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SAVANNAH RIVER LABORATORY ENVIRONMENTAL TRANSPORT AND EFFECTS RESEARCH

ANNUAL REPORT - FY 1975

SAVANNAH RIVER LABORATORY
AIKEN, SOUTH CAROLINA 29801

PREPARED FOR THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION UNDER CONTRACT AT(07-2)-1

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ANNUAL REPORT - FY 1975

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ABSTRACT

Research on the transport of pollutants through the environment and effects of pollutants on ecosystems, performed at the Savannah River Laboratory during fiscal year 1975, is presented. A number of short articles within a wide variety of scientific disciplines describes, through computer modeling and field cxperiments:

- *Atmospheric transport studies* focused on new modeling techniques and experiments to develop tested methods for calculating the transport and dispersion of both routine and accidental releases of pollutants to the atmosphere of the southeastern United States (Articles 1-11).

- *Soil and terrestrial biology studies* focused on developing an understanding of the uptake of gaseous substances from the atmosphere by plants, biodegradation of oil, and the movement of plutonium in the terrestrial ecosystems of the southeastern United States (Articles 12-20).

- *Geologic studies* focused on developing a better understanding of the processes which govern movement of pollutants in ground water and seepage basins (Articles 21-22).

- *Aquatic transport studies* focused on developing predictive models of the SRP streams, on developing new field sampling systems, studying plutonium in estuaries of the southeastern United States, and removing plutonium from raw river water by domestic water treatment plants (Articles 23-26).

- *Aquatic biology studies* focused on studying the hydrothermal effects of Par Pond reservoir on periphyton, plankton, zooplankton, macrophytes, human pathogens, and microbial activity; the variability between the artificial streams of the Flowing Streams Laboratory and Upper Three Runs Creek; and the bacterial production of methane in SRP aquatic systems (Articles 27-38).

- *Dose-to-Man Studies* focused on developing computer data handling and computer modules which permit easy, rapid assessment of the dose to southeastern United States populations from routine or accidental releases to atmospheric and stream systems (Articles 39-41).

FOREWORD

This report is the second in a series of annual reports prepared by the Savannah River Laboratory (SRL) on environmental transport and effects research. This report covers research performed during fiscal year 1975. The general objective of the environmental sciences research at SRL, particularly within the Environmental Transport Division, is to develop (or adapt), test, modify, and apply models for calculating transport, dispersion, and effects of various materials moving through environmental systems such as the atmosphere, streams, ponds, rivers, estuaries, ocean, ground water, soil, plants, etc. That part of the research which has specific applicability to the operation of the Savannah River Plant (SRP) is funded by the Division of Nuclear Fuel Cycle and Production (DNFCP), and that part of the effort which has general applicability to the energy industry of the southeastern United States is funded by the Division of Biomedical and Environmental Research (DBER) of the Energy Research and Development Administration (ERDA).

In FY-1974, DBER had funded four separate environmental sciences programs at SRL (Thermal Effects in Par Pond, Thermal Effects Studies in Streams, Tritium Tracer Studies in Estuarine and Coastal Waters, and Radiation Dose-To-Man). In addition to some changes in these four programs, FY-1975 saw the addition of three new DBER-funded programs (Transuranics in Environmental Systems, Atmospheric Release Advisory Capabilities in the Southeastern United States, and Krypton-85 Measurements). The new transuranic program was focused primarily on terrestrial ecosystems in FY-1975, and this goal, coupled with the transuranics focus in the estuarine research, resulted in a significant involvement of onsite personnel in research on the environmental behavior of transuranic elements.

The DBER-funded environmental science research programs are centered in the Environmental Transport Division (ETD), but with heavy collaboration with the Environmental Effects Division (EED) and support from other SRL divisions. Many of these programs involve direct collaboration with other groups on and off the Savannah River site, through coordination by the Savannah River Operations Office of ERDA. For instance, the new work on transuranics in terrestrial ecosystems was performed in collaboration with a separately funded program at the Savannah River Ecology Laboratory (operated by the University of Georgia), has involved the environmental monitoring group of the Health

Physics Section of SRP, and has received assistance from the U. S. Forest Service group on the Savannah River site. The expanded estuarine research is in collaboration with the National Oceanic and Atmospheric Administration (NOAA) Marine Laboratories at Beaufort, North Carolina. The Atmospheric Release Advisory Capabilities-Southeastern United States program has involved direct interaction with SRP, and joint research with Lawrence Livermore Laboratory (LLL) personnel. The Krypton-85 Measurements program is in collaboration with the Air Resources Laboraties of NOAA at Silver Spring, Maryland, and involves Krypton-85 analyses by the Argonne National Laboratory (ANL).

The collection of summaries which comprise this report illustrate the breadth of SRL environmental sciences research activities on the Savannah River site and in its environs.

This report was prepared by the ETD of SRL with contributions in the environmental sciences from other SRL divisions and with other collaborators from both on- and off-site. This report includes the major research activities of the ETD during FY-1975; in addition, many applied short-range jobs were completed. Other environmental efforts performed by Du Pont at the site, such as the large-scale effort of the SRP Health Physics Section in environmental monitoring, are recorded elsewhere.

Todd V. Crawford, Research Manager
Environmental Transport Division

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I. ATMOSPHERIC TRANSPORT STUDIES

1. A WEATHER INFORMATION AND DISPLAY SYSTEM FOR RESEARCH AND EMERGENCY RESPONSE †

INTRODUCTION

To provide for emergency meteorological response to accidental releases and to conduct research on the transport and diffusion of radioactive nuclides in the routine releases, a series of high-quality meteorological sensors have been placed on towers in and about the Savannah River Plant (SRP) with communications to a Weather Information and Display (WIND) minicomputer located at the Savannah River Laboratory (SRL) Weather Center-Analysis Laboratory (WC-AL).

This system is designed to provide useful, timely data to decision makers to permit rapid decisive action to limit the consequences of accidental releases. Although focused on support to SRP, the emergency response capabilities of the system can also be extended to more general offsite use, such as providing assistance to ERDA Savannah River Operations office personnel for fulfilling their responsibilities for general radiological assistance in the Southeast.

DATA COLLECTION

A television tower within 15 km of the plant boundary is instrumented at seven levels between 2 and 304 m above the ground surface with temperature sensors and turbulence quality wind sensors. Adjacent to main SRP operating areas, seven 62-m high towers were erected in nearby pine forests. Mounted on each tower is a commercially available, vector-vane wind sensor which measures and transmits horizontal and vertical wind directions and total wind speed data. In addition, an acoustic sounder provides continuous real-time measurements of the vertical mixing characteristics of the lowest 1 km of the atmosphere. The data from these sensors are brought to the WC-AL for storage and for subsequent computer processing.

---

† Work done by C. D. Kern. Presented at the Third ERDA Environmental Protection Conference, Chicago, Illinois, on September 23-25, 1975.

The WC-AL also has a National Facsimile Circuit, which prints out analyses of large-scale observations and forecasts from the National Weather Service; an FAA Teletype Service A receiver, providing hourly surface weather observations and some forecasts; and a National Weather Service C receiver, providing upper air and surface synoptic information.

A PDP-11/40 (Digital Equipment Corp., Maynard, Mass.) minicomputer has been installed within the WC-AL. A DATACOM data acquisition system (DATACOM Corp., Ft. Walton Beach, Fla.) provides storage capability compatible with the SRL IBM 360-195 computer. A data-phone link to the Lawrence Livermore Laboratory (LLL) was established for the purpose of data exchange during joint SRL-LLL tests of the Atmospheric Release Advisory Concept.

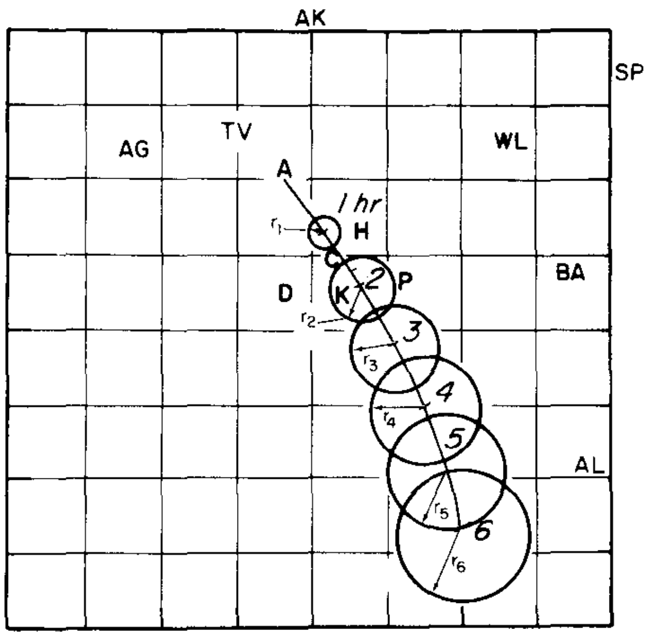
EMERGENCY RESPONSE OF *WIND* SYSTEM

The WIND system supports countermeasures for accidental atmospheric releases by providing predictions of release behavior which are needed to:

1. Assess promptly the situation.
2. Provide a basis for actions to minimize immediate consequences to personnel and equipment.
3. Provide a basis for an environmental sampling plan.
4. Develop strategies and actions for recovery in such a way as to minimize consequences.

In the WIND system, the source term is supplied by SRP personnel during a simulated or actual emergency release to the atmosphere. When this information is supplied and adequate meteorology is provided, then downwind concentrations, location, and time of arrival data are supplied by tabular listings and graphical output from the WIND system. These are supplied quickly and in a form which is useful to the decision makers within the SRP Emergency Operating Center (EOC). The WIND system has some very simple graphical and computational programs. Dispersion of pollutants in the atmosphere is calculated using simple Gaussian puff and Gaussian plume equations. Maps display trajectories and extent of the dispersion as calculated from time-dependent two-dimensional wind fields.

Presently, the system works in a time-shared mode whereby the WIND minicomputer asks certain questions and, when supplied with the answers, provides graphical output. An example of a graphical display is shown in Figure 1. A map of the local area with each square representing 10 km shows a simulated release from the A Area with the circle centered on the location at the end of each hour of travel of the puff. The circle radius represents a two-sigma deviation from the centerline concentration. It is possible to know the centerline concentration at the end of each hour, the concentration value within the two-sigma limit, and the geographical position of these values. This information provides the information necessary to decide what consequence-limiting action, if any, need be taken. The time to execute this program and provide a columnar printout is minimal in the minicomputer (a few milliseconds), whereas the bulk of the time is taken in answering the time-shared questions and displaying the graphical output. The overall program from start to finish takes less than two minutes for an accomplished operator. These displays are available within the WC-AL or within the EOC on call from either location.



AG = Bush Field
TV = WJBF Tower
AK = Aiken
WL = Williston
SP = Springfield
BA = Barnwell
AL = Allendale
Grid = 10-km squares
D, H, K, P = SRP Areas
r_1 through r_6 = 2σ of horizontal dispersion per hour along puff trajectory

FIGURE 1. Graphical Output from WIND System Simple Gaussian Puff/Plume Trajectory

2. A NEW TECHNIQUE FOR COMPUTING EDDY DIFFUSIVITY FROM TEMPERATURE DATA †

The temperature phase shift and amplitude attenuation methods for the calculation of eddy diffusivity, K_z, have been utilized by Crawford and Pendergast[1] to estimate K_z profiles for the Savannah River Plant (SRP) in order to obtain K_z estimates to use in diffusion calculations. These methods require K_z to be constant in space and time, a constraint not likely to be respected by the real atmosphere. Therefore, a numerical model was constructed (see Article 6 of this report, *Numerical Techniques Applied to Planetary Boundary Layer Modeling*) to test the above procedures with a time-varying K_z (still constant with height) and a sinewave surface temperature. The techniques did not fare well. The numerical model's results emphasized, as can be shown analytically, that a pure sinewave surface temperature and a diurnally varying K_z produce harmonics above the surface and also amplitude attenuations and phase shifts which are not predicted by the simple constant K_z theory.

Since a closed-form solution to the K_z problem is unlikely, a program has been written, not yet fully debugged, which inverts the turbulent heat transfer equation. The relation

$$K_z(z,t) = \frac{\int_a^z dz \, \frac{\partial\theta}{\partial t} + K_z(a,t)\left(\frac{\partial\theta}{\partial z}(a,t) - \gamma_D\right)}{\frac{\partial\theta(z,t)}{\partial z} - \gamma_D} \tag{1}$$

requires temperature shears and tendencies at finer intervals than those provided by the coarse level spacing of the tower data. (γ_D results from Deardorff's counter-gradient heat flux theory[2]). Obtaining a finer resolution for the model is accomplished by introducing interstitial computational levels, whose temperatures are determined by solving the spatial cubic spline matrix relations. Tendencies are calculated using cubic splines in time. $K_z(a,t)$, the K_z at an arbitrary height (a) within the tower levels, generates a one-parameter $[K_z(a,t)]$ family of $K_z(z,t)$. The best value of $K_z(a,t)$ is determined by solving the heat equation with chapeau functions using each member in the family, computing a root-mean-square error, and then locating the $K_z(a,t)$ which produces the

† Work done by P. E. Long and M. M. Pendergast.

least error. The complete profile is reconstructed from the knowledge of $K_z(a,t)$. The error calculation will give a direct indication of the validity of K-theory.

In order to help make the raw data amenable to the above analysis, the data will be time-filtered using a new weighted variational technique which demands that the integral

$$I = \int dt \left\{ (T - T_o)^2 + \alpha(t)\ (T-T_e)^2 + \beta(t) \left(\frac{\partial T}{\partial t} - \frac{\partial T_e}{\partial t} \right)^2 \right\} \quad (2)$$

be minimized. T, T_o, and T_e are the filtered temperature, observed temperature, and climatologically averaged ensemble diurnal temperature. The weighting functions are α and β. An application of the Euler-Lagrange equation yields a differential equation in $T(t)$, some of whose filtering effects on computer-generated noisy data are illustrated in Figure 1.

