical Technology Division, as a major assistance effort to DOE. Management of these programs has included subcontract procurement, program synthesis, interprogram coordination, technical monitoring, and in-house research efforts in support of all but the BPP. These research efforts include nutrient studies of intensive forest management, economic analyses of biomass production, and recently initiated resource evaluations for various biomass production strategies for the United States.

Each of the four program areas is discussed separately in this section. In each case, a brief description of the program is followed by a review of progress during the year and a discussion of significant results. In presenting the SRWC program and the EA program, results of work by subcontractors are mentioned along with research activities at Oak Ridge National Laboratory (ORNL).

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Biofuels Program Planning

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Biofuels are renewable fuels that are produced from biomass or municipal solid wastes. Current use is small, less than 3% of the annual U.S. energy consumption, but there is the potential for biofuels to provide between 15% and 20% of U.S. needs early in the next century (DOE 1983). To reach that potential, however, much research and development is needed, including work on production techniques, conversion techniques, systems development, and infrastructure. This activity was designed to identify research priorities and to plan that research for the next 5 years according to priorities and expected budget availability.

The program planning activity is being accomplished by an ORNL team with guidance from DOE headquarters staff and technical support from DOE's organization of field program management centers. The resultant program plan is to be a document for use by senior DOE administrators and Congress. Thus, research directions must be rational and budgets must be justifiable, while maintaining appropriate time for evaluation and technical detail.

In general, technologies that convert feedstocks to usable fuels are more mature than are technologies for producing greater quantities of feedstocks. Many of these conversion technologies have been used for centuries but remain poorly understood. For example, production of methane by the anaerobic digestion of organic substrates is well-known but poorly understood due to limitations of working in oxygen-depleted environments. Major advances in production rates and efficiencies are thought to be possible. Production of fuel-grade ethanol, a premium liquid fuel, from grains is now commercial. DOE has established that production of up to 130 PJ annually of this fuel will not adversely affect food supply or price, but concedes that further increases in production would eventually lead to competition with food and livestock feed (DOE 1981). Planned research is expected to replace grain-based fuel alcohol production with production from cellulosic feedstocks. As research into conversion technologies leads to commercial feasibility, it is expected that they will be applied to conventional feedstocks such as wood and wood waste. New feedstock sources can be used as they are developed. Increased production of wood through short-rotation intensive culture (SRIC) is expected to provide over 6 EJ of feedstocks early in the next century, while herbaceous crops grown for their energy content contribute another 2.6 EJ or more (DOE 1983). Longer-term research is directed at significant energy production in the form of biologically produced hydrogen and oils.

Biofuels may be delivered as solid, liquid, or gaseous fuels and are, thus, competitive with a broad spectrum of other fuels. Because they are renewable and domestic, they can contribute to supply and price stability. To realize these advantages, continuing research is needed and planning is required to make the best use of the research funds that are available.

Herbaceous Energy Crops Program

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The Herbaceous Energy Crops (HEC) program is a new effort. ESD began planning a research program on herbaceous biomass for DOE's BET Division in the third quarter of FY 1983. The HEC program is expected to start in FY 1984. With ESD as field manager, the planning will proceed to the development of a research strategy and the release of one or more requests for research proposals.

The overall goal of the HEC is to identify systems for producing herbaceous species for energy uses and to develop them to the point that they are attractive to the private sector. Four tasks are envisioned for FY 1984: (1) HEC planning, (2) species screening studies, (3) crop management studies, and (4) environmental and economic analyses. Planning as a separate task will be completed during the year, although planning will be a continuing part of ORNL's program management. The remaining tasks will continue into future years.

The major goal of the HEC planning task is to develop a research strategy for the program. This strategy must include a rationale for choosing the types of research that will be supported. There are four major classes of herbaceous energy crops, and they can be converted to an even greater number of energy products (Table 6.1). The HEC planning task must set priorities for the

Table 6.1. Major types of herbaceous biomass crops and their energy products

Crop type	Uses and energy products
Cellulosic crops	Combustion (heat, electricity) Gasification (synthesis or pipeline gas, methanol) Fermentation (ethanol) Digestion (methane)
Carbohydrate crops	Fermentation (ethanol)
Oilseed crops	Diesel substitute (liquid fuel)
Hydrocarbon crops	Chemicals and liquid fuels

program and determine which types of crops or products will be emphasized. The planning process will also include developing cost goals for specific types of herbaceous energy crops and projecting timetables for reaching those goals.

The species screening studies task will identify promising species and varieties for further study. The species selection criteria will be determined by the strategy developed in the planning task and will be based on the ecological requirements of the crop species, their productivity rates, the types of products they produce, and their potential for improvement through research.

The crop management studies task will consist of research designed to establish the productivity rates of selected species and strains under field conditions and to determine the costs of production. Management studies for crops grown primarily for an oil or extract (instead of their cellulosic components) may include laboratory-scale experiments in extracting the desired products. Work in the crop management studies task may also include field studies measuring the environmental impacts of producing herbaceous energy crops. The results from research in this task will become part of the data used in the fourth task, environmental and economic analyses.

The environmental and economic analyses task will consist of studies designed to assess the overall status of herbaceous crops for energy uses. The task will include analyses to evaluate the potential contributions of herbaceous crops to the national energy supply. The major environmental and economic problems of herbaceous energy crops will be identified in the later stages of HEC planning. A major goal of the environmental and economic analyses task will be to quantify progress as HEC research attempts to reach its goals.

The potential of herbaceous energy crops is essentially unexplored. Some conventional crops systems, or modifications of them, could provide energy products very quickly in a national emergency if conversion systems were available. Other herbaceous crops will require a very long period of research and development before useful quantities of fuels or feedstocks are produced. Herbaceous crops can produce an extremely wide range of products, and, with a large number of species to work with, some type of herbaceous crop can be developed for almost any site without severe climatic or physical limitations.

To date, research on herbaceous energy crops has consisted of large but preliminary screening studies and field trials of a few species. Before individual crop species are developed, it is necessary to plan a coordinated national approach. A range of crops and products is possible, from near-conventional to highly specialized and unconventional. Most potential crops will require at least field testing to establish yields on a range of sites. Many of the more unconventional crops will require long-term breeding and selection programs to increase yields to useful and economic levels. Although it is not difficult to describe the types of research that will be needed, it is very difficult to put priorities on the crop species, the product types, the region, and the sites to emphasize. Before any additional screening or management studies are begun, a rationale for such choices will be produced.

Short-Rotation Woody Crops Program

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The Short-Rotation Woody Crops (SRWC) program was initiated in 1978 to address concerns about an adequate supply of biomass for energy use. Improving biomass supply requires research on three interacting objectives: (1) to minimize costs, (2) to maximize productivity, and (3) to optimize these two elements while maintaining a high rate of productivity. Figure 6.1 suggests how these objectives may relate in general. This relationship is highly dependent on site quality but is still a function of genetic improvements, site/crop management, and equipment handling and hauling costs, the precise areas of research in the SRWC program. Three additional areas of research involve fuel characterization of SRIC biomass, economic evaluations, and nutrient utilization, the last two being primarily in-house research. Most research is conducted under subcontracts.

Species Screening and Selection

Increasing of production yields to achieve the 20 to 27 dry Mg ha^{-1} $year^{-1}$ by 1990, the DOE goal, is expected to rely heavily on tree selection and breeding. The purpose is to select the species, clones, and hybrids that will perform best under SRIC systems on land that is available for biomass

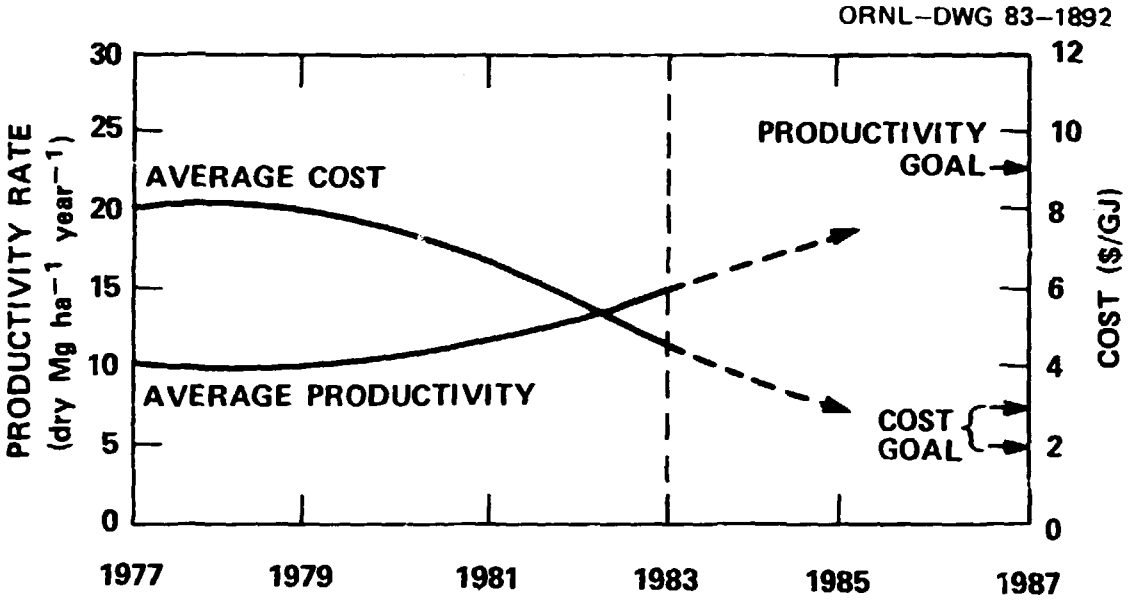

Fig. 6.1. The Short-Rotation Woody Crops Program: Improvements in productivity and economic efficiency of specialized wood energy crops in research plots.

production. Since the quality of sites available for biomass production varies considerably, with much of it being of very poor quality, a wide variety of species must be tested and selected.

The primary criteria applied to selecting the best species include high energy content per unit weight, high dry-weight production per unit area, and wide site adaptability. Other very significant criteria are coppicing ability, pest tolerances, cold hardiness, and drought tolerance. As the end use of the woody biomass becomes more clearly defined, additional selection criteria may become important.

Species with a large amount of genetic diversity are more likely to be adaptable to several site types and offer the greatest potential for increasing biomass yields. To adequately determine the genetic diversity available within a species, range-wide collections of seed sources must first be made. One such collection completed in 1983 was a collection of alder (*Alnus*) half-sib progenies from eastern North America. A total of 775 seed lots were collected: 201 seed lots of *Alnus serrulata* and 574 seed lots of *Alnus incana*. These accessions will be available for researchers throughout the world. Seed source collections were also conducted during the past year by the University of Houston for progenies of the Chinese tallow tree, by the University of Alaska for several species from three Alaskan provenances, and by the University of Minnesota for willow clones from Sweden and Canada.

Results suggest that the potential is very good for improving biomass productivity under SRIC conditions (Table 6.2). Studies on sycamore (*Platanus occidentalis*) provide a good example. Land (1982) evaluated 160 family sources (seeds from a single parent tree) collected from 16 geographic locations throughout a four-state region of the southern United States. He recommended that the top 5% of families that showed good general performance over all test sites be selected, for which a 17 to 22% genetic gain in biomass productivity could be expected in the first generation depending on whether selection is for all sites or specific site types. Investigators at North Carolina State University have reported a somewhat more optimistic picture of potential genetic gains in sycamore

Table 6.2. Estimates of first-generation genetic gain in biomass production based on selection of the best geographic or parent tree sources

Species	State	Age	Predicted gain[a] (%)
Sycamore	Miss.	5	22
Sycamore	N.C.	10	29–37
Red alder	Wash.	3	20
Sand pine	Fla.	6	28
Slash pine	Fla.	8	46
Jack pine	Mich.	15	6–13
Yellow birch	Mich.	15	17
Tamarack	Mich.	14	30
Black walnut	Mich.	16	37
Hybrid poplar	Mich.	7	199
White birch	Mich.	7	30
Red maple	Mich.	9	15
Green ash	Mich.	5	29
White ash	Mich.	6	8

[a]Percent gain in biomass production was calculated using heritability estimates based on family selection. Level of selection varied between species.

[b]Percent gain in biomass production based on selection of best provenances (geographic source of seed) for use in Michigan.

this year (Frederick et al. 1983). They indicate that genetic gains of 29.1 to 37% could be obtained in a rogued first-generation seed orchard, and gains of 47.01 to 51.7% could be obtained in the second generation.

The U.S. Department of Agriculture (USDA) Forest Service, Pacific Northwest Forest and Range Experiment Station, is investigating genetic variability in red alder. A 3-year-old inheritance trial of 33 half-sib red alder families from seven local stands has been analyzed for height and diameter and heritabilities estimated. Preliminary results suggest that a 20% gain in biomass could be obtained by selecting the best families for height and for diameter at breast height.

Michigan State University has completed estimates of biomass improvement that can result just from selection of the best seed sources for nine potential biomass species. Several other species are still being evaluated. Their investigations show that use of seedlings produced from specific seed sources can result in an 8 to 37% increase in whole-tree biomass yields over local sources. Their findings also show that collection of seeds from the wrong area may result in production losses as high as 40% compared with local sources. Based on such results, it is imperative that plantations be established with selected planting stock if maximum biomass production is to be obtained.

Results of extensive evaluation of 55 black cottonwood and hybrid cottonwood clones at the University of Washington show excellent promise for improvement of biomass production. They report a 7.5-fold difference in volume and an estimated biomass difference of 4.9-fold between the poorest and best clones. The best clone has an estimated biomass production rate of 29 dry Mg ha^{-1} $year^{-1}$ after 3 years of growth at a 1.22 × 1.22 m spacing. Among these 55 clones, wood quality parameters are being measured in addition to height and diameter.

Stand Management

Stand management is the largest research area in the SRWC program, covering the largest number of research topics. The objective of this research is to improve productivity and minimize the cost of SRIC through the development of efficient stand establishment and management techniques. Research in this area includes the evaluation and development of plant propagation, planting density, weed control, nutrient utilization, irrigation, rotation length, and pest management techniques.

Development of stand management techniques is dependent on the species, site, and desired end product. In addition, the stand management techniques employed in wood energy production directly influence the economic cost of the end product. The identification of the best stand management and cultural practices is vital to achieving the objectives and goals of the SRWC program.

The first step in stand management is developing great quantities of high quality planting material. Research in tissue culture of hardwoods, as a means to this end, has concentrated on several species over the past year. These are sweetgum, mesquite, red alder, and sycamore. Other species investigated are black locust (*Robinia pseudoacacia*), honey locust (*Gleditsia triacanthos*), yellow poplar (*Liriodendron tulipifera*), Siberian elm (*Ulmus pumila*), catalpa (*Catalpa bignioidies*), and royal paulownia (*Paulownia tomentosa*).

In vitro plants, when produced, do not necessarily mean that a propagation method is successful. These plantlets are susceptible to desiccation and exhibit very atypical leaf anatomy and cell structure that must be corrected for outdoor planting. Large and numerous leaf stomata are one particular problem to overcome. Leaves have undifferentiated inner leaf structures with large intercellular spaces which, when examined at the cellular level, showed great differences when compared with conventional greenhouse and field plants. Plant conditioning and factors that can be modified in vitro to assist in plant development are as important as determining how to initiate the primary steps in organogenesis for successful tissue culture.

Once plantlets are produced and field planted, they must survive and grow well. Weeds are considered one of the most critical problems in stand establishment. Previous studies have shown that on most sites and with most species, controlling of competing vegetation is absolutely necessary to ensure any success in SRIC with hardwoods. Successful weed control will be dependent on several factors: (1) the weed species, (2) the tree species, (3) the site type, and (4) the desired effectiveness.

Past studies have concluded that fertilization is required on most sites for maximum biomass productivity. However, as a more cost-effective alternative to fertilizer application, several projects in the SWRC program have experimented with nitrogen-fixing species interplanted with non-nitrogen-fixing species. The University of Georgia (Steinbeck et al. 1983) planted sycamore (*Platanus occidentalis*) and sweet gum (*Liquidambar styraciflua*) with the leguminous species European black alder (*Alnus glutinosa*) and black locust (*Robinia pseudoacacia*). After four growing seasons, biomass production was determined for pure stands and mixed stands. Productivity varied by species and mixture. All species grew less in the mixed stands than when planted in pure stands. Sycamore grew better in mixture with alder than in mixture with the more vigorous black locust. Sycamore took advantage of more available growing space with the less competitive alder. However, total productivity of the black locust and sycamore mixture was greater than that of the sycamore and alder mixture. Species planted in mixture should be equally adapted to the site and should

exhibit equal vigor and dominance. Otherwise, the dominant or more vigorous species will outcompete the secondary species, and total stand yield will be decreased.

The University of Washington/Washington State University project evaluated the growth of black cottonwood (*Populus deltoides*) clones in pure stands and in stands mixed with red alder, a nitrogen-fixing species. Cottonwood growth, both height and diameter, in mixed plantings exceeded that of the pure plantings. This is contrary to the results reported by the University of Georgia, where all species grew best in pure stands. However, the two studies showed similar results with respect to total production. The University of Washington/Washington State University project found that on the average, total bole volume was 12.8% higher in pure stands than in mixed stands after 4 years. This difference is attributed to the poor growth of red alder, which has decreased each year relative to the total mixed stand growth. Consequently, mixed stand production is less than pure stand production. These results support the premise that species planted in mixture should be of equal vigor and dominance.

Serious risks are involved in growing trees in a monoculture at close spacings (Ostry and McNabb 1983). Conditions that favor rapid tree growth can favor pathogen and insect infestations. Even though many projects in the SRWC program are monitoring pests and diseases, additional research is needed to further identify potential pests in hardwood monoculture plantations. Research is also needed to quantify the effects of cultural practices such as fertilization, irrigation, and spacing on disease incidence and pest populations. Future research efforts will focus on assessment of risks and losses due to pests and diseases in SRIC plantations.

The USDA Forest Service, North Central Forest Experiment Station, has monitored pests and diseases in hybrid poplar plantations for more than 5 years. Ostry and McNabb (1983) advocate careful planning before plantation establishment. Planning should include consideration of planting site, selection of disease-resistant clones, use of disease-free stock, and maintenance of high tree vigor. In addition, plantations should be monitored for disease development so that impacts can be minimized. Incorporation of pest management strategies into silvicultural practices is recommended.

Self-renewing energy feedstocks will be provided by SRIC plantations. The viability of these systems is dependent in part on successful and successive coppice rotations. Coppice production has been measured by only a few projects to date. The USDA Forest Service, North Central Forest Experiment Station (Hansen 1983), reported that second-rotation productivity of hybrid poplar clones after 3 years exceeds first-rotation productivity by almost two times. Pennsylvania State University measured the diameter growth of first- and second-rotation hybrid poplars at 5 years. The results indicate that second-rotation trees have a diameter 1.5 times greater than that of first-rotation trees. Additional research is needed to further quantify productivity rates achievable in coppice rotations.

In general, the evaluation of stand management procedures has been limited to small plantations or experimental plots (less than 10 ha). Actual testing and verification of the best procedures will be delayed until large-scale plantations (greater than 80 ha) are established in several geographic regions. Establishment of large-scale or operational plantations will also be required to quantify productivity rates and costs and, thus, to verify SRWC program goals.

Equipment and Fuel Characterization

Examination of small-tree-diameter handling equipment and wood fuel characterization are considered critical by researchers and wood users in gaining acceptance of the energy plantation

concept. Research has been conducted either as a necessary part of research plans, such as examination of concept energy and cost efficiency, or as a result of very practical near-term needs, such as the harvest of scale-up intensive culture plantations.

Conventional harvesting schemes using a baling device, which assists in the densification and handling of small woody material, have been suggested. The device was developed at Virginia Polytechnic Institute and State University and tested in the Pacific Northwest. Cost evaluations conducted by the University of Washington and Seattle City Light Department indicate that baling could be competitive with chipping ($3.60/green ton for the baler vs $2.90 to $4.20/green ton for chipping) while increasing the green bulk density over chips by 50%. Other alternatives such as bundling (tying groups of trees together) and billetting (cutting trees into very short lengths) have potential for drying and storage with minimum energy loss. Studies of chunking, similar to billetting, by the USDA Forest Service show that this form of processing consumes roughly one-third the amount of energy consumed by conventional chipping.

Small-tree-diameter harvesting devices of innovative designs for plantations are still very much at a concept testing stage. Three major concepts are now under investigation in the United States: (1) the spiral cutting auger felling head, which mills through a section of the trunk roughly the diameter of the auger; (2) the paired and horizontal circular saw harvester, which saws through the bases of trees and lifts them to a storage wagon; and (3) guillotine shearing. All show promise under various kinds of use but require further testing and improvement to attract the attention of private industry. Costs of operating these new harvesting systems have not been sufficiently determined under operational conditions to rely on their accuracy in economically evaluating SRIC systems.

Impacts of mechanized equipment on productivity are being evaluated but at a relatively low level of effort. Various harvesting devices, both conventional and innovative, have been evaluated for their impact on stump condition and subsequent coppicing or resprouting ability. Given that harvesting is conducted during the most dormant time of year for the plant, there has been relatively little significant impact on coppice ability because of the type of severance equipment used at harvest. However, in a study conducted at Purdue University (Pope and Gibson 1983), soil compaction and inflicted stump damage by equipment passes showed some very significant impacts on coppice yields. Tracked vehicles caused more stump damage than rubber-tired vehicles, but only stumps assessed as being heavily damaged showed significant productivity declines. Also, by the sixth pass over a site, conventional rubber-tired tractors reduced height growth of stump sprouts because of soil compaction. Use of tracked vehicles was believed to cause root damage as a result of severance by grousers (ridges on tracks), but this was not statistically evaluated. This type of information is in extremely short supply and is needed both to quantify actual coppice yields following mechanized harvesting and to provide engineering data for further guidance in equipment design.

Characterization of energy plantation wood as a fuel feedstock is an ever-increasing need. Those in biomass conversion technologies must know what kind of feedstock will be available to them. In addition, critical wood characteristics for conversion technologies must be understood with respect to variation and genetic control to properly improve them for conversion to other energy forms.

Most research has reported that the heat of combustion in kilojoules per dry kilogram varies significantly between species but not within a single species. This, linked with observations that heating value has low heritability, has discouraged further research in improving species heating value except through the selection of particular species and the control of other more heritable factors affecting energy production such as specific gravity, moisture content, and dry woody-weight

productivity rate. Estimated heating values of many trees do not vary much across species, genera, regions, wood age, and wood forms (18,750 to 22,570 kJ/dry kg). The only exception is perhaps average values between conifers and hardwoods, 21,370 and 19,680, respectively. However, specific studies examining the effect of age (1, 2, and 3 years) and crop treatment such as fertilization and irrigation on wood characteristics of hybrid poplar have shown no significant effects on heating value.

Stand management alternatives also affect specific gravity and moisture content. Apparently, the intensive culture concept may slightly reduce specific gravity and may increase moisture content. On a dry weight basis, moisture content varies widely and consistently exceeds 100% (more than one-half of total weight is water).

Preliminary studies at the University of Florida with *Eucalyptus* species suggest moderate family heritability for wood moisture content and specific gravity. Modest levels of selection of one in five parent trees could accomplish gains estimated at 4 to 5%. Poorer sites will generally yield wood of a higher specific gravity. Moisture content trends by site quality are less clear. Limited studies on the effects of planting density on moisture content and specific gravity at the University of Florida using *Eucalyptus grandis* showed that greater planting densities definitely increase moisture content and reduce specific gravity of woody material when compared with wider spacings of the same age.

In studies of cellulose and lignin, only lignin content appears to be appreciably decreased in intensively cultivated material. Lignin in 2-year-old hybrid poplar was found to vary according to site amendments (control, fertilization, irrigation, fertilization + irrigation) and was least with the irrigation-only treatment (Blankenhorn et al. 1983). The lignin content under all treatments and control varied between 16 and 18%, a figure lower than values for older wood. Tests on sugar maple and white ash at Michigan Technological University yielded different results, showing that lignin content in young wood was maintained or slightly increased over literature values for older wood.

All work suggests that more information on wood characteristics is needed for selection and management purposes as research plots are examined. This year a standardized format is being developed to characterize wood composition in a manner useful to those handling energy conversion feedstocks and to those who will be working with genetic control and manipulation of these feedstocks. To conduct research properly in controlling wood composition, it will be necessary to determine how some wood substances are formed and allocated within the plant. Much can be gained from existing literature, but specific focus of substance formation during the very early years of growth in traditionally noncommercial species will require research complementary to the existing base of knowledge.

Environment and Analysis Program

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Three areas of research have emerged as major projects in the Environment and Analysis (EA) program: plant productivity and site nutrient analysis, which is concerned with long-term productivity of sites subjected to SRIC for energy; whole-tree removal effects on the environment, which

again concerns long-term productivity of sites when total aboveground woody biomass is removed because of whole-tree harvesting; and the economic analysis of SRIC for woody biomass production. The plant productivity and soil nutrient study is entirely in-house research, with major support from the DOE Office of Basic Energy Research and additional support from DOE's BET Division. The study concerned with whole-tree harvesting is entirely supported by BET. The economic analysis effort is in-house research and is also supported by BET.

Plant Productivity and Site Nutrients

The maximization of woody biomass production on nutrient-poor sites using nondegrading site management practices has been of concern in intensive culture wood energy production. The purpose of research in this area is to determine how to more efficiently produce biomass on nutrient-poor sites through an evaluation of nutrient availability, movement, plant nutrient content, and growth/weight of plant components.

Loblolly pine (*Pinus taeda*), yellow poplar, sweet gum, and black locust species were established on about 20 ha of nutrient-poor upland sites once used for agriculture and since abandoned due to low productivity. These species are being evaluated for differences in survival and growth, including the causal physiological processes and soil plant interrelationships, under various combinations of cultural treatments. Treatments included infection of species with appropriate root symbionts (*Pisolithus tinctorius, Glomus fasciculatus,* and *G. mosseae*), mulching, fertilization alternatives, and controls (nontreatments). Leaf, stem, and root tissues were sampled for nutrient content (total N, P, K, Ca, and Mg), carbohydrates, lipids, and proteins. Also, water samples were collected after each rainfall from lysimeters located in each study plot and prepared for the analysis of several of the major plant nutrients, including NO_3^-, NH_4^+, P, and Ca. Collectively, these chemical analyses of plant tissue and soil-water samples provide insight into the mechanisms and pathways of nutrient movement and availability under the intensive management practices required for the optimization of biomass.

Although few statistically significant effects of treatments have been observed at this early date in the experiment on growth, the trend for pine and poplar is that both fertilizer treatments result in greater height-diameter growth than controls, and that a single large fertilizer application in early spring causes slightly greater diameter-height growth than multiple but smaller fertilizer applications throughout the year.

Root-shoot weight data through the spring of 1983 have provided interesting comparisons of root-shoot weights and ratios between species. Although there were no treatment effects on root-shoot ratios, two results were readily observed. First, the root-shoot ratio for poplar is much higher ($\simeq$1.5) than the ratios for locust ($\simeq$0.65) and pine ($\simeq$0.6). Second, total biomass of locust was nearly 2.5 times that of pine and nearly 3.5 times that of poplar at the beginning of the 1983 growing season. Implications for species growth behavior and ability to utilize limited soil nutrients may be tightly linked to root biomass and root-shoot ratios.

Aspects of efficiency of nitrogen fertilization under different fertilization regimes and effects of short-rotation biomass farming on site nutrient depletion and groundwater contamination have been examined.

After 1.5 years of study, we have shown that, as many have speculated, one-time fertilization in very early stages of plantation growth (year 1) is inefficient, and growth responses are small. This is because soil available-nitrogen levels remain high for only a short period (6 to 8 months)

following one-shot fertilization. No longer-term benefit on site nitrogen fertility was detected (i.e., other measures of soil-nitrogen availability at 12 months after fertilization showed no change in response to fertilization). Thus, trees must take up and accumulate fertilizer nitrogen during a fairly brief period, and if trees are very small, only a small proportion of nitrogen is taken up and conserved for later growth.

Fertilization on this poor site has caused an increase in soil solution NO_3^- levels, but in all cases the values remain well below the 10 ppm NO_3^--nitrogen EPA standard even with repeated fertilization (maximum values to date are <4 ppm). This is due to the high biological demand for nitrogen on this site. Effects of harvesting on site nutrient drain will be calculated at the end of year 4, when harvesting has been scheduled.

Whole-Tree Removal Effects

Environmental Sciences Division staff are coordinating research in several regions and at ORNL that involves site analysis of residue removal and whole-tree utilization for several forest types in the United States. All sites have been dedicated to intensive forestry research for some time, and research effects of aboveground woody biomass removal were built on a broad foundation of baseline data. The research design, in general, has been to (1) measure the erosion and nutrient loss from traditionally cut watersheds with and without woody biomass removal, and thereby quantify the effects residue removal can be expected to have on water quality; (2) quantify the changes in nutrient supply associated with residue removal; and (3) assess what these changes mean in terms of subsequent biomass productivity following the different techniques of harvesting. Studies have included N, P, K, Ca, Mg, and C. The study sites were selected from those geographic regions and site locales that are the most heavily forested and harvested areas in the United States. From these general areas, specific research sites that had large data bases already in existence were selected. Biomass removal has been completed at all of the sites, and system nutrient budgets have been compiled for most sites.

By combining the estimated export of nutrients in harvested material with estimated nutrient inputs and losses from unharvested stands and the total amounts of nutrients present in soil and unharvested material, rates of depletion (or accumulation) of nutrients are in the process of being calculated for the two harvesting intensities. Depletion rates vary widely from site to site for different harvesting intensities and for different nutrients. For the five sites for which data are currently available, two have shown depletion rates of calcium as high as 30% for a single rotation with whole-tree harvesting. Both of these sites, Oak Ridge and Coweeta, are in similar vegetation--that is, mixed upland hardwoods (Table 6.3). The Coweeta site has shown almost as great a depletion rate with sawlog harvest. Calcium is also being depleted at the Mt. Success, New Hampshire, northern hardwood site but at a much lower rate (3 to 4%). Timber harvest has apparently been less of a drain on phosphorus and potassium than it has on calcium. Because of relatively high rates of input of nitrogen (even without considering nitrogen fixation), low loss rates, and moderate amounts removed in harvest, nitrogen has in some cases shown increases from 1 to 24%, depending on the site and harvest intensity.

Although the calcium data imply that even conventional harvest will deplete calcium supplies at the Oak Ridge and Coweeta sites to such an extent that future productivity will be severely curtailed, this may not be the case. Depletion estimates are based on total amounts of calcium and include soil sources but not weathering of rocks. Amounts of calcium available from weatherable

Table 6.3. Estimates of depletion rates of nutrients

(Rotation = 70 years at Coweeta, 80 years at Oak Ridge, 40 years at Clemson and Mt. Success, and 30 years at Bradford Forest)

Site	N			P			K			Ca		
	Total[a] pool (kg/ha)	Change[b] by end of one rotation (%)		Total[a] pool (kg/ha)	Change[b] by end of one rotation (%)		Total[a] pool (kg/ha)	Change[b] by end of one rotation (%)		Total[a] pool (kg/ha)	Change[b] by end of one rotation (%)	
		Commercial harvest	Whole-tree harvest		Commercial harvest	Whole-tree harvest		Commercial harvest	Whole-tree harvest		Commercial harvest	Whole-tree harvest
Pack Forest, Wash.												
Douglas fir, high fertility	3,007	−6.6	−14.9									
Douglas fir, low fertility	830	13.9	−5.9									
Mt. Success, N.H.[c]	7,996	0.5	−0.8	2,257	−0.3	−0.7	10,244	−0.8	−1.3	15,736	−3.0	−3.9
Coweeta, N.C.[c]	7,307	6.4	3.6	2,650	−0.1	−1.3	124,317	−0.3	−0.4	3,288	−15.8	−27.0
Oak Ridge, Tenn.	3,652	4.5	−1.1	1,370	0	−1.1	21,999	−2.0	−2.4	6,327	−24.4	−36.6
Clemson, S.C.	2,018	24.4	20.1	662	4.1	2.9	15,437	0.1	−0.1	15,393	−0.1	−0.5
Bradford Forest, Fla.	4,156	−2.4	−2.3	532	−5.8	−6.0						

[a] Estimated soil total plus above-soil amounts.
[b] [Either commercial harvest or whole-tree harvest removals] plus [input minus losses for duration of one rotation] divided by [total pool].
[c] System changes via groundwater leaching as estimated from lysimeter collections not included.

sources are not currently known and are not easily estimated. It is also difficult, if not impossible, to estimate rates at which total amounts of soil nutrients become available for plant growth. If weathering and mineralization of nutrients cannot "keep up" with growth, depletion of nutrients may be more severe than the estimates in Table 6.3 indicate. Although soil extraction procedures are used to estimate nutrients available for plant growth, these values indicate only the amounts currently available and give no indication of the rates of mobilization of other soil sources. In addition, the rates of accumulation of nutrients in harvestable material may not be correlated with growth. If this is the case, species may be accumulating nutrients in excess of that necessary for optimal growth. Future measurements of both extractable and total soil nutrient pools and above-soil accumulation of nutrients is necessary to assess what effect nutrient removals with harvest are having on regeneration and future productivity.