This new method for computing K_z will have the advantage of permitting K_z to vary with time and height and will determine whether any $K_z > 0$ is appropriate for predicting the complete diurnal temperature cycle. The new method seeks the $K_z(z,t)$ which produces the smallest error in reproducing the diurnal temperature wave. The method will enable the comparison of the relations of Deardorff's[3] K_z with those of Pielke's[4] use of the O'Brien Hermite cubic (invoking the integrated surface layer relations of Long and Shaffer).[5] A new variational filter is used to smooth the temperature data. An overly strong n-point smoother applied directly to the raw data could damp the meaningful diurnal wave; this over-damping is unlikely with the variational filter.

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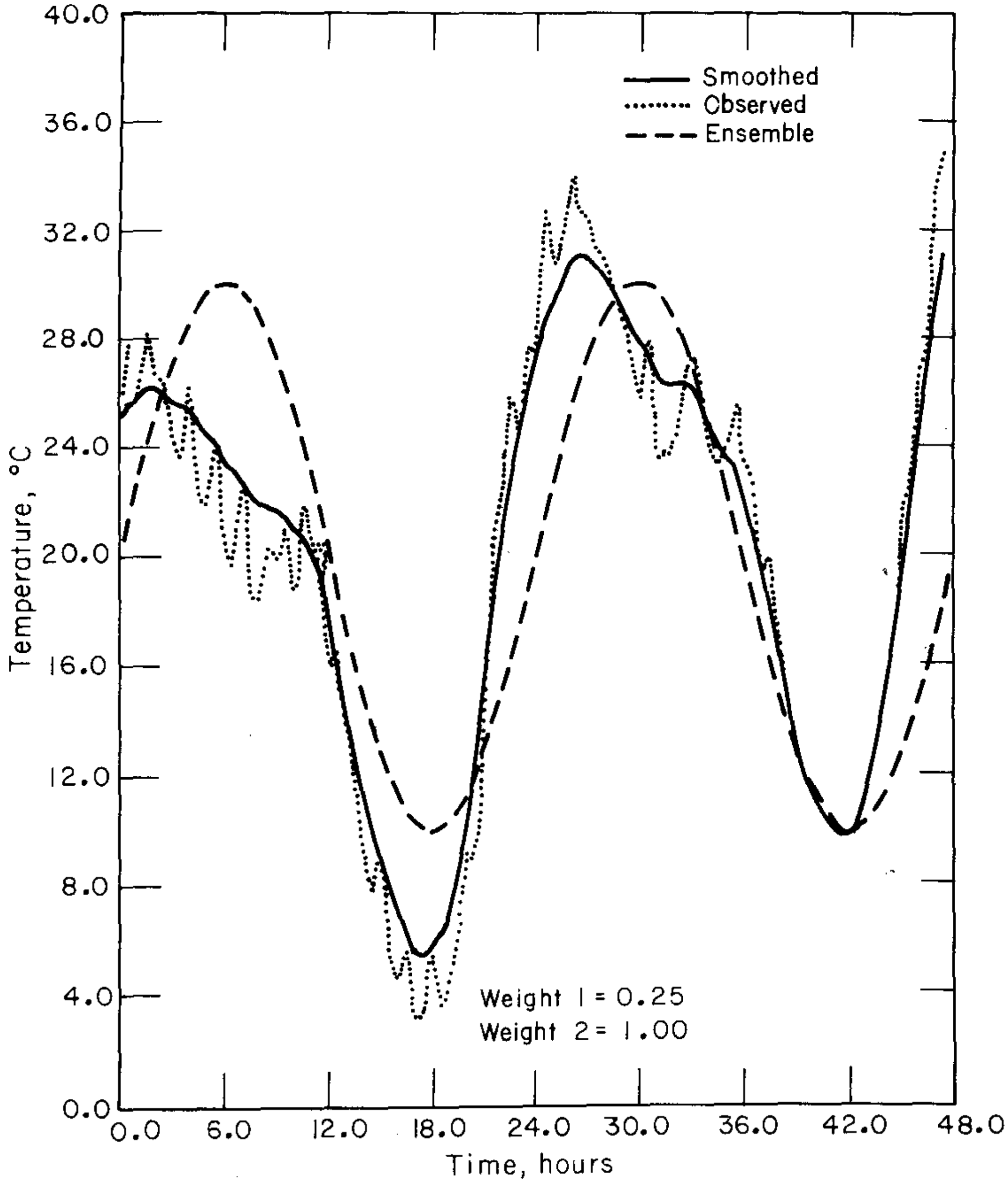

Figure 1. The Variational Method is Used to Filter (Solid Curve) Computer-Generated "Observed" Data (Dotted). The Ensemble Average is Denoted by the Dashed Curve.

3. A COMPARISON OF OBSERVED ONE-WEEK AVERAGE CONCENTRATIONS OF ^{85}Kr WITH CALCULATED VALUES USING A WIND ROSE MODEL AND A TIME-DEPENDENT TRAJECTORY MODEL †

INTRODUCTION

The assessment of long-term environmental effects of industrial pollution is frequently obtained through use of a so-called stability wind rose model in combination with the Gaussian plume equation. Concentrations obtained using this model should be correct to within a factor of 2 or 3 when meteorological conditions at the point of release are identical with those conditions at the valid point of the calculation, normally within 1 km.[1] As the distance between these two points increases, the validity of the wind rose model degrades. The wind rose model is reasonably successful for predicting long-term average concentrations out to distances of 10 km from the source.

As increased emphasis is placed on regional transport of air pollution, the wind rose model is being applied (without verification) over distances in excess of 50 km. This report presents some preliminary tests of the wind rose model through use of one-week-averaged concentrations of ^{85}Kr observed at 13 sites. These sites were located 25 to 100 km from a point source at the Savannah River Plant. A test was also made of one-week-averaged concentrations obtained by a technique based on time-dependent wind trajectories. Both techniques utilize meteorological data from Bush Field, near Augusta, Georgia, located 30 km from the source emitting ^{85}Kr.

WIND ROSE MODEL

A stability wind rose gives the frequency of occurrence for stability, wind direction, and wind speed for the period under consideration. The estimates of the mean concentration, $\bar{\chi}$ (x,θ) for a particular direction (θ) and downwind distance (x) is given by

$$\bar{\chi}(x,\theta) = \sum_{S\ N\ L} \frac{\sum Q\ f(\theta,S,N)}{u_N \left(\frac{2\pi x}{N_s}\right)}$$

† Work done by M. M. Pendergast.

where:

Q = averaged source term

$f(\theta,S,N)$ = frequency during the period of interest that the wind is from the direction θ, for the stability condition S, and the wind speed class N

L = mean height of the well-mixed layer

u_N = representative wind speed for the wind speed class N

N_s = number of wind direction sectors.

Normally the wind directions are taken over 16 sectors. The wind directions within each sector are assumed to be distributed randomly throughout the period. It is further assumed that the airborne effluent is uniformly distributed in the horizontal plane within the sector and within the well-mixed layer.

TIME-DEPENDENT CURVED TRAJECTORY METHOD

In this method, dispersion of an airborne effluent is calculated through use of sequential wind observations made at a single station.[2] The model constructs successive trajectories of one-hour wind vectors during the period of concern and distributes the pollutant according to the distribution of these trajectory endpoints (see page 65 in Reference 2).

RESULTS

Figure 1 presents the results of the comparison of these two techniques for the two-month period of May through June 1975. The ordinate is the ratio of the calculated to the observed concentration. The absissa for the 13 points is plotted as a function of increasing distance from the point of release. The ratios provided by the time-dependent trajectory technique (open symbols) appear to be closer to unity than the ratios determined from the wind rose technique (solid symbols) when the wind speeds are low. When the average wind speed is higher, there is little difference between the two techniques.

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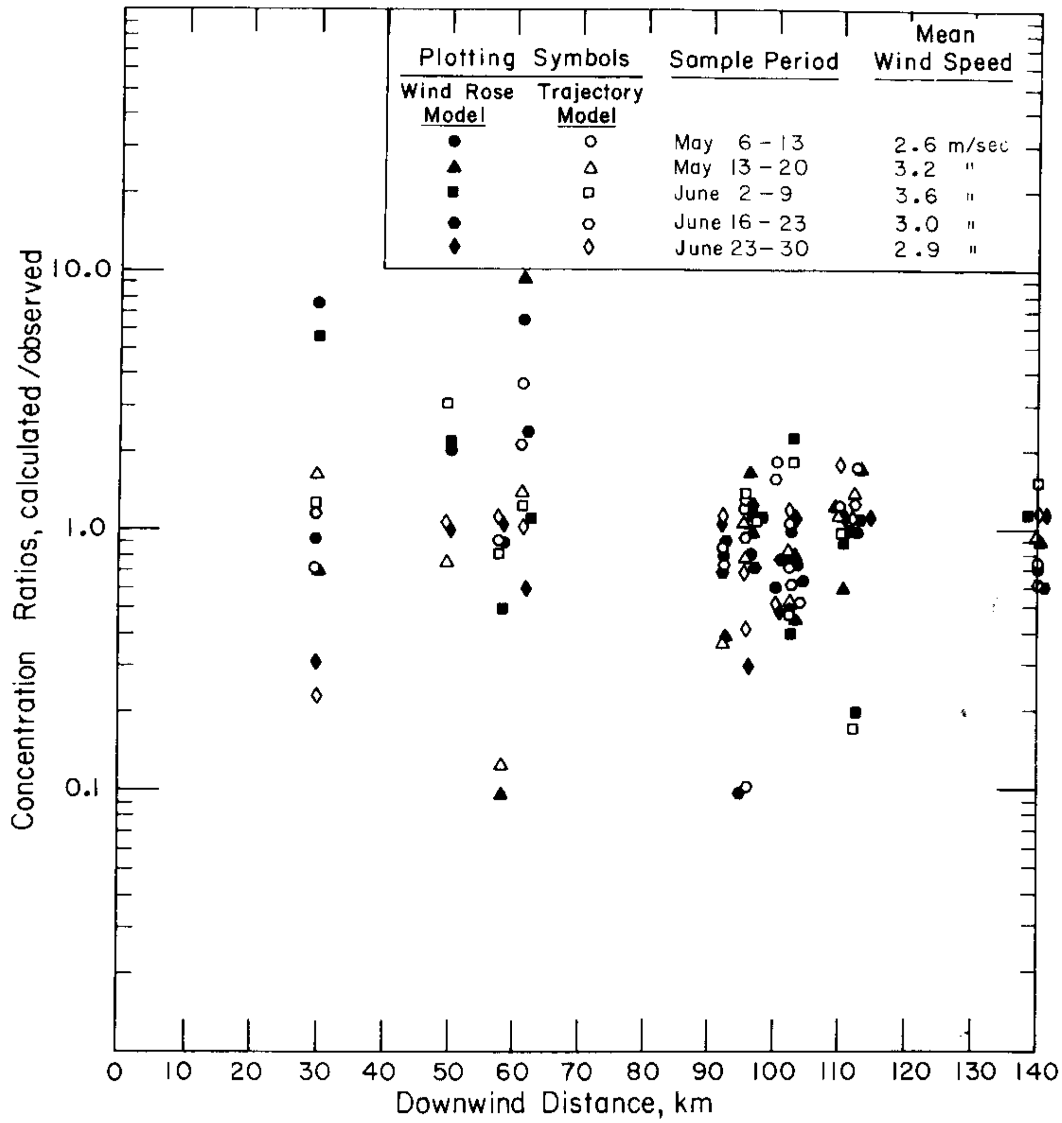

FIGURE 1. Ratio of Calculated-to-Observed Concentrations for ^{85}Kr for Several One-Week Periods, May through June 1975. The solid symbols represent ratios for the wind rose model and the open symbols represent ratios for the trajectory model. The legend at the top of the figure gives average wind speed for each of the periods used for the comparison.

4. TURBULENT DIFFUSION IN THE PLANETARY BOUNDARY LAYER OVER THE SAVANNAH RIVER PLANT DURING PERIODS OF DIFFERING THERMAL STRUCTURE †

INTRODUCTION

The magnitude of turbulent diffusion in the planetary boundary layer (PBL) determines the rate at which an airborne contaminant would be diluted as it is transported through the atmosphere. The larger the magnitude of turbulence, the lower the concentration of contaminant. Turbulent diffusion is a complicated function of ground roughness, vertical temperature gradient, and wind speed. Near the ground, the magnitude of turbulent diffusion is directly related to ground roughness and wind speed and indirectly related to the vertical temperature gradient. A temperature increase with height indicates a stable condition; whereas, a temperature decrease with height indicates an unstable condition.

Numerous studies have been performed of the turbulent diffusion conditions in the PBL during both unstable and stable periods, although much remains to be understood.[1] Few studies have been conducted of turbulent diffusion during periods of complex thermal structure, because normally these conditions are merely transition periods and occur rather infrequently.

Climatogically, South Carolina ia frequently under the influence of a large high pressure area which is responsible for low wind speeds a large percentage of time. These low wind speeds and corresponding clear skies produce marked diurnal changes in the temperature structure within the lower 300 m of the PBL. The depth of the PBL may range from several meters to about 2 km depending upon stability conditions. The climatological pattern of South Carolina is characterized by a relatively high percentage of stable conditions. The vertical extent of the stable layer can be quite variable.

---

† Work done by M. M. Pendergast and A. M. Cope (Undergraduate Summer Trainee, North Carolina State University, Raleigh, North Carolina). Results of a portion of this research was presented at the Fall 1974 Meeting of the *American Geophysical Union* at San Francisco, California.

PROCEDURE

Meteorological data from the WJBF-TV tower[2] during 260 days of 1974 were used to construct a climatology of atmospheric diffusion as a function of thermal structure for the Savannah River Plant area. For the purpose of this report, the magnitude of turbulent diffusion in the horizontal direction is given by σ_a (the standard deviation of the wind azimuth) and in the vertical direction by σ_e (the standard deviation of the elevation angle).