Economic Analyses

Economic analyses help determine ways to increase the economic efficiency of producing wood energy feedstocks from SRIC by integrating economic factors into system design and research planning. The economic evaluation research serves to assess the market potential of SRIC, to determine the most efficient combination of practices, species spacings, and harvesting under investigation, and to identify areas within the production system design where major technological uncertainties exist and where research should be directed to improve upon economic efficiency.

Results, although based upon very preliminary data, tend to confirm that the optimal rotation age is shortened by increases in selling price and by higher discount rates, and lengthened with decreases in selling price and by lower discount rates. Clearly, increases (decreases) in selling price increase (decrease) the value and consequently the carrying costs of the standing biomass, indicating the attractiveness of a shorter (longer) rotation age. For systems examined, optimal rotation ages were 5 to 6 years at selling prices of \$35 to \$45 per dry megagram.

Preliminary analysis of the sensitivity of discounted average cost to variation in productivity and major system component costs was conducted. A 20% variation in yield would have an impact of \$0.49/GJ for the mesquite, a semiarid plant, and \$0.40/GJ for the hybrid poplar (1 GJ = 10^6 kJ, or roughly 10^6 Btu). The effect of varying the number of coppices from 3 to 2 and 4 produces only a \$0.17/GJ and \$0.14/GJ change in discounted average cost for the mesquite and hybrid poplar, respectively. Variation in major system costs has similar results, except for variation in the cultural management costs for the hybrid poplar and the harvesting costs for both examples. This is a result of the management intensity of the hybrid poplar and the significance of harvesting costs on the overall plantation economics. Sensitivity analysis is very useful in identifying the more important cost parameters, in defining the acceptable range in variation in productivity and system costs, and in suggesting where limited research funds should be directed to have the greatest impact on economic viability. These types of studies characterize much of the inquiry ongoing in this area.

It must be realized that direct measurements of full-scale operational costs and productivities for SRIC are not available. Many of these entered in economic evaluations are derived from agriculture, forestry, and SRIC research plots. Larger-scale studies would assist greatly in improving the accuracy of evaluating costs of production.

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7. LOW-LEVEL WASTE RESEARCH AND DEVELOPMENT PROGRAM

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Introduction

The Low-Level Waste (LLW) Research and Development Program integrates work directed toward waste-management activities at Oak Ridge National Laboratory (ORNL) with generic LLW studies and demonstration projects conducted for the U.S. Department of Energy (DOE) Low-Level Waste Management Program (LLWMP). Site-specific ORNL work involves solid-waste disposal area studies of three ORNL burial grounds; vegetation management studies for burial grounds; monitoring and corrective measures analyses for inactive, liquid LLW radioactive waste sites; and waste-management-related studies of local and regional geology. Generic tasks are focused on improving shallow land burial (SLB) methods and instituting corrective measures for older sites; primary emphasis is on disposal in environments with >750 mm of annual precipitation.

Site-Specific Low-Level Waste Studies

D. D. Huff

The purpose of site-specific LLW studies is to provide environmental research and development support to LLW management activities at ORNL. Support is also provided for site characterization work at the Central Waste Disposal Facility (CWDF), which will serve the three plants in the Oak Ridge complex. Objectives of the work include identification of environmental processes that affect waste disposal operations, assistance in evaluation of environmental safety and regulatory compliance associated with waste disposal operations, and development of practices to ensure that environ-

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mental safety and regulatory goals are met. Activities in this task include solid waste storage area (SWSA) studies; status of liquid LLW pits and trenches; long-term vegetation management studies; geophysical/structural characterization of Melton Valley; consultations—remedial actions; and operations and characterization of the surface water hydrology at the proposed CWDF.

Solid Waste Storage Area-3 Studies (E. R. Rothschild and J. Switek)

Previous studies have demonstrated that small amounts of ^{90}Sr migrate from SWSA-3 to the northwest tributary of White Oak Creek, which is to the east of the disposal area, and to Raccoon Creek, which is to the west. So that possible remedial actions for SWSA-3 can be evaluated, a characterization of the site hydrogeology is required. During FY 1983, several studies were undertaken to characterize the lithology, structural geology, and the potential contaminant pathways existing at the site. The geology at SWSA-3 differs from the other ORNL SWSAs in that it is underlain by the Chickamauga Group. The Chickamauga is structurally and lithologically complex and has a hydrologic regime regulated by an extensive solution cavity system.

As a starting point for hydrogeologic characterization, a combined review of all available geologic data and detailed geologic mapping at the site were used to produce a draft report that describes the detailed geologic structure at SWSA-3. The report is an interpretation of well logs, strike and dip observations, and field studies of outcrop areas. This information has been supplemented by a series of geophysical surveys, conducted in part by the Geophysical Engineering Group of the U.S. Corps of Engineers, based at the Waterways Experiment Station in Vicksburg, Mississippi.

The characterization work completed during FY 1983 will aid in focusing more-detailed studies in the future and, in conjunction with work being performed by the U.S. Geological Survey, will produce a sound data base for evaluating remedial actions on SWSA-3.

Solid Waste Storage Area-4 Studies (D. D. Huff and N. D. Farrow)

The major emphasis in FY 1983 at SWSA-4 was on continued characterization of the distribution of radionuclide contaminants at the south-central edge of the disposal area. Soil samples obtained from a percussion-coring operation were subjected to radiochemical analysis for ^{90}Sr, ^{137}Cs, ^{60}Co, ^{239}Pu, and ^{244}Cm content. Based on the results of these analyses, maps of the patterns of surface contamination for ^{90}Sr, ^{137}Cs, and ^{60}Co have been prepared. In addition, plots of radionuclide distribution with depth have been drawn. As an overall characterization of general patterns, Fig. 7.1 shows the distribution of surface radioactivity readings obtained by a Geiger-Müller (G-M) survey meter. Details differ for specific radionuclides, but the basic features of the patterns are consistent. The results of vertical sampling show a systematic pattern of highest concentrations at the surface and rapidly decreasing concentrations with increasing depth. The combined surface patterns and depth profiles leave little doubt that the major mode for transport observed in this part of SWSA-4 is via the bathtub effect, followed by overland transport to surface drainages.

To respond to the need for stabilizing SWSA-4 against additional radionuclide migration, a surface-water diversion system was designed and constructed. Construction was completed at the end of September 1983. The diversion system captures surface flows from the watershed upslope of SWSA-4 and carries the water away from the disposal area in large storm drains. The water is subsequently discharged into White Oak Creek without the opportunity to become contaminated. As an added part of the project, drain tiles have been installed adjacent to the buried storm drains to

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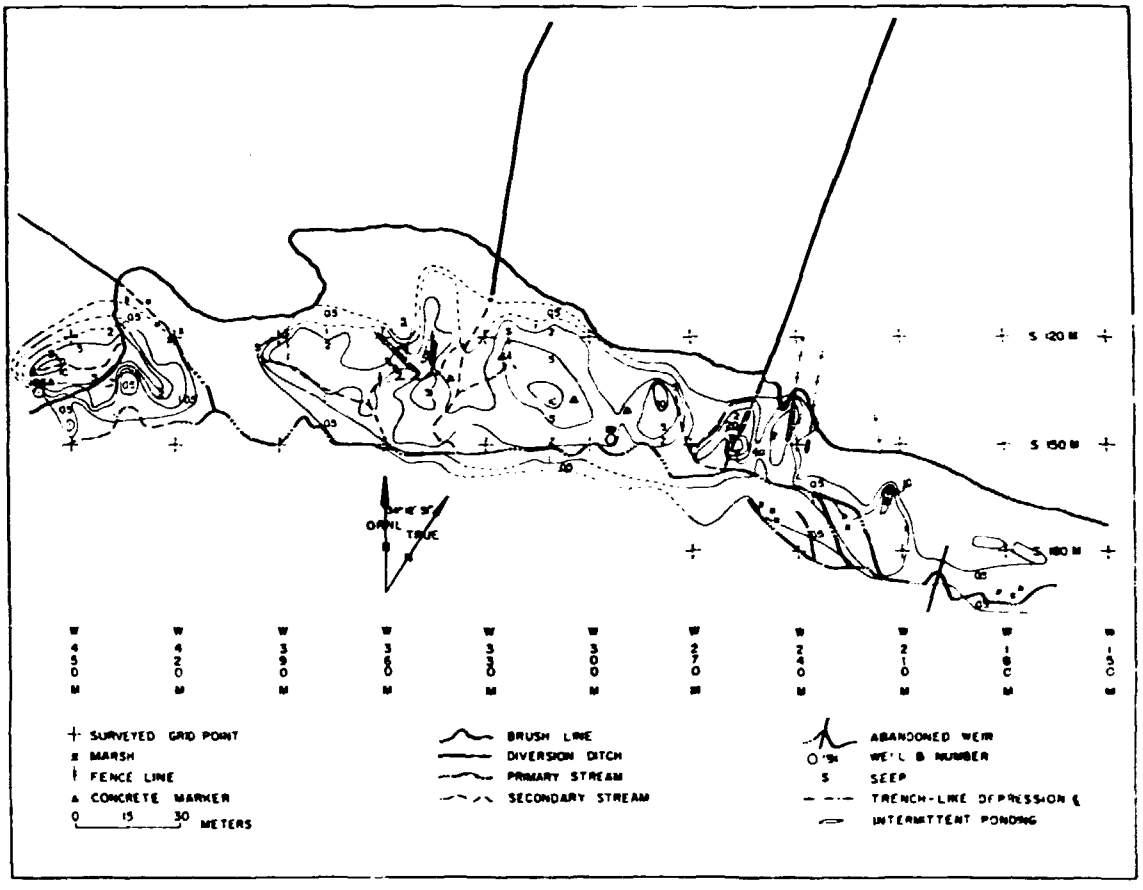

Fig. 7.1. Contours of surface radiation readings at the south-central edge of SWSA-4 in thousands of counts per minute, using a standard G-M survey meter. Calibration indicates that 3100 counts per minute is equivalent to ~1 mR/h.

capture some of the shallow groundwater that moves downslope into SWSA-4. It is anticipated that as much as 80% of the ^{90}Sr release from SWSA-4 will be controlled by this diversion project. To evaluate the effectiveness of the diversion, several actions have been taken. New trapezoidal flumes were installed to monitor flows and ^{90}Sr transport in the SWSA-4 tributary. These results, together with direct measurements of flows diverted around SWSA-4, will make it possible to accurately estimate the effectiveness of the diversion in controlling ^{90}Sr releases from SWSA-4.

Design and Construction of a Groundwater Barrier in Solid Waste Storage Area-6 (E. C. Davis, R. G. Stansfield, N. H. Cutshall, and B. P. Spalding)

One of the major concerns with the practice of SLB of LLW in the eastern United States is the potential for water-waste contact and resulting radionuclide migration (Carter, Moghissi, and Kahn 1979). Engineering modifications or engineered barriers have been suggested as a possible means of improving the performance of these disposal sites, particularly where the natural hydrologic conditions may not be ideal. The objective of this project was to design and construct an engineered barrier to intercept lateral subsurface flow and thus isolate a group of LLW trenches from their upslope recharge area.

From a group of design alternatives, the passive French drain was selected for detailed design. The drain was to consist of a narrow trench lined with filter fabric and backfilled with crushed rock to facilitate drainage. Drain construction began in September 1983, when the water table in the disposal area was at a seasonal low. Excavation of the 1-m-wide by 264-m-long by 9-m-deep (maximum depth) drain took approximately 4 weeks and was delayed by numerous side-wall slides, which resulted from deep excavation in the highly fractured Conasauga shale.

Midway through the construction phase of the project, groundwater began to drain from the eastern leg of the drain and an immediate impact was observed in the disposal area as the water level in nearby wells began to fall. Keeping the water table suppressed to a level below the bottoms of the waste trenches was one of the design criteria considered in planning the project and will be evaluated throughout the coming year. If successful, the French drain concept could be applied to several other disposal sites at ORNL where groundwater has intersected and seeped into closed trenches.

Hydrogeologic Characterization of Proposed Solid Waste Storage Area-7 (E. R. Rothschild, D. D. Huff, C. S. Haase, D. F. Farmer, and N. D. Farrow)

The hydrogeological characterization of SWSA-7 is one part of the development of a burial facility for LLW. The role of SWSA-7 is to succeed currently operated SWSA-6 and to supplement the three-plant CWDF. SWSA-7 will be utilized primarily for low-volume Class B and C (equivalent) wastes.

The proposed site is located in Melton Valley, lies within the Melton Branch Watershed, and is underlain by rocks of the Conasauga Group. The characterization of the proposed SWSA-7 site includes detailed investigations of the surface water and groundwater flow regimes, the hydraulic and chemical characteristics of the bedrock and soils, and geologic mapping.

A draft geologic map for SWSA-7 was produced based on surface mapping, analysis of air photos, and site topography. Subsequently, surface geophysical surveys were undertaken, three deep core holes were drilled (two at 100 m and one at 215 m), and extensive borehole logging was performed in the core holes. The geophysical work and the core holes were used to study possible large-scale faulting on the site. After the data have been analyzed, a final geologic map will be produced.

To investigate the hydrologic regime of SWSA-7, a flume on the central drainage of the site was installed, and 18 monitoring wells were installed. The flume is an experimental design intended to allow monitoring of the wide range of stream flows on the site. Stream flow is being monitored continuously while water levels in the wells are being monitored on a weekly basis. Continuous water-level data have been collected at several of the monitoring wells. Background water quality data have been collected from both surface waters and groundwaters on the site. In situ hydraulic testing has been performed in all the wells, and an expanded testing program is planned to evaluate aquifer properties.

A detailed soils map was prepared for the site and, in conjunction with a proposed site utilization map, appropriate soil types were evaluated. Soil samples were collected for hydraulic testing, chemical testing, mineralogical analyses, and determination of radioisotope adsorption properties. In situ hydraulic testing of soil borings was also performed.

An additional aspect of site characterization is an evaluation of the effect of devegetation on the hydrology of the site. A controlled clear-cutting experiment was planned and preclearing baseline studies were initiated in FY 1983.

Significant data on the hydrogeologic characteristics of proposed SWSA-7 have been collected during FY 1983. The data will be analyzed, assimilated, and presented in a hydrogeologic characterization report at the end of the second quarter of FY 1984.

Status of Liquid Low-Level Waste Pits and Trenches (C. R. Olsen, S. Y. Lee, P. D. Lowry, and N. H. Cutshall)

From 1951 to 1966, shallow land seepage pits and trenches were used for the disposal of liquid LLW generated from routine ORNL operations. Waste liquids (adjusted with sodium hydroxide to a pH of approximately 12) were allowed to percolate through the weathered rock (pH ~5), and radionuclide migration was retarded by sorption reactions with the surrounding geologic media. Over 10^6 Ci of fission products, with some activation products, actinides, and transuranics, were disposed in this manner prior to the implementation of deep-well hydrofracture. (1 Ci = 3.7 × 10^{10} Bq.)

A report was completed during the fiscal year (Olsen et al. 1983), which summarizes our findings concerning (1) the operational history and nuclide inventory for one of these formerly used seepage trenches (liquid LLW trench 7); (2) the chemical forms of several of the radionuclides migrating from the trench; and (3) the geochemical, geological, and hydrological processes that promote their migration. Well gamma-log data presented in this report indicate that the waste liquids (disposed between 1962 and 1966) seeped along discrete layers parallel to bedding and along the strikes of folds and faults (Fig. 7.2).

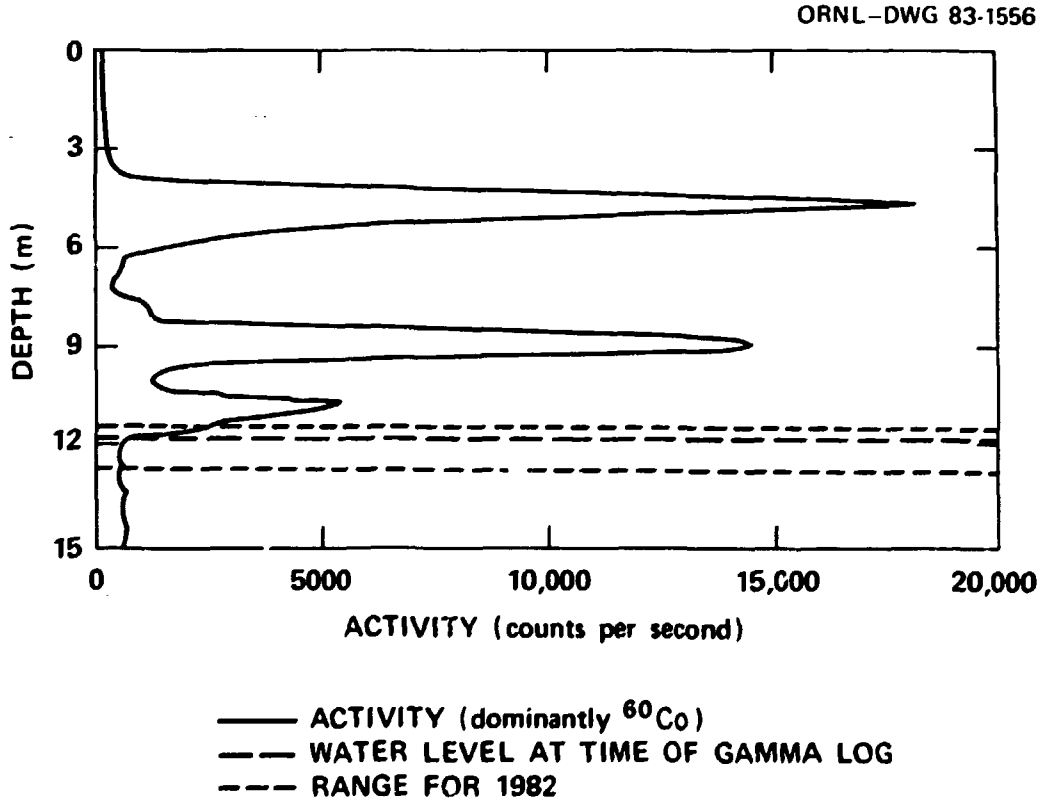

Fig. 7.2. The vertical distribution of gamma activity in the weathered bedrock of well T7-20 near liquid LLW trench 7.

Although most of the radioactivity has been retained be sorption reactions with the trench fill, soils, and weathered bedrock, groundwater characteristics in the vicinity of liquid LLW trench 7 are still greatly influenced by the constituents of the waste liquids disposed two decades ago. Most of the radioactivity measured in the groundwaters consisted of ^{3}H, ^{99}Tc, ^{60}Co, and ^{233}U, and concentrations may range as high as 12,000, 3,200, 1,700, and 41 Bq/L, respectively. The mobility of ^{99}Tc, ^{60}Co, and ^{233}U has been attributed to low-molecular-weight anionic complexing (i.e., TcO_4^-, organocobalt complexes, and uranyl carbonates and phosphates, respectively). One possible mechanism for retarding the migration of these nuclides involves coprecipitation with groundwater components to form secondary minerals (Lee et al. 1983).

A groundwater sample collected in the vicinity of liquid LLW trench 7 has been treated with metal [Al(III), Fe(III), Fe(II), Mg(II), Mn(II), Sn(II)] chlorides, and the pH was adjusted to >8. The results of the coprecipitation experiment are presented in Table 7.1. The $^{99}TcO_4^-$ was precipitated with ferrous and stannous hydroxide. A decrease in particle size of the ferrous hydroxide with increasing $^{99}TcO_4^-$ concentration was noted and suggests that ^{99}Tc was incorporated into the mineral structure after reduction to a lower valence state. Likewise, the chelated $^{60}Co(III)$ was removed by ferrous hydroxide (but only partially by other hydroxides from the aqueous phase), suggesting that the $^{60}Co(III)$ was reduced to $^{60}Co(II)$ and exchanged with Fe(II). Conversely, the uranyl carbonate was precipitated with all of the hydroxides following carbonate decomposition or precipitation without involving redox processes.

Table 7.1. Removal of mobile species of ^{99}Tc, ^{60}Co, and ^{233}U radionuclides in contaminated groundwater by metal treatment

Metal treatment	Percent removed from groundwater		
	$^{99}TcO_4^-$	$^{233}UO_2^{2-}$	$^{60}Co(III)$-EDTA
Fe(II)	99	99	97
Fe(III)	0	83	48
Al(III)	0	99	39
Sn(II)	99	71	64
Mn(II)	12	99	46
Mg(II)[a]	0	99	51

[a]Adjusted to pH 10.8.

Concentrations of ^{90}Sr and ^{137}Cs in the groundwaters were extremely low. The lack of ^{90}Sr mobility is attributed to the chemical treatments and the precautions taken to obtain and maintain an alkaline environment near the trench, which allows for ^{90}Sr sorption and precipitation. The lack of ^{137}Cs mobility is attributed to its strong affinity for being irreversibly sorbed by illite, the dominant clay mineral in the surrounding Conasauga bedrock and soils. Plutonium isotopic ratios indicate that the plutonium contamination near the trench results primarily from the migration of ^{242}Cm and ^{244}Cm and their subsequent decay to ^{238}Pu and ^{240}Pu, rather than reflecting migration of plutonium itself.

Radionuclide concentrations in the groundwaters near the north end of liquid LLW trench 7 undergo seasonal variations, with the lowest activities occurring in the fall and winter and the highest activities occurring in the spring and after prolonged rainstorm events. The rise in radioactivity in these wells is correlated with a rise in the groundwater level and a concurrent increase in groundwater pH. This suggests two possible sources of contamination and two possible mechanisms for leaching contamination into the groundwater system. The two possible sources are (1) the

trench itself and (2) the relict contamination layers in the surrounding weathered bedrock (Fig. 7.2), which served as preferred migration pathways for the waste liquids disposed over two decades ago. The two mechanisms for leaching contaminstion are (1) seasonal rise in the groundwater level and (2) macropore infiltration of precipitation during periods of heavy rainfall.

Installation of a groundwater interceptor at the north end of liquid LLW trench 7 will help maintain a dry, alkaline environment for the trench and ensure its integrity for nuclide retention. In addition, the asphalt trench cap should be extended to prevent infiltration and lateral movement of water along the relict contamination layers, which are currently above the water table. To work effectively, the runoff from the extended asphalt cover must be collected and directed away from the area in which the soils are highly contaminated.

Long-term Vegetation Management Studies (F. G. Taylor)

The focus of work in FY 1983 was on the use of vegetative covers for both short-term and long-term management of former solid, low-level waste burial sites. Because the ideal cover should cause negligible radionuclide "mining" and reduce groundwater recharge through high evapotranspiration, demonstration plots to evaluate the effectiveness of various cover species must be located on actual site closures. This will provide a means to monitor vegetation for radionuclide mining while assessing the ability of the plant species to prosper (i.e., ability to cover and to resist succession by invading species) in the relatively shallow soil overburden. A design for evaluating vegetation effectiveness has been completed, and the plot locations have been surveyed. Each closure plot is approximately 55.6 m^2 in area (12 × 50 ft). In addition to monitoring plant growth, moisture dynamics within closures will be evaluated. A randomized block design, consisting of three replications and four treatments, has been established, and the study plots have been cordoned off. Prior to preparing the surface for seeding and planting, access tubes will be placed in each closure plot to evaluate changes in moisture dynamics as the cover crop becomes established.

The four treatments will consist of (1) Kentucky-31 tall fescue; (2) broomsedge; (3) Kentucky-31 tall fescue, perennial ryegrass, and crown vetch; and (4) broomsedge with European alder and Virginia pine in altering rows.

Geophysical/Structural Characterization of Melton Valley (C. S. Haase, J. Switek, and S. H. Stow)

During the first half of FY 1983, the primary activities centered on obtaining a complete geologic section of the Conasauga Group and the Rome Formation. A borehole, collared in the Knox Group on Copper Ridge, was completed to a depth of 828.4 m (2718 ft). Core recovery was better than 99%, which is excellent. The complete core has been logged (see Fig. 7.3) and photographed and is stored in the recently completed core-storage facility. Geophysical logs, consisting of caliper, gamma ray, neutron, temperature, acoustic velocity and waveform, and acoustic televiewer logs, have been obtained from the borehole by USGS personnel. Geophysical log response patterns from the borehole have been correlated with lithologic and rock fabric data obtained during geologic logging of the core to provide the first comprehensive description of the Conasauga-Rome stratigraphic interval at the ORNL site. Work is continuing with samples of the core; primary activities are petrographic characterization and measurement of porosity and permeabilities of the various constituent formations of the Conasauga Group. A report summarizing the stratigraphic and lithologic data obtained from the borehole is in preparation and a draft copy will be ready by January 1984.

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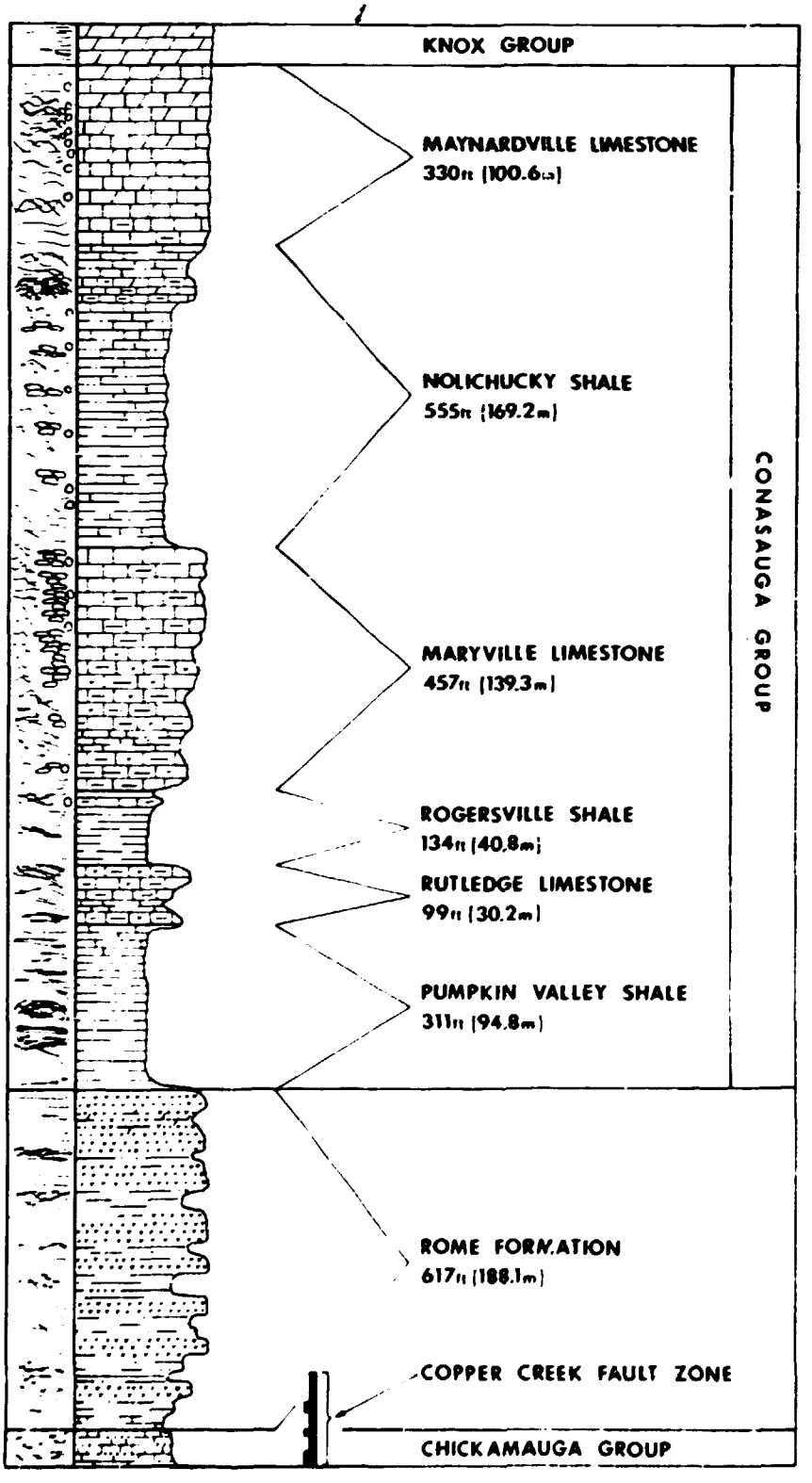

Fig. 7.3. Generalized lithologic log for borehole ORNL-Joy No. 2, illustrating the stratigraphy of the Conasauga Group and the Rome Formation in Melton Valley. Total depth of the borehole is 828.4 m (2718 ft).

A literature search and analysis of data on the regional lithostratigraphy of the Consasuaga Group throughout East Tennessee was completed. A draft manuscript [*Lithofacies and Paleogeography of the Conasauga Group (Middle and Late Cambrian) in the Valley and Ridge Province of East Tennessee*] is in ORNL internal review and will be submitted for open literature publication.

During the second half of FY 1983, the emphasis of this subtask was redirected toward support of the ORNL Hydraulic Fracturing Facility. The primary activity was implementation of a program to evaluate available techniques to monitor the extent and orientation of hydraulically induced fractures. The techniques identified for evaluation were (1) measurement of the surface uplift caused by hydraulic fracturing by precise leveling, (2) real-time measurement of the surface uplift pattern by a tiltmeter array, and (3) measurement of microseismic signals from the propagating hydraulically induced fracture. Personnel from Lawrence Berkeley Laboratory assisted in the planning and design of the experiments. All fabrication of on-site facilities necessary to implement the experiments has been completed. The benchmark network for the precise leveling was completed in June 1983, and the tiltmeter and microseismic experiments will be conducted during injections planned for October and November 1983.

Data from the precise leveling activities have been obtained for the hydrofracture injections of July and August 1983. The design of the benchmark network provides better resolution of the three-dimensional shape of the surface uplift pattern than provided by previous networks installed at other ORNL hydraulic fracturing facilities. Uplift patterns measured are asymmetric with respect to the position of the injection well (see Fig. 7.4). Preliminary analysis of the uplift patterns suggests that the observed shape is consistent with a hydraulic fracture orientation that dips slightly to the southeast. This is not the only possible interpretation, however, and additional study and analysis are in progress. Results obtained thus far indicate that precise leveling measurement of surface uplift patterns caused by hydraulic fracturing will provide useful fracture-orientation data.

Consultation—Remedial Actions and Operations (N. H. Cutshall, D. D. Huff, and N. D. Farrow)

This subtask provides response to requests for technical information required for remedial action decisions as well as day-to-day operations of disposal areas. The primary activities in FY 1983 included liquid LLW pipeline surface-leak remedial actions, investigations of a "new" contamination zone in SWSA-4, development of recommendations for corrective measures at liquid LLW trench 7, and review and direct measurements of performance of effluent monitoring stations in White Oak Creek. In addition, technical staff participated in National Research Council studies of waste disposal options, evaluation of ORNL radioactive waste management operations, and presentations to various individuals and groups visiting ORNL. Initial participation in hydrologic characterization studies for the proposed SWSA-7 and the CWDF were partially supported by this subtask.

During FY 1983, zones of surface contamination along the route of the old liquid LLW waste transfer line were cleaned up, fixed in place, or both. These zones were situated at locations where leaks had occurred during use of the transfer line. Staff participated in field examination of the sites and in conceptual design of fixation and water control measures.

Following a particularly heavy series of rainstorms in late spring, a mower being used in SWSA-4 was found to be contaminated. A small area identified as the contamination source was intensively surveyed to determine the cause of the surface contamination so that corrective actions could be considered. Field gamma-ray spectrometry showed that a ~3-m-diam zone was contami-

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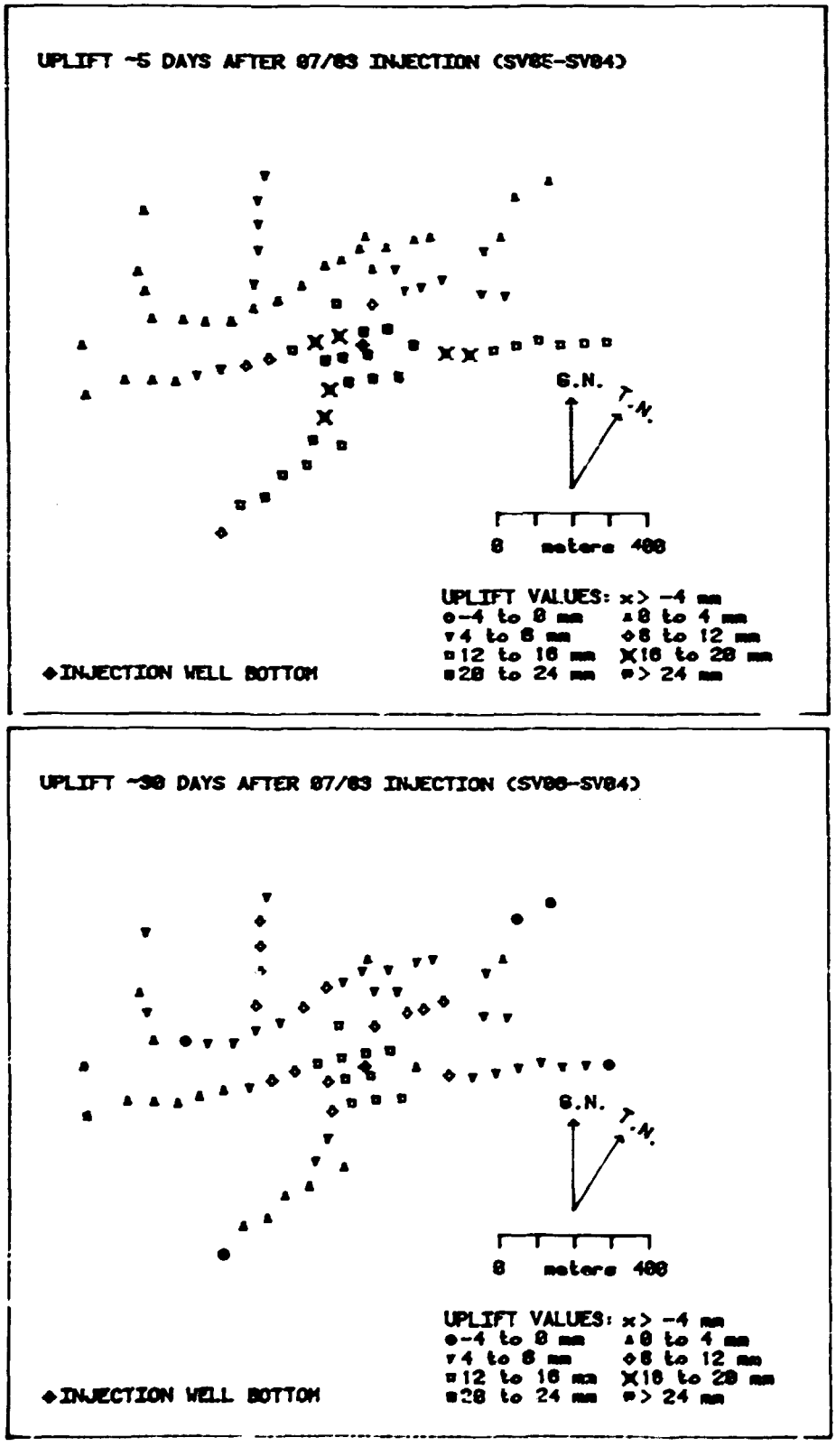

Fig. 7.4. Plan view of the benchmark network, illustrating uplift values measured after the July 1983 injection.

nated with ^{60}Co and ^{137}Cs, which surfaced at the base of a power-line pole. Using seismic equipment and probes, the source was determined to be a concrete-capped disposal pit that appeared to be filled with water and was overflowing in the "bathtub" fashion. Removal of the contaminated surface soil and replacement with clean fill was recommended as a short-term remedial action. No long-term action was planned at this time because the area is so small, and it is possible that the major surface water diversion project at SWSA-4 may improve the hydrologic conditions to alleviate the problem. The possible use of the pit for a remedial action grouting demonstration, a subtask of the DOE LLWP, was considered, but that subtask was cancelled by the Program Office.

Based on results of the liquid LLW pits and trenches subtask, a set of preventive remedial actions was recommended for liquid LLW trench 7. It is apparent that groundwater comes into contact with either the trench contents or nearby zones of subsurface contamination each year during the latter parts of the wet season (February through April). As a result, radionuclide content in groundwater and in a surface seep approximately 60 m away increases during the spring. In addition, pH of the water increases strikingly because of contact with the highly alkaline zones that were affected by the pH 12 waste solutions. Radiochemical analysis of trench contents and nearby strata show that, despite the intrusion of groundwater, mobilization of the major trench contents of ^{137}Cs or ^{90}Sr has not occurred. Nonetheless, improved hydrologic isolation of the trench area is needed to prevent the continued leaching of its contents and the possible acidification of a portion of the disposal zone by groundwater. The conceptual design for improved isolation involves a combination of a French drain along the north side of the trench to prevent lateral flow and extension of the present surface asphalt cover to prevent recharge adjacent to the trench. These remedial actions are planned as an FY 1984 GPP-funded construction activity.

Characterization of the Surface Water Hydrology at the Proposed Central Waste Disposal Facility
(D. D. Huff and B. J. Frederick)

In support of site characterization work to allow evaluation of an area on Chestnut Ridge for suitability as a CWDF for the three plants in the Oak Ridge complex, hydrologic studies of surface water flows have been in progress. The work has included establishment of temporary sites for periodic flow monitoring, collection of precipitation data, a limited monitoring of piezometers to determine depth to water, and upgrading of the temporary surface flow measuring sites to continuous flow measuring installations.

The network of streamflow monitoring sites that exists as of October 1, 1983, is shown in Fig. 7.5, together with the rain gage installation site and the nearest meteorological observation tower site. During FY 1983, flow measurements were made at the gaging sites shown at approximately 2-week intervals. A major goal of this task was to provide information on flow variability at low flows (runoff per unit area) as well as the expected range of flows to be used in designing a permanent monitoring station. Comparison of flows in first- and second-order catchments on Chestnut Ridge and one site in a different geologic setting in the nearby Melton Valley (approximately 1.5 km south of Chestnut Ridge) is shown in Table 7.2. The combined area flow rates are fairly consistent for Chestnut Ridge catchments that are about 100 ha or larger in area. However, as shown for the smaller subcatchment areas, there can be considerable variability between one small area and the next at exactly the same time. The large range in variability evident at the central Chestnut Ridge location (approximately 5 km east of the site shown in Fig. 7.5) was an important factor in eliminating it from consideration as a potential site for the proposed CWDF. High variability in

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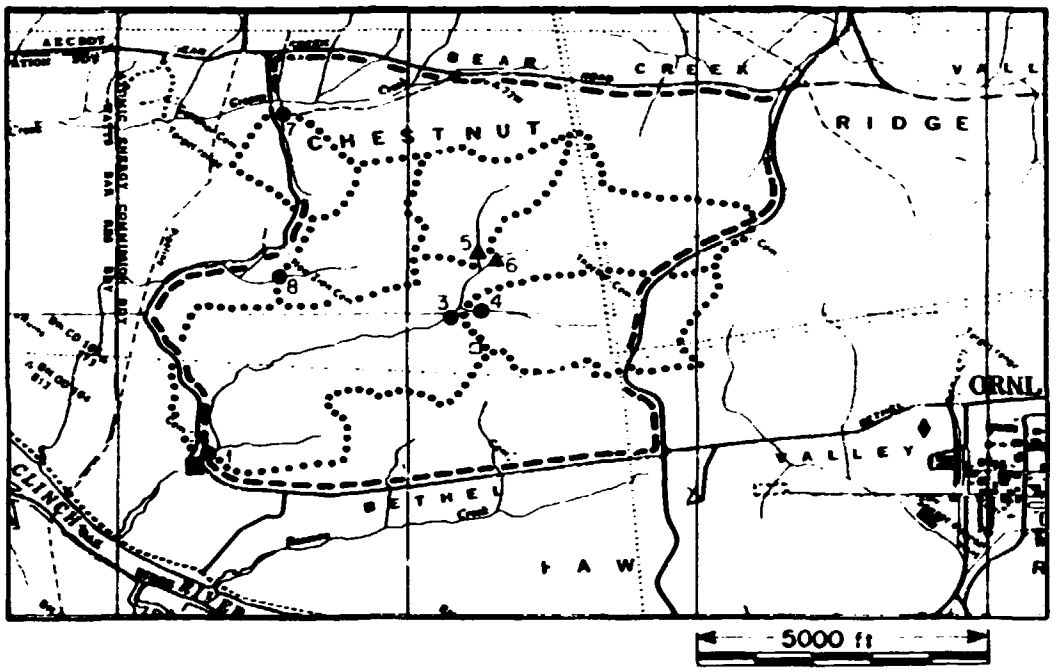

■ PERMANENT FLUME LOCATION
● NEW FLUME
▲ TIME-VOLUME LOCATION
□ RAINGAUGE
♦ METEOROLOGICAL TOWER
WEST CHESTNUT RIDGE SITE
CWDF CATCHMENT, SUBCATCHMENTS
SURFACE STREAMS

Fig. 7.5. Central Waste Disposal Facility: Surface water hydrologic characterization plan.

low-flow runoff has been suggested as an indicator of underlying solution cavities that capture streamflow in karst geologic settings (Hollyday and Goddard 1979). Over the annual cycle, low flows dropped below 1 L s^{-1} km^{-2}, providing a basic for establishing the lower design-flow limit. The upper limit, based on flow frequency analysis for site 1, was found to be 4500 L/s.

Toward the latter part of the year, more permanent installations of flumes or weirs were completed at sites 1, 3, 4, 7, and 8 in Fig. 7.5. These sites were instrumented with portable stage-height recorders, and continuous flow monitoring was initiated. Results will be summarized for subsequent use in the water-budget calculations for the site.

Table 7.2. Comparison of runoff per unit area in first- and second-order basins on Chestnut Ridge and in Melton Valley

Basin name	Instantaneous runoff rates in March 1983 (L s^{-1} km^{-2})		
	In subcatchments		In combined area
	Low	High	
Walker Branch	14	36	23
West Chestnut Ridge, proposed CWDF	11	23	23
Central Chestnut Ridge	5	280	18
Melton Valley, proposed SWSA-7	6	25	12

Generic Low-Level Waste Studies

B. P. Spalding

The purpose of generic studies is to provide environmental research and development for LLW disposal that is applicable to other sites as well as ORNL. Objectives of the work include improved technology for corrective measures applicable to previously buried waste and demonstrating methodology for improved isolation of waste that will be buried in the future.

Activities in these tasks include evaluation of remedial trench grouting, development of an in situ Cerenkov radiation detector, demonstration of chemical treatment of trenches and groundwater seeps with caustic soda and soda ash, testing of liners and grouts as improved shallow land burial techniques, and field verification and validation of models to demonstrate predictive methodology for water and solute transport. These projects provide state-of-the-art technology leading to technology transfer for generic application to shallow land burial of LLW, with special emphasis on humid site needs.

Corrective Measures Technology for Humid Sites (B. P. Spalding, I. L. Munro, and L. K. Hyder)

The corrective measures technology task is designed to address SLB problems with LLW disposal and is composed of three subtasks. The objective of the first subtask, the grouting technology demonstration, is to identify grout formulations that are compatible with waste/backfill (soil) mixtures and that are capable of penetrating buried waste in situ, resulting in its hydrologic isolation. Details of the methods used for grout formulation evaluation can be obtained from Spalding et al. (1983). Seven chemically distinct grout formulations were evaluated in the laboratory for their ability to penetrate into loosely packed soil columns and to reduce their hydraulic conductivities. Two ORNL trench backfill soils and one from Maxey Flats, Kentucky, were used in this phase. Grout formulations for this laboratory evaluation phase included sodium silicate, acrylamide, resorcinol-formaldehyde, urea-formaldehyde, cement-bentonite-fly ash, lime-fly ash, and bentonite alone.

The hydraulic conductivities of soil columns, before and after grouting with the various formulations, are listed in Table 7.3. In spite of the large porosity and hydraulic conductivity of all the soil columns, none of the particulate-containing formulations (cement, fly ash, or bentonite) could penetrate more than 1 cm into the columns before clogging. This inability to penetrate the backfill would obviate considering these particulate groups for in situ hydrologic isolation of buried waste. The remaining four grouts did not contain particulates and exhibited no problems in penetrating soil or sand columns. However, the urea-formaldehyde formulation failed to show much reduction in hydraulic conductivity. Both the acrylamide grout and the resorcinol-formaldehyde grout resulted in soil columns whose hydraulic conductivities were below detection (i.e., 10^{-9} m/s). Sodium silicate also exhibited an excellent reduction in hydraulic conductivity in all cases.

Two formulations, sodium silicate and acrylamide, which were successful in this laboratory phase, were selected for field demonstration of injection into closed trenches designed at 1:10 scale. Sodium silicate was selected because it was the best performing of the inorganic formulations, and acrylamide was selected because it performed best among the organic grouts. Two trenches were grouted with 7.6% sodium silicate and one trench with 11.7% acrylamide/bis-acrylamide in August through October 1982. Grout distribution within and hydraulic conductivities of the waste/backfill were measured periodically for about 8 months after grouting. Shallow observation wells were also constructed in the unperturbed soil formation surrounding each trench.

Table 7.3. Hydraulic conductivities of soil and sand columns before and after treatment with grout formulations

Soil	Grout	Bulk density (Mg/m^3)	Hydraulic conductivity [log (m/s)]	
			Before	After
Sand	Sodium silicate	1.56	−3.252	−7.674
	Acrylamide	1.65	−3.456	<−9.000
	Resorcinol-formaldehyde	1.58	−3.342	<−9.000
	Urea-formaldehyde	1.71	−3.442	−3.569
Maxey Flats	Sodium silicate	0.93	−4.169	−7.430
	Acrylamide	0.99	−4.294	<−9.000
	Resorcinol-formaldehyde	0.91	−3.789	<−9.000
	Urea-formaldehyde	0.95	−3.934	−4.877
ORNL Trench 350	Sodium silicate	1.13	−3.843	−8.353
	Acrylamide	1.02	−3.737	<−9.000
	Resorcinol-formaldehyde	1.13	−3.608	<−9.000
	Urea-formaldehyde	1.13	−3.582	−3.867
ORNL Trench 351	Sodium silicate	1.15	−3.506	−8.326
	Acrylamide	1.16	−3.661	<−9.000
	Resorcinol-formaldehyde	1.13	−3.497	<−9.000
	Urea-formaldehyde	1.10	−3.566	−4.060

The grouting with acrylamide was extremely successful. Grout was observed in all monitoring wells within the trench, and a measurable level of grout was even observed in wells surrounding the trench within the unperturbed soil. Apparently, the low viscosity of the acrylamide facilitated its penetration into the unperturbed soil formation and voids within the trench. Of particular importance, acrylamide grouting reduced the hydraulic conductivity of the trench in all but one well to below the detection limit. These reductions in hydraulic conductivity were stable for the postgrouting observation period.

Sodium silicate grouting of one dry trench met with considerable success. Grout was distributed throughout the trench, but hydraulic conductivities were not reduced as uniformly by the silicate as by the acrylamide. The mean hydraulic conductivity of this trench was reduced from 2.4×10^{-4} to 8.8×10^{-7} m/s; this postgrouting conductivity was less than that of the unperturbed formation (2.7×10^{-6} m/s). The sodium silicate grouting of a second water-saturated trench met with, at best, a qualified success. Hydraulic conductivities of the monitoring well decreased only marginally after grouting. Although this trench was pumped out before grout injection, seepage of water back into the trench during the 2 d of grout injection probably led to a considerable dilution of the grout, particularly along the walls of the trench where the monitoring wells were located.

The second subtask addresses the demonstration of ^{90}Sr fixation in a burial trench via in situ treatment with caustic soda and soda ash. A trench (No. 117) in SWSA-5 at ORNL was selected for a demonstration of chemical treatment for fixation of radiostrontium. This trench is a classical example of the "bathtub" effect; the 100-m trench length parallels the hillslope, resulting in a catchment for groundwater and precipitation in the lower portion of the trench. The accumulated interstitial water has been monitored periodically for several years and had shown ^{90}Sr concentrations of 50 to 100 MBq/L. Chemical treatments with caustic soda and soda ash were performed at several times between 1979 and 1981 in an attempt to distribute chemicals to all regions of the trench. The repeated chemical treatments were required to achieve an equitable distribution of caustic soda and soda ash throughout the trench; the earlier treatments via existing wells failed to

influence all regions of the trench. Periodic sampling of the wells within and outside of the trench has been performed through June 28, 1983.

In general, the treatment of trench 117 with caustic soda and soda ash has been successful in reducing the concentration of ^{90}Sr within the trench's interstitial water. One well, located at the foot of the trench, has shown a good reduction in ^{90}Sr concentration. The almost identical behavior of ^{90}Sr and water hardness was apparent; the correlation coefficient between these two chemical characteristics of this well was 0.933 (n = 54 samples). The continued decrease in ^{90}Sr concentration of standing water of a sump below the trench would indicate some abatement in the leaching of ^{90}Sr from trench 117 as a result of the chemical treatment. This effect has persisted for about 2 years after the final phase of chemical treatment. The form of this fixed ^{90}Sr has been identified as a coprecipitate with calcium carbonate. Chemical modeling of calcium carbonate precipitation and dissolution is required to assess the longer-term effectiveness of the treatment.

The goal of the third subtask is to demonstrate how groundwater ^{90}Sr contamination can be traced using in situ Cerenkov radiation detection. An additional goal is to demonstrate seep discharge abatement using soda ash treatment. Treatment of a groundwater seep with soda ash to reduce the discharge of ^{90}Sr has been reported by Spalding and Munro (1983). A major additional portion of this subtask, however, involves the identification and detection of ^{90}Sr contamination plumes that lead to such surface seeps. Samples of groundwater were collected along the perimeters of SWSA-4 and -5 at ORNL. Single-use boreholes were used to obtain these water samples in a manner similar to the anticipated sampling procedure for the in situ detection of ^{90}Sr via Cerenkov radiation measurement.

The ^{90}Sr concentrations determined by the standard radiochemical method (APHA 1980) and those determined by Cerenkov radiation emission were in excellent agreement. The correlation coefficient between the two methods was 0.996 (n = 42 samples). The next phase of this subtask is to construct and test an in situ Cerenkov detector within a contamination plume of mixed radionuclides. The in situ Cerenkov counting technique for ^{90}Sr has a distinct advantage over other in situ techniques because it measures only what is in the aqueous dissolved phase. In situ Bremsstrahlung or gamma radiation detection cannot distinguish between adsorbed and dissolved radionuclides. Thus, such an in situ ^{90}Sr detector could serve a valuable role in contamination detection.

Engineering Demonstration of In Situ Grouting at Maxey Flats (L. E. Stratton and T. Tamura)

The objective of the engineering demonstration is to stabilize a section of an existing LLW burial trench at the Maxey Flats NWDF owned by the Commonwealth of Kentucky and to thereby demonstrate, at a field scale, the viability of in situ grouting technology. The primary goal is to demonstrate that trench cover subsidence and the resulting migration of water into the trench can be mitigated by injecting a grout into the water material. This corrective measure will fill the accessible voids. The demonstration planned for FY 1984 will provide needed technical information and economic data to evaluate and select long-term engineered solutions for stabilizing the trenches at Maxey Flats and demonstrate technology transferrable to other existing disposal sites.

During FY 1983, ORNL, in consultation with the Kentucky Department for Environmental Protection, designed, constructed, tested, and shipped a grouting module to Kentucky and assisted them in preparation of a test plan for the conduct of the grouting demonstration. The grouting module consists of two 1893-L (500-gal) tanks, each with a heavy-duty agitator connected through a 76-L/min progressive-cavity pump. The module was operationally tested and shipped to Maxey Flats in September 1983.

A test plan for the demonstration was prepared for the Kentucky project, and ORNL personnel were consulted on site preparation, grout selection, grout emplacement, and data evaluation. Kentucky has submitted a 29-page final test plan, describing the details for conducting the test, to DOE for program approval before proceeding with their test plan in FY 1984.

Shallow Land Burial Technology—Humid (E. C. Davis, G. T. Yeh, D. L. DeAngelis, and W. J. Boegly, Jr.)

Shallow land burial of industrial and municipal solid wastes has been the most common disposal practice in the United States (Wilson 1977), primarily because land for disposal has been easy to obtain, and the methods used are relatively inexpensive. Like other industrial wastes, essentially all LLW produced in the United States has been disposed by using SLB practices. Some of these LLW sites have provided less than ideal geological/hydrological site conditions and, as a result, have led to localized groundwater contamination outside of the burial trench boundaries. In addition, most sites in humid regions have experienced problems with trench cover subsidence. Although these occurrences have not resulted in significant off-site movement of radioactivity or exposure of the general public, their presence raises concern with the long-term performance of SLB facilities (USDOE 1983, USNRC 1982).

Applying engineered modifications to present SLB practices is a possible method of stabilizing trenches and improving overall disposal site performance. Two such engineered modifications, trench lining and grouting, are currently being demonstrated and evaluated at the Environmental Sciences Division Engineered Test Facility (ETF). The experimental design for the demonstration consists of nine trenches (approximate trench volume, 28 m^3), three grouted, three lined, and three serving as untreated controls. The trenches are arranged in a 3 by 3 matrix with each treatment being present in each row and column of the trench matrix. In addition to the trenches, an array of 12 preconstruction monitoring wells and 24 tracer monitoring wells (located approximately 1 m from the side walls of each trench) have been constructed at the ETF for purposes of trench treatment evaluation.

Of the large number of liners and grouts currently in use, reinforced Hypalon fabric and a Portland cement–bentonite grout slurry were selected for demonstration in the experimental trenches, which contained compacted LLW generated at ORNL (activity 200 mR/h). The selection of these two trench treatments was based on a number of considerations, which included availability of materials, cost of materials and of their installation, ease of application, and, to a certain extent, the degree of waste isolation afforded. The cement–bentonite grout applied as a waste backfill material was hypothesized as providing an intermediate level of waste isolation, ranking somewhere between the two extremes of the control (untreated) trenches and those lined trenches that completely isolate the waste in a sealed Hypalon liner.

During the demonstration, a total of 29 m^3 of grout was delivered to three of the demonstration trenches at a cost of \$164/m^3 (cost includes mixing and delivery fee). With each trench having roughly the same void volume (estimated to be 50% of the total volume) and thus requiring the same volume of grout, the cost, on a per-demonstration trench basis, equals \$1585 for the grout treatment. For comparison, the cost of grouting a typical ORNL trench (3.0 × 3.7 × 15.2 m), using the same methods and materials, is estimated at \$13,850.

Unlike grouting, where the entire void volume of buried waste needs to be filled with the impermeable grout material, lining requires that only the surfaces of a trench be covered so that the

large void volume within the waste surrounded by the liner need not be considered. As a result, grouting costs can be calculated, almost exclusively, on the trench void volume, whereas lining costs depend on the surface area of the total aggregate of waste or, more directly, on trench dimensions. Thus, the economic comparison of lining and grouting is quite dependent on scale (Table 7.4).

Table 7.4. Cost comparison of improved shallow land burial techniques demonstrated at the Engineered Test Facility

Trench treatment	Cost ($/trench)	
	ETF scale (28 m³)	ORNL scale (169 m³)
Cement–bentonite grout	1,585	13,850
Hypalon liner	1,055	2,330

In addition to demonstrating a successful trench lining and grouting operation, an important part of the ETF experimental design involves evaluating trench treatment effectiveness. Two criteria have been selected to make this evaluation—the movement and detection of unique chemical tracers associated with each of the nine experimental trenches, and the reduction in waste/backfill hydraulic conductivity when compared to the untreated trenches. Both of these criteria reflect the ease with which water can come into contact with the buried waste, leach, and potentially transport radionuclides. To date, sampling of the 12 preconstruction and 24 tracer monitoring wells has not indicated leachate movement from any of the nine demonstration trenches. Even tritium, which is highly mobile and often the first sign of leachate movement from LLW trenches, has not been detected in any of the monitoring wells. Further evidence that the lined trenches are not leaking yet can be seen by the fact that their intratrench water levels, which resulted from direct rainfall infiltration during trench filling, have not fluctuated as the ETF water table has, and the levels remain between 1.5 and 3 m above the existing water table. If significant leakage were occurring, these levels would fluctuate and drop below the trench bottom during the drier summer months. This has not been observed nor has water been detected in wells located in the control or grouted trenches. As a result, it is concluded that, for the 1-year period of monitoring since the trenches have been closed, there has been no detectable leachate generated from the nine demonstration trenches.

One of the objectives of the ETF experiment is to use data obtained for the calibration and validation of groundwater flow and radionuclide transport models. Before calibration and validation can be accomplished, these models must be constructed and verified to ensure their accuracy and applicability to real-world problems. The models should offer versatility and flexibility in treating the distributed as well as point transient source/sinks, in considering spatially-temporally dependent boundary conditions, and in dealing with heterogeneous and anisotropic media. This will allow the models to be adapted for field applications after calibration and validation. A finite-element flow model that meets these requirements has been constructed, verified, and documented (Yeh and Huff 1983). A companion finite-element transport model has been developed for applications to confined or unconfined aquifers or partially confined and partially unconfined aquifers, with possible leakage to or from the aquifer of interest. The verification and documentation of this model is being undertaken (Yeh and Huff 1984). Recent findings have shown that radionuclide transport through fractures in the subsurface environment is a common occurrence rather than an exception. Thus, modeling of radionuclide transport in subsurface media is incomplete without explicit treat-

ment of continuous macropores and interaction between macropores and the soil matrix. A computer model, FRACPORT, that simulates the transport of a solute through fracture porous media has been developed and verified (DeAngelis et al. 1984). The model uses the integrated compartment method to reduce the governing differential equations to a set of ordinary differential equations. A two-time-scale technique is used to integrate this set of ordinary differential equations, which allows substantial saving in computational time (at least one order of magnitude) and makes its applications to real time simulation feasible.

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8. DEPARTMENT OF ENERGY LOW-LEVEL WASTE MANAGEMENT PROGRAM

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R. B. Fitts W. H. Pechin[2]
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Introduction

In early FY 1979, Oak Ridge National Laboratory (ORNL) was assigned the associate lead contractor role in the U.S. Department of Energy (DOE) Low-Level Waste Management Program (LLWMP). This role is carried out under the overall management of the Program Manager at DOE's Idaho Operations Office, the lead contractor (EG&G Idaho) at the Idaho National Engineering Laboratory, and DOE's Oak Ridge Operations Office.

The overall objective of the LLWMP is to develop and promote environmentally sound techniques for safely and efficiently managing the disposal of all types of low-level wastes (LLW).

Low-level wastes result from such activities as energy production, manufacturing, and the use of radioisotopes in medical and research activities. Specific program technology objectives include development of waste treatment and packaging technology; development of improved shallow land burial (SLB) technology; establishment of corrective measures for stabilizing and improving performance of existing burial grounds; identification and evaluation of alternative methods for storage and disposal of LLW that provide greater confinement than shallow land burial; and development of guidelines or standards for waste characterization, disposal, and monitoring.

ORNL, in its role as associate lead contractor of the DOE LLWMP, has responsibility for the management of program-funded technology development activities. In this role, with general guidance provided by DOE and the lead contractor (EG&G Idaho), the ORNL program office is charged with the responsibility to (1) develop program plans for the major technology areas, (2) recommend allocations of the program resources, (3) review the technology development tasks to ensure that program objectives are being met, and (4) assist the lead contractor in coordinating the DOE LLWMP with other ongoing U.S. and foreign waste technology programs. Although the ORNL office generally assists the lead laboratory in the management of the total program, our emphasis is on management of research and development activities related to the development of basic technology and assessment of concepts for alternative systems of processing and disposing of LLW.

Technical progress for each of the tasks of this program for FY 1983 follows.

Low-Level Waste Management

L. J. Metzga M. S. Moran L. E. Stratton*
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Technical Planning

Details for the technology development portions of the LLW Five-Year Program Plan were developed in conjunction with EG&G Idaho. The actual issuance of the detailed overall Program

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[2]Operations Division.
*Mr. Stratton left the program in March 1983 and is currently managing the ORNL DOE LLWMP participating contractor activities.

Plan for FY 1983 was carried out by EG&G Idaho. The following reviews of technology status were prepared by this office in support of program planning and control:

- Update of position paper on modeling, including a description of models developed, validated, or used by program participants and a list of selected references to modeling (L. J. Mezga and M. S. Moran)
- "Evaluation Factors for Verification and Validation of Low-Level Waste Disposal Site Models" (M. S. Moran and L. J. Mezga)
- "DOE Position Paper: Recommendations Concerning the Disposal of Low-Level Waste by Methods Providing Greater Confinement than Near Surface Disposal," ORNL/NFW-83/01 (L. J. Mezga and G. B. Levin, EG&G Idaho)
- Summary Comparison of Well-to-Well Tomography and Other Geophysical Characterization Techniques (M. S. Moran)
- Preliminary Summary of Technology Development Activities Supported by the DOE Interim Waste Operations Program (D. J. Wilkes, L. J. Mezga, and R. B. Fitts)

In order to ensure that program outputs are of consistently high quality and delivered on schedule, the following program guidance was developed for technology development tasks:

- Technical Guidance for the Preparation of FY 1984 Current Year Work Plans
- Technical Guidance for the Preparation of FY 1985 Field Task Proposals/Agreements (FTP/A)

Resource Allocation

The major effort during FY 1983 focused on the development and prioritization of the FY 1983, 1984, and 1985 budgets. These activities included: (1) preparation of FTP/A and budget call technical guidance, (2) evaluation and revision of the FY 1983, 1984, and 1985 budgets, (3) evaluation and revision of the FY 1983 and 1984 Current Year Work Plans, and (4) prioritization of the FY 1983, 1984, and 1985 budgets. These were iterative processes based on changes in the proposed budgets for these years and were made more complex because of the problems associated with operating under a continuing resolution.

Program Review

Program review activities during FY 1983 included: (1) conducting site visits to existing contractor facilities, (2) briefing DOE headquarters and field offices, and (3) conducting the Fifth Annual Information Meeting. Site visits were conducted to review and discuss current fiscal year activities and to develop the elements of the Current Year Work Plan for the coming fiscal year. LLWMP staff provided guidance to the various contractors relative to program goals and technical needs, anticipated funding levels, and program organization during these visits. The information gained during these exchanges was used in evaluating and prioritizing the FY 1983, 1984, and 1985 budgets.

Information exchange and program coordination within the LLWMP occurred during the site visits and the Fifth Annual Information Meeting held in Denver, Colorado, on August 30–September 1, 1983. The proceedings of the fourth annual meeting were published as ORNL/NFW-82/18. The proceedings of the fifth annual meeting are in preparation at EG&G Idaho as an LLWM Program document. During these meetings, the various contractors reported on

the status of projects funded during the current fiscal years (FY 1982 and 1983). The fourth and fifth annual meetings consisted almost entirely of small-group, technical sessions to maximize information exchange and discussion among the participants. The participation in these meetings was expanded to include representatives of the U.S. Nuclear Regulatory Commission (NRC), the U.S. Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS), several states, and private consultants and facility operators. Contractors from all four federal agencies presented reports on their work, allowing for better coordination and understanding of the overall federal program in low-level waste.

Coordination With Other Waste Technology Programs

Information exchange and program coordination with other Doe and federal waste programs continued. The major effort on coordination with other federal waste programs occurred at the Annual DOE LLWM Program Participants' Meeting. This meeting brought together representatives from DOE, EPA, USGS, and NRC. Coordination with other defense waste programs was maintained through participation in the Headquarters Field Coordination Meetings, preparation of a summary of technology development activities supported by the DOE Interim Waste Operations Program, and participation in the TRU Program Annual Meeting and meetings of the DOE Ad Hoc Operating Contractors Committee.

Corrective Measures Handbook

D. J. Wilkes

The Corrective Measures Handbook describes the experience of SLB site operators with the implementation of corrective measures to eliminate conditions that result, or could result, in the site's failure to meet its stated performance objectives. The report provides operators with documentation of previous efforts to correct conditions common to several SLB disposal sites that result in inadequate site performance. As such, the report is a state-of-the-art document and will be the reference point for the final Corrective Measures Handbook.

The report is based on a literature review and on visits to six DOE and five commercial disposal sites. Experience indicates that the most effective corrective actions are those developed based on an understanding of the site conditions that caused the problems. Accordingly, the report is organized by causative factors (i.e., conditions that have resulted in problems). These factors include: (1) unstable trench cover, (2) permeable trench cover, (3) subsidence, (4) groundwater entering trenches, (5) intrusion by deep-rooted plants, (6) intrusion by burrowing animals, and (7) chemical and physical conditions in the trench. In discussion of each, the condition is briefly introduced and is followed by an itemization of actions to correct it.

A draft of the initial Corrective Measures Handbook was prepared in FY 1983 on schedule. A peer-review committee was established, with representation from both the DOE and the commercial disposal facility sector. All members of the committee represent potential users of the handbook. The handbook is currently in review. Committee recommendations will be incorporated in a peer-review committee report for consideration and inclusion in the handbook as appropriate.

The current practices corrective measures report entitled "Experience and Related R&D in Applying Corrective Measures at the Major Low-Level Radioactive Waste Disposal Sites" was updated.