The procedure was to use the temperature profile to define different categories and to accumulate values of σ_a and σ_e for each category. To reduce scatter of the results, all data were expressed as differences from the value at the 10-m level. Profiles of mean wind speed, S, normalized in the above manner were constructed to aid in the analysis.

RESULTS

Figure 1 shows mean profiles of normalized temperature, wind speed, σ_a, and σ_e for the four predominant thermal categories. The horizontal lines show the observation height. The length of these lines is a measure of the range ($\pm 1\ \sigma$) of the data used to calculate the mean profiles. The frequency of occurrence of each group is shown at the left of the figure. For the most part the profiles of σ_a and σ_e agree with theoretical profiles presented by Slade.[3]

An examination of vertical temperature profiles at the meteorologically instrumented WJBF-TV tower indicates 12% of observed profiles depict conditions in transition from stable to unstable (morning) and 9% from unstable to stable (evening). The structure of turbulent diffusion, as characterized by actual statistics on the horizontal and vertical fluctuation of wind direction, showed general agreement with a theoretical structure based on the measured temperature profiles.

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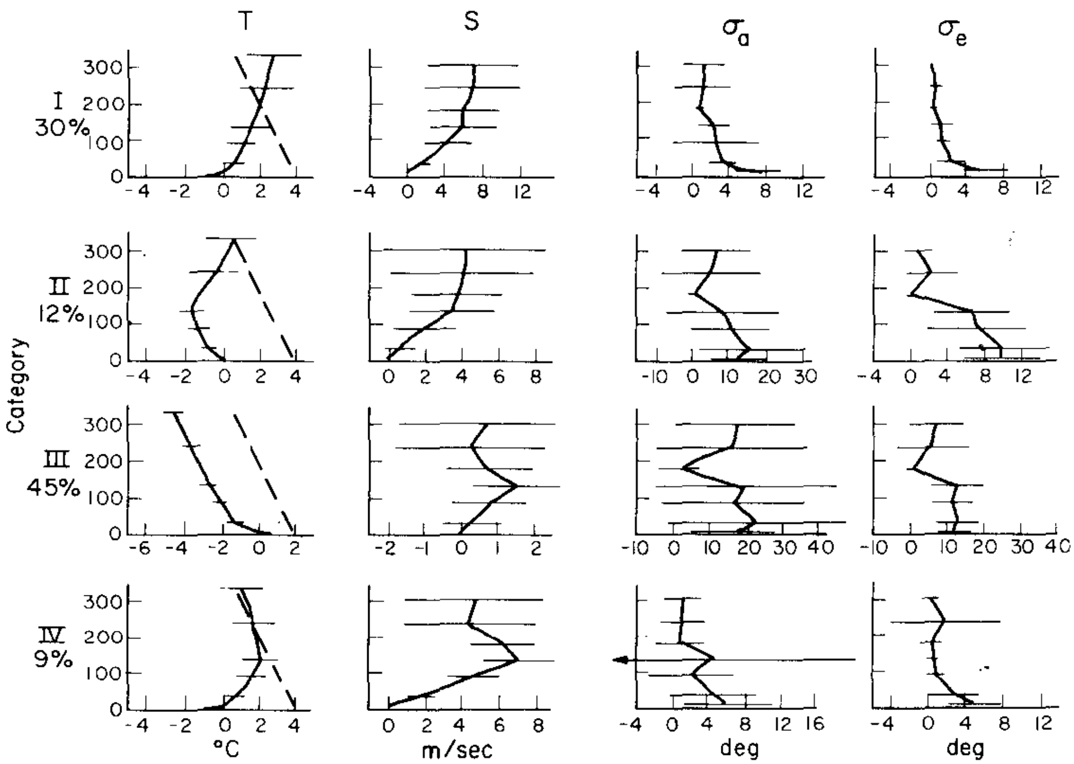

FIGURE 1. Mean Profiles of Wind Speed (S), Standard Deviation of Wind Azimuth (σ_a) and Wind Elevation Angle (σ_e) as Functions of the Four Predominant Thermal Categories. The dashed lines represent the adiabatic lapse rates.

5. PLANETARY BOUNDARY LAYER MODELING †

INTRODUCTION

The Savannah River Laboratory (SRL) and the Techniques Development Laboratory (TDL) are developing a joint three-dimensional planetary boundary layer model which forecasts wind, temperature, and humidity fields within the lowest 2 km of the atmosphere. The model, in conjunction with an appropriate regression analysis, will compute local wind and stability fields used by transport and diffusion models. These models are required to support emergency response efforts for controlling and monitoring accidental releases to the atmosphere. The intended forecast area was originally a 25 x 25 grid covering the area just east of Rockies and barely reaching the middle of South Carolina. The model's coverage was more recently expanded to a 35 x 30 grid with an approximately 80 km mesh spacing (Figure 1).

Part of SRL's effort is to telescope the current grid down to a mesh spacing of about 40 or perhaps 20 km. Even with such a spacing, it is unlikely the model will predict winds and stabilities on a scale fine enough for diffusion studies within the immediate area of SRP. It will be necessary to use model output statistics to correlate the output of the model with local measurements. This technique allows the prediction of variables not accessible to current models and also improves the raw model output.

THE THREE-DIMENSIONAL MODEL

Models (such as described in Article 9 of this report) which are available to calculate transport and diffusion are not self-contained; the required meteorological variables will be provided by the TDL-SRL telescoping grid model. The time-dependent inflow boundary conditions at the lateral and upper surfaces will be supplied by the National Meteorological Center's Limited Area Fine Mesh (LFM) model. A discussion of the outflow boundary

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† Work done by P. E. Long in conjunction with the Techniques Development Laboratory of the National Weather Service, Silver Spring, Maryland.

conditions and other computational matters may be found in this report in Article 6, *Numerical Techniques Applied to Planetary Boundary Layer Modeling*.

The three-dimensional model is based upon numerical experiments with a one-dimensional model which uses Obukhov surface profile relations as determined by Businger et al.[1] and an implicit vertical diffusion scheme. The surface profile relations diagnose the boundary conditions required for the transition layer (50 to 2000 m). Surface temperatures are computed using an energy balance. The eddy diffusion coefficients are currently computed by invoking the surface relations and an O'Brien Hermite cubic interpolating polynomial.[2] Recent experiments show that it is useful to attach the top of the O'Brien profile to the rising and falling inversion lid. Longwave radiative flux divergences modify the model's temperature field. The model is now baroclinic; pressures are diagnosed hydrostatically from the model's predicted temperature field.

Proper initialization is crucially important. Plausible but unbalanced wind fields caused the output of the model to oscillate for up to 48 hours. The preliminary analysis package consists of wind, temperature, humidity, and pressure data determined at the model's grid points. The rawinsonde data are analyzed by the Cressman method[3] followed by a variational wind analysis in the vertical. The variational initialization uses a generalized Ekman equation as a weak constraint to help balance the initial wind field. Advection terms are estimated from the analyzed wind field.

RESULTS

Values of surface roughness (z_0) have been estimated over the eastern half of the United States on a 1/2° x 1/2° grid. These z_0 estimates are based solely on land usage and do not reflect subgrid terrain effects, a problem relegated to a future task.

Flows were simulated over elongated roughness strips; these strips can be visualized as mountain ranges or forests with no elevation changes. Results show a complex flow with a decided diurnal oscillation.

The one-dimensional prototype was run using data from the Wangara, Australia, experiment (to exclude complicated terrain and advection effects).[4] Results show that model temperatures do not fall quickly enough at night (causing unphysically large inversions) unless longwave radiative flux divergence is included.

CONCLUSIONS

The TDL-SRL three-dimensional planetary boundary layer model predicts temperature, wind vectors, and humidity from the surface to 2000 m. Results from tests in which horizontal terms are small suggest the physical and numerical aspects of the model are reasonably well handled. The model runs quickly and is economically practicable. Local wind forecasts and stabilities will come from a combined numerical model and statistical approach. The three-dimensional model will be telescoped down to a relatively finc mesh to aid in predicting local fields.

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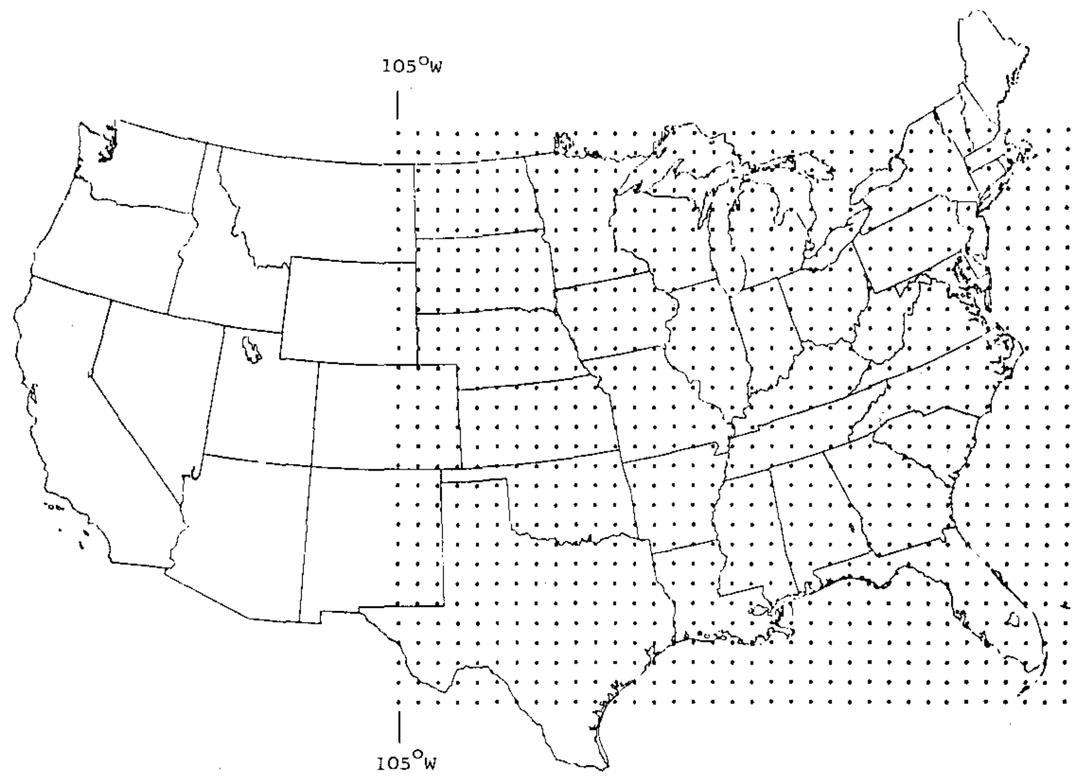

FIGURE 1. Boundary Layer Model Grid
(the mesh point separation is about 80 km).

6. NUMERICAL TECHNIQUES APPLIED TO PLANETARY BOUNDARY LAYER MODELING †

INTRODUCTION

The TDL-SRL planetary boundary layer model (BLM3), described in Article 5, Planetary Boundary Layer Modeling, of this report, should have accurate numerics and should consume an economically practicable amount of computer time. To help achieve this goal, implicit Galerkin techniques and the method of "splitting" are used.[1] Chapeau functions (a particular basis set in the Galerkin method for solving time-dependent differential equations) are used for solving both the advection relations and also the vertical turbulent transfer equations.

Chapeau functions provide a logical method of telescoping a numerical grid and permit a satisfactory specification of outflow and flux boundary conditions for advection and diffusion equations.

TELESCOPING GRIDS AND HORIZONTAL AND VERTICAL RESOLUTION

Large-scale meteorological prediction models conventionally consist of grids with more-or-less constant grid spacing of equal to or greater than 100 km. Forecasts with ultra-fine mesh grids over large areas would be prohibitively expensive without some compromising. A telescoping grid is a practical compromise in which a coarser grid is telescoped into a finer grid, allowing the boundaries to be pushed far enough away from the forecast area of greatest interest that the importance of boundary conditions is diminished, although not completely eliminated.

Another factor which determines the running time, cost, and accuracy of a boundary layer model is the number of vertical levels. The BLM3 has a surface layer with a thickness of 50 m; a computational expedient which allows us to compute the surface fluxes needed for solving the equations for the transition layer (50 to 2000 m, Figure 1). The transition layer equations with time, height, and stability-dependent diffusion coefficients are solved with a vertical level system whose separation increases

† Work done by P. E. Long.

upward. Fewer than eight levels cause unrealistic oscillations in the lower-level winds and temperatures. It is possible that the application of vertical chapeau functions will eliminate these spurious oscillations.

SPLITTING AND CHAPEAU FUNCTIONS

Standard explicit finite difference schemes used in numerical models have criteria which, when violated, cause the schemes to become numerically unstable. In the BLM3, an alternative method is used; i.e., the method of "splitting" in which the differential equations are solved alternately as three one-dimensional equations, each of which is expressed in stable, implicit form. The variable to be solved is approximated by chapeau basis functions defined at each point on a one-dimensional grid. The difference-differential equation which follows can be solved by many methods. A forward time-difference and a Crank-Nicolson treatment of the spatial part produces an absolutely stable scheme for constant grid spacing. A comparison of the chapeau function method and a standard second-order finite difference solution[2] shows the former method to be the better of the two, with the finite difference method exhibiting a diminished amplitude and a pronounced wake. Although the chapeau function method remains stable for all Courant numbers ($U\Delta t/\Delta x$), its superiority over the standard difference scheme decreases with increased Courant numbers.

OUTFLOW BOUNDARY CONDITIONS AND MESH CHANGES

The manipulation of outflow boundary conditions for spatially-centered, finite-difference schemes is the subject of several papers[3,4] in which the authors seek to reduce the computational noise which reflects from the outflow point back into the interior of the grid by using *ad hoc* outflow conditions. As suggested by P. Gresho,[5] the Galerkin method supplies a useful outflow condition which virtually eliminates the reflection (Figure 2).

An analogous procedure is also useful at the interface of a fine-to-coarse mesh grid in which an object too small to be correctly resolved without aliasing in the coarse mesh is prevented from reflecting back into the fine mesh.

The chapeau function method may be extended to the turbulent diffusion equations to yield relations which may be applied to any reasonable set of levels with a natural set of flux boundary conditions. The one-dimensional boundary layer model with vertical transfer has been re-programmed using the chapeau function method and is functioning satisfactorily.

CONCLUSIONS

When coupled with the general technique of splitting, chapeau functions provide a stable and accurate method of solving both the advection and vertical turbulent diffusion equations without *ad hoc* boundary point assumptions. Both sets of equations may be solved on grids of variable mesh spacing. Non-linear instability has not occurred in examples run to date.

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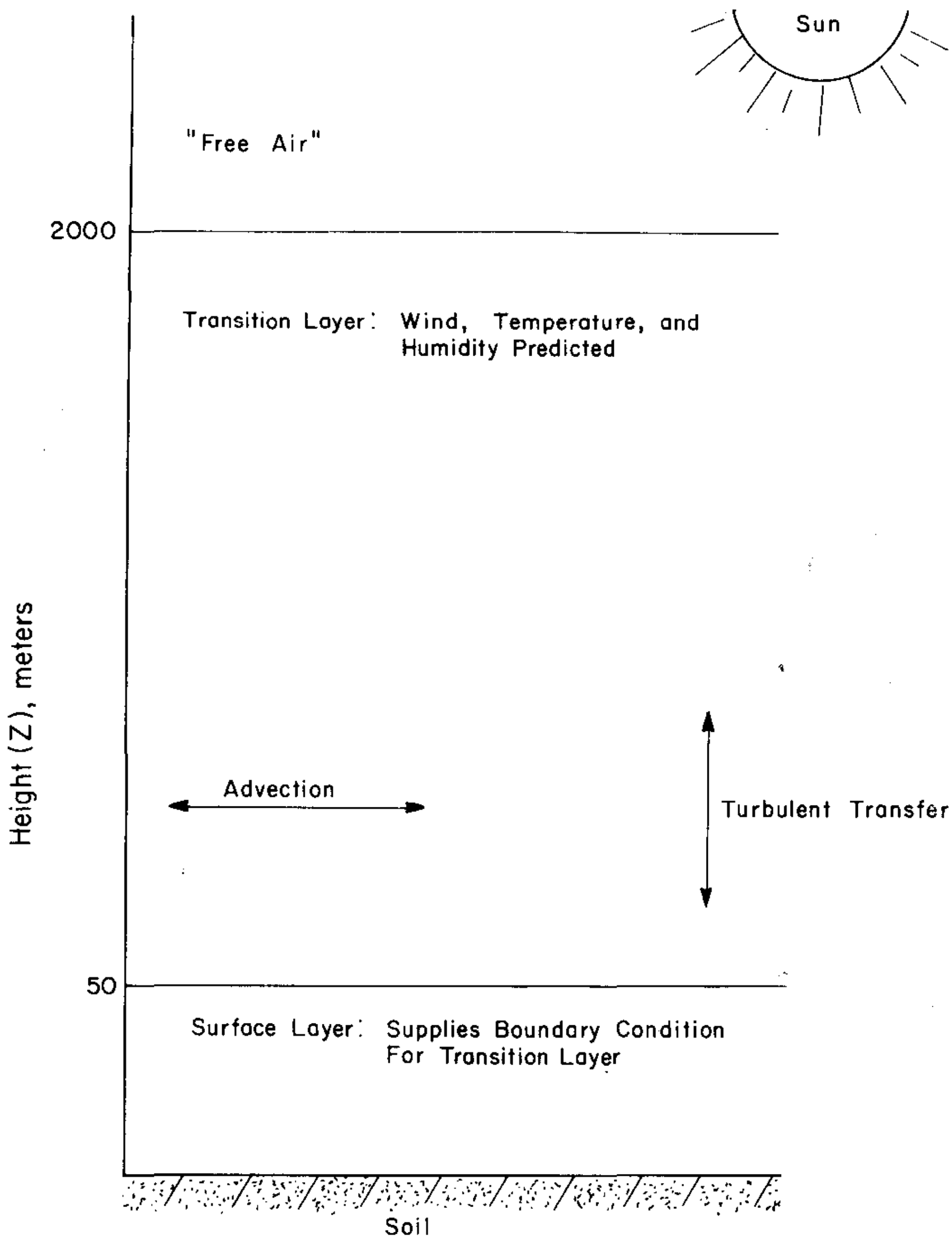

FIGURE 1. Vertical Structure of the Boundary Layer Model

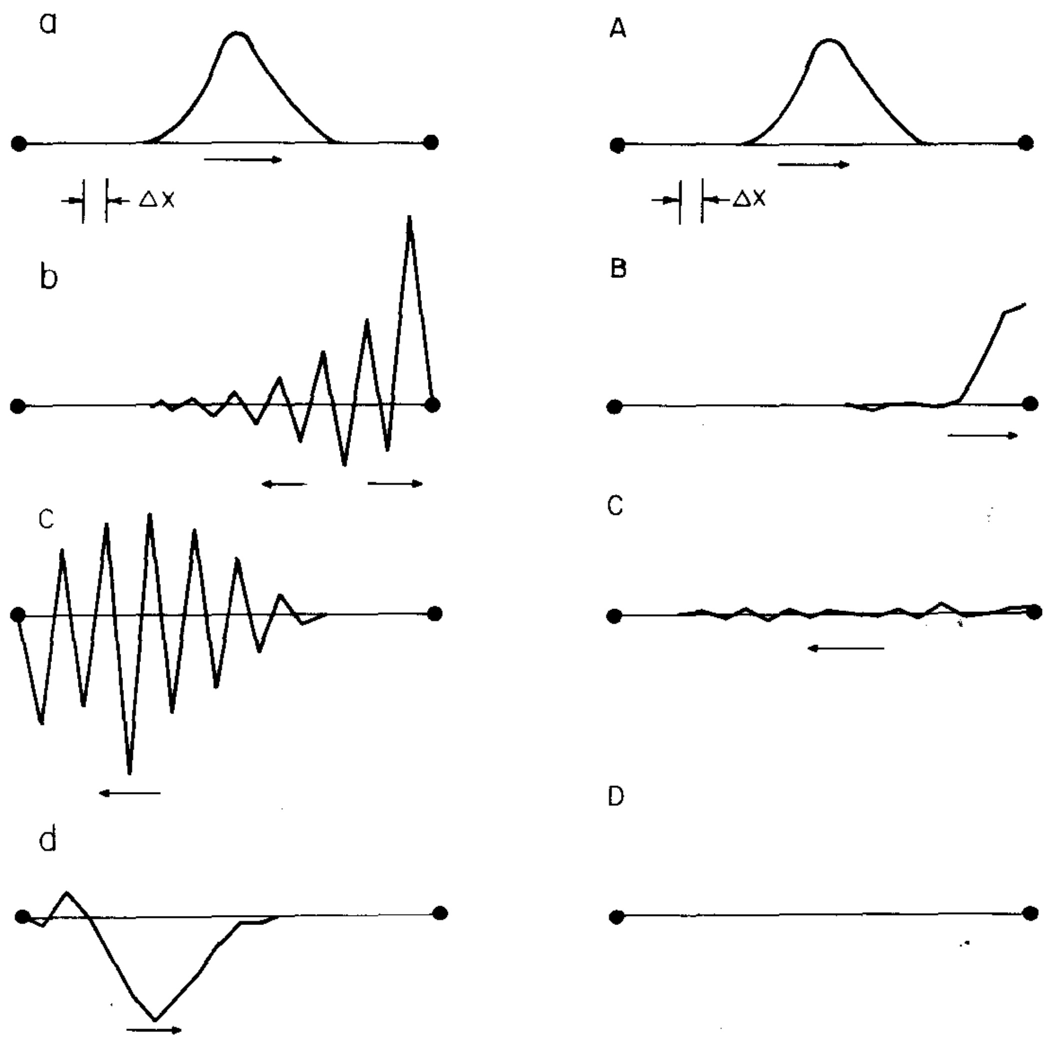

FIGURE 2. The Left-Hand Sequence Shows the Creation of a Computational "Ghost". (The "Ghost" is removed when Galerkin outflow conditions are applied in the right-hand sequence.)

7. A CONCISE CLIMATOLOGY OF SRP USING ACOUSTIC METHODS†

INTRODUCTION

The acoustic sounder provides a means for compiling a continuous record of the temperature-turbulence characteristics and their distribution with height in the atmospheric boundary layer. From these data, both the synoptic (analysis of climate in terms of simultaneous weather information) and complex (analysis of the climate of a single place by the relative frequencies of various weather types of groups of such types) climatologies of the Savannah River Plant (SRP) are being documented.[1] The various phenomena of climatological interest have been categorized (Table 1 and Reference 2). By identifying the data in this manner, a statistical combined climatology can be developed for this area.

MIXED LAYER BY CATEGORY

Examples of the categories listed in Table 1 are shown in Figures 1 through 4. Most of the returns (35%) were from a well-mixed layer (Category 2) interpreted to be caused by the vertical fluxes of heat and turbulence,[3-5]. Daytime thermal plume activity (Category 13) was responsible for 31% of the returns. Returns from thermal plume activity should be interpreted with caution. The sensitivity of the acoustic sounder is such that the base of the plume is well defined, but the top of the plume is not very well depicted because the lapse rate of the core is essentially adiabatic.[3,6] This can cause the height of the mixed layer to be underestimated during periods of thermal plume activity.

HEIGHT OF THE MIXED LAYER

The data were tabulated by maximum height and frequency of occurrence for each height for each hour the sounder was in

† Work done by J. F. Schubert. Presented in part at the *Third Symposium on Meteorological Observations and Instrumentation, Washington, D. C., February 10-13, 1975.* Being prepared for publication in the *Journal of Applied Meteorology*.

operation. Table 2 shows that the top of the mixed layer was between 300 and 1000 m for 76% of the time during the sampling periods. The annual mean of the maximum mixed-layer height for afternoon for the SRP area was calculated to be 1400 m.[7,8] This is 500 m higher than 80% of the daytime signals recorded by the sounder.

CONCLUSION

The calculated heights of the mixed layer are much higher than those measured by the sounder. These differences, if real, could cause significant discrepancies between actual and predicted concentrations of air pollutants.

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TABLE 1. Categories of Acoustic Sounder Data

Category 99:	No data, just wind/rain noise
Category 1:	Abrupt change from stable multiple layers to a well-mixed layer
Category 2:	Back-scattered layer
Category 3:	Back-scattered layer with waves
Category 4:	Very complex; many waves in the bottom layer
Category 5:	Two layers in the bottom
Category 6:	Two layers, separate one over the other, large separation from the top to the bottom layer
Category 7:	Multiple weak layers with waves
Category 8:	Strong multiple layers with waves
Category 9:	Ascending layer from the surface
Category 10:	Ascending layer, but not starting at the surface
Category 11:	Descending layer, but not merging with the surface
Category 12:	Descending layer merging with the surface layer
Category 13:	Thermal plumes only
Category 14:	Stable multiple layers
Category 15:	Inversion layer with waves

TABLE 2

Observed Frequencies of Mixed Layer Heights for Daytime and Nighttime Measurements (February 1974 to August 1975)

Height in Meters	*Frequency in Hours*	*Percent*	
0	1	0.022	
100	123	2.686	
150	58	1.266	
200	223	4.869	
250	126	2.751	
300	707	15.437	
350	322	7.031	
400	586	12.795	47%
450	120	2.620	
500	354	7.729	
550	172	3.755	
600	68	1.485	62%
650	272	5.939	
700	62	1.354	
750	110	2.402	
800	315	6.878	79%
850	71	1.550	
900	59	1.288	
950	110	2.402	
1000	131	2.860	87%
9999	590	12.882	
Totals	4580	100.000	

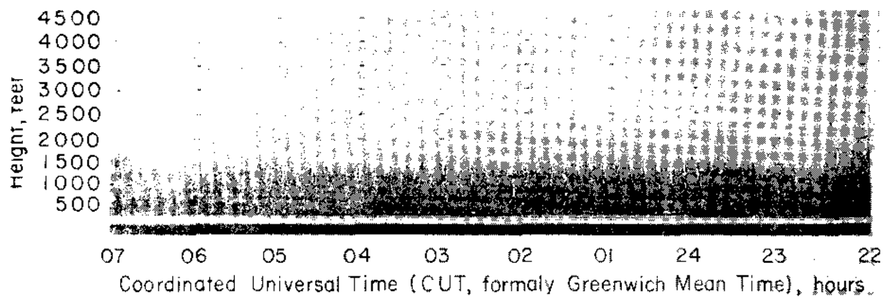

FIGURE 1. Category 2, Back-Scattered Layer

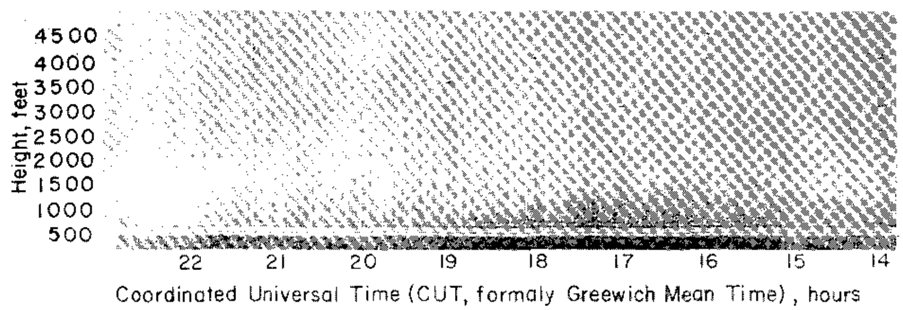

FIGURE 2. Category 13, Thermal Plumes

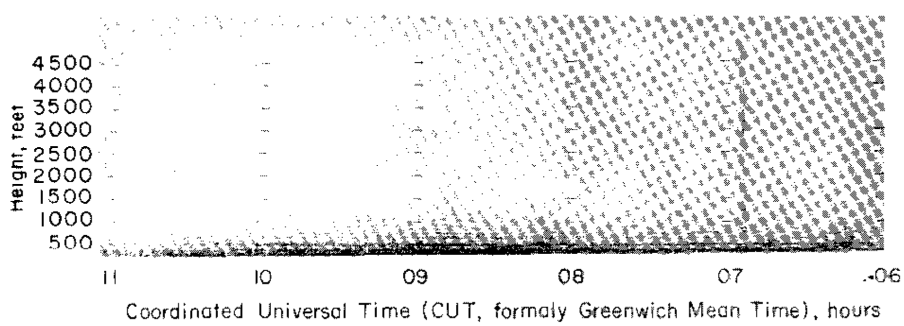

FIGURE 3. Category 14, Stable Multiple Layers Near the Surface

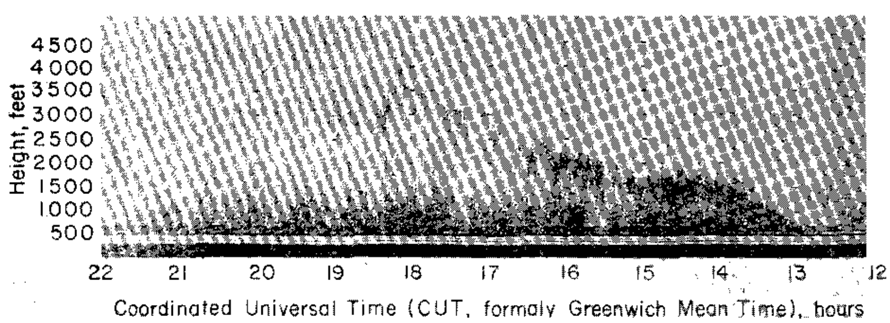

FIGURE 4. Category 9, Ascending Layer Starting Near the Ground Surface

8. ACOUSTIC DETECTION OF MOMENTUM TRANSFER DURING THE TRANSITION FROM A LAMINAR TO A TURBULENT ATMOSPHERIC BOUNDARY LAYER †