9. DEPARTMENT OF ENERGY GLOBAL CARBON CYCLE PROGRAM

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J. R. Trabalka

M. D. Burtis J. S. Sanford
L. D. Voorhees

Introduction

The principal purpose of the Global Carbon Cycle Program is to provide assistance to the Division of Carbon Dioxide Research in development, management, and research activities for the carbon-cycle research program of the U.S. Department of Energy (DOE). In carrying out this task, the program is responsible for monitoring research progress of Oak Ridge National Laboratory (ORNL) subcontracts, DOE contracts, and in-house projects, identifying research needs to support global carbon-cycle model development, and the recommending of methods for fulfilling these needs. This work involves the preparation and updating of multiyear research plans for DOE. The ORNL staff executes and administers subcontracts to universities and major research institutions for new or continuing research supporting this effort, concentrating on model development and oceanic and terrestrial biospheric data acquisition. The ORNL staff prepares technical and topical reports to update research progress, to provide responses to specific questions, and to resolve technical issues. A major activity in this area involves the coordination of efforts and integration of contributions from DOE contractors and the international carbon dioxide (CO_2) research community for a 1984 state-of-the-art report for DOE on the global carbon cycle.

In support of the state-of-the-art report, ORNL staff members organized and hosted the Sixth ORNL Life Sciences Symposium. The topic was *The Global Carbon Cycle: Analysis of the Natural Cycle and Implications of Anthropogenic Alterations for the Next Century.* The symposium, held in Knoxville, Tennessee, October 31 through November 2, 1983, was sponsored jointly by DOE, the National Science Foundation, the Electric Power Research Institute, the National Oceanic and Atmospheric Administration, and the Gas Research Institute. The symposium was attended by 180 scientists, representing 10 countries. It was organized to examine the scientific basis for extrapolating present knowledge about fluxes, sources, and sinks in the global carbon cycle to predict changes in atmospheric CO_2 concentrations resulting from anthropogenic influences. The published proceedings, containing invited contributions by internationally recognized scientists, will provide a major resource of state-of-the-art information to both scientists and decision makers.

The principal technical objective of this program is to develop a quantitative basis for understanding the global biogeochemical cycle of carbon and implementing simulation models to describe its dynamic behavior. Another objective of this research is to further the scientific methodology for assessing the response of the global carbon cycle—particularly changes in atmospheric CO_2 concentration—to further releases of CO_2 by fossil-fuel combustion. Mathematical models of the carbon cycle are being developed and updated with refinements in basic understanding and improved estimates of key parameters. Sensitivity and error analyses provide a basis for selecting aspects of models that require refinement. Basic data sets underlying carbon-cycle models are refined and augmented where indicated.

Particular attention in both the in-house and external research projects during the past year was devoted to improving our understanding of the terrestrial component of the cycle. In this regard, the impact of land-use change on the global carbon cycle was a major area of concern.

Results obtained from a variety of activities in the program this past year support an overall lowering of the magnitude of carbon fluxes to the atmosphere resulting from changes in terrestrial land use. The development of the ORNL Global Carbon Cycle Program has led to a significant expansion in the number of extramural subcontractors for the DOE-supported ORNL program. A listing of relevant institutional affiliations, research topics, and principal investigators' names is provided in Table 9.1. The projects and investigators associated with intramural research at ORNL are listed in Table 9.2.

Table 9.1. Extramural subcontractors in the DOE Global Carbon Cycle Program

Institution	Investigator	Project title
Columbia University	W. S. Broecker	Ocean tracer modeling
Columbia University	I. Y.-S. Fung	Study of CO_2 source-sink distributions with a 3-D model[a]
Cornell University	C. A. S. Hall	Merging the tropical biosphere model and carbon inventory estimates with land-use change estimates
Duke University	J. F. Richards	Land use and vegetation changes in South and Southeast Asia, 1700–1980 AD
Duke University	W. H. Schlesinger	Arid zone soil carbonates in the global carbon cycle
Duke University	W. H. Schlesinger	Changes in the flux rates of the soil carbon to the atmosphere due to disturbance
Marine Biological Laboratory	R. A. Houghton	Mathematical models for use in defining the role of the terrestrial biota in the global CO_2 cycle
NASA Goddard Space Flight Center	D. Rind	Study of CO_2 source-sink distributions with a 3-D model[a]
Scripps Institution of Oceanography	R. B. Bacastow	Development of a three-dimensional model of the natural carbon cycle in the ocean and its perturbation by anthropogenic CO_2
University of Arizona	A. Long	Accurate determination of $^{13}C/^{12}C$ in CO_2 of past atmospheres from $^{13}C/^{12}C$ in tree rings by removal of climatic interferences
University of Illinois	S. Brown	The role of tropical forests in the global carbon cycle[a]
University of Oklahoma	R. J. Mulholland	Using the airborne fraction as an index for comparing model response with atmospheric CO_2 data
University of Puerto Rico	A. E. Lugo	The role of tropical forests in the global carbon cycle[a]
University of Washington	M. Stuiver	Geochemical determination of biospheric CO_2 fluxes to the atmosphere

[a] Joint project.

Table 9.2. In-house research projects in the DOE Global Carbon Cycle Program

Project	Investigators
Global carbon cycle and climate	W. R. Emanuel[a] C. F. Baes, Jr.[b] D. L. DeAngelis[a] R. H. Gardner[a] G. G. Killough, Jr.[c] A. W. King[a] J. S. Olson[a] T.-H. Peng[a]
Soil carbon in the global carbon cycle	W. M. Post[a] L. K. Mann[a] J. J. Pastor[e] H. H. Shugart[a]

[a]Environmental Sciences Division.
[b]Chemistry Division.
[c]Health and Safety Research Division.
[d]Graduate student, The University of Tennessee, Knoxville.
[e]Postdoctoral fellow, Oak Ridge Associated Universities, Oak Ridge, Tenn.

Extramural Research

Changes in Soil Carbon Storage and Associated Properties with Disturbance and Recovery (W. H. Schlesinger)

Approximately two-thirds of the carbon stored in terrestrial ecosystems lies in the soil carbon pool, and thus has a significant influence on the global carbon cycle. The soils of the world store about 1400×10^{15} to 1700×10^{15} g of carbon in soil organic matter and 800×10^{15} g of carbon as soil carbonate (Schlesinger, in press). Because this reservoir of carbon can be affected by human disturbance through changes in land use (e.g., conversion to agriculture), it is important to understand how this system responds to anthropogenic disturbance and subsequent recovery.

The study of the effects of conversion of undisturbed land to agricultural use must account for several factors, including experimental design, conversion interval, basis of loss estimate, and depth of sampling. A compilation from the scientific literature suggests that temperate forest soils lose about 34% of their content of soil carbon when subject to long-term conversion to agriculture. Similar values for temperate grasslands and tropical forests are 29% and 21%, respectively. The tropical forest value is probably an underestimate because most studies have examined only a short period of agricultural conversion. Field studies are needed in regions of tropical savanna and in arid ecosystems, in which soil organic carbon and carbonate may change upon irrigation. The loss of soil carbon upon land-use conversion follows a negative exponential pattern, with the greatest losses occurring in the first 20 years. This pattern suggests that soil organic matter can be divided into two general categories, labile and refractory, with the losses occurring from the labile forms. The decline in soil carbon due to cultivation is largely the result of a lower production of plant residues and increased decomposition rates. Thus, the carbon lost is released to the atmosphere as CO_2. Increased losses of carbon in runoff account for only a small portion of the change in soil content upon cultivation.

Studies of recovery of disturbed lands primarily focus on plant ecology. Those studies that do examine soil organic matter generally show a linear recovery of soil carbon with time, a result that is consistent with a simulation model developed by the Marine Biological Laboratory (Houghton et al. 1983).

The principal finding of this research is that the loss of carbon from soil profiles upon cultivation is about 30% over a 20- to 50-year interval. This value is significantly lower than parameters used in most recent models of anthropogenic changes in the global carbon cycle.

Role of Tropical Forests in the Global Carbon Cycle (S. Brown and A. E. Lugo)

Two significant aspects have resulted from our project research. The first is a result of the sampling of tropical forest and agriculture soils in two contrasting climatic environments for organic carbon in Puerto Rico. The results (Glubczynski et al. 1983) suggest that:

1. Continuous agriculture depletes soil carbon by a greater fraction of the original amount in humid climates than in arid ones.
2. The rate of soil carbon accumulation through forest succession after abandonment occurs at approximately the same relatively fast rate in both humid and arid environments. Although the input (litterfall) and output (decomposition) of organic matter to the soil is vastly different in the two environments, the net difference between the two rates appears to be similar.
3. Carbon accumulates in soils under lands that have been in pasture for many years to levels approaching that of the original forest.

The second significant result from this year's work is a new estimate of the organic carbon content of tropical forests. For this estimate, we used the forest volumes and area estimates given in the recently published Food and Agriculture Organization (FAO) reports (FAO 1981) and the information and insight Brown gained from her trip to the FAO headquarters in Rome. We converted volumes to total biomass, using wood densities and factors to convert stemwood biomass to total biomass, based on our work in the carbon budget phase. The results of this analysis (Brown and Lugo, in press) suggest the following:

1. The total carbon pool in tropical forest vegetation is 100×10^9 t, giving a weighted carbon density of 52 t/ha, or about one-half that previously reported by us (Brown and Lugo 1982).
2. The weighted volume-derived carbon density for undisturbed closed forests is 88 t/ha, and that for open forests is 30.5 t/ha.
3. The volume-derived carbon density for the open forests is similar to the average value of 40 t/ha that we used in our earlier report (Brown and Lugo 1982), indicating that volume-derived estimates are comparable to those obtained by direct harvest methods for these types of forests.
4. The volume-derived carbon density for undisturbed closed forests is about one-half the average values of 145 to 185 t/ha obtained by the direct method.

We suggest that the reasons for the large difference between the volume-derived estimates and those made by us and others previously are:

1. Previous estimates assumed that all tropical forests were undisturbed, which is apparently not the case.
2. It was assumed that biomass estimates based on direct measurements of small plots for a few different forest types could be extrapolated to all tropical forests. This is apparently not the case,

because volume data collected over vast areas produce lower biomass estimates than those from the direct harvest methods for small plots.

Biomass data are generally collected in ecological studies for describing the structure and function of "typical" forests; the selection of such plots may be biased by a preconceived notion about the typical forest conditions. Volume data, on the other hand, are collected by foresters whose goal is to assess the resource for potential economic ventures; they tend to survey and sample larger areas with more plots (thousands of hectares) without bias in the selection.

The immediate implication of the soil carbon work and the lower estimate for the carbon pool in tropical forests is that less carbon dioxide would be produced when tropical forests are cleared, thus reducing the source of atmospheric carbon dioxide from the terrestrial biota. The new estimate of the carbon pool of tropical forests also raises new questions about the size of the global terrestrial carbon pool.

Merging a Tropical Biosphere Model and Carbon Inventory Data with Estimates of Land-Use Change (C. A. S. Hall)

Our research group has developed a comprehensive, flexible, and transportable computer model designed to quantify the carbon exchange that occurs as land is subject to various uses over time. The focus of this work has been on the tropics, but the model is readily adaptable to other environments. With our colleagues, we have synthesized various existing data on carbon content of vegetation and soils and on land-use change into formats compatible with the model. Preliminary assessments of carbon release from the tropics to the atmosphere as a result of land-use change have been made, based on a number of different data sets and assumptions. These preliminary assessments suggest that it is unlikely for carbon release to exceed about 2×10^{15} g of carbon per year. One of the chief remaining sources of uncertainty for both past and present estimates of carbon release is past patterns of land use.

The overall goal of this project was to give a detailed estimate for recent years of carbon released to the atmosphere from human impact on ecosystems for all 76 tropical countries by integrating (1) our existing land-use change/carbon exchange model; (2) biomass estimates derived by our colleagues Brown and Lugo, and soil carbon estimates by Post et al.; and (3) country-by-country estimates of land-use change derived for 76 countries by Lanly, Singh, and others at FAO Forestry, Rome (FAO 1981). The development of the data base required for items 2 and 3 was a specific objective of the year's work.

Principal problems encountered were that only 51 of 76 countries in the FAO study had all of the data needed for a complete run, and that the soil analysis given in Post et al. (1982) required additional interpretation for our purposes. Nevertheless, we have been able to derive approximate estimates based on extrapolating the results of the 51 countries to all of the tropics, using approximate values for conversions, and temporarily ignoring soils.

Our results using the new data are consistent with our earlier analyses, which suggest that land-use change in the tropics results in a modest release of carbon to the atmosphere but that there cannot be a very large release of carbon to the atmosphere if the FAO data sources are even reasonably accurate. Specifically, our model runs suggest that—based on extrapolating 51 countries to the entire tropics, and for data appropriate to the late 1970s—about 0.6×10^{15} g of carbon per year was released from the vegetation to the atmosphere. We expect that later inclusion of soil analyses will raise that number by perhaps 20 to 50%.

The model of the effects of land-use change and the data collected to run the model are organized, where possible, according to the Holdridge Life Zone System. So that the analysis of carbon changes in the soil be compatible with the analysis of changes in the vegetation, estimates of soil carbon based on the Life Zone System (Post et al. 1982) were used in this analysis. These estimates are given as kilograms of carbon per square meter to a depth of 1 m.

Although evidence is limited, it appears that clearing and cultivation do not affect the carbon content of tropical soils to the depth of 1 m, although there may be large changes (generally a loss) at the surface. Some studies have found that soil that has been cleared contains less carbon in the surface layers than the undisturbed soil, but more in the deeper layers. It appears from these studies that the effects of land use on soil carbon content become negligible somewhere between 10 and 60 cm of depth, with the wide range most likely a result of differences in Life Zone, soil type, and use. Post et al. (1982) recorded the cumulative carbon content at 10, 20, 40, 60, 80, and 100 cm for 464 tropical and subtropical soil profiles they examined for their analysis. Using the same methods that they used, we calculated estimates of the cumulative carbon storage by Life Zone for each of these depths. Considering the information concerning the depth at which land use effects diminish and the choice presented by the data of Post et al. (1982), the initial carbon storage of soils apparently should be calculated to a depth of 40 cm. This required a recalculation of the analysis of soil carbon by Post et al. from the original data, for which we have derived a new data base of the raw data.

Our study of tropical soils will produce the information necessary to estimate the total release of carbon due to land-use change. The modification of the data of Post et al. will provide an estimate by Life Zone of the carbon stored in the soil of tropical and subtropical Life Zones before disturbance. Although the evidence we have gathered indicates that land use does not greatly affect soil carbon below 40 cm, our modification of the data of Post et al. allows us to test the sensitivity of this assumption by using the estimates of cumulative storage to different depths in our analysis.

$^{13}C/^{12}C$ Ratios in Tree Rings and the Effect of the Terrestrial Biosphere on Atmospheric CO_2 (J. R. Trabalka)

A controversy regarding the contribution of the terrestrial biosphere to the rise in atmospheric CO_2 content is now well-known. The CO_2 released as a result of deforestation and agricultural manipulation of soils could have equaled or even exceeded that from the combustion of fossil fuels. Geochemists, interested in fossil fuel CO_2 uptake by the sea, have generally been critical of the contemporary forest-soil contribution estimates because their models fall short of explaining the difference between the amount of CO_2 produced by fossil fuel burning and the amount of excess CO_2 accumulated in the atmosphere.

The most promising approach to resolving the controversy appears to make use of the $^{13}C/^{12}C$ record for atmospheric CO_2 contained in tree rings. Because both fossil-fuel CO_2 and forest-soil CO_2 have significantly lower $^{13}C/^{12}C$ ratios than that of atmospheric CO_2, the addition of CO_2 from either source will decrease the atmospheric ^{13}C value. After the ^{13}C change due to known fossil-fuel CO_2 releases is subtracted from the record obtained from measurements on tree rings, one can then calculate past CO_2 releases from the terrestrial biosphere, as well as preindustrial CO_2 levels in the atmosphere.

The controversial aspects of interpretation of tree ring ^{13}C records involve the separation of the isotopic noise caused by local environmental conditions, climatic effects, CO_2 fertilization responses,

and air pollution. New research results for trees from Pacific Coast sites and the southwestern United States, in which the ^{13}C records were partially corrected for some of these factors, produced strikingly different results when compared with those from tree-ring records which did not take these phenomena into account. The corrected ^{13}C records indicate a much slower rate of change in the ^{13}C content of the atmosphere and a correspondingly lower rate and total amount of historical carbon input from the terrestrial biosphere. This also results in a higher estimate of the preindustrial atmospheric CO_2 level; results from the uncorrected and corrected tree-ring data now bracket the preindustrial CO_2 level estimated from other sources such as ice core measurements.

The new results appear to reinforce hypotheses about the potential variability of the tree-ring ^{13}C record. The new data also confirm that basic research on the physiological mechanisms that control isotope fractionation in trees to reduce the residual noise level will be a necessary precursor to further use of tree-ring data in carbon cycle research. Because tree-ring records contain potentially important information on past climates and on CO_2 fertilization of the biosphere, in addition to carbon cycle processes, a high priority will be placed on restructuring tree-ring research to focus on critical physiological questions identified by the ongoing research program.

Transfer of Biospheric Carbon to the Atmosphere Indicated by Pacific Coast Tree-Ring Records Corrected for Growth Rate Effects (M. Stuiver)

The ratio of the two natural stable carbon isotopes (^{12}C and ^{13}C) is generally given as a $\delta^{13}C$ value in parts per mill. For instance, atmospheric CO_2 has $\delta^{13}C$ values of about -7 per mill, which implies a $^{13}C/^{12}C$ ratio 7 per mill less than the $^{13}C/^{12}C$ ratio of the PDB calcium carbonate standard. The $\delta^{13}C$ values of organic and inorganic carbon compounds result from (1) the physical and chemical processes that lead to their formation and (2) subsequent isotope exchange. For instance, the biochemical reactions occurring during photosynthesis result in $\delta^{13}C$ values of about -25 per mill for most plants. Fossil fuels have similar $\delta^{13}C$ values in the -22 to -28 per mill range. Thus, both fossil fuel and biospheric CO_2, when added to the atmosphere, tend to lower atmospheric $\delta^{13}C$ values (δ_a).

In addition to reflecting the global δ_a change, the tree's $\delta^{13}C$ record (δ_t) is influenced by variable discrimination against the heavier ^{13}C during photosynthesis. Part of the in situ variability of ^{13}C fractionation is tied to the rate of growth and can be corrected for by normalizing on constant ring area. Sequoia specimens provide the best examples of the relationship between ring area and δ_t, with correlation coefficients of about 0.8.

Ring-area-normalized δ_t records (Stuiver, Burk, and Quay, submitted) have been produced for a number of Pacific Coast trees: (1) a bristlecone pine, (2 and 3) two sequoias, (4) a Douglas fir, (5) a Sitka spruce, and (6) an Alerce tree. The average δ_t record of these trees, when used in conjunction with a carbon reservoir model (Stuiver, Burk, and Quay, submitted) results in a calculation of the integrated biospheric carbon flux to the atmosphere (Fig. 9.1, heavy solid line). From an analysis (sometimes referred to as a deconvolution) of this $\delta^{13}C$ record, 149×10^{15} g of biospheric carbon was released between 1600 and 1975. This cumulative amount is similar to that released by fossil fuel combustion alone (135×10^{15} g; short-dashed line in Fig. 9.1), and is also comparable in magnitude to the Houghton et al. (1983) estimate of biospheric change (168×10^{15} g of carbon between 1850 and 1975). However, the latter estimate of the biospheric release occurs mainly during the twentieth century, whereas the new Pacific Coast tree-ring $\delta^{13}C$ record suggests the biospheric CO_2 is released over several centuries.

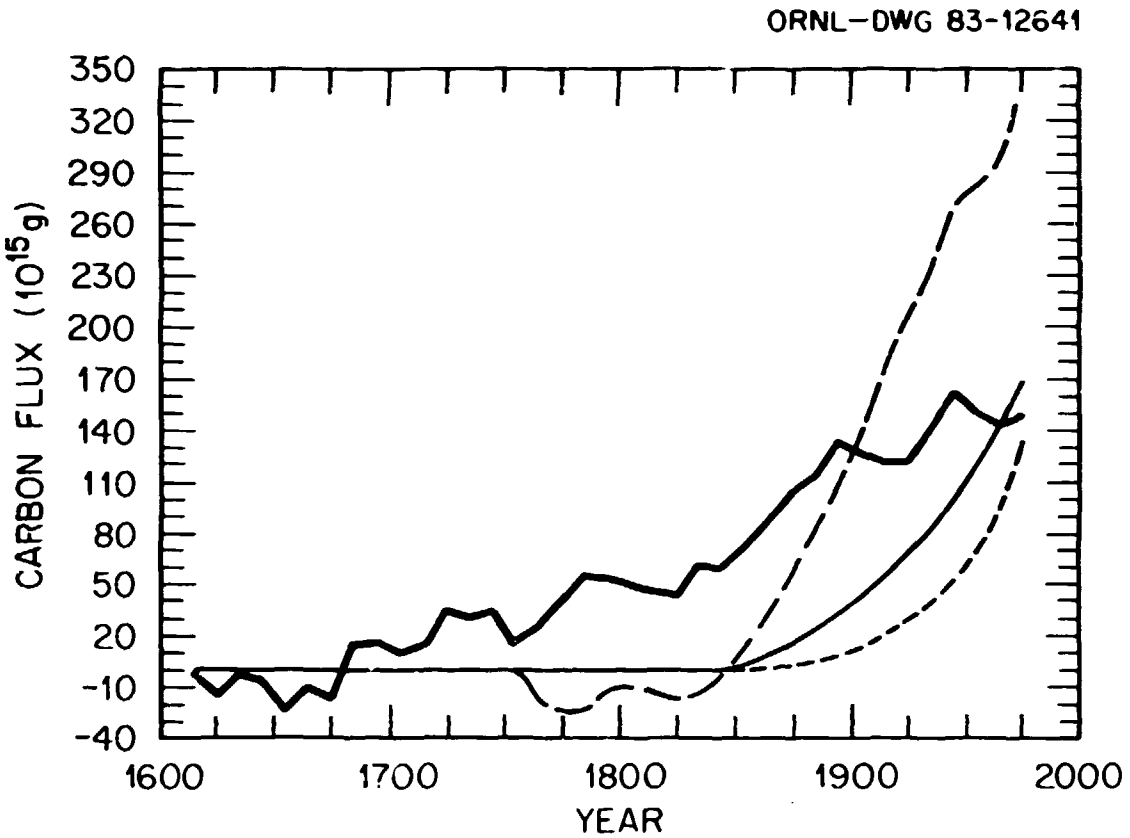

Fig. 9.1. Cumulative biospheric carbon flux calculated from Pacific Coast average δ_t record (heavy solid line) and the Freyer and Belacy (1983) δ_t record (long-dashed line). The Houghton et al. (1983) estimates yield the light solid line. The cumulative fossil fuel CO_2 flux is given for comparison (short-dashed line).

A much larger integrated biospheric flux of 345 × 10^{15} g between 1760 and 1975 is obtained from the Freyer and Belacy (1983) measured δ_t change (long-dashed line in Fig. 9.1; see also Peng et al. 1983).

Preindustrial atmospheric CO_2 levels, calculated from the Pacific Coast δ_t record, are given in Fig. 9.2 (heavy solid line). For the year 1600, a value of 268 parts per million by volume (ppmv) is obtained, with atmospheric CO_2 levels averaging 276 ppmv for the AD 235–1850 interval.

The Houghton et al. (1983) estimates of biospheric fluxes, when combined with known fossil fuel CO_2 releases, result in an atmospheric CO_2 level of 257 ppmv for the year 1860 (light solid line in Fig. 9.2). The Freyer and Belacy (1983) δ_t record yields atmospheric CO_2 levels around 1800 AD of about 230 ppmv (long-dashed line in Fig. 9.2). If only fossil fuel releases have occurred, a preindustrial level of 295 ppmv is calculated.

The above values can be compared with the measured preindustrial CO_2 levels of 260 ppmv in air bubbles that were trapped in polar ice during recent millennia (Barnola et al. 1983).

Of critical importance in the determination of preindustrial CO_2 levels is the derivation of an unambiguous global δ_a signal from the δ_t record. From the data presented here, it is evident that substantial differences exist between the δ_t records from Pacific coastal sites and those mainly from Europe (the Freyer and Belacy record). Clearly, additional studies are needed to identify and eliminate the sources of variability in the δ_t records.

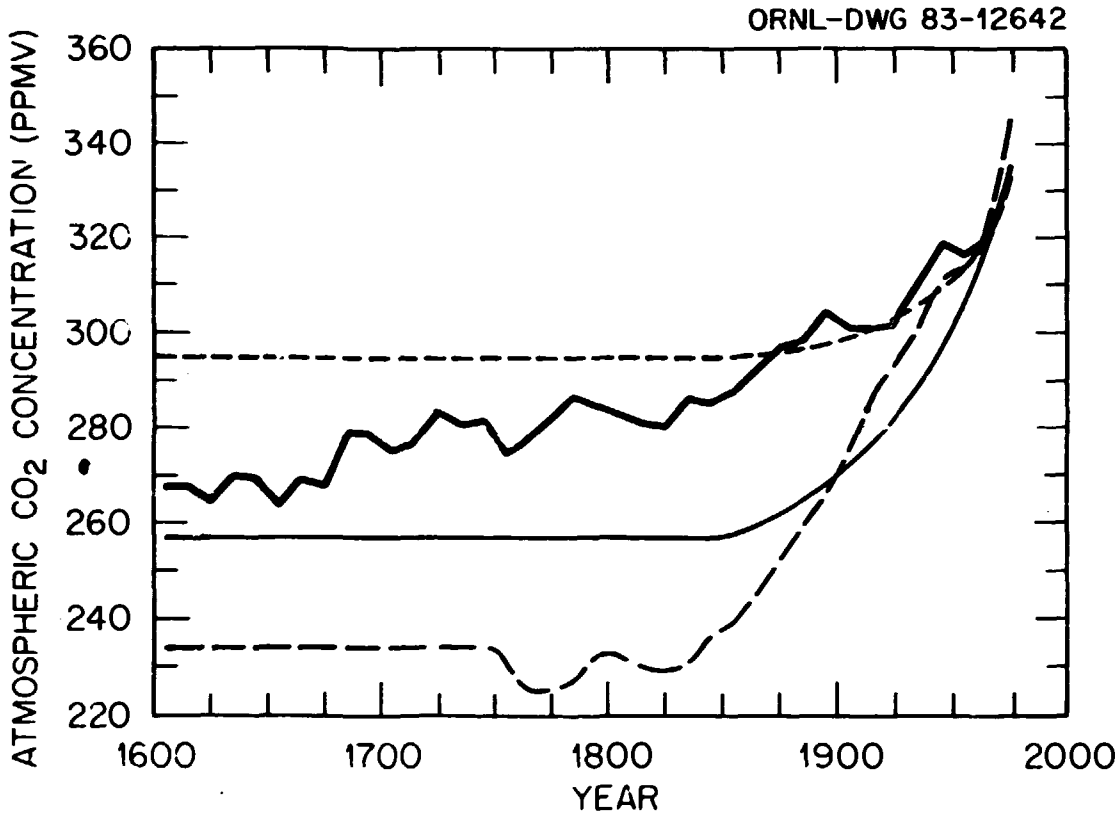

Fig. 9.2. Calculated atmospheric CO_2 levels when only fossil fuel CO_2 is released (short-dashed line). The addition of biospheric fluxes as calculated from the Pacific Coast δ_t record yields the heavy solid line, and similarly the Freyer and Belacy (1983) δ_t record yields the long-dashed line. Adding biospheric CO_2 according to the Houghton et al. (1983) estimates yields the light solid line.

New Evidence from Carbon Isotopes in Tree Rings from the Southwestern United States: Removal of Climatic Interferences (S. W. Leavitt and A. Long)

As noted in the previous section, different approaches to $^{13}C/^{12}C$ analysis of tree rings have yielded contradictory reconstructions. Contributing to some of this divergence are site selection, the wood component chosen for analysis, environmental influences on fractionation, and natural intra-individual and intrasite isotopic variability. A recent study by Leavitt and Long (1983) was aimed particularly at eliminating both climate effects on isotopic fractionation and the radial isotopic variations within individuals, as contained in a 50-year juniper (*Juniperus* spp.) tree-ring record from Arizona. The research reported here examines a much longer set of $^{13}C/^{12}C$ measurements from pinyon pine trees growing at nine sites in Arizona and New Mexico.

Because local meteorological measurements are typically limited to the past 50 to 100 years, ring width measurements have been used as proxy climate indicators (Fritts 1976). From raw ring-width plots, each tree's standardized tree-ring indices (STRI) were obtained by removing the growth trend. The removal of the growth trend also serves to reduce the sensitivity of the indices to long-term ($\approx$ the tree's lifetime) climatic shifts. From previous studies each locality already had site STRIs, which are a linear combination of 10 to 20 individual STRIs.

Environmental influences on these curves were tested by regressing the δ_t values of each tree with their respective site STRI, individual raw ring-width measurements (RRW), individual stand-

rdized ring-width measurements (ISTRI), and ring areas (AREA). In the broadest of terms, STRI could be considered a measure of local climate variations, with long-term trends removed (Fritts 1976), RRW contains a growth curve superimposed on the individual's response to local climate and other environmental influences, ISTRI is RRW without the growth curve, and ring areas may be a measure of net carbon assimilation by the tree (Stuiver 1982). Regarding the ring areas, the plant carbon-fractionation model of Francey and Farquhar (1982) had indicated the $\delta^{13}C$ of a plant to be dependent on the rate of CO_2 assimilation, and Stuiver has determined that for trees under certain conditions the ring areas may be a proxy indicator of net assimilation.

An observed correspondence of δ_t maxima with minima and maxima of the STRI curves suggests an influence of climate on δ_t of pinyon pine. However, there was no single proxy environmental parameter that was strongly correlated to δ_t in all sites. There were more statistically significant (or nearly so) relationships for δ_t with STRI than with any of the other parameters. Because the other three parameters represent measurements of the individual's growth response, it appears that gross factors affecting the whole site (e.g., temperature, rainfall) generally seem to influence δ_t of the individual more than other specific individual influences (e.g., competition, heredity). Exceptions include trees at two sites which show a significant relationship of δ_t with individual ring thickness (RRW). The fact that these two relationships are positive suggests a correlation between the decreasing ring thickness of the natural growth curve with generally decreasing δ_t values. This is supported by no significant correlations between δ_t with ISTRI (raw thickness with growth curve removed) for these two sites. On the other hand, δ_t values at one site seem to be independent of any of these parameters. Additional samples from this site are being examined in an attempt to gain better understanding of this anomaly.

The mean δ_t curves show a generally decreasing trend. The drop from preindustrial (1800–1850) to present is only about 0.5 per mill, considerably less than the 1.5 to 2 per mill drop found by Freyer (1979) for European trees or the 1.3 per mill drop found in Arizona juniper trees for 1930–1979 alone (Leavitt and Long 1983). The pinyon curve, however, does show a δ_t increase from about 1930 to 1960, approximately coincident with one observed by Freyer (1979), which he suggested may be related to hemispheric cooling of that interval.

Another feature of the mean δ_t curve is that the 1955–1980 period actually shows a drop of about 0.5 per mill. Given errors of $\sim$0.3 per mill for the 1955–1980 points, this drop is consistent with the measured atmospheric $\delta^{13}C$ shift from 1956 to 1978 of -0.65 ± 0.13 per mill (Keeling et al. 1979). Whereas the pinyon post-1955 trend is continuously downward, that measured in Arizona juniper rings was downward with a flattening after 1965.

When the δ_t trends were "corrected" for environmental effects (using a multiple regression of δ_t vs STRI and RRW), the mean δ_t curves were smoothed and the drop from preindustrial to present was further reduced. This resembles the flat δ_t trends observed in Tasmanian tree rings (Francey 1981). If these then represent atmospheric $\delta^{13}C$ curves and the fossil-fuel contribution is removed, a generally flat curve with a post-1930 upward trend results. This suggests a previously neutral biosphere which has become a net carbon sink over the last 50 years.

The δ_t trends in tree rings of sites widely scattered about the American Southwest show remarkably similar short-term features. On the basis of strong inverse δ_t with site STRI serial correlations, good growth years (cool, wet) favor more negative $\delta^{13}C$ values, and poor years (warm, dry) favor less negative values. If this is a temperature effect, then it may serve as the basis for a carbon-isotope tree-ring paleothermometer.

Sufficient errors remain in these $\delta^{13}C$ reconstructions so as to allow other interpretations, but these results seem to be quite distinct from the very large $\delta^{13}C$ drop measured in European trees

(Freyer 1979, Freyer and Belacy 1983). In addition to reducing scatter by accounting for climatic influences, errors may be further reduced if the natural variability of δ_t in and among trees is known and considered in the sampling process.

Arid-Zone Soil Carbonates in the Global Carbon Cycle (W. H. Schlesinger)

The soils of arid and semiarid ecosystems store carbon in inorganic form, primarily as calcium carbonate. This secondary carbonate occurs in a variety of forms, ranging from precipitates in the interstitial spaces of the parent material (caliche or calcic horizons) to almost pure, laminated layers of carbonate (calcrete or petrocalcic horizons) (Gile et al. 1981). Although some of these deposits are very old, carbonate precipitation is also a present-day pedogenic process. Therefore, it is important to understand the role of natural formation of arid-zone soil carbonates in the global carbon cycle.

Soil samples were collected from four undisturbed soil profiles in the eastern Mojave Desert, with care taken to avoid calcareous parent material. Samples from two of these profiles have been analyzed for carbonate content and ^{14}C age. By dividing the age-at-depth into the carbonate content above that depth, one can calculate that the rate of carbon storage in caliche formation ranges from 0.2 to 0.4 g C m^{-2} $year^{-1}$ in these soils. The ^{14}C ages have been validated by independent dating using the uranium-thorium series. These measurements were performed by Dr. Richard Ku (University of Southern California), using his published methods (Ku et al. 1979). The stable isotope measurements ($^{13}C/^{12}C$ and $^{18}O/^{16}O$) suggest that the carbonate precipitates in arid soils as a result of evaporation of water from the soil profile, not as a result of an interaction of root respiration by desert plants with the soil carbonate equilibrium.

Carbonate precipitation in arid soils ranges from the low values measured in the Mojave Desert to values as high as 1.4 g C m^{-2} $year^{-1}$ (Gile et al. 1981) in some soils of southern New Mexico. These results indicate that an earlier, preliminary estimate of a worldwide flux of 2.3×10^{13} g C $year^{-1}$ (based on an average annual precipitation rate of 0.5 g C m^{-2}, Schlesinger 1982) for the storage of carbon in desert caliches is not likely to change radically. Thus, the existing source term for carbon flux in desert soils is generally acceptable unless anthropogenic activities (e.g., cultivation, irrigation) affect this natural precipitation process.

Geographic Variation of Fossil Fuel CO_2 in the Ocean (I. Y.-S. Fung)

Many 1-D models (e.g., Oeschger et al. 1975, Broecker et al. 1979) have been used to investigate the capacity of the ocean to take up fossil fuel CO_2. In this study, a first attempt was made to couple a 3-D atmospheric tracer transport model to a diffusive ocean to study the geographic variation of the fossil fuel CO_2 signal in the ocean. This work does not address the issue of the fate of the total fossil fuel signal in the ocean, but rather, the difference over some period in total carbon content in the ocean due to fossil fuel release.

GEOSECS measurements of bomb-produced tritium in the ocean have provided an excellent picture of the penetration of tritium into the upper thermocline (Ostlund et al. 1976, 1979, 1980). Assuming that the transport of tritium and other tracers can be mimicked by a diffusion process, we have used the tritium profiles to derive k, the effective thermocline diffusion coefficient at each GEOSECS station. These diffusion coefficients are found to be well correlated with the Brunt-Vaisala frequency (N^2) at the base of the winter mixed layer. The empirical relationship thus obtained is used with N^2 at each ocean grid point in the model to yield a global map of the effective thermocline diffusion coefficients. The equivalent global k is 1.7 cm^2/s, close to that estimated

independently by Peng et al. (1982). The map shows low diffusion rates $k \approx 0.2$ cm^2/s in the eastern equatorial Pacific where upwelling and high stability at the base of the mixed layer inhibit vertical mixing. In the Greenland–Norwegian Sea area, convective overturning results in $k > 10$ cm^2/s.

Rotty (1983, and personal communication) has estimated the temporal and geographic distribution of fossil fuel release of CO_2. This is used as input to the 3-D tracer model (cf. Fung et al. 1983) coupled to the diffusive ocean. In this model, CO_2 released into the atmosphere by fossil fuel burning is advected by winds generated by a global general circulation model of the atmosphere. Some of this CO_2 enters the mixed layer where it is subjected to diffusion into the thermocline.

The model was integrated from an initial state of air-sea equilibrium, and the fossil fuel release figures for 1957 to 1959 were used. Because most of the fossil fuel release is in the northern hemisphere and the release is increasing exponentially in time, and because the interhemispheric exchange time in the atmosphere is 1 to 2 years, most of the fossil fuel CO_2 has remained in the northern hemisphere in the 3-year integration. As is expected from the fossil fuel release patterns and the resultant atmospheric CO_2 distribution, ΔC (the 3-year difference in total carbon content in the upper 1250 m of the ocean due to the fossil fuel released from 1957 to 1959) is largest in the coastal areas of the northern hemisphere and decreases southwards. However, because of their large areal extent, the total uptake of CO_2 in the southern oceans (5×10^{10} kg) is about one-third that of the northern oceans. In the 3-year reference period, most of the uptake remains in the mixed layer; the largest penetration into the thermocline occurs where both the atmospheric concentration and diffusion coefficients are large (e.g., in the Greenland–Norwegian Sea area).

Several caveats must accompany these preliminary results. We have assumed that the transport of carbon from the mixed layer can be mimicked by a vertical diffusion process. On longer time scales, lateral transport processes dominate and cannot be neglected. We have also assumed that air-sea equilibrium existed initially. This is, of course, not true. Because of the long history of anthropogenic release of CO_2 into the atmosphere and the long diffusive time scale of the thermocline, the globally averaged CO_2 concentration in the atmosphere must be higher than that in the ocean. Therefore, these results only represent the ocean's response to the fossil fuel CO_2 released from 1957 to 1959 and, hence, a lower estimate of the actual 1957 to 1959 difference in total carbon content of the ocean. These assumptions of the model are currently under investigation. We plan to continue integration of the model (with improvements) so that model results can be compared with measurements of oceanic carbon concentration obtained in the last decade.

Intramural Research

Effect of Agriculture on Soil Carbon Change (L. K. Mann)

The response of soil carbon density to perturbation is a significant component of the global carbon cycle. Total soil carbon has been estimated under native vegetation, but quantitative changes in soil carbon following cultivation are poorly defined, and rates of change are known only for a few specific cases.

Most global estimates of soil carbon range from 1400×10^{15} to 2200×10^{15} g (Bohn 1982; Schlesinger 1977, Post et al. 1982) and are based on uncultivated soils. Previous estimates of changes in carbon following deforestation and/or cultivation indicate 20 to 50% loss of carbon in the first 20 to 50 years (Bauer and Black 1981, Tiessen et al. 1982). These estimates were based on changes primarily in the plow layer of soils. To evaluate past shifts and to predict future changes in

atmospheric CO_2, the effect of cultivation on soil carbon in the entire rooting zone of the profile must be more fully understood.

Major agricultural soils in the central United States were first cultivated during a relatively short period in the late 1800s. These soils, which have also developed from homogeneous parent material, therefore represent a large sample area that has been in continuous cultivation for nearly 100 years. Most soils in this area are derived from loess and developed under one of two main vegetation types: prairie or deciduous forest. The taxonomy of soils currently in use in this country groups soils by characteristics that are pedogenic in origin, providing natural groupings for comparisons of carbon content in cultivated and uncultivated soils. Changes in carbon content to 1.5 m depth were estimated from profile carbon data from 76 uncultivated and 246 cultivated soils. These were grouped by soil suborders. Data were obtained from Soil Conservation Service surveys over an 11-state area. The major soil types in the area were Udolls, well-drained soils formed under prairie vegetation, and Udalfs, well-drained soils formed under forest.

Within the top 15 cm (plow layer depth) of the soil profile, differences in soil carbon of cultivated compared with uncultivated lands were similar for all taxonomic groups to those previously reported in the literature (25 to 50% loss). However, the major soil type in the study area (Udolls) was not different in total carbon in cultivated and uncultivated soils (Table 9.3). Although the

Table 9.3. Estimated organic carbon content in cultivated and uncultivated soils

	Carbon (kg/m^2 to a depth of 1.5 m)	
	Cultivated	Uncultivated
Soils formed primarily under prairie		
Udolls	15.4	15.3
Aquolls	19.3	22.6
Ustolls	12.0	12.3
Soils formed primarily under forest		
Udalfs	5.1	7.6
Udults	4.6	5.9
Entisols	7.0	9.6

upper 15 cm was significantly lower in carbon content in these cultivated soils compared with uncultivated samples, the lower horizons were significantly higher (Fig. 9.3). The other major soil type in the area (Udalfs) had significantly less carbon throughout cultivated profiles. Estimated net losses of organic carbon are 3% from Mollisols in the study area and 32% from other soils. The estimated 11-state regional average loss is 11%.

The mechanism for this apparent accumulation of carbon below the plow layer in cultivated soils and the timing of changes in all soils are not known. Relative accumulations may be due to changes in rooting depth as a result of changes in infiltration of moisture and differential complexing of organic compounds with calcium and clays. In these data, profiles that were samples under pasture vegetation had slightly greater organic carbon content than profiles sampled under wheat, corn, other cultivated crops, or fallow. These results indicate that total soil carbon does not necessarily decrease following cultivation; however, they emphasize the importance of evaluating changes in carbon content below the plow depth, as well as understanding the rates at which such changes are taking place. Better understanding of the relationships between soil carbon and soil type, chem-

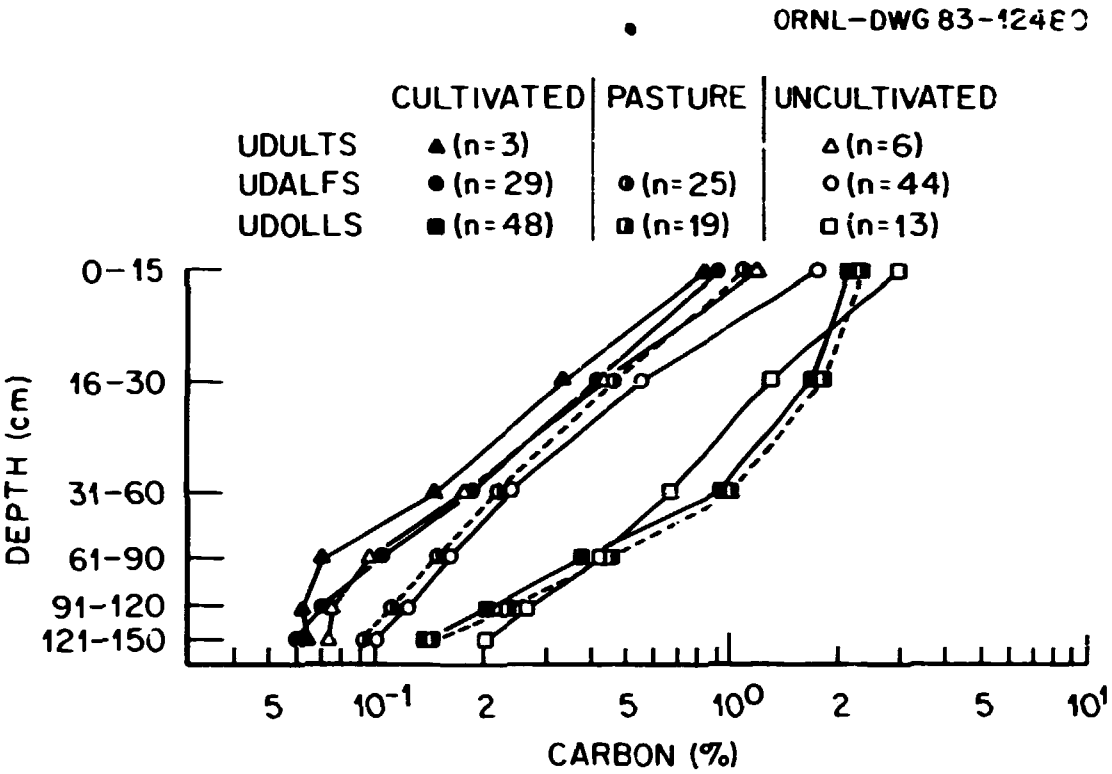

Fig. 9.3. Depth distribution of percent carbon in well-drained loess-derived soils of the midwestern United States. Udolls (formed primarily under prairie vegetation) and Udalfs (formed primarily under forest) are the major soils of the area.

istry, depth, and rates of change can have a major impact on reducing the uncertainty of CO_2 flux to the atmosphere from land-use change.

Global Patterns of Soil Carbon and Nitrogen Storage (W. M. Post)

Vegetation productivity and organic matter decomposition are primary components of the global cycle of several major elements—notably, carbon and nitrogen. Plant productivity removes carbon from the atmosphere and, through litterfall and root production, contributes organic materials to the soil. These soil organic materials provide an energy source for decomposer organisms that are responsible for various chemical transformations that determine the availability of essential plant nutrients. The availability of plant nutrients, particularly nitrogen, which depends on the quality of organic material available for decomposition and soil moisture and temperature, in turn influences plant productivity. Thus, the role of terrestrial ecosystems in the global cycle of elements, particularly carbon, depends on the interaction of elements in soil. As a result, it is necessary to determine the patterns of organic carbon and nitrogen in soils. From these patterns we can generate hypotheses concerning the role of regional soil-forming factors in determining soil fertility and carbon dynamics.

Data on organic carbon and total nitrogen from over 3100 soil profiles were assembled into a data base (Zinke et al., in press). Each soil profile was classified according to the Holdridge Life Zone in which it was found. A Holdridge Life Zone is defined by the climate variables biotemperature and annual precipitation (Fig. 9.4). Biotemperature is the annual mean of unit-period tempera-

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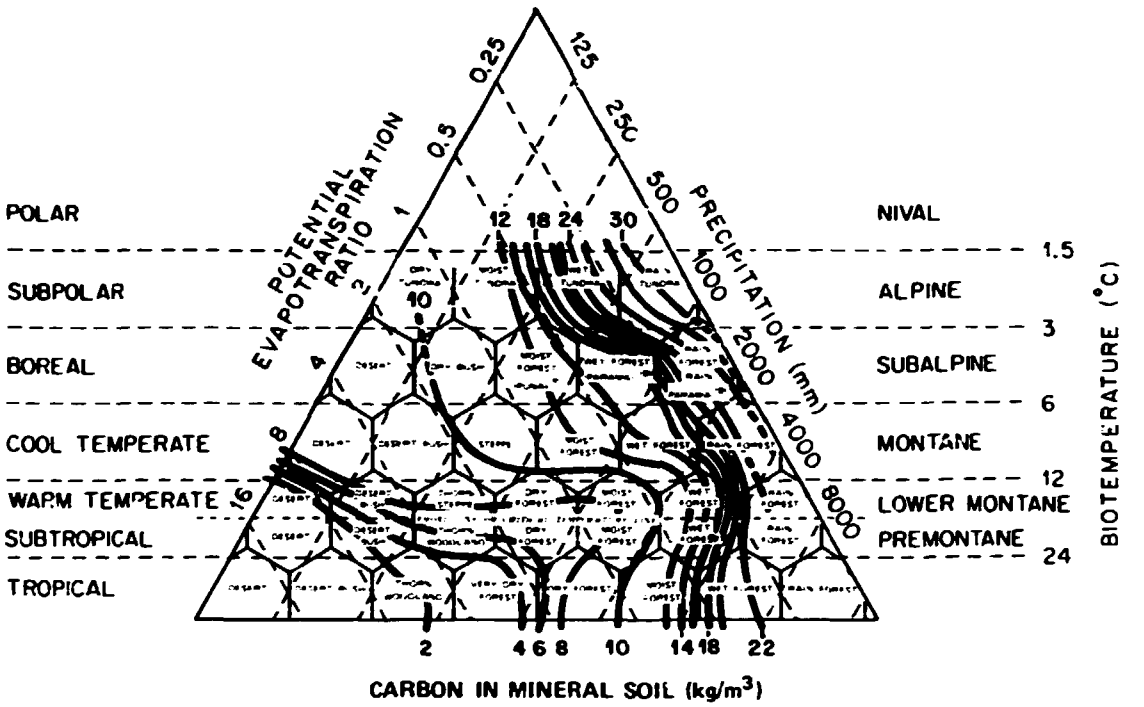

Fig. 9.4. Contours of soil carbon density plotted on Holdridge schematic for world life-zone classification. Values of biotemperature and precipitation uniquely determine a life zone and associated vegetation. Dash lines indicate probable extrapolation of contour lines in climatically extreme life zones from which data were not available.

tures with substitution of zero for all temperature values below 0°C and above 30°C. Summary statistics were computed for each life zone class in order to examine the relationships between climate and soil organic carbon and nitrogen pools.

Organic carbon storage in soil ranges from 2 kg/m^3 in warm deserts to over 36 kg/m^3 in rain tundra (Fig. 9.4). Nitrogen shows a similar general pattern, ranging from 200 g/m^3 in warm deserts to over 2000 g/m^3 in rain tundra with an additional peak in subtropical wet forests (Fig. 9.5). However, nitrogen storage with climate differs in detail from carbon storage. Detailed patterns of carbon storage are related to the potential evapotranspiration ratio. Where this ratio is 1, carbon storage is around 10 kg/m^3; it decreases as this ratio increases (evapotranspiration exceeds precipitation) and increases as this ratio decreases (precipitation exceeds evapotranspiration). This carbon storage pattern is modified by low storages in dry subtropical and dry, warm-temperate deciduous forests where seasonality is important. This low carbon storage is also apparent in the pattern for nitrogen storage but extends into cool temperate and boreal moist and wet forests where there is 800 to 1200 mm of annual precipitation. Thus, while soil nitrogen storage, like soil carbon storage, is influenced by vegetation productivity and decomposition processes largely corresponding to the potential evapotranspiration ratio, nitrogen storage has a component that is strongly influenced by precipitation, particularly in forested life zones. This reflects the role of precipitation in direct inputs of nitrogen and losses by leaching inorganic nitrogen from the soil.

Carbon-nitrogen (C-N) ratios range from less than 10 in tropical deserts to over 20 in cool wet or rain forests. Cool life-zone C-N ratios average between 15 and 20, whereas warm life-zone C-N

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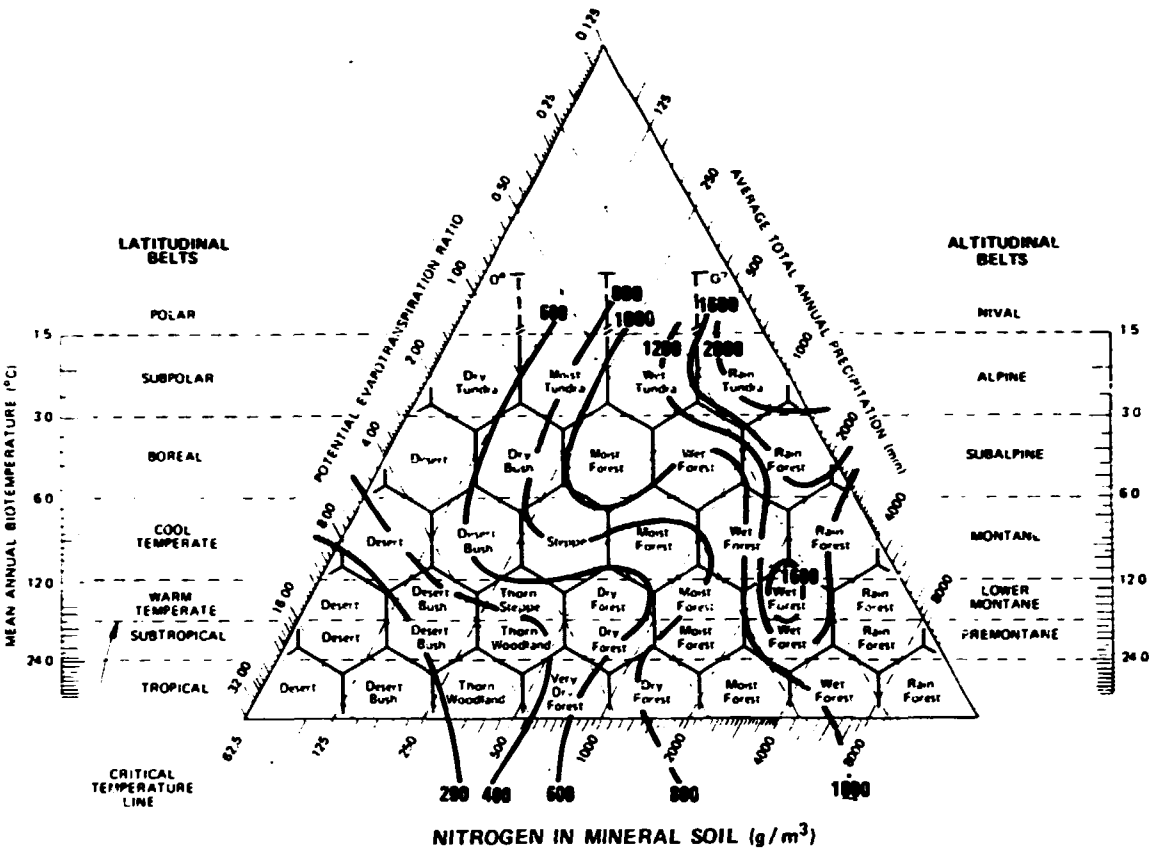

Fig. 9.5. Contours of soil nitrogen density.

ratios are somewhat lower—between 10 and 15. These results indicate that (1) relatively large amounts of soil nitrogen in tropical regions are associated with humic materials resistant to decomposition, resulting in low C-N ratios; (2) seasonality in dry subtropical regions leads to moderate productivity and high decomposition rates, resulting in low soil carbon and nitrogen storage; and (3) extremely slow decomposition in wet tundra regions results in high carbon and nitrogen storage with high C-N ratios.

Expected Biomass Dynamic of Forested Landscapes (H. H. Shugart, W. R. Emanual, and A. M. Solomon)

A small patch of forested landscape has a longer-term dynamic pattern that is characterized by a cycle. Following the death of a large tree, a cohort of small trees in the resultant break in the forest canopy begins to grow. Some of the trees in this cohort may have been in the vegetative layers below the dead canopy tree, and some of the trees may have germinated after the dominant tree died. The trees grow and compete with one another. According to the sizes and species attributes of the particular assemblage of trees at the site (and with a degree of randomness), some of the trees die as others grow toward the canopy. A few trees dominate the forest canopy in the small area, and ultimately a single tree is dominant. When this canopy-dominant tree eventually dies, a new cohort begins to grow and the cycle is closed. This underlying pattern is a unifying aspect in the dynamics of the forests of the world.

If the mass of material on a small (~0.10 ha) part of a forested landscape were plotted over time, the resultant graph of this biomass would be a cyclical saw-toothed curve. One can think of the total landscape as a mosaic of such small patches and can use a succession model to predict the fate of each of these patches. By tabulating the fate of the hundreds of such patches that comprise a natural landscape, one can obtain the expected response of the landscape mosaic over time.

Gap models developed at ORNL have been used to determine the successional change of a landscape composed of many patches. When all the patches are altered by a single widespread event, each patch begins a synchronized regrowth. If there are no strong interactions among the patches that make up the forest mosaic, this case can be simulated by summing the responses of several gap model runs with each run initiated on a bare plot. Such a Monte Carlo simulation of a landscape is based on the assumption that each patch is independent of the others. This approach is being used to understand the carbon dynamics of forested landscapes as an important initial step in understanding the dynamic role of the forested landscape in the global carbon cycle.

Based on experiments using a variety of gap models, one would expect a monospecies-dominated landscape to feature a biomass overshoot response followed by a return to stochastic equilibrium. In forests of low diversity in which there is a composition shift of the dominant species following the breakup of the even-aged initial canopy, the overshoot can be amplified if the initially dominant species are larger than the species that dominate the mixed-size forest that develops over long periods. Extremely dramatic cases of such a landscape biomass dynamic are found in the successional sequences involving Douglas fir (*Pseudotsuga menziesii*) in the North American Pacific Northwest and involving *Eucalyptus regans* and *E. obliqua* in Tasmania. In other systems of low diversity, a compositional shift at the time of first canopy breakup does not amplify the biomass overshoot response, but the overshoot behavior is still quite discernable. The persistence of such dynamics in the presence of moderate diversity is a consequence of the similar size and longevity among the dominant species that cause the biomass dynamics of the landscape elements to have the synchrony needed to produce the landscape overshoot response. Some low-diversity forests show a loss of the overshoot of the landscape biomass response. Generally, in diverse forests that have a mixture of growth rates, tree species sizes, and mortality rates, the synchrony across the patches that make up the landscape is lost due to the differences in the attributes of the species that are locally abundant at a given patch (with a resultant loss of landscape biomass overshoot).

An important implication of these studies is that the dynamics of the earth's two large living carbon reservoirs, the low-diversity boreal forest and the high-diversity tropical rain forest, probably have very different patterns in their biomass dynamics following a large-scale change.

Effects of Ocean Model Structure on CO_2 Uptake (T.-H. Peng)

Until valid ocean general-circulation models are constructed, the uptake of fossil fuel CO_2 by the sea will have to be determined from reservoir models calibrated through use of the distribution of natural radioisotopes and transient tracers. One important question in connection with this interim strategy is: how sensitive is the uptake of excess CO_2 to the design of these models? We have looked into this problem and made computations using various models.

One basic one-dimensional (1-D) ocean model we chose is the box-diffusion model of Oeschger et al. (1975). The characteristics of this original model were calibrated with the distribution of natural radiocarbon in the ocean. With the availability of GEOSECS data, this model was then calibrated with the distribution of bomb-produced radiocarbon. The mixing rate and CO_2 exchange

rate thus obtained are not the same as those derived from the natural radiocarbon data. The global box-diffusion model is also segregated into eleven regional models to take into account the diversities of world ocean dynamics. These regional box-diffusion models are then calibrated on GEOSECS tritium and ^{222}Rn data. Comparison of CO_2 uptake indicates that the integrated uptake by regional models is essentially the same as that by the original box-diffusion model. However, the bomb-produced radiocarbon calibrated model shows about 15 to 45% more uptake than the original model.

Several structural modifications have been made to the basic box-diffusion model by several researchers. These include one or more of the following features: polar outcrop, biological activity, nutrient cycles, upwelling, new deep-water formation, and separate deep-water reservoirs for the major oceans. Our modified box-diffusion model shows about 25% more uptake than the basic model. This increase in uptake is still too small to resolve the balance in the fossil fuel CO_2 budget.

It is believed that further elaboration of basic 1-D models is not likely to significantly increase the absolute accuracy of estimated CO_2 uptake by the ocean. Further improvement of ocean models is expected from two-dimensional (2-D) or three-dimensional (3-D) models of ocean circulation. However, not enough is now known about the ocean to construct and properly calibrate these multidimensional models on a global scale.

Two-dimensional thermocline ventilation models of the north temperate Atlantic with widely differing circulation patterns (see Fig. 9.6) were calibrated to yield the tritium distribution observed

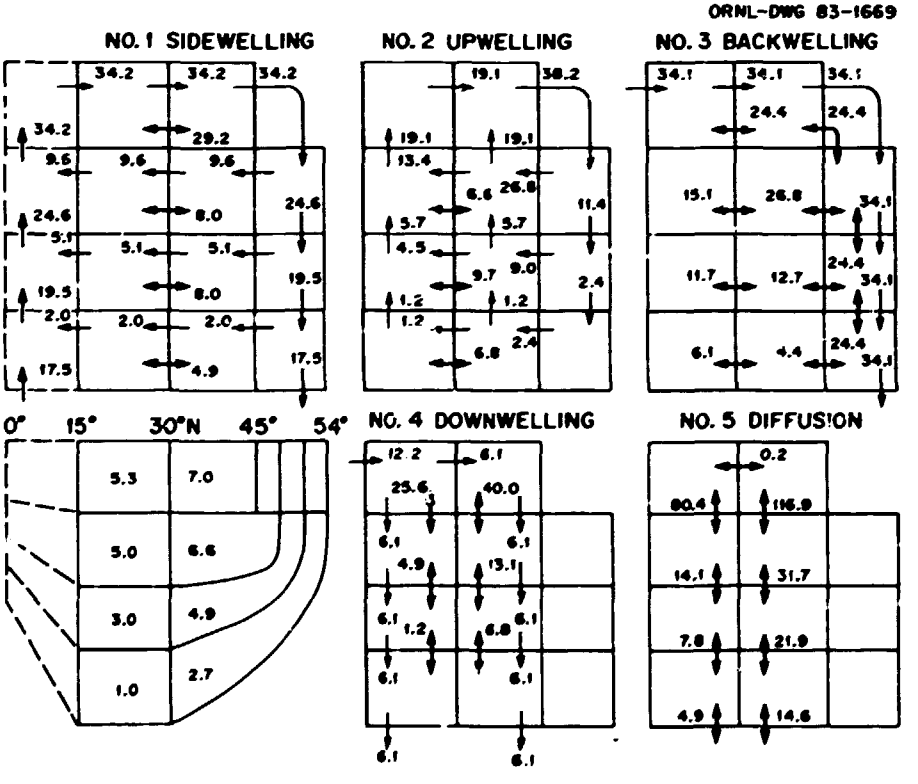

Fig. 9.6. Diagrams of the two-dimensional temperate thermocline model of the North Atlantic between 15 and 54° N. The isopycnal horizons and their outcrops are shown at the lower left. For convenience in presenting the circulation patterns, the surface outcrops between 45 and 54° N are moved to the side in the remaining diagrams. Models 1 through 3 are isopycnal ventilation patterns. Models 4 and 5 are vertical-mixing patterns without polar outcrop. The water fluxes given in the diagram are in units of Sverdrup (10^6 m^3/s).

during the GEOSECS surveys. These models were then run for the ^3He, bomb-produced ^{14}C, radiokrypton, the freons, and anthropogenic CO_2. Comparison among the model results and between the model and the observed data set suggests that the information carried by the distributions of multiple tracers is not sensitive in distinguishing among thermocline models of the north temperate Atlantic. Uptake of anthropogenic CO_2 by 2-D isopycnal ventilation models with polar outcrops does not show a significant difference from the uptake by the 1-D vertical mixing model without polar outcrops. The model-to-model differences in the uptake of excess CO_2 are small, confirming the validity of the analogue approach. This preliminary computation implies that a 2-D isopycnal ventilation model may not necessarily facilitate a larger oceanic sink for CO_2 uptake. A final conclusion is not possible at this time and will not be obtained until a global model is developed and properly calibrated.

Uncertainties Associated with Predictions of Global Carbon Models (R. H. Gardner and J. R. Trabalka)

Global carbon cycle models describe the physical, chemical, and biological dynamics of carbon transport so that past and present trends can be simulated and future atmospheric carbon dioxide levels can be predicted. The sources of uncertainties associated with these predictions can be quantitatively determined by Monte Carlo simulations with Latin hypercube sampling (Gardner, in press). This method was applied to the global carbon model of Killough and Emanuel (1981) by varying model parameters and initial conditions over ranges limited by model assumptions or described by data. Each Monte Carlo iteration selected random, independent parameter values, initialized the system, and simulated global carbon dynamics from the year 1800 to 2075. Statistical analyses of the results were performed to relate the uncertainties of model predictions to the parameters, initial conditions, and processes they affected.

Results from these sensitivity-uncertainty analyses were dependent on the time interval and the state values being considered. Deviations of simulated atmospheric CO_2 from the Mauna Loa record (1958 to 1980) are most sensitive to the uncertainties associated with PTER (the forest clearing record from 1800 to 1980), ACTO (the average depth distribution of ^{14}C in the ocean), CAO (the preindustrial concentration of CO_2 in the atmosphere in 1800), and DTEMP (the temperature response of the ocean surface waters to CO_2-induced climate change). PTER represents the principal data that must be examined in attempting to resolve the role of the terrestrial biosphere in the global carbon cycle. ACTO determines the effective rate of vertical transport of carbon from the surface waters to the deep ocean and, in part, the air-sea exchange rate of CO_2. CAO represents critical information needed for accurate carbon cycle model simulations and the evaluation of potential climate responses to increasing CO_2. The last factor, DTEM, is important because it represents one facet of a potential climate feedback on the carbon cycle. Warming of the ocean surface waters can affect the highly temperature-sensitive chemical equilibria that partially control the magnitude of air-sea exchange of CO_2.

Estimated levels of uncertainty in future fossil emissions are very high, and, when incorporated in this analysis, they dominate total prediction uncertainties. The relative contribution to the uncertainty in projected atmospheric CO_2 concentration from the carbon cycle model component declines with time from 1980 to 2075, contributing less than 20% to the total variance in 2075. The high level of uncertainty associated with the fossil fuel scenario is due to the difficulty in making long-

term projections of the impact of the world's economy and associated energy needs on fossil fuel CO_2 emissions.