INTRODUCTION

One of the primary objectives of the study of turbulence at the Savannah River Plant (SRP) is to obtain sufficient knowledge of the dynamics of the atmospheric boundary layer so that numerical models of the transport and diffusion of the fluxes of heat, water vapor, momentum, and other atmospheric pollutants can be improved. Comparisons of calculated Richardson numbers to observed transitions should lead to a better understanding of the turbulent fluxes of the boundary layer.

During the period from June 8, 1975, to August 14, 1975, nine momentum-burst phenomena were recorded on the acoustic sounder, one of which is shown in Figure 1. Day 160 (June 9) was selected for investigation because temperature and wind data from a nearby meteorological tower for this period were available.

DESCRIPTION

The conditions necessary for the onset of the momentum-burst phenomena start during the afternoon period of a clear day. The heat flux changes sign from upward to downward, and the lowest part of the boundary layer becomes stable. Shortly after this period, the entire boundary layer becomes stable. On June 9, 1975 the entire boundary layer was in turbulent motion because of both bouyancy (surface heating) and shear energy production. As the day progressed, the turbulence ceased and the lower boundary layer stabilized, creating a classical situation for the onset of the momentum-burst phenomenon that was observed. The upward heat flux continued at higher altitudes for some period of time after the lower part of the boundary layer became stable. The maximum flux Richardson number was reached after the transition from unstable to stable at some height relatively close to but above the surface. As soon as this happened, the turbulence dampened and a laminar layer formed.[1] This layer was an effective barrier for all

† Work done by J. F. Schubert.

the fluxes.[2] The transfer of momentum and heat from the upper levels was blocked, the wind decreased, and a period of calm occurred. (This is a typical fair weather condition in the southeastern United States.[3]) The temperature near the surface dropped dramatically because the outgoing net radiation was not compensated for by the downward heat flux (Figure 2). At the same time above the laminar layer, momentum was still being transferred downward, whereas little heat was transferred. This resulted in a momentum increase in the upper part of the laminar layer. Because motion could not pass through this layer, a strong wind shear developed above the laminar layer (Figure 3). However, because there was not a similar effect of the heat flux, the Richardson number for the layer between 10 m and 137 m decreased (Figure 4). This meant that the laminar layer began to be eroded by turbulence from above. Eventually, the turbulence reached the ground and was associated with the observed burst of momentum and heat (Figure 1). The decoupling of the layers with a large wind shear caused an instability between the layers, transporting momentum as in a breaking wave.

CONCLUSION

Data from the acoustic sounder combined with other pertinent meteorological parameters enhance the prediction and verification of transitions from laminar to turbulent flow in the atmospheric boundary layer.

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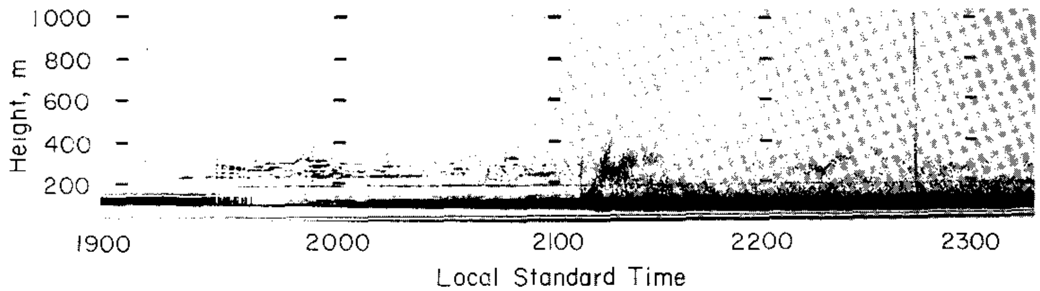

FIGURE 1. Acoustic Sounder Record of the Transition from a Laminar to a Turbulent Atmospheric Boundary Layer at 2110 Hours (local standard time), June 9, 1975.

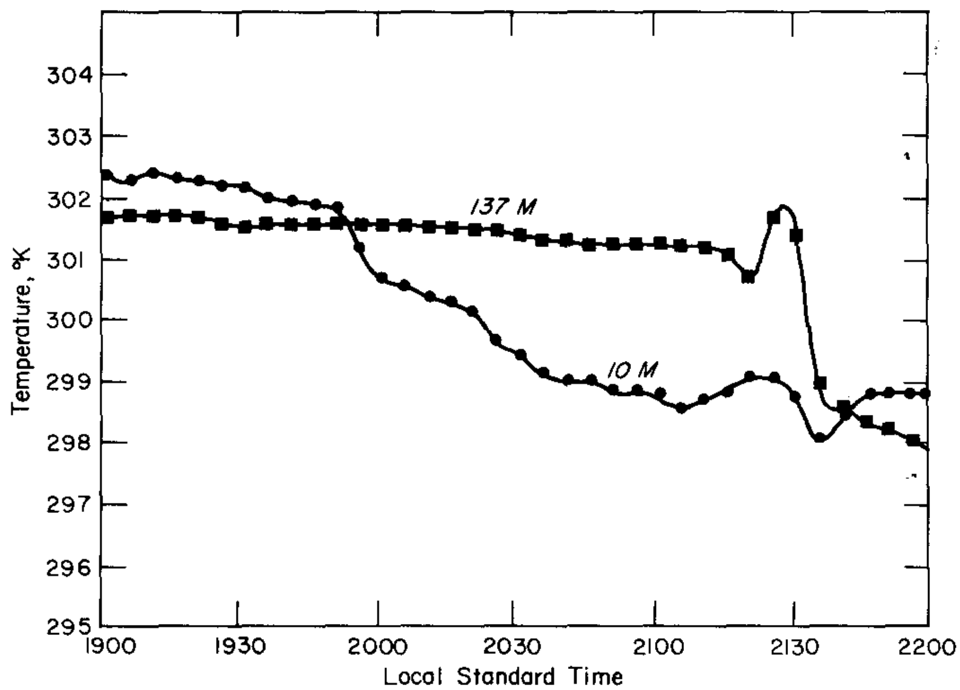

FIGURE 2. Comparison of the Temperature at 10 Meters and 137 Meters as a Function of Time.

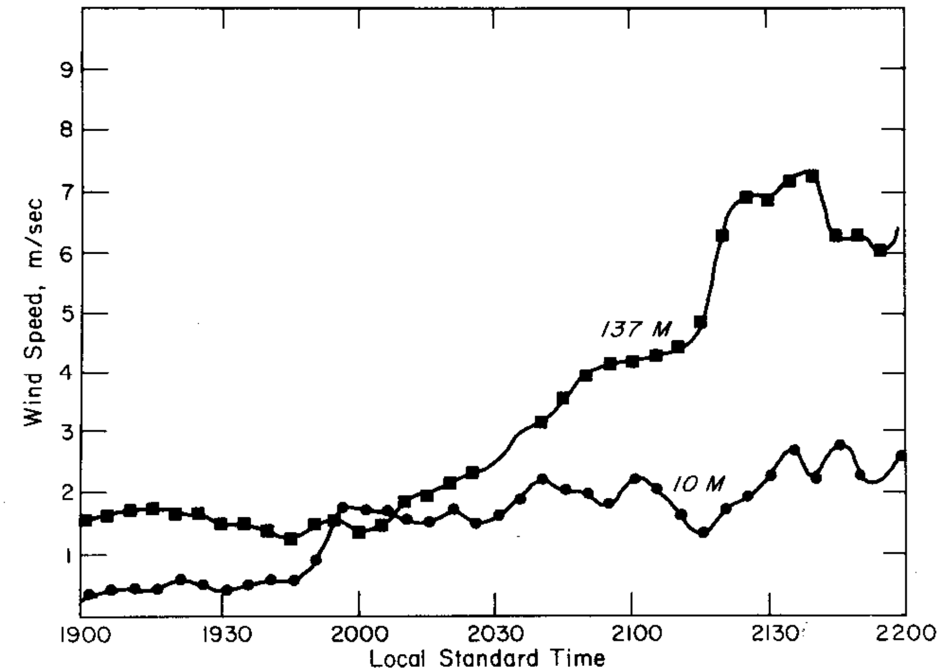

FIGURE 3. Comparison of the Wind Speed at 10 Meters and 137 Meters as a Function of Time.

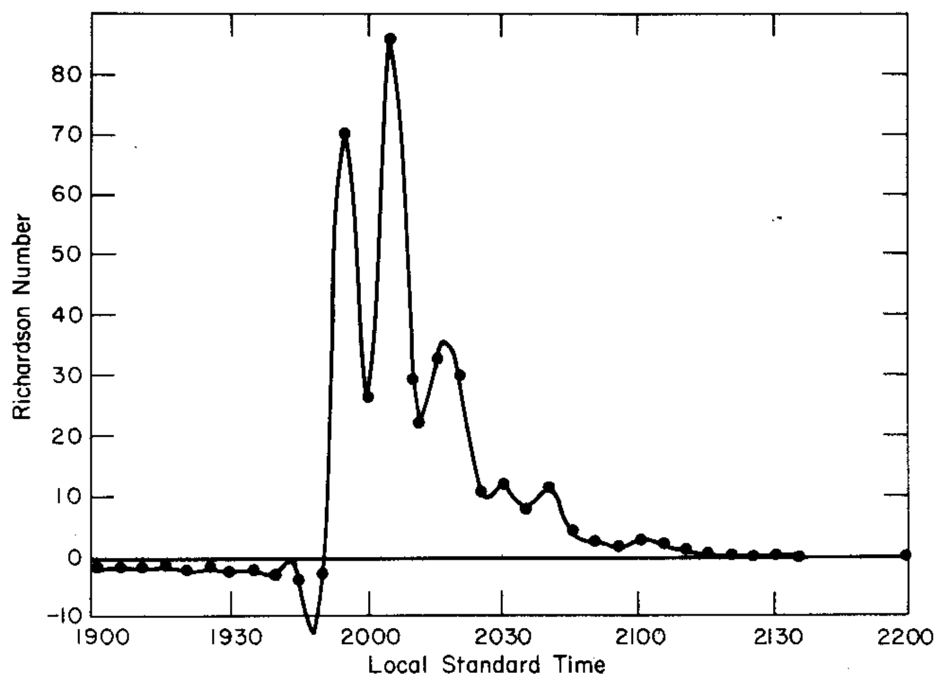

FIGURE 4. Richardson Number as a Function of Time.

9. MULTI-DIMENSIONAL MODELING OF CONCENTRATION OVER SRP USING THE STRONGLY IMPLICIT TECHNIQUE (SIP) †

INTRODUCTION

Multi-dimensional transport problems occur in many environmental situations which require solutions for species concentrations to be extended from local to regional scales under rapidly changing atmospheric conditions. Projected concentration distributions over large regions are significantly influenced by mesoscale motion which changes with time. Analytical methods become severely restricted in simulating pollutant dispersal when spatial and temporal variations in the wind occur over short periods of time. To simulate more realistically the dispersion of atmospheric pollutant concentrations under such conditions, multi-dimensional computational methods must be employed.

Much effort has been made in recent years to solve multi-dimensional transport equations directly with numerical finite difference methods.[1] In particular, implicit methods for calculating transport phenomena are advantageous because they are unconditionally stable, allowing large time intervals to be used in the calculational procedure. Another property of implicit diffusion methods is that dispersion occurs in all directions instantaneously. While this property is realistic for the diffusion terms in an advection-diffusion equation, it is unrealistic for the advection terms. Hence a coupling of an explicit method for advection with an implicit method for diffusion is normally undertaken to ensure reasonable accuracy.

The strongly implicit procedure (SIP) is a fully implicit finite difference technique originally developed by Stone[2] for solving two-dimensional transport and two-phase flow problems in reservoirs. Weinstein, et al.[3] have used the SIP method to solve three-dimensional parabolic and elliptic transport equations simultaneously for multi-phase flow in reservoir problems. Results obtained by Pepper[4] indicate that the ability of the SIP method to handle multi-dimensional transport equations and main-

† Work done by D. W. Pepper and C. D. Kern and presented in part at the *First Conference on Regional and Mesoscale Modeling, Analysis and Prediction*, Las Vegas, Nevada, May 6-9, 1975.

tain computational stability over large time intervals appears to be advantageous for modeling atmospheric motions that vary with time.