Critical data needs for this model-scenario combination are those that both define the model structure and reduce parameter uncertainties. These results reinforce the importance of key data collection activities designed to improve (1) the understanding of the role of the terrestrial biosphere, (2) the information on air-sea exchange and transport of CO_2 in the oceans, (3) estimates of preindustrial levels of CO_2, and (4) continued generation of accurate data on the behavior of CO_2 in the atmosphere. It is difficult to quantify possible scenario changes, such as those associated with land-use practices and fossil fuel use, and the uncertainties associated with alternate model structures; however, these are likely to be more important than present uncertainties associated with model parameters.

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PART III. EXTRAMURAL ACTIVITIES

10. EDUCATIONAL ACTIVITIES

Seminar Program

During the past year, the seminar committee offered a diverse program of guest lectures to inform Environmental Sciences Division (ESD) staff and other interested members of the local scientific community about topics of general interest in environmental sciences (Table 10.1). The seminar series relies largely on suggestions from ESD staff members concerning the selection of outstanding speakers.

Table 10.1. Seminar speakers, Environmental Sciences Division: October 1, 1982—September 30, 1983

Date	Speaker	Title
10/14/82	Dr. Arthur H. Johnson University of Philadelphia Philadelphia	Red spruce dieback in New England: evaluating hypotheses regarding the cause
2/4/83	Dr. Graham P. Harris McMaster University Hamilton, Ontario	Some thoughts on the history and future of ecological ideas
2/23/83	Dr. Zvika Abramsky Ben-Gurion University Beersheba, Israel	Community ecology of desert rodents in Israel
3/14/83	Dr. Christopher Uhl Pennsylvania State University University Park	Biological and chemical responses of a stressed Amazon basin ecosystem
3/17/83	Dr. James Kitchell University of Wisconsin Madison	Predator-prey systems in the Great Lakes: past, present and possibilities
3/24/83	Dr. G. P. Patil Pennsylvania State University University Park	Multimodel modeling and data analysis with applications to recruitment
3/31/83	Dr. John Totter Oak Ridge Associated Universities Oak Ridge, Tenn.	Environmental stress, aging, and natural selection
4/18/83	Dr. Donald Mackay University of Toronto Toronto	Air-water exchange processes
4/26/83	Dr. Warwick Vincent University of California-Davis Davis	Nutrient limitation and productivity in the world's freshwaters: can we generalize?
5/19/83	Dr. James R. Gosz University of New Mexico Albuquerque	The use of $^{87}Sr/^{86}Sr$ ratios for calculating atmospheric and weathering inputs to ecosystems
5/27/83	Dr. Thomas Fontaine III Savannah River Ecology Aiken, S.C	Fate of heavy metals in acidic streams: models, uncertainties, and risk analysis

Table 10.1. (cont.)

Date	Speaker	Title
6/27/83	Dr. Hugh Miller Macaulay Institute Aberdeen, Scotland	Cycles of nutrients and hydrogen ions in Scottish forests
7/20/83	Dr. Virginia Adams Pacific Northwest Forest and Experiment Station Corvallis, Oreg.	Plant recovery on Mt. St. Helens

Graduate Education Program

The ESD provides opportunities for graduate and postdoctoral research consistent with the mission of ORNL. During this reporting period, 16 graduate students were supported through a contract with The University of Tennessee Program in Ecology, two through a contract with Indiana University, and one through a contract with the University of Oklahoma. Supported students receive stipends administered by each student's university, and their research is guided by selected ESD staff members, one of whom serves on each student's university academic guidance committee. In addition, research done by students not requiring ESD support was accommodated on a more limited basis.

During this past year, periodic meetings were held involving all the graduate students and the ESD's graduate education coordinator. The purpose of the meetings was to explain ESD programs to new students and to provide a forum for comments and suggestions relating to the graduate program.

Undergraduate Education Program

Several programs for undergraduate student participation in ESD research and assessment projects provide a continuing opportunity for interaction between students and staff. A summary of these programs is provided in Table 10.2. Students involved in these programs are assigned to individual ESD advisors who guide each student through an experiment or project associated with one of the ESD programs. Each student is required to document results in a report and present a seminar to the ESD staff. These experiences in research participation are designed to expose the student to the research process in a large laboratory. The greatest benefits to students are frequently an expanded outlook on career opportunities in research and an understanding of practical approaches to research problems.

Table 10.2. Number of students in ESD undergraduate programs, October 1, 1982—September 30, 1983

Program	Number
Oak Ridge Associated Universities	3
Southern College and University Union	2
Emory University	1
Great Lakes College Association	3

11. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT SUBCONTRACTS AND INTERAGENCY AGREEMENTS

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Wood for energy in the Taiga—evaluation of potential species and their growth rates	Alaska, University of	J. H. Cushman
Preparation of a Manual of Engineering Practice for the manual series of the American Society of Civil Engineers	American Society of Civil Engineers	C. C. Coutant
Monitor data on surface deformation resulting from hydrofracture injection of nuclear waste by use of tiltmeter survey	Applied Geometrics, Inc.	S. H. Stow
Verification of predator scales to determine their age and monthly growth	Aquatic Consultants, Inc.	G. F. Cada
Assist in the development of a national operational plan for acid precipitation effects research	Argonne National Laboratory	D. S. Shriner
Research to determine accurately the ^{13}C:^{12}C isotopic ratio in atmospheric CO_2 over the past 150 years by analyzing the corresponding isotopic record in tree rings by removal of climatic interferences	Arizona, University of	J. R. Trabalka
Assist in developing a national operational plan for acid precipitation effects research	Battelle Pacific Northwest Laboratories	D. S. Shriner
Fuels and chemicals from Woody Biomass Program	Bioenergy Development Corporation	R. I. Van Hook
Assist in developing a national operational plan for acid precipitation effects research	Brookhaven National Laboratory	D. S. Shriner
Assistance in developing the preliminary relationships between remote sensing-derived surface classes and stored organic carbon in soil	California, University of	R. I. Van Hook
Development of a three-dimensional transport model of the carbon cycle to the ocean	California, University of	J. R. Trabalka
Assist in the study to make a broad comparison of acid rain vs natural acid production and harvesting on forest nutrient status	Clemson University	D. W. Johnson
Ecosystem effects of whole-tree harvesting	Clemson University	D. C. West
Involvement with the National Atmospheric Deposition Program that requires sample analysis by a central analytical laboratory for comparability of data on atmospheric deposition on a national scale	Colorado State University	S. E. Lindberg

11. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT SUBCONTRACTS AND INTERAGENCY AGREEMENTS (continued)

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Developing a model to estimate turnover of organic matter in soil using tracer methodology	Columbia University	W. M. Post
Using an existing simulation model to produce net carbon exchanges between vegetation and the atmosphere resulting from land use changes in the tropics	Cornell University	J. R. Trabalka
Ecological effects of acidification on low-order woodland streams, with particular emphasis on the chemistry and effects of aluminum	Cornell University	J. W. Elwood
Changes in soil carbon storage when natural ecosystems are converted to managed use	Duke University	W. M. Post
Compile historical data on patterns of land use and vegetation cover for South and Southeast Asia from the period 1700 to 1980 AD	Duke University	J. R. Trabalka
Complete a literature survey and experimental work designed to define the role of carbonate formation in arid-zone soils in the global carbon cycle	Duke University	J. R. Trabalka
Supply materials, perform research, and consult and advise on various aspects of the Legionnaire's Disease Bacterium Project	Ecological Microbes Unlimited	S. W. Christensen
Prepare a revised draft Corrective Measures Handbook based on the current draft Corrective Measures Manual	Evaluation Research Corporation	R. B. Fitts
Provide support for planning, conduct, and documentation of the Third Annual Information Meeting of the U.S. Department of Energy (DOE) Low-Level Waste Management Program (LLWMP)	Evaluation Research Corporation	R. B. Fitts
Provide technical services to the Environmental Sciences Division (ESD) on the conduct of the DOE Low-Level Waste Management Annual Information Meeting	Evaluation Research Corporation	L. E. Stratton
Revise the draft document titled "Experience in Applying Remedial Action of Shallow Land Burial Facilities"	Evaluation Research Corporation	L. E. Stratton
"Eucalyptus for Biomass Production in Florida." This project is part of DOE's Short-Rotation Woody Crops Program	Florida, University of	J. W. Ranney
Collection and assembly of basic data and development and testing of mathematical models for carbon cycling in managed forests	Florida, University of	W. R. Emanuel

11. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT SUBCONTRACTS AND INTERAGENCY AGREEMENTS (continued)

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Evaluation of receptor mitigatory techniques applicable to acid deposition effects	General Research Corporation	D. S. Shriner
Studies to increase the biomass production of short-rotation coppice forest	Georgia, University of, Research Institute	J. H. Cushman
Prepare a set of technology-specific environmental guidance documents for synfuels	Georgia Institute of Technology	R. M. Reed
Material spiraling in stream ecosystems: feasibility of manipulating natural streams using pesticides	Georgia, University of	W. Van Winkle
Chemical analyses for soil and plant tissue samples. This work is part of the project, Forest Responses to Anthropogenic Stress	Georgia, University of	D. C. West
Studies on the tissue culture of hardwoods. This project is part of DOE's Short-Rotation Woody Crops Program	Georgia, University of	J. W. Ranney
Cultural and management practices for the Chinese tallow tree as a biomass fuel source	Houston, University of	R. I. Van Hook
Calibration of pollen records with biomass	Illinois State Museum Society	A. M. Solomon
Provide access to the CDC Cyber 175 computer at the University of Illinois and the Habitat Simulation System	Illinois, University of	M. J. Sale
Species spacing and management alternatives for short-rotation woody biomass production	Illinois, University of	R. I. Van Hook
The role of tropical forests in the global carbon cycle	Illinois, University of	J. R. Trabalka
Cooperation between Indiana University School of Public and Environmental Affairs and Oak Ridge National Laboratory (ORNL) on environmental sciences research and education programs	Indiana University	S. G. Hildebrand
Provide high-quality student interns who are well suited to ESD programs	Indiana University	L. W. Barnthouse
Changes in carbon dynamics and vegetation associated with cultivation practices in West African tropical forests	International Institute of Tropical Agriculture	W. M. Post
Breeding *Alnus* for intensive culture of biomass for energy. This project is part of DOE's Short-Rotation Woody Crops Program	Iowa State University	L. L. Wright

11. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT SUBCONTRACTS AND INTERAGENCY AGREEMENTS (continued)

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Preparation of an overview document on bioenergy R&D in the United States. This document will be utilized for the Short-Rotation Woody Crops Program	JAYCOR	R. I. Van Hook
Review and update strategic analysis of DOE's Biofuels Programs	JAYCOR	R. I. Van Hook
Furnish the necessary labor and materials and install the necessary equipment to perform drilling services to ORNL	Joy Machinery Company	C. S. Haase
Determination of the best species and management techniques for short-rotation production of fuel wood in the Great Plains	Kansas State University	J. W. Ranney
Assemble and evaluate oceanographic data in support of ocean model development	Lamont-Doherty Geological Observatory, Columbia University	W. R. Emanuel
Research designed to identify and quantify principal sources and sinks of atmospheric CO_2 on a global scale	Lamont-Doherty Geological Observatory, Columbia University	J. R. Trabalka
Computer-based data base in support of biomass programs as part of the larger DOE Advanced Conservation Technology (ACT) Information System at Lawrence Livermore National Laboratory	Lawrence Livermore National Laboratory	R. I. Van Hook
Consistent description and energy balance studies for specific biomass conversion technologies	Los Alamos National Laboratory	J. H. Cushman
Description of the status and well-being of the Ohio River fish community to provide a background against the impacts of site-specific projects that can be assessed by regulatory agencies	Louisville, University of	S. M. Adams
Development and testing of mathematical models for use in defining the role of the terrestrial biota in the global CO_2 cycle	Marine Biological Laboratory	J. R. Trabalka
Collect historical literature on waste disposal operations at ORNL and synthesize a document summarizing this literature	Maxima Corporation	T. Tamura
Internship program	Miami University	S. I. Auerbach
Tree species and management strategies for biomass production in the Great Lakes states	Michigan State University	R. I. Van Hook

11. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT SUBCONTRACTS AND INTERAGENCY AGREEMENTS (continued)

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Application of sugar maple and black locust to the biomass-energy plantation concept	Michigan Technological University	R. I. Van Hook
Use of wetlands for production of woody plants for fuels and petrochemical substitutes	Minnesota, University of	R. I. Van Hook
Quantify genetic variation in biomass yields and disease resistance for sycamore and identify superior seed sources and parent trees	Mississippi Agricultural and Forestry Station	R. I. Van Hook
Evaluation of biomass feedstock production projects	National Aeronautics and Space Administration	R. I. Van Hook
Computer support to run models of the atmosphere	National Aeronautics and Space Administration	J. R. Trabalka
Species selection and silvicultural systems for producing fuels from woody biomass in the southeastern United States	North Carolina State University	R. I. Van Hook
The influence of NO_2, SO_2, and O_3 combined at three concentrations on the growth of several plant species	North Carolina State University	D. S. Shriner
Analyze the relationships between airborne fraction, mathematical models of the global carbon cycle, and measurements of atmospheric CO_2 concentration	Oklahoma, University of	J. R. Trabalka
Proxy-climate records determined from modern pollen applied to fossil pollen records	Oregon, University of	A. M. Solomon
Evaluation of woody biomass production on a commercial-scale basis	Packaging Corporation of America	R. I. Van Hook
Maximizing woody biomass production through the use of municipal wastewater and sludge	Pennsylvania State University	R. I. Van Hook
Evaluate responses of acid deposition in natural systems	Pennsylvania State University	S. B. McLaughlin
Evaluation, on paper, of the economic efficiency of wood-energy plantations and delineation of needed further research to evaluate properly and accurately wood-energy plantations	Pennsylvania State University	J. W. Ranney S. B. McLaughlin
The role of tropical forest in the global carbon cycle	Puerto Rico, University of	J. R. Trabalka
Collect, validate, and analyze data on woody biomass plant growth models in use in the United States	Science Applications, Inc.	J. H. Cushman

11. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT SUBCONTRACTS AND INTERAGENCY AGREEMENTS (continued)

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Perform a survey and preliminary assessment of modeling and monitoring techniques associated with radionuclide containment/release from the burial of low-level waste	Science Applications, Inc.	R. S. Lowrie
Provide control of incoming analysis (status of sample analysis and detection of error) as well as available access to existing data and associated statistical analysis	Science Applications, Inc.	C. W. Francis
Provide word-processing and editorial support for preparation of proceedings	Science Applications, Inc.	J. F. McBrayer
Site-specific environmental data acquisition and review for small hydroelectric demonstration sites	Science Applications, Inc.	S. G. Hildebrand
Terrestrial and aquatic ecology support for Fossil Energy Environmental Project	Science Applications, Inc.	S. G. Hildebrand
Development of models to predict long-term dynamics of forests	Science Applications, Inc.	H. H. Shugart
Development, implementation, and analysis of models used to forecast the fate and effects of chemical contaminants in aquatic systems	Science Applications, Inc.	S. M. Bartell
The role of terrestrial ecosystems in the global carbon cycle and the effects of climate change on carbon amounts and distribution	Southern Illinois University	R. I. Van Hook
Ecological effects of acidification of low-order woodland streams, with particular emphasis on the chemistry and effects of aluminum	Syracuse University	J. W. Elwood
Estimate quantities of specific chemical groups in effluents and products by commercial-scale direct coal liquefaction, indirect coal liquefaction, and oil shale processing facilities	TRW, Inc.	L. W. Barnthouse
Impact of acid precipitation on forest soils	Tennessee Valley Authority	R. I. Van Hook
Sample collection for experimental watersheds	Tennessee Valley Authority	R. I. Van Hook
A cooperative venture between ORNL's ESD and The University of Tennessee Graduate Program in Ecology	Tennessee, University of	R. E. Millemann
A cooperative venture between ORNL's ESD and The University of Tennessee Graduate Program in Geological Sciences	Tennessee, University of	T. Tamura
Assess the presence of wood rot fungi among timbers of the Oak Ridge Gaseous Diffusion Plant Cooling Towers	Tennessee, University of	F. G. Taylor

11. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT SUBCONTRACTS AND INTERAGENCY AGREEMENTS (continued)

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Field collection of data and sediments from lakes and ponds in Tennessee adjacent to Kentucky	Tennessee, University of	A. M. Solomon
Model morphological characteristics of impoundments using surface area and slopes of reservoir bottom configurations as variables	Tennessee, University of	S. G. Hildebrand
Survey of cooling towers within the Oak Ridge Operations for presence of the Legionnaire's Disease Bacterium	Tennessee, University of	R. L. Tyndall
Assistance with the Legionnaires' Disease Bacterium Project	Tennessee, University of	S. W. Christensen
Development and implementation of risk analysis methods for determining the fate and effects of synfuels chemicals	Tennessee, University of	G. W. Suter
Provide graduate student support in the geosciences area	Tennessee, University of	S. H. Stow
Provide technical assistance in conducting DOE-sponsored limnological research on watershed-reservoir interactions	Tennessee, University of	B. L. Kimmel
Staff members of the Department of Civil Engineers are to provide assistance in waste-management-related programs	Tennessee, University of	L. D. Eyman
Extending systems analysis in ecology	Texas A & I University	R. I. Van Hook
Ecosystem effects of whole-tree harvesting	U.S. Department of Agriculture	R. I. Van Hook
CO_2 effects on seedling trees	U.S. Department of Agriculture	R. I. Van Hook
Research in variations in crop response to acid rain	U.S. Department of Agriculture	R. I. Van Hook
Identify risks of cultural treatments, coppice productivity, and improved productivity for energy through genetic research and selection	U.S. Department of Agriculture	J. W. Ranney
Increasing the biomass production of alder plantations in the Pacific Northwest	U.S. Department of Agriculture	J. W. Ranney
Impact of acid precipitation on forest soils	U.S. Department of Agriculture	R. I. Van Hook
Geophysical investigations at SWSA-7 and SWSA-3 sites in Oak Ridge	U.S. Department of the Army	E. R. Rothschild

11. ENVIRONMENTAL SCIENCES DIVISION RESEARCH AND DEVELOPMENT SUBCONTRACTS AND INTERAGENCY AGREEMENTS (continued)

Title of subcontract/interagency agreement	Subcontractor	Division technical contact
Evaluation of wastewater treatment models for their suitability for use by the U.S. Environmental Protection Agency in assessing the fate of organic chemicals in the environment and their risks to human and nonhuman populations	Vanderbilt University	C. C. Coutant
Production of biomass on abandoned farmlands in the Northeast	Vermont, University of	R. I. Van Hook
Materials spiraling in stream ecosystems: effects of physical, chemical, and biological factors on organic-matter spiraling	Virginia Polytechnic Institute	R. I. Van Hook
Forest responses to anthropogenic stress	Virginia Polytechnic Institute	S. B. McLaughlin
Design and development of a short-rotation plantation harvesting system	Virginia Polytechnic Institute	J. H. Cushman
Evaluation of the effect of atmospheric sulfur deposition on the nutrient status of soil and plants from two forested ecosystems in western Washington	Washington, University of	D. W. Johnson
Impact of whole-tree harvesting and residue removal on productivity and nutrient loss from selective soils of the Pacific Northwest	Washington, University of	D. C. West
Evaluation and genetic improvement of black cottonwood for short-rotation coppice culture	Washington, University of	J. W. Ranney
Reduce the variability in carbon isotope data from tree rings by considering the tree's physiology	Washington, University of	J. R. Trabalka
Study growth responses of forest trees to air pollution stress	Yale University	S. B. McLaughlin

PART IV. APPENDICES

PUBLICATIONS, PRESENTATIONS, THESES, AND PROFESSIONAL ACTIVITIES

Publications

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"Fates of aromatics model (FOAM): Description, application, and analysis," Conference on Modeling the Fate and Effects of Toxicants in the Environment, Vaedbeck, Denmark, June 1983.

Bartell, S. M., J. M. Giddings, and A. J. Stewart

"Structure-activity relationships and potential effects of hydrocarbons on growth of *Selenastrum*," Society for Environmental Toxicology and Chemistry, Arlington, Va., November 1982.

Blasing, T. J.

"Response of the North American corn belt to climatic warming," DOE Carbon Dioxide Indirect Effects Principal Investigators Workshop, Berkeley, Calif., March 1983.

"Recent developments in dendroclimatology in the eastern United States," Colloquium, Geography Department, The University of Tennessee, Knoxville, April 1983.

"Three centuries of drought record from tree rings in the central United States," Arid Lands Studies Section, Western Social Science Association, 25th Annual Conference, Albuquerque, N.M., April 1983.

"Recent research on effects of acid rain," Norwood Kiwanis Club Luncheon, Knoxville, Tenn., July 1983.

"Climatic changes and impact on natural and agricultural ecosystems," Faculty Workshop on Fossil Fuels, Carbon Dioxide, and Acid Rain, Oak Ridge Associated Universities, Manpower Education Research and Training Division, Oak Ridge, Tenn., July 1983.

Bondietti, E. A., and I. L. Larsen

"Vegetation interception of submicron atmospheric aerosols," American Chemical Society Annual Meeting, Washington, D.C., August–September 1983.

Cada, G. F.

"Water quality," "Dredging" and "Case study," Workshop on Environmental Impacts of Small Hydropower Development, Chicago, May 1983.

Cada, G. F., and M. Kenna

"Effectiveness of product upgrading in reducing the toxicity of synthetic H-Coal oil to juvenile channel catfish," 113th Annual Meeting, American Fisheries Society, Milwaukee, August 1983.

Cada, G. F., M. J. Sale, R. M. Cushman, and J. M. Loar

"Field test of a biological assumption of instream flow models," Waterpower '83, Knoxville, Tenn., September 1983.

Christensen, S. W., R. L. Tyndall, J. A. Solomon, and C. B. Fliermans

"Legionnaires' disease bacteria in power plant cooling systems: First downtime sampling scenario," Electric Power Research Institute, Legionnaires' Disease Bacterium Project Advisory Committee, Atlanta, June 1983.

Christensen, S. W., R. L. Tyndall, J. A. Solomon, C. B. Fliermans, and S. P. Gough

"Legionnaires' disease bacterium in power plant cooling systems: Phase I highlights," Electric Power Research Institute, Legionnaires' Disease Bacterium Project Advisory Committee, Atlanta, October 1982.

"Infectivity of *Legionella* in power plant cooling systems and implications for control," Second International Symposium on *Legionella*, Atlanta, June 1983.

Coutant, C. C.

"Environmental management for striped bass," ORGDP Supervisors' Meeting, January 1983.

"Resource partitioning in striped bass," seminar, Tennessee Technological University, Cookeville, February 1983.

"Environmental quality in Oak Ridge—The Koppers Synfuel Plant review," seminar, Southern Colleges and Universities Union, Oak Ridge, Tenn. March 1983.

"Evaluation of mixing zones with dose-response bioassay data," Seventh Annual Symposium on Aquatic Toxicology, American Society for Testing and Materials, Milwaukee, April 1983.

"Thermal pollution," Sigma Xi regional lecture, Western North Carolina University, Chilhowee, N.C., April 1983.

"Aquatic ecology," Treemont Environmental Education Center, Great Smoky Mountains National Park, May 1983.

"ORNL aquatic ecology research related to Columbia River salmon problems," Bonneville Power Administration, Portland, Oreg., June 1983.

Cushman, J. H.

"Herbaceous and short-rotation woody biomass energy crops," DOE Workshop for Historically Black Colleges and Universities, Washington, D.C., January 1983.

Cushman, R. M.

"Biotic effects of rapidly varying flow from hydropower facilities," Waterpower '83, Knoxville, Tenn., September 1983.

DeAngelis, D. L.

"A model of naticid gastropod predator-prey coevolution," International Symposium on Mathematical Ecology, Trieste, Itaiy, November–December 1982.

"An introduction to modeling fish migratory behavior," NATO Advanced Research Institute, Mechanisms of Migration in Fishes, Maratea, Italy, December 1982.

"Modeling solute transport in fractured porous media," American Geophysical Union Meeting, Baltimore, May–June 1983.

Eddlemon, G. K.

"Environmental issues of oil shale development in the eastern and western United States: A comparison," International Association of Science and Technology for Development's International Symposium: Energy '83—Modeling, Simulation, Policy, Planning, and Economics, San Francisco, May 1983.

Edwards, N. T.

"Uptake of polycyclic aromatic hydrocarbons by bean plants." DOE Plant Uptake and Soil-Plant Processes Meeting, Gaithersburg, Md., May 1983.

Elmore, J. L., G. F. Cada, J. M. Loar, P. Kanciruk, and D. K. Cox

"Comparison of fish communities from two watersheds in Cades Cove, Great Smoky Mountains National Park," Annual Meeting on Scientific Research in the National Parks of the Uplands Section of the Southeast Region, Headquarters, Great Smoky Mountains National Park, Tenn., May 1983.

Elser, J. J., and B. L. Kimmel

"Patterns of alkaline phosphatase activity in a three-reservoir series," Great Plains Limnology Association Meeting, University of Oklahoma Biological Station, Kingston, October 1982.

"Nutrient availability for phytoplankton production along a headwater-to-mainstream reservoir gradient," American Society of Limnology and Oceanography, St. John's, Newfoundland, June 1983.

Elwood, J. W.

"Acidic deposition impact on aquatic systems," Oak Ridge Associated Universities, Fossil Fuel–CO_2–Acid Deposition Faculty Workshop. Oak Ridge, Tenn., July 1983.

"Effects of acidic deposition on aquatic ecosystems," Tennessee Technological University Biological Station, Cookeville, July 1983.

Elwood, J. W., P. J. Mulholland, J. D. Newbold, L. A. Ferren, and R. J. Perkins

"Phosphorus cycling during microbial conditioning of leaves in streams," American Society of Limnology and Oceanography Annual Meeting, St. John's, Newfoundland, June 1983.

Emanuel, W. R.

"Modeling the global carbon cycle," Research Conference on Canadian Carbon Cycle Studies, Environment Canada, Downsview, November 1982.

"Scientific issues: The global energy balance, hydrologic cycle, and the biogeochemical element cycles," Office of the Associate Administrator for Space Science and Applications, NASA, Washington, D.C., January 1983.

Emanuel, W. R., and H. H. Shugart

"The Holdridge Life-Zone Classification: Climate change and the distribution of terrestrial ecosystems," UNEP Study Conference on Sensitivity of Ecosystems and Society to Climate Change: Possible Impacts of CO_2 in the Atmosphere, Villach, Austria, September 1983.

Fitts, R. B.

"Overview of DOE LLWMP Technology Development Activities," U.S. Department of Energy–Headquarters Review of Oak Ridge National Laboratory Waste Disposal Activities, Oak Ridge, Tenn., January 1983.

"Review of the ORNL Role in DOE LLWMP Technology Development for Low-Level Waste Disposal," Japanese Atomic Industrial Forum Study Team, Oak Ridge, Tenn., May 1983.

Franco, P. J., and J. M. Giddings

"Calibration of laboratory bioassays with results from microcosms and ponds," Symposium on Validation and Predictability of Laboratory Methods for the Assessment of Fate and Effects of Environmental Contaminants in Aquatic Ecosystems, University of North Dakota, Grand Forks, August 1983.

Gardner, R. H.

"CO_2 uncertainty workshop," Carbon Dioxide Research Division, Office of Energy Research, April 1983.

"Ecosystem risk analysis," University of Texas, Dallas, April 1983.

"The effect of uncertainties in environmental assessments," University of Aarhus, Denmark, August 1983.

"Statistical methods of uncertainty analysis," Studsvik, Nykoping, Sweden, September 1983.

Garten, C. T.

"Factors influencing vegetation concentrations of long-lived radionuclides," DOE Plant Uptake and Soil-Plant Processes Meeting, Gaithersburg, Md., May 1983.

"A summary of field and greenhouse experiments at ORNL on the plant-soil relationships of technetium," Journee d'Etude sur le Technetium, CEN/SCK Nuclear Research Center, Mol, Belgium, June 1983.

"Uptake and distribution of technetium in several marine algae," International Symposium on the Behavior of Long-Lived Radionuclides in the Marine Environment, Forte St. Teresa, Lerici, Italy, September 1983.

Giddings, J. M.

"Coal liquefaction product spills in freshwater ecosystems: A preliminary environmental assessment," Pittsburgh Energy Technology Center, Penn., November 1982.

Giddings, J. M., P. J. Franco, S. E. Herbes, J. D. Newbold, G. R. Southworth, and A. J. Stewart

"Chronic additions of a coal-derived oil to pond microcosms: Fate of the oil and effects on the ecosystems," Third Annual Meeting, Society of Environmental Toxicology and Chemistry, Arlington, Va., November 1982.

Groeger, A. W., and B. L. Kimmel

"Patterns of carbon metabolism in reservoir phytoplankton communities," Great Plains Limnology Association Meeting, University of Oklahoma Biological Station, Kingston, October 1982.

Hildebrand, S. G.

"Ecological perspectives on hydroelectric development," 1983 Annual Meeting of the American Nuclear Society, Detroit, June 1983.

Hildebrand, S. G., and J. M. Loar

"ORNL environmental research in support of the DOE Hydroelectric Development Program," DOE Program Review, Washington, D.C., December 1983.

Hunsaker, C. T.

"The water bubble concept: Its suitability to coastal embayments," Third Symposium on Coastal and Ocean Management, American Society of Civil Engineers, San Diego, June 1983.

Johnson, D. W.

"Sulfur cycling in forests," Sulfur Symposium, 1983 AIBS Meeting, Grand Forks, N.D., August 1982.

Johnson, D. W., and J. O. Reuss

"Soil mediated effects of atmospherically deposited sulphur and nitrogen," The Royal Philosophical Society Meeting, London, September 1983.

Johnson, D. W., and D. D. Richter

"Combined effects of acid deposition and harvesting on forest mineral cycles," U.S.–Canadian Conference on Forest Responses to Acidic Deposition, Orono, Maine, August 1983.

Johnson, D. W., H. Van Miegroet, D. W. Cole, and D. D. Richter

"Contributions of acid deposition and natural processes to cation leaching from forest soils: A review," Air Pollution Control Association Annual Meeting, June 1983.

"The effects of acid precipitation and natural processes on cation leaching from four diverse forest soils," Sixth North American Forest Soils Conference, Knoxville, Tenn., June 1983.

Kimmel, B. L., and A. W. Groeger

"Limnological and ecological changes associated with reservoir aging," American Fisheries Society Symposium on Reservoir Fisheries Management: Strategies for the 80s, Lexington, Ky., June 1983.

Kimmel, B. L., A. W. Groeger, J. J. Elser, and S. M. Adams

"Phytoplankton productivity in a headwater-to-mainstream reservoir series," Great Plains Limnology Association Meeting, University of Oklahoma Biological Station, Kingston, October 1982.

Kitchings, J. T.

"Ecology of bobcats in eastern Tennessee," Department of Biology Seminar, James Madison University, Harrisonburg, Va., October 1982.

"Ecological research at Oak Ridge National Laboratory," Advanced Ecology Class, James Madison University, Harrisonburg, Va., October 1982.

"NERP Environmental Study Center," Tennessee Environmental Education Association Annual Meeting, Kingston Springs, Tenn., September 1983.

Krummel, J. R., and C. C. Gilmore

"Locating vegetation at risk to air pollution: A regional approach," 34th Annual Meeting, American Institute of Biological Sciences, Grand Forks, N.D., August 1983.

Li, Y.-H., T.-H. Peng, W. S. Broecker, and H. G. Ostulund

"The average vertical eddy diffusion coefficient of the ocean," American Geophysical Union Fall Meeting, San Francisco, December 1982.

Loar, J. M.

"Mitigating the effects of flow regulation on biotic resources: The instream flow controversy," Second EPRI Hydro Working Group Meeting, Vicksburg, Miss., February 1983.

"Generic overview of environmental issues associated with small hydropower development: Fish passage, cumulative impacts, and development at new vs existing dams," EPA Workshop on Environmental Impacts of Small Hydropower Development, Chicago, May 1983.

Lovett, G. M.

"Atmospheric deposition in high-elevation forests," Symposium on the Southern Appalachian Spruce-Fir Ecosystem, Great Smoky Mountains National Park, Gatlinburg, Tenn. May 1983.

"Wet and dry deposition processes in forests," U.S.–Canadian Conference on Forest Responses to Acidic Deposition, Orono, Maine, August 1983.

Lovett, G. M., and S. E. Lindberg

"Dry deposition of nitrate to a deciduous forest canopy," Ecological Society of America Meeting, State College, Penn., August 1983.

Lovett, G. M., and W. A. Reiners

"Deposition of cloud water and dissolved ions to subalpine forests of New England," Fourth International Conference on Precipitation Scavenging, Dry Deposition, and Resuspension, Santa Monica, Calif., November 1982.

Luxmoore, R. J.

"Water budget of an eastern deciduous forest stand," Soil Science Society of America Annual Meeting, Anaheim, Calif., November 1982.

"Modeling chemical uptake in soil-plant systems," Plant Uptake and Soil-Plant Processes Meeting, U.S. Department of Energy, Gaithersburg, Md., May 1983.

"Temperate forest response to elevated atmospheric CO_2," Division of Forest Research, CSIRO, Canberra, Australia, September 1983.

Luxmoore, R. J., R. J. Norby, and D. G. Weller

"Forest response to elevated atmospheric CO_2," Soil Science Society of America Annual Meeting, Washington, D.C., August 1983.

Mann, L. K.

"Natural regeneration one year after clear-cutting with and without residue removal in East Tennessee upland hardwoods," Ecological Society of America Meeting, Grand Forks, N.D., August 1983.

McCarthy, J. F, and B. D. Jimenez

"Effect of humic substances on the bioaccumulation of organic contaminants by aquatic organisms," Annual Meeting of the International Humic Substances Society, Estes Park, Colo., August 1983.

"Adsorption of organic contaminants to dissolved humic substances and the effect on uptake by aquatic organisms," Annual Meeting of the Society of Environmental Toxicology and Chemistry, Crystal City, Va., November 1983.

McConathy, R. K.

"Results of a chamberless technique for within canopy measurement of gas exchange," 15th Annual Air Pollution Workshop, Knoxville, Tenn., April 1983.

McLaughlin, S. B.

"Modeling effects of SO_2 on forest productivity," Conference, Effects of SO_2 on Plant Productivity, Monterey, Calif., December 1982.

"Dendroecological analysis of forest growth responses," National Acid Precipitation Assessment Program Effects Research Review, Raleigh, N.C., February 1983.

"Interactive effects of acid rain and gaseous air pollutants on natural terrestrial vegetation," National Acid Precipitation Assessment Program Effects Research Review, Raleigh, N.C., February 1983.

"Effects of acidic deposition on forest productivity and related interactions," Acid Rain National Program Review, Raleigh, N.C., February 1983.

"Measuring effects of air pollution stress: some perspectives, problems, and approaches," Technical Association of the Pulp and Paper Industry, 1983 Annual Meeting, Atlanta, March 1983.

"Effects of acid deposition on forest productivity," review by Interagency Task Force Heads, Washington, D.C., April 1983.

"An overview of FORAST," 15th Annual Air Pollution Workshop, Knoxville, Tenn., April 1983.

"Studies of forest growth decline in the eastern United States," Southern Appalachian Spruce Fir Workshop: Status, Threats, and Management, Gatlinburg, Tenn., May 1983.

"Effects of acid rain and gaseous pollutants on forest productivity: A regional approach," 76th Annual Meeting of Air Pollution Control Association, Atlanta, June 1983.

"Effects of acid rain on forest ecosystems," ORNL Summer Seminar Series, Oak Ridge National Laboratory, Oak Ridge, Tenn., July 1983.

"Effects of acid deposition on forest productivity," Deutsch Acid Rain Committee Review, Washington, D.C., September 1983.

Mulholland, P. J., J. W. Elwood, and J. D. Newbold

"The nutrient spiralling concept—Its utility in analyzing streams and rivers as ecosystems," winter meeting, American Society of Limnology and Oceanography and the American Geophysical Union, San Francisco, December 1982.

Mulholland, P. J., J. W. Elwood, J. D. Newbold, J. R. Webster, L. A. Ferren, and R. E. Perkins

"Phosphorus uptake by decomposing leaf detritus: Effect of microbial biomass and activity," 22nd Congress of Societas Internationale Limnologie, Lyon, France, August 1983.

Norby, R. J.

"Growth analysis studies of acid rain effects," EPRI Acid Deposition Program Review, Washington, D.C., November 1982.

Norby, R. J., and R. J. Luxmoore

"Physiological responses of soybeans to acid rain and gaseous pollutants," Annual Meeting, American Society of Plant Physiologists, Fort Collins, Colo., August 1983.

Olson, J. S.

"World land clearing and the conversion of land to agriculture: Conversion of area changes to changes of carbon dioxide," Symposium on the World Ecology and World Forests in the Twentieth Century, National Humanities Center, Durham, N.C., April 1983.

"Litter dynamics and turnover of organic matter in spruce-fir ecosystems," Spruce-Fir Symposium, Great Smoky Mountains National Park, Gatlinburg, Tenn., May 1983.

"Global carbon dioxide," Releases from Clearing Vegetation, Environmental Sciences, Gordon Research Conference, New Hampton, N.H., June 1983.

"Mapping world vegetation for ecosystem cycling," Botanical Society of America poster session, American Institute of Biological Sciences, Grand Forks, N.D., August 1983.

"Ecology of Chicago around midcentury: Paradigms revisited," H. C. Cowles Memorial Symposium, Ecological Society of America, Grand Forks, N.D., August 1983.

Olson, R. J.

"Status of integrated data base systems: Results of a partial survey," 1982 Integrated Data Users Workshop, Reston, Va., October 1982.

O'Neill, R. V.

"Hierarchy theory in ecology," Colorado State University, Fort Collins, March 1983.

"Ecosystem analysis and hierarchy theory," Cornell University, Ithaca, N.Y., May 1983.

Parr, P. D.

"Effect of fluoride fumigation and acid precipitation on accumulation of fluoride in grass and soil," Association of Southeastern Biologists, Plant Ecology Section, Lafayette, Ind., April 1983.

"Response of bush beans to HF gas fumigation," poster session, Air Pollution Workshop, Knoxville, Tenn., April 1983.

"Rare plants on the Oak Ridge Reservation," The University of Tennessee Plant Ecology Class, Oak Ridge National Laboratory. Oak Ridge, Tenn., November 1982 and July 1983.

Peng, T.-H.

"Invasion of fossil CO_2 into the ocean," International Symposium on Gas Transfer at Water Surfaces, Cornell University, Ithaca, N.Y., June 1983.

"A comparison of one-dimensional and two-dimensional ocean models with respect to CO_2 uptake," at session entitled "The Ocean and the CO_2 Climate Response," 18th General Assembly of the International Union of Geodesy and Geophysics, Hamburg, Federal Republic of Germany, August 1983.

Post, W. M., P. J. Zinke, and A. G. Stangenberger

"Global patterns of soil nitrogen," 1983 Annual Meeting of Soil Science Society of America, Washington, D.C., August 1983.

Reed, R. M., L. D. Voorhees, and F. E. Sharples

"Assessing impacts of energy projects on prime farmland," Energy '83 Symposium, International Association of Science and Technology for Development, San Francisco, May 1983.

Richter, D. D.

"Complexities in acid rain research," Annual Meeting, Mississippi Chapter, American Fisheries Society, Starkville, Miss., February 1983.

Richter, D. D., and D. W. Johnson

"Effects of acid rain on forest soil change," Atmospheric Deposition Specialty Conference, Air Pollution Control Association, Detroit, November 1982.

Richter, D. D., D. W. Johnson, C. B. Craft, J. M. Kelly, D. E. Todd, and J. W. Webb

"Effects of acid precipitation on soil acidity and base-cation status of infertile soils in eastern Tennessee," Second National Symposium on Acid Rain, Pittsburgh, October 1983.

Richter, D. D., D. W. Johnson, J. M. Kelly, and D. E. Todd

"Sulfur cycling and sulfur-nitrogen interactions in deciduous forests in Tennessee," Annual Meeting, Soil Science Society of America, Washington, D.C., August 1983.

Sale, M. J., J. M. Loar, G. F. Cada, and P. Kanciruk

"Application of the incremental methodology to trout streams in the southern Appalachians," poster session, 113th Annual Meeting of the American Fisheries Society, Milwaukee, August 1983.

Sharma, M. L., and R. J. Luxmoore

"Soil heterogeneity effects on evapotranspiration and plant water status," Soil Science Society of America Annual Meeting, Anaheim, Calif., November 1982.

Shriner, D. S.

"Air pollution effects on forest trees, acid deposition," First U.S.S.R.–U.S. Symposium on Air Pollution Effects on Forest Ecosystems, Tallinn, Estonian Soviet Socialist Republic, October 1982.

"Acid deposition effects on forest ecosystems," First U.S.S.R.–U.S. Symposium on Air Pollution Effects on Forest Ecosystems, Puschino, U.S.S.R., October 1982.

"Acid rain," science lecture, Webb School, Knoxville, Tenn., November 1982.

"Acid rain and potential ecological consequences," Southern College University Union Science Semester Colloquium, Oak Ridge, Tenn., March 1983.

"Acidic deposition effects on agricultural crops," ORAU Fossil Fuels–Carbon Dioxide–Acid Rain Faculty Workshop, Oak Ridge, Tenn., July 1983.

"Acid rain: What to do about it?" ORAU Fossil Fuels–Carbon Dioxide–Acid Rain Faculty Workshop, Oak Ridge, Tenn., July 1983.

"Effect of acid deposition of sulfur compounds in terrestrial ecosystems," AAAS Symposium on Acidic Effects of Sulfur Deposition on Terrestrial Ecosystems, Grand Forks, N.D., August 1983.

Shriner, D. S., and J. W. Johnston

"Acid rain—Gaseous pollutant interactions with agricultural crops," National Acid Precipitation Assessment Program Review, Raleigh, N.C., February 1983.

Shugart, H. H.

"Computer models of forest succession," Wildlife Department, Utah State University, January 1983.

"Succession models: Some theoretical and practical aspects of computer models of forest dynamics," San Diego State University, January 1983.

"Modeling long-term changes in forested landscapes and their relation to the earth's energy balance," NASA Global Cycle Symposium, Arlington, Va., March 1983.

"Theoretical consequences of succession models," Syracuse University, N.Y., April 1983.

"Modeling forest landscapes and the role of disturbance in ecosystem and communities," American Institute of Biological Sciences Meeting, Grand Forks, N.D., August 1983.

"Succession models," Cornell University, Ithica, N.Y., August 1983.

"The practical and theoretical implications of computer models of landscape dynamics," University of Minnesota, November 1983.

Sigal, L. L.

"Lichens as bioindicators of air pollution," 15th Air Pollution Workshop, Knoxville, Tenn., April 1983.

"Lichen research and regulatory decisions," American Institute of Biological Sciences Meeting, University of North Dakota, Grand Forks, August 1983.

Solomon, A. M.

"The carbon dioxide problem: Lessons from the past," Jet Propulsion Laboratory, NASA Office of Technology and Space Program Development, Pasadena, Calif., December 1982 (invited).

"The carbon dioxide problem: Lessons from the past," Department of Botany, University of Washington, Seattle, February 1983.

"Reconstructions of quaternary forest vegetation based on simulation models," Quaternary Research Center, University of Washington, Seattle, February 1983 (invited).

"The global CO_2 question in geologic time perspective," Department of Geography, University of Oregon, Eugene, February 1983.

"Response of the North American corn belt to climate warming," Symposium on Climate and Biosphere Interactions, University of Osnabrück, Federal Republic of Germany, March 1983 (invited).

"Integrating forest-stand simulations with paleoecological records to examine long-term forest dynamics," Workshop on Forest Dynamics sponsored by European Science Foundation, University of Uppsala, Sweden, March 1983 (invited).

"The global carbon dioxide question: Lessons from the past," Departments of Geology and Geography, Western Carolina University, Cullowhee, N.C., April 1983 (invited).

"Effects of seasonal temperature extremes on terrestrial carbon storage: Model simulations and confirmation by full-glacial pollen," Annual Ecological Society of America Meeting, Grand Forks, N.D., August 1983.

Solomon, J. A., S. W. Christensen, R. L. Tyndall, C. B. Fliermans, and S. B. Gough
"Distribution of *Legionella* in the power plant environment," Second International Symposium on *Legionella*, Atlanta, June 1983.

Solomon, J. A., and R. L. Tyndall
"Legionnaires' disease bacterium in power plant cooling systems: Phase II progress report," Electric Power Research Institute Project Advisory Committee Meeting, Atlanta, June 1983.

Southworth, G. R., S. E. Herbes, P. J. Franco, and J. M. Giddings
"Persistence of phenols in aquatic microcosms receiving chronic synthetic fuel inputs," Society of Environmental Toxicology and Chemistry, Arlington, Va., November 1982.

Suter, G. W., II
"Extrapolation of ecotoxicology data: Choosing tests to suit the assessment," ORNL Life Sciences Symposium, Synthetic Fossil Fuel Technologies: Results of Health and Environmental Studies, Gatlinburg, Tenn., October 1982.

"Analysis of the risk to fish of toxic chemicals," Annual Meeting of the Society for Environmental Toxicology and Chemistry, Arlington, Va., November 1982.

"Risk analysis for nonhuman biota," Risk Analysis Society Symposium on Health and Environmental Risk Analysis, Washington, D.C., March 1983.

"Extrapolating from the laboratory to the field: How wrong can you be?" Seventh ASTM Symposium on Aquatic Toxicology, Milwaukee, April 1983.

"Examination of a proposed test for effects of toxicants on soil microbial processes," First International Symposium on Toxicity Testing Using Bacteria, The National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ont., May 1983.

Taylor, F. G.
"Uptake and cycling of chromium and fluoride in a plant-soil system," DOE Plant Uptake and Soil-Plant Processes Meeting, Gaithersburg, Md., May 1983.

"Environmental effects of hydrogen fluoride gas from uranium enrichment plants," Joint Seminar, Soil Physics Department, Swiss Federal Institute of Technology and the Swiss Federal Institute of Forestry Research. ETH Zentrum, Zurich, August 1983.

"Cycling and retention of hexavalent chromium in a plant-soil system," International Conference, Heavy Metals in the Environment, University of Heidelberg, Federal Republic of Germany, September 1983.

Taylor, G. E., Jr.

"Comparative toxicity of ozone and sulfur dioxide in *Phaseolus vulgaris* L," Annual Meeting, American Society of Plant Physiologists, Fort Collins, Colo., August 1983.

Taylor, G. E., Jr., and S. B. McLaughlin

"Effects of SO_2 on dicot crops: some issues, mechanisms, and indicators," Symposium, The Effects of SO_2 on Plant Productivity, Monterey, Calif., December 1982.

Taylor, G. E., Jr., S. B. McLaughlin, N. T. Edwards, W. J. Selvidge, and M. Ross-Todd

"Developing energy technologies and plant productivity: Coal conversion as an example," 15th Air Pollution Workshop, Knoxville, Tenn., April 1983.

Tolbert, V. R.

"Assessment and related analyses," National Research Council Board on Army Science and Technology Assessment, Oak Ridge National Laboratory, Oak Ridge, Tenn., January 1983.

"NEPA and nuclear power plants," Oak Ridge Associated Universities, Oak Ridge, Tenn., May 1983.

Tolbert, V. R., A. M. Goldsmith, and E. E. Brewer

"Comparisons of growth responses of creek chubs from an undisturbed and surface-mining disturbed streams," 113th Annual Meeting of the American Fisheries Society, Milwaukee, August 1983.

Trabalka, J. R.

"Other sources of CO_2 and the carbon cycle," Oak Ridge Associated Universities Fossil Fuels–CO_2–Acid Deposition Workshop, Oak Ridge, Tenn., July 1983.

"Analysis of the 1957–1958 Soviet nuclear accident," Sandia National Laboratories Colloquium, Albuquerque, N.M., November 1982; University of Michigan Seminar Series on Nuclear War and Public Health, Ann Arbor, March 1983; Environmental Sciences Division Seminar, Oak Ridge National Laboratory, Oak Ridge, Tenn., April 1983; Medical Planning and Protocols for Nuclear Accidents, Lincolnshire, Ill., September 1983.

"The DOE-sponsored state-of-the-art report on the global carbon cycle: Outline and preparation plans," American Association for the Advancement of Science Review Committee, Washington, D.C., October 1982.

Trabalka, J. R., W. R. Emanuel, D. E. Reichle, R. H. Gardner, J. Edmonds, J. Reilly, and B. Moore III

"Atmospheric CO_2 projections with globally averaged models," Sixth ORNL Life Sciences Symposium, Knoxville, Tenn., November 1983; DOE-OHER Biomedical Program Directors Meeting, Oak Ridge National Laboratory, Oak Ridge, Tenn., November 1983.

Turner, R. S.

"Aluminum fluxes in soils of a forested watershed in the New Jersey pine barrens," Soil Science Society of America, 1983 Annual Meeting, Washington, D.C., August 1983.

Tyndall, R. L.

"Sources of microorganisms in nature and the evidence for airborne transmission of infection to man," Gordon Conference on Aerobiology, New London, N.H., August 1983.

Tyndall, R. L., S. W. Christensen, J. A. Solomon, and C. B. Fliermans

"Legionnaires' disease bacteria in power plant cooling systems: Results of methodology study," Electric Power Research Institute, Legionnaires' Disease Bacterium Project Advisory Committee, Atlanta, June 1983.

Tyndall, R. L., S. W. Christensen, J. A. Solomon, C. B. Fliermans, and S. G. Gough.

"Legionnaires' disease bacterium in power plant cooling systems: Infectivity results," Electric Power Research Institute, Legionnaires' Disease Bacterium Project Advisory Committee, Atlanta, October 1982.

"Thermally altered habitats as a source of known and new *Legionella* species," Second International Symposium on *Legionella*, Atlanta, June 1983.

Tyndall, R. L., and R. A. Jernigan

"Etiology of legionnaires' disease," American Association of Industrial Hygiene, Philadelphia, May 1983.

Van Hook, R. I.

"Short rotation woody crops program," Annual Thermochemical Program Contractor's Meeting, Atlanta, March 1983.

Van Hook, R. I., and J. W. Ranney

"Short rotation woody crops program overview," to Assistant DOE Secretary J. J. Tribble, Washington, D.C., April 1983.

Van Winkle, W.

"Peer reviewers' evaluation of EPA's aquatic effects research program," Science Advisory Board Ad Hoc Committee to Review the National Acid Precipitation Assessment Program, Washington, D.C., September 1983.

Van Winkle, W., and J. E. Breck
"Fisheries and lake acidification, Fish population models," Electric Power Research Institute, Palo Alto, Calif., May 1983.

Voorhees, L. D.
"The use of pesticides on highwav rights-of-way," Third Annual Meeting of the Society of Environmental Toxicology and Chemistry, Arlington, Va., November 1982.

Voorhees, L. D., M. J. Sale, J. W. Webb, and F. J. Mulholland
"Long-term stabilization of uranium mill tailings," International Conference on Radioactive Waste Management, International Atomic Energy Agency, Seattle, May 1983.

Walker, R. F., D. C. West, and S. B. Mclaughlin
"The development of ectomycorrhizae on containerized sweet birch and European alder seedlings for planting on low quality sites," Second Biennial Southern Silvicultural Research Conference, Atlanta, November 1982.

Wright, L. L.
"Relevance of laboratory studies to the interpretation of observed field emergence patterns of *Hexagenia bilineata*," North American Benthological Society Meeting, Madison, Wis., April 1983.

Theses

Elser, J. J. 1983. Nutrient availability for phytoplankton production along a headwater-to-mainstream reservoir gradient. M.S. The University of Tennessee, Knoxville.

Hom, C. L. 1982. The effect of grazing by the snail, *Goniobasis Clavaeformis* Lea, on aufwuchs in artificial streams. M.S. The University of Tennessee, Knoxville.

Professional Activities

ADAMS, S. M.

Chairman:	Awards committee. American Fisheries Society, 1982.
Participant:	National Laboratories workshop on a coordinated research plan for ecological effects of acid deposition, Washington, D.C., July 1983.
Advisor:	Ursula Boruta, ORAU science semester, St. Joseph's College, New York; secondary advisor, Jim Elser. M.S., The University of Tennessee, Knoxville.
Ad hoc reviewer:	NSF proposals; *Fishery Bulletin; Environmental Biology of Fishes;* American Fisheries Society.
Other:	Editorial board, *Transactions of the American Fisheries Society,* 1982–1984.

AUERBACH, S. I.

Chairman:	Environmental Studies Board, National Research Council, National Academy of Sciences.
Member:	National Laboratory Consortium, National Acid Precipitation Assessment Program.
Witness:	Testimony at a Joint Hearing of the Subcommittee on Energy Research and Production and the Subcommittee on Investigations and Oversight of the U.S. House Science and Technology Committee on the Impact of Mercury Releases at the Oak Ridge Complex. American Museum of Science and Energy, Oak Ridge, Tenn., July 1983.

BAES, C. F., III

Chairman:	Workshop, Food Chain Modeling for Risk Analysis, Washington, D.C., March 1983.
Participant:	15th Annual Air Pollution Workshop, Knoxville, Tenn., April 1983; Workshop on Southern Appalachian Spruce-Fir, Gatlinburg, Tenn., May 1983.
Ad hoc reviewer:	*Nuclear Safety; Health Physics.*

BARNTHOUSE, L. W.

Member:	Funding Panel, Hudson River Foundation for Science and Environmental Research, Inc.
Participant:	Hudson River monitoring plan review, New York State Department of Environmental Conservation, Albany, December 1982; Third Annual Meeting, Society for Environmental Toxicology and Chemistry, Arlington, Va., November 1982; EPA Workshop on Water Modeling for Risk Analysis, Atlanta, January, 1983; Joint Meeting on DOE and EPA Health and Environmental Risk Analysis Programs, Arlington, Va., February 1983; Workshop on Environmental Monitoring and Assessment in Estuarine Ecosystems, Cornell University Ecosystems Research Center, Ithaca, N.Y., February 1983; EPA Peer Review of Environmental Risk Analysis Project, Alexandria, Va., March 1983; Electric Power Research Institute Conference on Risk Assessment in Aquatic Ecology, Albuquerque, April 1983; International Conference on Renewable Resources Inventories for Monitoring Changes and Trends, Corvallis, Oreg., August 1983.
Advisor:	Leslie Hook, Ph.D., Southern Illinois University, Carbondale; Mary Cavendish, M.S., Indiana University, Bloomington.
Ad hoc reviewer:	*Ecology; Journal of Risk Analysis;* American Fisheries Society publications.

BARTELL, S.M.

Chairman:	ESD, Seminar Committee; ESD Aquatic Ecology Section Planning Committee.
Member:	ESD Computer Advisory Committee.
Advisor:	Alan Groeger, Ph.D. candidate, Department of Zoology, University of Oklahoma; Alan Johnson, Ph.D. candidate, Environmental Toxicology, University of Tennessee, Knoxville.

Ad hoc reviewer: *Journal of Environmental Toxicology and Chemistry;* EPA Competitive Grants Review Panel.

BLASING, T. J.

Participant: DOE Carbon Dioxide Indirect Effects Principal Investigators Workshop, Berkeley, Calif., March 1983; Arid Lands Section, 25th Annual Meeting, Western Social Science Association, Albuquerque, April 1983; Meeting of the Working Group in Global Dendroclimatology, Palisades, N.Y., September 1983.

Faculty: Adjunct Assistant Professor, Geography Department, The University of Tennessee, Knoxville.

Ad hoc reviewer: *Science; Nature; Journal of Climate and Applied Meteorology; Tellus; Monthly Weather Review;* NSF and DOE proposals.

BONDIETTI, E. A.

Advisor: L. A. Mahoney, M.S., Western Kentucky University, Bowling Green.

Ad hoc reviewer: *Science; Journal of Environmental Quality.*

CADA, G. F.

Participant: Workshop on Environmental Impacts of Small Hydropower Development (discussion leader), Chicago, May 1983; Introduction to the DEC System-10, ORNL in-house course, January 1983.

Ad hoc reviewer: *Transactions of the American Fisheries Society; Journal of Great Lakes Research;* Proceedings of the Seventh Annual Larval Fish Conference; abstracts for the 113th Annual Meeting of the American Fisheries Society; *North American Journal of Fisheries Management;* Proceedings of the 37th Annual Conference of the Southeastern Association of Fish and Wildlife Agencies.

CHRISTENSEN, S. W.

Member: ESD Aquatic Ecology Section Planning Committee.

Participant: Electric Power Research Institute, Legionnaires' Disease Bacterium Project Advisory Committee Meetings, November 1982 and June 1983.

Ad hoc reviewer: Illinois Department of Energy and Natural Resources; Nuclear Regulatory Commission Pathogenic Microorganism report; American Microscopical Society; *American Naturalist;* Hudson River Foundation; *Transactions of the American Fisheries Society.*

COUTANT, C. C.

Chairman: ASTM Task Group E47.06 on Modeling Transport and Fate of Chemicals; Program Committee, American Fisheries Society; ESD Scientific Achievement Award Committee; Environmental Quality Advisory Board, City of Oak Ridge.

Member: ORNL Wigner Fellowship Selection Committee; ORNL General Energy Conservation Committee; ORNL review panel for the Biomedical Graduate School; ORNL Long-Range Planning Committee; Nominating Committee, ASTM Committee on Biological Effects and Environmental Fate;

University of Washington Delphi Panel on Aquatic Monitoring Design; U.S. Fish and Wildlife Delphi Panel on Habitat Requirements of Striped Bass; Ohio River Valley Sanitation Commission program review panel; American Institute of Fishery Research Biologists Thompson Award review committee.

Faculty: Adjunct Professor, The University of Tennessee, Knoxville, and Tennessee Technological University, Cookeville.

Advisor: Jeff Durniak, M.S. candidate, The University of Tennessee, Knoxville.

Ad hoc reviewer: *Fisheries Bulletin;* Lamont-Dougherty Geological Observatory; *Transactions of the American Fisheries Society, Science; Water Resources Bulletin; Environmental Biology of Fishes;* Springer-Verlag Zoophysiology Series; Duke Power Co.; *Southwestern Naturalist;* ORNL Exploratory Studies Program; *Environmental Science and Technology.*

Other: Secretary/Treasurer, East Tennessee Chapter, American Fisheries Society; Vice Chairman, Applied Ecology Section, Ecological Society of America; Editor, *Underwater Telemetry Newsletter.*

CUSHMAN, J. H.

Participant: DOE Workshop for Historically Black Colleges and Universities, Washington, D.C., January 1983; 11th Meeting, Planning Group "B"—Production, International Energy Agency Implementing Agreement in Forestry, Quebec, Canada, April 1983; Energy from Biomass: Building on a Generic Technology Base, Argonne National Laboratory, Argonne, Illinois, August 1983; Short-Rotation Woody Crops Program Annual Contractors' Meeting, State College, Pa., August 1983.

Ad hoc reviewer: DOE proposals.

CUSHMAN, R. M.

Participant: Discussion leader, EPA Workshop on the Environmental Impacts of Small-Scale Hydropower Development, Chicago, May 1983; DOE Traveling Lecture Program; courses on Solid Waste Management, Remote Sensing, and Biogeography, and seminar in Aquatic Ecology, The University of Tennessee, Knoxville, September 1982–June 1983.

DeANGELIS, D. L.

Faculty: Adjunct Professor, The University of Tennessee, Knoxville.

Advisor: George Sugihara, Ph.D., Wigner Postdoctoral Fellow.

Ad hoc reviewer: *Ecology; The American Naturalist: Theoretical Population Biology; Canadian Journal of Fisheries and Aquatic Science; Mathematical Biosciences; Transactions of the American Fisheries Society;* NSF and DOE proposals.

EDDLEMON, G. K.

Member: Hydrology Committee for the Town of Farragut, Tenn.

Participant: Energy '83 International Symposium, San Francisco, May 1983; preparation of DEIA related to Babcock & Wilcox Naval Nuclear Fuel Fabrication Facility, Virginia; DEIA related to CU-1 Venture Geothermal Loan

Guaranty (South Brawley Unit No. 1), California; Draft Retrospective Examination of Geothermal Environmental Assessments; reviews of Environmental Monitoring Plan Outlines for synfuel projects; Critical Review on Coal Liquefaction Wastewaters; Interpretive Guidance for Compliance with Federal Laws and Regulations Relative to Paleontological Resources; Interim Progress Report—Assessing Stream Flows for the Protection of Fishery Resources: A Field Evaluation of Existing Methods in Southern Appalachian Trout Streams.

EDWARDS, N. T.

Ad hoc reviewer: *Pedobiologia:* DOE; NSF.

Participant: Plant Uptake and Soil Plant Processes Meeting, Gaithersburg, Md., May 1983; 15th Air Pollution Workshop, Knoxville, Tenn., April 1983.

ELMORE, J. L.

Participant: Annual Meeting on Scientific Research in the National Parks of the Uplands Section of the Southeast Region, Headquarters, Great Smoky Mountains National Park, Tenn., May 1983.

Ad hoc reviewer: *Journal of Freshwater Ecology.*

ELWOOD, J. W.

Member: Advisory Panel for Long Term Ecological Research (LTER) Workshop for Aquatic Research Sites and Coordination of Common Measurements, Manhattan, Kans., July 1983.

Faculty: Adjunct Professor of Ecology, The University of Tennessee, Knoxville.

Advisor: Carol L. Hom, M.S., The University of Tennessee, Knoxville; Richard P. Perkins, Ph.D., The University of Tennessee, Knoxville.

Ad hoc reviewer: *Ecology; American Midland Naturalist; Journal of Environmental Quality; Canadian Journal of Fisheries and Aquatic Sciences;* NSF.

EMANUEL, W. R.

Member: ESD Graduate Student Selection Committee; Steering Committee, Sixth ORNL Life Sciences Symposium; Land-Related Global Habitability Sciences Working Group, NASA.

Ad hoc reviewer: *Science; Ecology; Tellus; Geophysical Research Letters;* DOE, NSF, and NASA proposals.

FITTS, R. B.

Members: ASTM Technical Advisory Group on Standards for Low-Level Radioactive Waste Management (technical secretary).

Participant: Operational and Strategic Planning Seminar, Oak Ridge, Tenn., October 1982; Fundamentals of Groundwater Quality Control, St. Louis, October 1982; Fifth Annual Low-Level Waste Management Program Participants Meeting, Denver, September 1983.

Other: Section editor, *Nuclear Safety.*

GARDNER, R. H.

Faculty:	Adjunct Professor, Graduate Program in Ecology, The University of Tennessee, Knoxville.
Advisor:	D. E. Weller, Ph.D., The University of Tennessee, Knoxville; Y. I. Jager, M.S., The University of Tennessee, Knoxville.
Ad hoc reviewer:	*Journal of Environmental Toxicology and Chemistry; American Naturalist.*
Other:	Off-site assignment to Studsvik Energiteknik, Nykoping, Sweden.

GARTEN, C. T.

Participant:	EPA Workshop on Food Chain Modeling for Risk Analysis, Washington, D.C., March 1982; IAEA-CEC Seminar on the Environmental Transfer to Man of Radionuclides Released from Nuclear Installations, Brussels, October 1983.
Faculty:	Adjunct temporary graduate faculty, Western Kentucky University, Bowling Green.
Ad hoc reviewer:	NSF proposal.

GIDDINGS, J. M.

Member:	Program Committee, Society of Environmental Toxicology and Chemistry 4th Annual Meeting; Ecological and Environmental Effects Subcommittee, Great Plains Gasification Project.
Faculty:	Adjunct graduate faculty, Department of Zoology, Southern Illinois University at Carbondale; temporary graduate faculty, Ohio State University, Columbus.
Advisor:	Andrea Leeson, B.S., Eastern Kentucky University; Leslie Hook, Ph.D., Southern Illinois University; Alan Johnson, Ph.D., The University of Tennessee; Michele Moore, M.S., Ohio State University.
Ad hoc reviewer:	*Archives of Environmental Contamination and Toxicology; Environment International;* NSF; EPRI; American Chemical Society.

HILDEBRAND, S. G.

Chairman:	ORNL Water Research Committee; Special Session: Hydropower, A New Outlook at the 1983 Annual Meeting of the American Nuclear Society.
Member:	Assessment and Policy Analysis Task Group of the Interagency Task Force on Acidic Deposition; DOE/EPRI Small Hydroelectric Technology Transfer Technical Committee; EPA Integrated Environmental Management Technical Review Committee.
Participant:	First Annual Acid Precipitation Task Force Meeting, Fredericksburg, Va., September 1982; EPA Peer Review of Enviromental Risk Analysis Project, Alexandria, Va., March 1983; Briefing on Acid Rain Legislation, Arlington, Va., June 1983; program review for ORNL hydroelectric research, DOE Headquarters, Washington, D.C., December 1982; ORNL in-house course, Effective Time Management; ORNL in-house course, Operational and Strategic Planning.
Faculty:	Faculty Associate, The University of Tennessee, Knoxville; taught graduate course on environmental policy, spring 1983.

Ad hoc reviewer: *Ohio Journal of Science;* NSF; Mississippi River Research Consortium; *Environmental Science and Technology.*

HUNSAKER, C. T.

Member: Water Pollution Control Federation, Ecology Committee.

Participant: Woman in the Work Force: A Manager's Role, The University of Tennessee, Knoxville, November 1982; Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants, EPA, Atlanta, April 1983; STORET Training, EPA, Research Triangle Park, N.C., July 1983; preparation of draft of Ocean Dumping of Low-Level Radioactive Waste: United States and International Laws and Biological Effects, DOE Office of Environmental Compliance, Washington, D.C.; Water Research Opportunities in the 1980s, An Analysis of Selected Topics, ORNL; Environmental Resources of the Tennessee-Tombigbee Corridor, summary, U.S. Army Corps of Engineers, Nashville; Draft of Southeastern Regional Geologic Characterization Report, Office of Crystalline Repository Development, Battelle Memorial Institute, Columbus, Ohio, May 1983.