GAUSSIAN *vs.* SIP MODELS

A preliminary investigation of a three-dimensional SIP method was made by simulating the mesoscale transport of a pollutant puff over grids centered on the Savannah River Plant (SRP), using persistent winds and time-varying eddy diffusion coefficients. The eddy diffusion coefficients were calculated with the Lange technique[5] as functions of standard deviations, energy dissipation rate, and time.

Advection terms, modeled with a modified form of upwind differencing, allowed the advection of concentration to be qualitatively modeled to ensure the correct transportive and conservative nature of advection.

Wind velocities were determined over the gridded mesh using techniques described by Kern[6,7,8] for SRP. A Gaussian puff was used for comparison with the SIP method in simulating a release on May 2, 1974 from SRP.

The pollutant was assumed to be released from a point source and allowed to grow for 30 minutes to a large puff. A Gaussian puff model simulated the initial concentration distribution. For times greater than 30 minutes, the governing equation for species concentration was solved using a rectangular gridded mesh. The analytical solution supplied enough information to the grid points surrounding the location of the instantaneous point source to ensure that early time concentration distributions were adequately modeled.

A 33 x 33 mesh was used in this study with five levels being used in the vertical direction. Grid spacing was kept constant with $\Delta x = \Delta y = 2500$ m and $\Delta z = 35$ m. The time step was chosen such that $\Delta t = 120$ sec.

The winds in and about SRP at 1200 UT (Universal Time, GMT) on May 2, 1974 were used in the model to represent horizontal and lateral advection velocities. The maximum concentration at the center of the puff at the end of the initial 30-minute computation was equal to 3060 pCi/m^3 for a height of 70 m.

Figure 1 depicts puff center locations and concentrations for several hourly intervals after initialization at time 1230 UT. Gaussian puff and SIP results are retained for concentration levels at 2 pCi/m^3 or above at a level of 70 m above the ground.

The difference in concentration at the puff centers between the two methods is due to the fact that vertical diffusion is not effectively modeled with respect to time in the SIP method. The shape of the SIP generated concentration contours are more realistic, however, than the perfect circles of the Gaussian puff solution.

CONCLUSIONS

The Gaussian puff model produces concentric circles of subsequently decreasing concentration in an everwidening path as time progresses. The SIP method appears to predict more realistically the size and shape of the puff, by including the wind shearing effect the regional winds have on the cloud together with horizontal and lateral diffusion from eddy viscosity. This is important if three-dimensional concentrations over mesoscale distances are to be modeled correctly.

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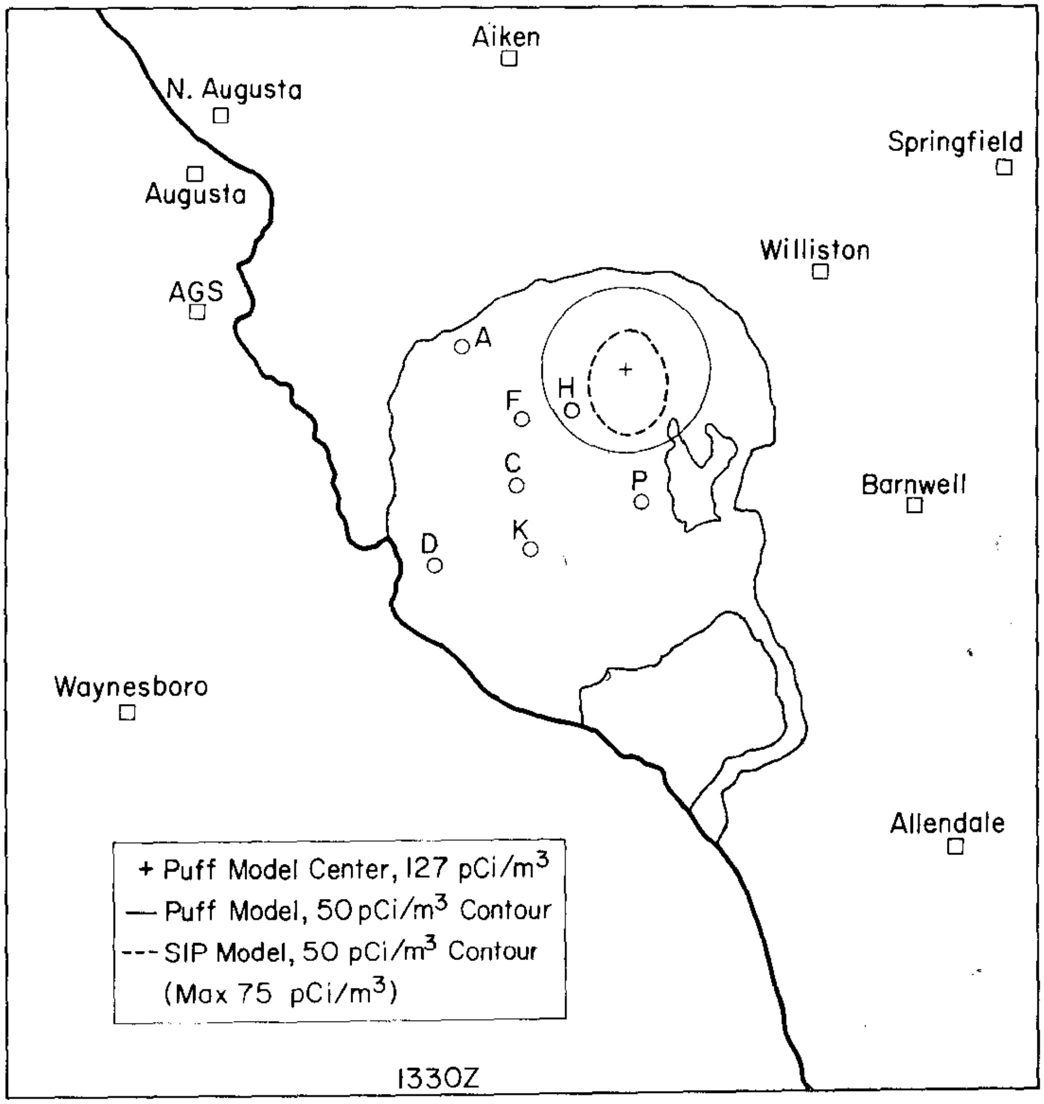
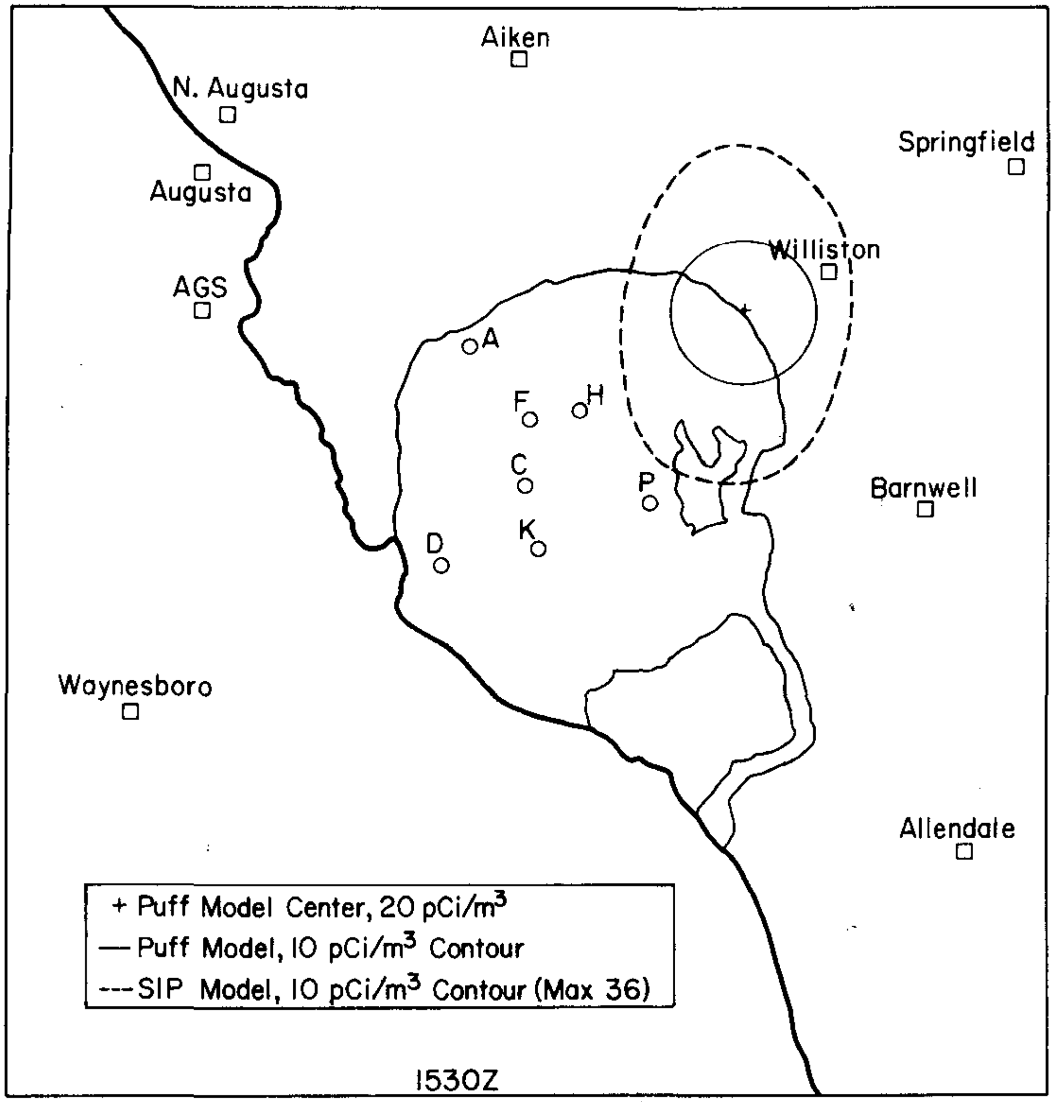


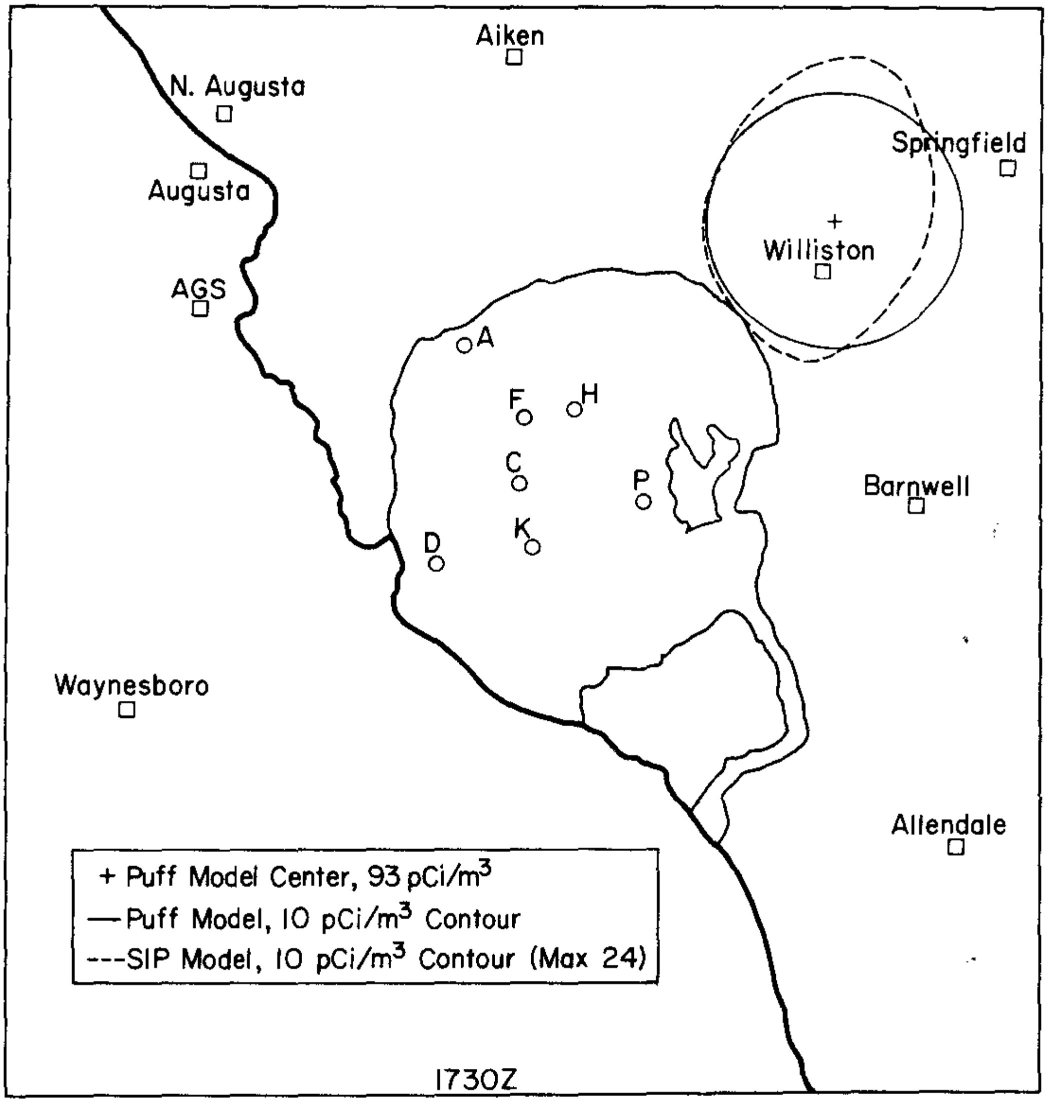
a. Time after assumed release, 1.5 hr

FIGURE 1. Simulated Temporal Mesoscale Transport of a Pollutant Puff from an Initial Point Source



b. Time after assumed release, 3.5 hr

FIGURE 1. Simulated Temporal Mesoscale Transport of a Pollutant Puff from an Initial Point Source



c. Time after assumed release, 5.5 hr

FIGURE 1. Simulated Temporal Mesoscale Transport of a Pollutant Puff from an Initial Point Source

10. FINITE DIFFERENCE COMPUTATION OF RECIRCULATING FLOW IN FREE CONVECTION STUDIES †

INTRODUCTION

Finite difference solutions to the Navier-Stokes and related equations have been obtained by numerous workers. In order to solve the complex nature of recirculating flow in the atmosphere, however, the use of a numerical method is necessary which will permit the simultaneous solution of several partial differential equations without requiring excessive computation time or complexity. The transient solution of the equations governing the conservation of mass, momentum, and energy is assessed in this paper by analyzing the problem of free convection between rigid horizontal plates heated from below, using the strongly implicit procedure (SIP) developed by Stone[1] and utilized by Pepper & Kern[2] in atmospheric flow studies.

Parallel plate convection and atmospheric convection are both governed by similar driving forces and characteristics. This similarity was investigated by Deardorff[3] in simulating, both experimentally and numerically, the problem of turbulent convection between parallel plates when heated from the bottom plate.

Explicit finite difference methods have been used to solve transient convection problems in two dimensions.[3-8] Unfortunately, explicit methods are somewhat restricted because they require rather severe limitations on time intervals and stability criteria. Implicit methods, however, permit large time intervals to be used with unconditional stability. Wilkes and Churchill[9] used the alternating implicit direction method (ADI) of Peaceman and Rachford[10] to obtain solutions to the problem of convection in a mathematical model of a two-dimensional flow in a cavity heated on one wall. Pearson[11] likewise analyzed time dependent two-dimensional viscous flow with an ADI technique. Aziz and Hellums[12] solved the complete Navier-Stokes equations in three dimensions with an extended form of the ADI method.

SIP procedures have been applied to simulate transport phenomena in both two and three dimensions.[13,14] The SIP method

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† Work done by D. W. Pepper.

is a fully implicit technique which has the advantage of not requiring a splitting of the timestep as in the ADI method, and is computationally superior to ADI for complex flow problems.[13,14]

TECHNIQUE AND RESULTS

A two-dimensional SIP technique was used to calculate the transport of momentum and energy in an enclosed rectangle. To simplify the solution of the governing equations of motion, the two-dimensional vorticity equation (obtained by taking the curl of the x and z equation of motion) and the Poisson equation (coupling streamfunction and vorticity) were solved simultaneously. Vorticity in this sense is defined as a measure of local rotation of the fluid normal to the x-z plane. The streamfunction is a parameter which is constant along a line whose tangent at any point in the fluid is parallel to the instantaneous velocity.

Reducing the momentum equations produces two equations and two unknowns which can be readily solved by numerical techniques. Coupling of these two equations with the energy equation subsequently allows one to investigate the influence of temperature on the transport of momentum. Thus the two-dimensional temperature and velocity vector fields can be visualized by streamlines and isotherms.

Figure 1 shows streamlines and isotherms at selected time intervals for the case of a large-scale initial temperature disturbance within an enclosed rectangle. A computational mesh size of 80 x 40 was chosen with non-dimensional grid units $\Delta X = \Delta Z = 0.02$ and an initial non-dimensional flow time step $\Delta t = 0.0001$. The initial conditions chosen for this case could lead to either a single vortex or a vortex pair. A single vortex does develop at first, but eventually gives way to a double vortex. Convergence to a steady-state condition occurs rapidly after the onset of the vortex pair.

Results obtained by the implicit method agree very well with the transient results obtained by Deardorff.[3] Deardorff's[3] explicit model required 23 machine hours of CDC 3600 CPU time. The SIP method required 4 minutes of IBM 360/195 CPU time to reach steady-state conditions. The biggest drawback in using implicit methods is the requirement that boundary conditions must be known prior to calculation of the internal mesh. This is not necessarily a problem at low or moderate Reynolds numbers and Rayleigh numbers, but does become significant at higher values. It can be overcome by iterating the boundary conditions and using second-order equations for the boundary values.

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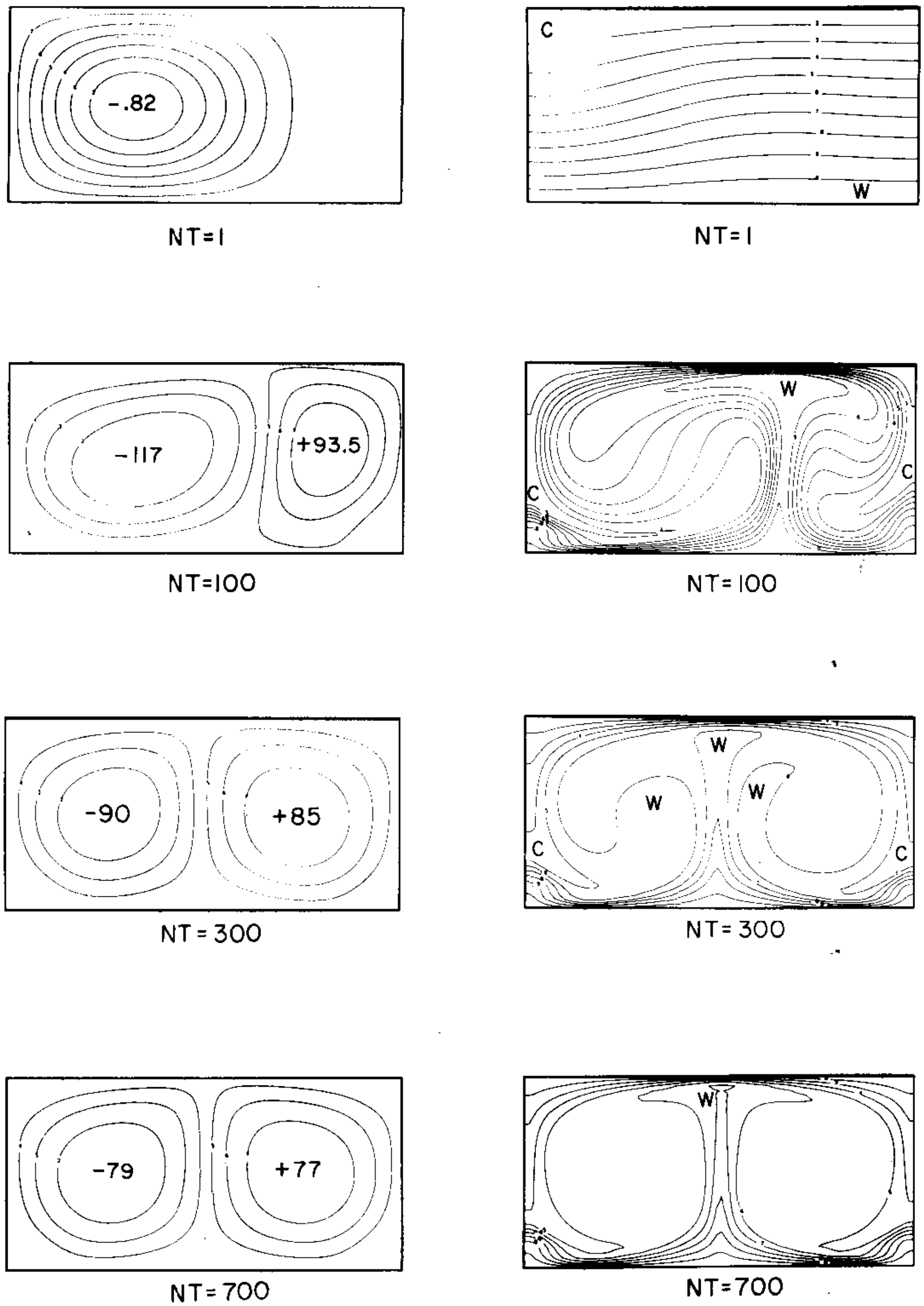

FIGURE 1. Streamlines and Isotherms at Selected Time Intervals (NT) for a Large-Scale Temperature Disturbance.

11. TORNADO DIFFUSION MODEL †

INTRODUCTION

Tornadoes are violently rotating winds which normally occur in the spring and summer months. While occurring predominately in the North American continent, tornadoes have been known to strike nearly every country in the world. The effects of tornadoes are apparent from visual observations and photographs of the ground damage after tornado disasters. Although tornadoes have been studied and their motions analyzed for a number of years, little progress has been made in an effort to understand completely their dynamics. Even less progress has been made to understand the diffusion of pollutants pulled into a tornado vortex. Yet it is necessary to make rough estimates of the diffusion of radioactive particles which might be released by a tornado hitting a nuclear facility. This paper presents a simple tornado diffusion model for making sets of calculations which provide conservative estimates of the problem.

DIFFUSION MODEL

The model neglects gravitational settling and precipitation scavenging. It makes use of a Gaussian solution to an initial point source. The standard deviations of the concentration distribution are calculated as a function of the turbulence within the tornadic storm. Turbulence is characterized by the rate of energy dissipation per unit mass, ε, which is set equal to 1 m^2/sec^3 in accordance with estimates obtained from Slade[1] and MacCready[2] for thunderstorm interiors, and 0.0005 m^2/sec^3 outside the thunderstorm. Standard deviations are calculated from the general expression:[3]

$$\sigma_i^2 (t) = \left[\sigma_{o_i}^{2/3} + \frac{2}{3} C \varepsilon^{1/3} t\right]^3 \qquad (1)$$

where σ_{oi} is the original standard deviation of the source, and i denotes x,y,or z.

† Work done by D. W. Pepper.

Instantaneous particulate concentrations, χ, are calculated from the Gaussian diffusion model by Slade[1] as:

$$\chi(x,y,z,H) = \frac{2Q}{(2\pi)^{3/2}\sigma_x(t)\sigma_y(t)\sigma_x(t)} \qquad (2)$$

$$\exp - \left[\frac{(x-Ut)^2}{2\sigma_x(t)^2} + \frac{y^2}{2\sigma_y(t)^2} + \frac{(z-H)^2}{2\sigma_z(t)^2}\right]$$

where Equation 2 has been multiplied by 2 to account for ground reflection; U is the mean horizontal velocity in m/sec; H is the height of the initial center of the concentration in m; Q is the source strength in gm; and $\sigma_x(t)$,$\sigma_y(t)$, and $\sigma_z(t)$ are calculated from Equation 1. Ground-level concentrations for distributions at the center of the pollutant cloud are calculated from Equation 2 by letting x = Ut, y = 0, and z = 0 such that:

$$(x,o,\sigma,H) = \frac{Q}{2^{1/2}\pi^{3/2}\sigma_x(t)\sigma_y(t)\sigma_z(t)} \exp\left[\frac{-H^2}{2\sigma_z(t)^2}\right] \qquad (3)$$

Lateral ground level concentrations are calculated from

$$\chi(x,y,o,H) = \frac{Q}{2^{1/2}\pi^{3/2}\sigma_x(t)\sigma_y(t)\sigma_z(t)} \exp\left[- \frac{Y^2}{2\sigma_y(t)^2} + \frac{H^2}{2\sigma_z(t)^2}\right] \qquad (4)$$

Assuming initial standard deviations of σ_{o_x} = 10 m, σ_{o_y} = 10 m, and σ_{o_z} = 20 m, non-dimensional downwind concentration profiles (χ/Q, Figure 1) are calculated for the case of a cluster of particles diffusing in the mother cloud for the lifetime of a typical thunderstorm cell (≈30 minutes) and then diffusing at a slower rate ($\varepsilon = 0.0005\ m^2/sec^3$) once outside the thunderstorm cell.

CONCLUSIONS

A more complete understanding of tornado dynamics is being sought. Numerical simulations of dispersion are severely limited by the incomplete knowledge available on thunderstorm activity and tornado characteristics. Subsequent research is necessary to provide more precise data for adequately modeling diffusion in storms. In the meantime, however, a number of different kinds of problems can be solved with this model to obtain possible solutions to diffusion following a tornado strike.

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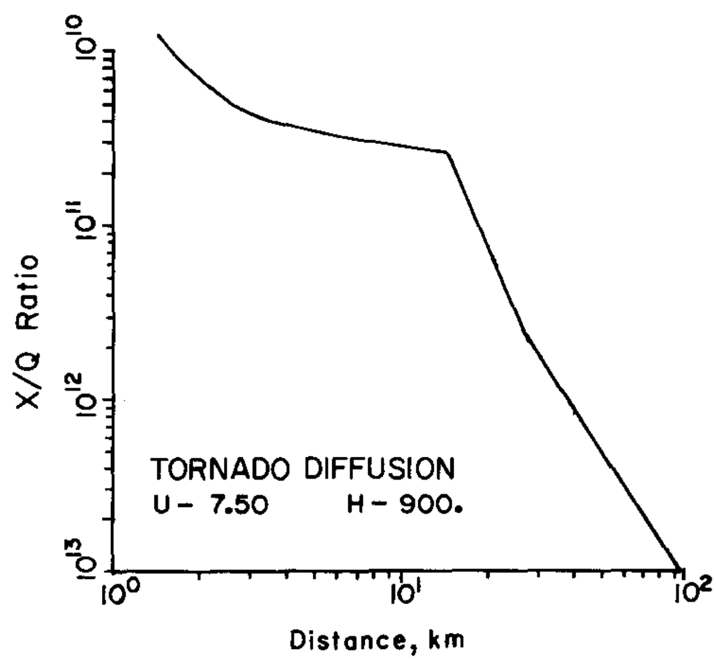

FIGURE 1. χ/Q Ratio as a Function of Distance (average horizontal speed = 7.5 m/sec, and release height = 900 m).