Other: President, Association for Women in Science, East Tennessee Chapter.

JOHNSON, D. W.

Member: Society of American Foresters Task Force on Acid Deposition; La Selva Advisory Committee, Organization for Tropical Studies.

Faculty: Adjunct professor, College of Forestry, Fisheries, and Wildlife, The University of Tennessee, Knoxville.

Ad hoc reviewer: *Science; Journal of Environmental Quality; Soil Science Society of America Journal; Water, Air, and Soil Pollution.*

KANCIRUK, P.

Member: ESD Computing Advisory Committee; ORNL High-Speed, Broad Band Committee (division representative); Oak Ridge Resident Graduate Program, Student Advisory Committee (representative for computing science).

Participant: 1982 MODCOMP Users Group Workshop, December, Ft. Lauderdale, Fla.

KIMMEL, B. L.

Member: ESD Seminar Committee.

Faculty: Adjunct Assistant Professor, Department of Zoology, University of Oklahoma, Norman; Faculty Associate in Ecology, The University of Tennessee, Knoxville.

Advisor: A. W. Groeger, Ph.D., University of Oklahoma, Norman; J. J. Elser, M.S., The University of Tennessee, Knoxville; M. A. Mueller, M.S., The University of Tennessee, Knoxville.

Ad hoc reviewer: *The Southwestern Naturalist;* NSF and DOE-OHER proposals.

KITCHINGS, J. T.

Chairman: ORNL Resource Management Committee working group on Wildlife Management.

Member:	ORNL Resource Management Overview Committee; coordination of Oak Ridge Reservation Resource Management Plan.
Participant:	Preparation of Wildlife Mitigation for the Tennessee-Tombigbee Waterway, U.S. Corps of Engineers.
Ad hoc reviewer:	NSF; *Journal of Mammalogy*.

KROODSMA, R. L.

Participant:	Preparation of Draft Shallow Land Burial Handbook, Draft Generic EIS for the Magnetic Fusion Energy Program, and Draft Primer on Technical and Environmental Aspects of Electric Power Transmission; participated in reviews of Environmental Monitoring Plans submitted to the U.S. Synthetic Fuels Corporation.

KRUMMEL, J. R.

Consultant:	Environmental Defense Fund, Nashville, Tenn.
Ad hoc reviewer:	*BioScience; Human Ecology*.

LOAR, J. M.

Chairman:	Work Group on Aquatic Habitats, Oak Ridge Reservation Resource Management Committee; EPA Workshop on Environmental Impacts of Small Hydropower Development, Chicago, May 1983.
Member:	Fishery Study Group, Oak Ridge Task Force.
Participant:	Second EPRI Hydro Working Group Meeting, Vicksburg, Miss., February 1983; Waterpower '83: International Conference on Hydropower, Knoxville, Tenn., September 1983.
Ad hoc reviewer:	*Water Resources Research; North American Journal of Fisheries Management; Environment International;* NOAA proposals.

LOVETT, G. M.

Participant:	Fourth International Conference on Precipitation Scavenging, Dry Deposition, and Resuspension, Santa Monica, Calif., November 1982; EPRI Acid Deposition Program Review, Washington, D.C., November 1982; 15th Annual Air Pollution Workshop, Knoxville, Tenn., April 1983; Ninth Annual Scientific Research Meeting, Great Smoky Mountains National Park, May 1983; U.S.–Canadian Conference on Forest Responses to Acidic Deposition, Orono, Maine, August 1983.
Faculty:	Graduate Program in Ecology, The University of Tennessee, Knoxville.
Ad hoc reviewer:	NSF.

LUXMOORE, R. J.

Chairman:	Whole Plant Physiology Working Party (S2.01.15) of the International Union of Forestry Research Organizations.
Member:	Grey-Zone Terminology Committee (S374.1) of the Soil Science Society of America; American Registry of Certified Professionals in Agronomy, Crops, and Soils.
Participant:	Session Chairman, Soil Science Society of America Annual Meeting, Anaheim, Calif., November 1982; Elevated CO_2 Effects on Vegetation

Workshop, DOE, Gaithersburg, Md., March 1983; Southern Regional Soil Water Technical Committee, Baton Rouge, La., April 1983; Workshop on the Impacts of Acidic Deposition on Forest and Aquatic Resources, Kearneysville, W.Va., April 1983; Plant Uptake Processes and Soil-Plant Interactions Workshop, Department of Energy, Gaithersburg, Md., May 1983; Aquatic Effects Task Group Workshop of the U.S. National Acidic Precipitation Assessment Program, Raleigh, N.C., July 1983; Session Chairman, Soil Science Society of America Annual Meeting, Washington, D.C., August 1983.

Faculty: Faculty member of the Plant Physiology and Genetics Program, Life Sciences Graduate Program, The University of Tennessee, Knoxville.

Ad hoc reviewer: *Soil Science Society of America Journal; Soil Science; Ecology; Environmental Science and Technology; Water Resources Research.*

Other: Secretary of Southern Regional Technical Committee (S-185) on Soil Water Research.

MANN, L. K.

Co-Chairman: Roane County Soil Conservation Service Board of Supervisors.

McBRAYER, J. F.

Chairman: American Society for Surface Mining and Reclamation Committee for Membership Directory.

Participant: ORNL workshop: Managing in the matrix, ORNL, November 1982; ORNL workshop: Training for ORNL supervisors, ORNL, April 1983; project manager, Alcohol Fuels Environmental Project; project manager, DOE Biofuels Program Multiyear Research Plan; preparation of New England Ethanol, Inc., Loan Guarantee EA, Agrifuels Refining Corporation Loan Guarantee EA, and Tennol, Inc., Loan Guarantee EA.

Ad hoc reviewer: *Pedobiologia; Journal of Arid Environments; Environmental Science and Technology;* NSF.

McCARTHY, J. F.

Advisor: Braulio Jimenez, ORAU Postdoctoral Fellow; C. P. Cirmo, M.S., Indiana University.

Ad hoc reviewer: *Environment International, Archives for Environmental Contamination and Toxicology.*

McCONATHY, R. K.

Participant: 15th Annual Air Pollution Workshop, Knoxville, Tenn., April 1983.

McLAUGHLIN, S. B.

Member: Air Pollution Control Association–TEII Effects Committee; Sigma Xi; American Association of Plant Physiologists.

Panel member: National Academy of Science (NRC) Panel on Monitoring and Assessing Trends in Acid Deposition (beginning July 1983).

Reviewer: DOE (2) and USDA proposals; *Environmental Science and Technology; Canadian Journal of Forest Research* (2); *Journal of Environmental Quality.*

Participant: Conference, Effects of SO_2 on Plant Productivity, Monterey, Calif., December 1982; National Acid Precipitation Assessment Program Research Review, Raleigh, N.C., February 1983; Technical Association of the Pulp and Paper Industry, 1983 Annual Meeting, Atlanta, March 1983; Review of Acid Rain Research by Interagency Task Force Heads, Washington, D.C., April 1983; 15th Annual Air Pollution Workshop, Knoxville, Tenn., April 1983, session moderator; Southern Appalachian Spruce Fir Workshop, Gatlinburg, Tenn., May 1983; 76th Annual Meeting of Air Pollution Control Association, Atlanta, June 1983; Deutsch Acid Rain Committee Review, Washington, D.C., September 1983.

Scientific advisor: Tom Doyle, Ph.D. candidate, The University of Tennessee, Knoxville; Ted Leininger, Ph.D. candidate, Virginia Polytechnic Institute and State University, Blacksburg.

MILLEMANN, R. E.

Chairman: ESD Education Committee.

Faculty: Adjunct Professor, The University of Tennessee, Knoxville.

Ad hoc reviewer: *Environment International.*

MORAN, M. S.

Participant: Introduction to the DEC System-10, ORNL in-house course, January–February 1983; First National Symposium and Exposition on Ground-Water Instrumentation, Las Vegas, March 1983; technical secretary of the Fifth Annual DOE Low-Level Waste Management Program (LLWMP) Participants' Information Meeting, Denver, August–September 1983; Defense Transuranic (TRU) Waste Management Program Update Meeting No. 7, Albuquerque, September 1983; preparation of DOE LLWMP Position Paper Update on Modeling, DOE LLWMP Position Paper on Evaluation Factors for Verification and Validation of Low-Level Waste Disposal Site Models, and DOE LLWMP Summary Comparison of Well-to-Well Tomography and Other Geophysical Characterization Techniques.

Ad hoc reviewer: DOE LLWMP proposals.

Other: Chairman, Education Committee, East Tennessee Chapter, Association for Women in Science; National Water Well Association's resident scientific expert, groundwater pollution, State of Tennessee.

MULHOLLAND, P. J.

Advisor: R. E. Perkins, Ph.D., The University of Tennessee, Knoxville; Michele Moore, M. S., Ohio State University, Columbus.

Ad hoc reviewer: *Ecology; Journal of Freshwater Ecology;* NSF proposals.

NORBY, R. J.

Participant: 15th Air Pollution Workshop, Knoxville, Tenn., April, 1983; Annual Meeting of the American Society of Plant Physiologists, Fort Collins, Colo., August 1983.

Ad hoc reviewer: *New Phytologist; Canadian Journal of Forest Research;* EPA.

OLSON, J. S.

Member: International Union of Forest Research Organization (IUFRO) Research Group S 1.01.06: Tropical and Subtropical Forest Ecosystems.

Participant: Carbon cycling, vegetation, soil and climate, National Center for Atmospheric Research, Climate Club, Boulder, Colo., April 1983; Gordon Research Conference, Environmental Sciences (Air), New Hampton School, N.H., June 1983; Duneland Horizons, public lecture series, Indiana Dunes State Park, Indiana Foundation for the Humanities, Beverly Shores, Ind., July 1983.

Faculty: Adjunct Professor, Botany Department and Ecology Graduate Program, The University of Tennessee, Knoxville; Visiting Distinguished Lecturer, Ecology Program, Colorado State University, Fort Collins, April 1983.

Consultant: Illinois Department of Energy and Natural Resources, 12th Annual Conference, Illinois Climate: Trends, Impacts, and Issues, Urbana, September 1983.

Ad hoc reviewer: *Ecology; Science; Climate Change; Canadian Journal of Forestry; Botanical Gazette;* Cornell University; Virginia Polytechnic Institute and State University; DOE and NSF proposals.

Editorial Board, *Ecological Studies,* Springer-Verlag, Inc.

OLSON, R. J.

Member: Planning Committee, 1983 Integrated Data Users Group.

Participant: 1982 Integrated Data Users Workshop, Reston, Va., October 1982; Renewable Resource Inventories for Monitoring Changes and Trends, Corvallis, Oreg., August 1983; Acid Deposition Assessment Workshop, Leetown, W.Va., April 1983; Assessment of Agricultural Impacts of Acidic Rain, Oak Ridge, Tenn., September 1983: Advanced Integrated Assessment Methodology Workshop, Oak Ridge, Tenn., June 1983.

O'NEILL, R. V.

Member: National Academy of Sciences Committee on Global Ecology and Exobiology.

Faculty: Adjunct Associate Professor, The University of Tennessee, Knoxville; Visiting Scientist, Cornell University, Ithaca.

Consultant: NSF Reclamation Project, Logan, Utah.

Ad hoc reviewer: *Ecology, American Naturalist,* Michigan State University Press, American Society of Testing and Materials; NSF proposals.

PARR, P. D.

Chairman: Endangered Plants Committee for Oak Ridge Reservation Resource Management Plan.

Member: DOE-ORR Resource Management Plan Committee.

Participant: 44th Annual Meeting of the Association of Southeastern Biologists, Lafayette, La., April 1983; 15th Annual Air Pollution Workshop, Knoxville, Tenn., April 1983; ORNL in-house courses: Introduction to the DEC Sys-

	tem-10, Introduction to System 1022 Data-Base Management System, Interpersonal Effectiveness.
Other:	Treasurer, Association for Women in Science, East Tennessee Chapter.

PENG, T.-H.

Ad hoc reviewer:	NSF marine chemistry, NSF polar studies, and DOE carbon dioxide research proposals; *Journal of Geophysical Research; Geophysical Research Letter; Science.*

REED, R. M.

Participant:	Fundamentals of Groundwater Protection Seminar, March, 1983; Soil Conservation Society of America Annual Meeting, August 1983.
Faculty:	Faculty Associate, Graduate Program in Ecology, The University of Tennessee, Knoxville.
Member:	Executive Committee, Graduate Program in Ecology, The University of Tennessee, Knoxville.

REICHLE, D. E.

Member:	National Board of Governors, The Nature Conservancy; Environment Project Advisor Group, Gas Research Institute: Advisor Panel for Ecosystem Studies, NSF; Committee on the Applications of Ecological Theory to Environmental Problems, National Academy of Sciences; Admissions Committee, Graduate Program in Ecology, The University of Tennessee.
Participant:	Program management team, Carbon Cycle Research, Carbon Dioxide Research Division, DOE; ORNL Site Development and Design Review Committee.
Faculty:	Adjunct Professor, Graduate Program in Ecology, The University of Tennessee, Knoxville.
Advisor:	Christopher Craft, M.S., The University of Tennessee, Knoxville; S. W. Seagle, Ph.D., The University of Tennessee, Knoxville.
Ad hoc reviewer:	*Ecology; Science; BioScience;* Cambridge University Press, Springer-Verlag; Academic Press; EPA, DOE, NOAA, NSF, USGS, and USDA proposals.
Other:	Editorial Board, *Pedobiologia;* series editor, Advance Texts in the Life Sciences, Springer-Verlag.

RICHTER, D. D.

Participant:	Second National Symposium on Acid Rain, Greater Pittsburgh Chamber of Commerce, October 1982; Atmospheric Deposition Specialty Conference, Air Pollution Control Association, Detroit, November 1982; Annual Meeting of Mississippi Chapter of American Fisheries Society, Starkville, February 1983; Annual Meeting of Soil Science Society of America, Washington, D.C., August 1983.
Member:	Secretary, Southern Forest Environment Research Council, 1982–1984.
Ad hoc reviewer:	*Soil Science Society of America Journal; Water Resources Research;* DOE proposals.

SALE, M. J.

Chairman:	ESD Computer Advisory Committee.
Member:	Review team of the FERC license application and DEIS preparation for the Susitna Hydroelectric Project, Alaska.
Ad hoc reviewer:	*Transactions of the American Fisheries Society; Water Resources Bulletin.*
Other:	Instructor, Workshop on Environmental Impacts of Small-Scale Hydropower Development conducted by ORNL personnel for EPA/Region V, May 1983.

SHRINER, D. S.

Chairman:	Effects Committee, National Atmospheric Deposition Program; National Laboratory Consortium Acid Deposition Effects Program; National Laboratory Consortium Acid Deposition Assessment Program.
Member:	Technical Council, Ecological Effects Committee, Air Pollution Control Association; Pollution Effects on Plants Committee, American Phytopathological Society; Task Group F, Terrestrial Effects, Interagency Task Force on Acid Precipitation; Acid Rain Special Grants Program Steering Committee, Cooperative State Research Service, U.S. Department of Agriculture.
Participant:	AAAS Symposium, Acidic Effects of Sulfur Deposition in Terrestrial Ecosystems, Grand Forks, N.Dak., August 1983; U.S. Fish and Wildlife Service Workshop, Acid Deposition Effects Assessment, Leetown, W.Va., April 1983; Workshop on Integrated Assessment Methodology for Acidic Deposition Impacts, Oak Ridge, Tenn., June 1983; Workshop on Crop Loss Assessment Methodology, Oak Ridge, Tenn., September 1983.
Faculty:	Adjunct Professor, Department of Plant Pathology and Physiology, Virginia Polytechnic Institute and State University, Blacksburg.
Ad hoc reviewer:	*Science; Journal of the Air Pollution Control Association; Journal of Environmental Quality; Environmental and Experimental Botany; Environment International; Pedobiologia;* NSF, DOE, EPA, EPRI, USDA, and Natural Sciences and Engineering Research Council of Canada proposals.

SHUGART, H. H.

Member:	United States Representative, UNESCO Expert Panel on Systems Ecology.
Faculty:	Part-time full professor, Ecology Program, Department of Botany, The University of Tennessee, Knoxville.
Advisor:	Daryl Moorehead, Ph.D.; Juan Saldarriaga, Ph.D.; John Schutt, Ph.D.; Tom Doyle, Ph.D.; Don Weller, Ph.D.; A. Hansen, Ph.D.; D. Urban, Ph.D., The University of Tennessee, Knoxville.
Ad hoc reviewer:	*Ecology; American Naturalist; Australian Journal of Ecology; Condor; Auk; BioScience; Science.*
Other:	Associate Editor, *Ecological Monographs/Ecology;* Editorial Board, *Annual Review of Ecology and Systematics;* review panel member, NSF

Ecosystems Program; member advisory board, Cedar Creek Long-Term Ecological Research Site, University of Minnesota; member review panel, Belle Baruch Marine Laboratory, Georgetown, S.C.; member review panel, Chesapeake Laboratory, Smithsonian Institute.

SIGAL, L. L.

Chairman: Session chairperson and organizer, Effects of Air Pollutants on Lichens and Lower Plants: Perspectives of Researchers and Regulators, 15th Air Pollution Workshop, April 1983.

Participant: 15th Air Pollution Workshop, April 1983; Annual Meeting American Institute of Biological Scientists, University of North Dakota, Grand Forks, August 1983; public meeting for the Critical Assessment Review Papers on the Acidic Deposition Phenomenon and Its Effects, Raleigh, N.C., November 1982.

Ad hoc reviewer: *The Bryologist; Journal of Chemical Information and Computer Sciences;* Gas Research Institute.

Other: Editor, *Tennessee Native Plant Society Newsletter.*

SMITH, E. D.

Member: ORNL review team for synfuels project environmental monitoring plans.

Participant: Third Annual Symposium on Aquifer Restoration and Ground-Water Monitoring, Columbus, Ohio, May 1983; American Geophysical Union Symposium on Groundwater Flow and Fractured Rocks, Baltimore, Md., June 1983; Coordination Meeting for the Nuclear Regulatory Commission's High-Level Waste Package Research, Washington, D.C., July 1983; panel discussion on Women in Scientific Professions: Rewards and Frustrations, Oak Ridge Chapter of Institute of Electrical and Electronics Engineers, Oak Ridge, Tenn., April 1983; preparation of Oak Ridge Reservation Resource Management Plan.

Consultant: Wisconsin's Environmental Decade Fund, Madison, Wis.

Other: Program chairperson for Association for Women in Science, East Tennessee Chapter.

SOLOMON, A. M.

Chairman: Education Committee, Ecological Society of America, 1983–1984.

Member: Ecological Society of America Council, 1983–1984.

Editor: Newsletter of American Quaternary Association, 1979–1984.

Participant: Symposium on Climate and Biosphere Interactions, Osnabrück, FRG, March 1983; Workshop on Forest Dynamics, Uppsala, Sweden, March 1983; Ecological Society of America Annual Meeting, Grand Forks, N.Dak., August 1983; FORTRAN IV Training Course, ORNL, September 1982; MAPPER Training Course, ORNL, January–February 1983; SAS Training Course, ORNL, January 1983.

Ad hoc reviewer: NSF Environmental Biology (Nichols et al.), NSF Division of Polar Programs (Askin et al.), NSF Division of Atmospheric Science (M. B. Davis), NSF Division of Polar Programs (H. E. Wright), DOE Carbon Cycling Office, Carbon Dioxide Research Division (Long et al.), and NSF Division

of Polar Programs (P. H. Glaser) proposals; *Ecology/Ecological Monographs; Science Magazine* (Tsukada); *Quaternary Research* (Prentice); *Torreya; Science Magazine.*

SOLOMON, J. A.

Chairman:	Arrangements Committee, Association for Women in Science, East Tennessee Chapter.
Participant:	Electric Power Research Institute, Legionnaires' Disease Bacterium Project Advisory Committee Meetings, November 1982 and June 1983.

SOUTHWORTH, G. R.

Participant:	Society of Environmental Toxicology and Chemistry, Annual Meeting, Arlington, Va., November 1983.
Advisor:	Burton Jaynes, B.S., Carleton College.
Ad hoc reviewer:	*Environmental Science and Technology.*

SUTER, G. W., II

Participant:	Scientific Group on Methods for the Safety Evaluation of Chemicals, Workshop on Methods for Assessing the Toxicity of Mixtures of Chemicals, Guildford Surrey, U.K., August 1983; Joint Meeting on DOE and EPA Health and Environmental Risk Analysis Programs, Arlington, Va., February 1983; EPA Peer Review of Environmental Risk Analysis Project, Alexandria, Va., March 1983.
Advisor:	Mary Cavendish, M.S., Indiana University, Bloomington.
Ad hoc reviewer:	*Environmental Management.*

TAYLOR, F. G.

Participant:	DOE Plant Uptake and Soil-Plant Processes Meetings, Gaithersburg, Md., May 1983; International Conference, Heavy Metals in the Environment, University of Heidelberg, FRG, September 1983; SRP/SREL Workshop, Land Application of Decontaminated SRP Salt Supernate, SRP/SREL, Aiken, S.C., March 1983.
Reviewer	*Journal of Environmental Quality.*
Other:	Recording Secretary, Tennessee Native Plant Society, 1983–84; DOE Traveling Lecture Program, 1983–83; ORNL auxiliary guard.

TAYLOR, G. E.

Chairman:	15th Air Pollution Workshop, Hyatt Regency, Knoxville, Tenn., April 1983.
Member:	Natural Sources Task Group, Interagency Task Force on Acid Precipitation.
Participant:	Session Chairman, 15th Air Pollution Workshop, Knoxville, Tenn., April 1983; Annual Meeting, American Society of Plant Physiologists, August 1983.
Advisor:	E. B. Carter, Ph.D., Emory University, Atlanta.
Ad hoc reviewer:	*Science; Journal of Environmental and Experimental Botany; Journal of Environmental Quality;* Ecological Research Series; Department of the Army and Gas Research Institute proposals.
Other:	Editor, *Physiological Section Newsletter,* Botanical Society of America.

TOLBERT, V. R.

Co-Chairman:	Membership Directory Committee, American Society for Surface Mining and Reclamation.
Member:	Special Membership Committee, North American Benthological Society; Glossary Surface Mining and Reclamation Terminology, Editorial Committee, American Society for Surface Mining and Reclamation; Fish and Wildlife in Relation to Mining Committee, American Fisheries Society; Rural Abandoned Mines Program (RAMP) State Implementation Committee.
Participant:	Affirmative Action training course, ORNL; Fusion Energy, ORNL, April 1983; Career Planning Course, ORNL, February 1983; Rate Processes in Environmental Pollution, The University of Tennessee, Department of Civil Engineering, Spring 1983; preparation of Review Draft, Southeastern Regional Geologic Characterization Report, Technical Report, May 1983; preparation of Preliminary Draft Environmental Statement related to the operation of the Bellefonte Nuclear Power Plant, September 1983; preparation of Preliminary Draft Environmental Assessment for renewal of the Special Nuclear Materials License for operation of the Kerr-McGee, Sequoyah Fuel Fabrication Facility, 1983.
Ad hoc reviewer:	*Environmental Entomology.*
Awards and Honors:	Outstanding Young Woman of America, 1982.

TRABALKA, J. R.

Co-Chairman:	Sixth ORNL Life Sciences Symposium, The Global Carbon Cycle. Analysis of the Natural Cycle and Implications of Anthropogenic Alterations for the Next Century, October–November 1983, Knoxville, Tenn.
Participant:	The World Economy and the World Forests in the Twentieth Century, April 1983, Research Triangle Park, N.C.
Member:	ORNL Professional Education Resource Committee for Life Sciences.

TURNER, R. S.

Participant:	Sixth North American Forest Soils Conference, Knoxville, Tenn. June 1983.
Advisor:	Alan Stam, Ph.D., The University of Tennessee.

TYNDALL, R. L.

Chairman:	Aerobiology of Legionnaires' Disease Bacteria, Gordon Conference.
Participant:	Electric Power Research Institute, Legionnaires' Disease Bacterium Project Advisory Committee Meetings, November 1982 and June 1983; DOE Task Force for developing guidelines for worker protection relative to Legionella exposure, Lawrence Livermore Laboratory, March 1983.
Faculty:	Research Associate Professor, Zoology Department, The University of Tennessee, Knoxville.
Advisor:	Audrey Nicholson, Ph.D., Zoology Department, The University of Tennessee, Knoxville.
Consultant:	Northern States Power, Minneapolis, Minn.
Ad hoc reviewer:	Illinois Department of Energy and Natural Resources; The American Microscopical Society.

VAN HOOK, R. I.

Advisor: E. R. Merchant, M.S., The University of Tennessee, Knoxville.

Faculty: Faculty Associate, Graduate Program in Ecology, The University of Tennessee, Knoxville.

VAN WINKLE, W.

Co-Chairman: Aquatic Effects Review Committee, National Acid Precipitation Assessment Program, Effects Research Review, North Carolina State University, Raleigh, February 1983.

Participant: Emergency Striped Bass Study Workshop, Alexandria, Va., January 1983; Workshop on Use of the Computer-Based Physical Habitat Simulation System (PHABSIM), Colorado State University, Fort Collins, May 1983; Meeting of the Science Advisory Board Ad Hoc Committee to Review the National Acid Precipitation Assessment Program, Washington, D.C., September 1983; Moderator, Contributed Papers Session on Population Studies, Annual Meeting of the American Fisheries Society, Milwaukee, August 1983.

Faculty: Adjunct Professor in Ecology, The University of Tennessee, Knoxville.

Ad hoc reviewer: *Canadian Journal of Fisheries and Aquatic Sciences, Science,* Hudson River Foundation for Science and Environmental Research.

VOORHEES, L. D.

Member: Committee on Roadside Maintenance, Transportation Research Board for the National Research Council.

Participant: Third Annual Meeting of the Society of Environmental Toxicology and Chemistry, Arlington, Va., November 1982; Introduction to the DEC System-10, ORNL Management Resource Development Program, January–February 1983; Rapid Reading, ORNL Management Resource Development Program, February–March 1983; International Conference on Radioactive Waste Management, Seattle, May 1983; preparation of EIA related to General Atomic nuclear fuel fabrication facility, California, EIA related to Babcock and Wilcox commercial nuclear fuel fabrication facility, Virginia, DEIA related to Babcock and Wilcox Naval nuclear fuel fabrication facility, Virginia, and DEIA related to Cabot Berylco, Inc. nuclear source material license, Pennsylvania.

Other: Section Editor, *Nuclear Safety.*

WALKER, R. R.

Participant: Presented paper at the Second Biennial Southern Silvicultural Research Conference, Atlanta, November 1982.

WALTON, B. T.

Member: Committee on Systematic Resources, Entomological Society of America, 1982–1985; ESA Hazardous Chemicals Committee, 1982–1983.

Participant: Session moderator for "Toxicology, Biochemistry, and Physiology," Joint Meeting of the Entomological Societies of Canada, America, and Ontario in Toronto, December 1982; Society of Toxicology, Meeting of Regional

Chapter and Specialty Section Executives, Chicago, May 1983; Annual Meeting of the Society of Environmental Toxicology and Chemistry, Arlington, Va., November 1982; lecturer for Environmental Toxicology 5610, The University of Tennessee, Knoxville, February 1983.

Faculty: Adjunct Faculty Associate, Ecology Program, The University of Tennessee, Knoxville.

Advisor: E. R. Merchant, M.S., The University of Tennessee, Knoxville.

Ad hoc reviewer: *Science; Environmental Entomology; Annals of the Entomological Society of America; Journal of Economic Entomology;* NSF and ORNL Seed Money proposals.

Other: Visiting scientist, Department of Zoology, University of Washington, Seattle, January–February, 1983; Program Chair, 1983 Annual Meeting of the Society of Environmental Toxicology and Chemistry; selected for membership in the Society of Toxicology, 1983; secretary-elect, Section B, "Toxicology, Biochemistry, and Physiology," Entomological Society of America, 1983.

WATTS, J. A.

Chairperson: "Climate and First Detection Data Meeting, A Status Report," presentation and discussion with DOE Carbon Dioxide Research Division program and area managers, January 1983, Washington, D.C.

Participant: ORNL In-House Education Programs: Perry Oral Presentation, May 1983; Platform Skills, May 1983; Effective Time Management, September 1983.

WEBB, J. W.

Advisor: Christopher Craft, M.S.. The University of Tennessee, Knoxville.

Ad hoc reviewer: *Annals of the Entomological Society of America; Environmental Entomology; Ecology; Environment International;* NSF proposals.

Participant: Review of geothermal environmental analyses; preparation of draft final report, "Retrospective Examination of Geothermal Environmental Assessments" (project manager); EIS, Braidwood Nuclear Power Station, Operating License; DES, Bellefonte Nuclear Power Station, Operating License.

WRIGHT, L. L.

Ad hoc reviewer: Proceedings of the Second International Corbicula Symposium.

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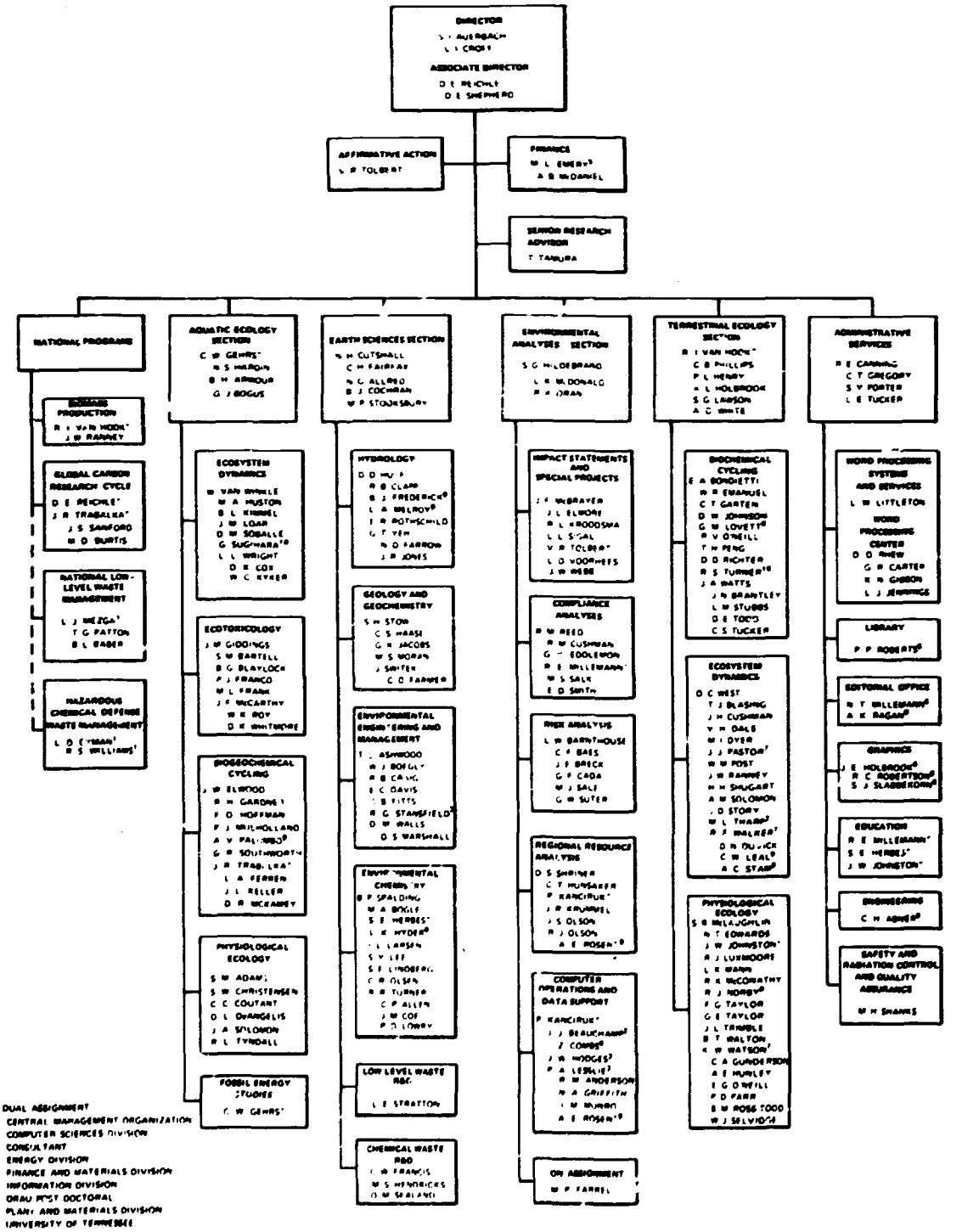

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