II. SOIL AND TERRESTRIAL BIOLOGY STUDIES

12. MODELING UPTAKE OF GASEOUS SUBSTANCES BY VEGETATION †

INTRODUCTION

An integral part of any model of an atmospheric release of gaseous material is the uptake by the vegetation under the plume of the material. Among the gases of potential interest to the Savannah River Plant are SO_2, $^{14}CO_2$, ^3HHO, $^3H_2$ and possibly $NH_2{}^3H_2$, $C^3H_2H_2$ or $^{14}CH_4$. This study was begun to develop and test models for describing gaseous movement into the plant canopy and for measuring uptake of gas by the plants. Simulations have been carried out to measure the uptake of sulfur dioxide by vegetation under steady-state, one-dimensional diffusion. The model will be expanded to simulate multi-dimensional, nonsteady-state diffusion. The simulations indicate that the uptake of sulfur dioxide by Savannah River Plant (SRP) forests in January will be approximately 0.091 kg/ha, and the uptake in July will be 0.19 kg/ha.

MODEL FOR SULFUR DIOXIDE UPTAKE

The process by which gaseous air pollutants are absorbed from the atmosphere by plant canopies can be divided into 1) the atmospheric processes of turbulent and molecular diffusion between the source and the ultimate sink at the plant surfaces and 2) the sink processes of surface absorption, solubility, and metabolic fixation in the canopy. The diffusion of gases in the atmosphere is accomplished by turbulent diffusion. The rate of transfer is proportional to the gradient of the concentration of the material and the turbulent diffusivity. The turbulent diffusivity is only a function of the state of the atmosphere.

Molecular diffusion is an important process in the boundary layer near the plant leaves and in the pores on the leaf surface if gas is absorbed internally. To a reasonable degree of accuracy, the ratio of the molecular diffusivities for two gases is inversely

† Work done by Charles E. Murphy, Jr. of SRL; Thomas Sinclair, USDA, ARS, Cornell University, Ithaca, New York; and K. R. Knoerr, School of Forestry, Duke University, Durham, North Carolina, and presented at the *Conference on Urban Physical Environment*, Syracuse, New York.

proportional to the square root of the ratio of the molecular weights for the gases. Thus, the molecular diffusion of individual gases can be programmed using this physical law.

The sink for a gaseous air pollutant can be associated with the leaves, branches or trunk of the vegetative canopy, or the soil below the canopy. The leaves normally make the largest contribution because of their greater relative area and the access to wet surfaces through the leaf pores. This is of importance to sulfur dioxide absorption because of the great solubility of sulfur dioxide.

It is also important that sulfur dioxide is metabolized by the plant into organic sulfur compounds.[1] If the atmospheric concentration of sulfur dioxide is small (<10 parts per hundred million volume), the sulfur dioxide may be removed at nearly the rate at which it reaches the site of metabolism. Under this circumstance, the effective concentration at the sink may be near zero. In this case, the uptake is limited by diffusion through the atmosphere, into the leaf, and through the cell sap to the metabolic site in the plant cell.

The basic equation that must be solved to simulate these processes is:

$$\frac{d}{dz}\left(K\frac{dC_a}{dz}\right) + \frac{dA}{dZ}\left(\frac{SC_a - C_i}{S(r_a + r_s) + r_i}\right) = 0 \qquad (1)$$

where

- K = the turbulent diffusivity for mass transfer
- C_a = the pollutant concentration (mass/volume) in the air
- Z = height above the ground
- A = the surface area of the canopy
- S = the solubility of sulfur dioxide in the cell water
- C_i = the concentration of sulfur dioxide at the sink
- r_a = the leaf boundary layer resistance
- r_s = the leaf resistance associated with diffusion through the leaf pores (i.e., stomatal resistance)
- r_i = the diffusion resistance associated with the cell walls and the cytoplasm

The equations of the model were coded in the Continuous System Modeling Program (CSMP) developed by IBM.[2] In addition to boundary values of wind speed and sulfur dioxide concentration, tables of leaf area and relative crown volume, leaf aerodynamic length, and the relationship between pore size of the leaf and light are needed to make a simulation.

TYPICAL COMPUTATIONS FOR SRP

The results of simulations for two days representing climatologically average, clear days during January and July at SRP are illustrated in Figures 1 and 2. The vegetation is a pine plantation typical of much of the land area at SRP. The diurnal patterns are similar. The uptake of sulfur dioxide is at a minimum in the morning and evening, and at a maximum sometime before noon. The uptake is inversely related to the average stomatal resistance of the canopy, demonstrating the large effect of this resistance expressed in Equation 1. The diurnal pattern of stomatal resistance assumes that the resistance is a function of light intensity.

The solubility of sulfur dioxide in water is inversely related to temperature; and thus, the maximum absorption takes place at the coincidence of a low stomatal resistance and a high solubility of sulfur dioxide during the cooler morning period. This is demonstrated by the uptake maximum occurring before the minimum stomatal resistance at noon (Figures 1 and 2).

A comparison of the total uptake for the January day, 0.091 kg/ha, and the July day, 0.19 kg/ha, shows the type of annual variation that can be expected. As illustrated in Figures 1 and 2, one of the sources of this variation is the shorter day length during January. However, even the instantaneous uptake values are lower in January. This is caused by a smaller needle area in January than in July. Although a lower average stomatal resistance might be expected during the winter because of the lower incident solar radiation, this is not the case because there is more shaded needle area in the denser summer canopy. The effect of the average stomatal resistance is reflected in the fact that uptake per unit needle area is greater for the January simulation than for the July simulation.

Thus, the diurnal pattern of sulfur dioxide uptake reflects the effect of changing solar radiation and temperature on stomatal resistance and sulfur dioxide solubility. The seasonal pattern is affected by these variables and also by the seasonal change in day length and needle area.

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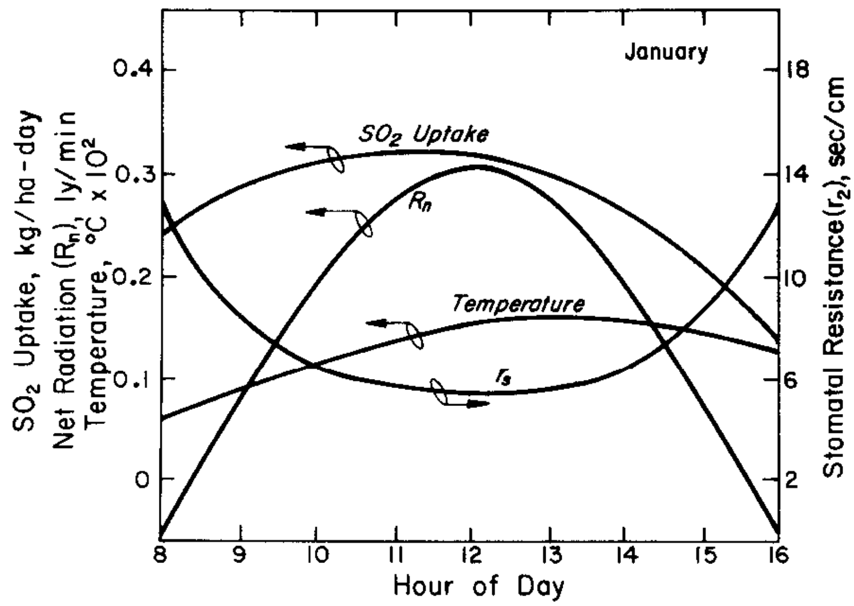

FIGURE 1. Stomatal Uptake of Sulfur Dioxide by Pine Needles in January. A simulation of the diurnal pattern of sulfur dioxide uptake, net radiation, temperature, and average stomatal resistance for a clear day characteristic of Aiken, South Carolina, during January.

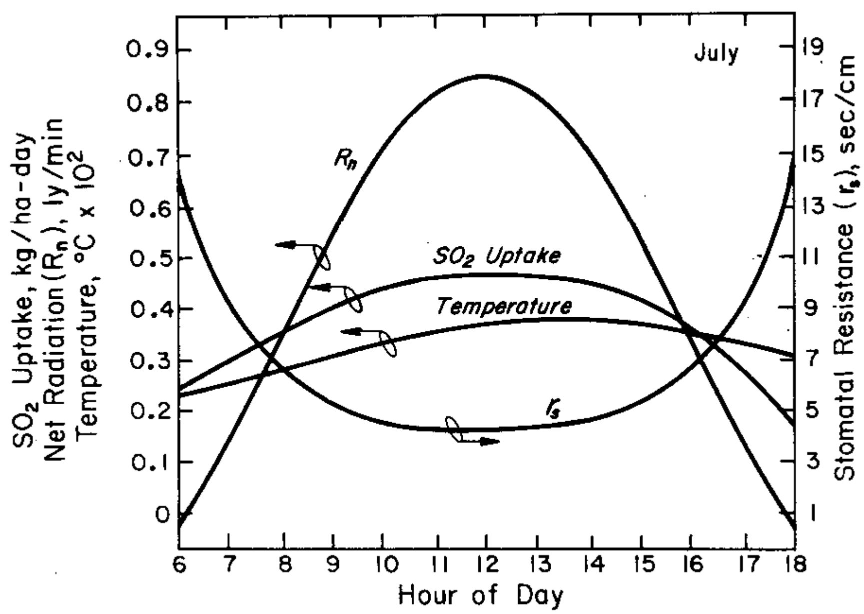

FIGURE 2. Stomatal Uptake of Sulfur Dioxide by Pine Needles in July. A simulation of the diurnal pattern of sulfur dioxide uptake, net radiation, temperature, and average stomatal resistance for a clear day characteristic of Aiken, South Carolina, during July.

13. MEASURING THE UPTAKE OF TRITIUM GAS AND TRITIATED WATER BY VEGETATION†

Uptake by vegetation, and especially forest vegetation, is a major sink for tritium from the atmosphere and thus is the lower boundary condition for atmospheric dispersion models. In addition, uptake of atmospheric tritium and its compounds is a major mode of entry of tritium into terrestrial ecosystems. The research reported here confirms that tritiated water moves into plants along the same vapor paths as normal water.[1,2,3,4] Tritium concentrations will trace the flow along these paths, including the stomatal resistance to vapor flow, which is of primary importance to the energy balance and water balance of plant canopies. Uptake of atmospheric tritium gas (T_2) and conversion to tritiated water (HTO) is much more rapid than in animals but probably less than conversion by microorganisms under optimal conditions. The half-time of this conversion is on the order of days rather than months or years as found in the atmosphere.

UPTAKE OF TRITIATED WATER VAPOR

If tritiated water vapor is absorbed by the same process that controls the movement of water vapor between a plant and the atmosphere, the absorption can be described by the resistance analogue used by investigators in plant-water relationships.[5,6]

$$Q = V\frac{dc}{dt} = \frac{0.691\ \rho A}{(r_s + r_a)}(P_a - P_l) \qquad (1)$$

This equation states that the flux of tritiated water (Q) is equal to the product of the volume of the leaves (V) and the time change in tritiated water concentration of the leaves (dc/dt); which, in turn, is proportional to the air-leaf partial pressure gradient for tritium ($P_a - P_l$), the ratio of molecular weights of tritiated water to air (0.691), the density of air (ρ), and the leaf area (A), and inversely proportional to the series of resistances associated with molecular diffusion through the aerodynamic boundary layer near the leaf (r_a) and the stoma in the leaf surface (r_s).

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† Work done by Charles E. Murphy, Jr. The work on HTO uptake was given at the Fourth National Conference on Radioecology, Corvallis, Oregon, May 7-12, 1975.

Equation (1) was tested by determining values of the stomatal resistance and comparing these to published values. Since leaf stoma normally close in the dark and open in light, light and dark treatments were made to obtain contrasting values of stomatal resistance. Two field-grown, slash pine saplings, *Pinus elliottii* Engelm, were used in this experiment. The results of these experiments are summarized in Table 1 and show that the average adjusted concentration increases with time of exposure, and that exposures in light are higher than those in the dark.

A simple, straightforward analysis to allow calculation of stomatal resistance under the conditions of this experiment was difficult to develop. However, a model of the experiment was constructed and implemented using the IBM simulation language CSMP. Successive solutions were produced for each experimental case until the values of the needle stomatal resistance were found which produced a mass balance of tritiated water and transpired water. The calculated resistances are shown in Table 1 and are consistent with previously reported values for pines.[7,8]

UPTAKE OF TRITIUM GAS

Little work has been done on the uptake of gaseous tritium by higher plants even though it has been known for some time that microorganisms can reduce the hydrogen molecule and use the energy of oxidation to water for performing metabolic work. Cline[1] exposed bean plants to gaseous tritium and found that the water freeze-dried from the plants was labeled with tritium. The research reported here was stimulated by the detection of measurable quantities of tritiated water in the water freeze-dried from vegetation in the path of the tritium puff from an accidental release.[9] The puff was measured downstream from the area in which the vegetation measurements had taken place and found to be largely tritium gas and not tritiated water. Therefore, the tritiated water seems to have come from conversion of tritium gas.

Loblolly pine (*Pinus taeda L.*), soybean (*Glycine max L.*) and rye grass (*Lolium spp.*) were exposed in sealed containers to atmospheres containing tritium gas. The soybean and rye grass plants were grown from seed, and the loblolly pines were six-months-old seedlings.

Glass slides were also inserted in the soil to allow colonization of soil microorganisms and fine roots. These were removed after the experiment and examined for tritium by microautoradiographic techniques (see Article 14, *Use of Microautoradiographs to Determine the Ability of Soil Microorganisms to Incorporate Tritium*, of this report).

The results are shown in Figure 1. The plants were the most highly labeled material, followed by the humus on the soil surface, and then the soil. While the plants were able to maintain this elevated activity for some days, indicating continued conversion of T_2 to HTO, it is evident that a great deal of the conversion took place in one day.

Because of the high activities and speed with which the conversion took place, the soybeans and rye grass seedlings were exposed to 10 μCi of tritium for periods up to 4 hours. In this set of experiments (Figure 2), the soil showed the highest relative concentrations at all times. The plants also showed tritium activity, but it was impossible to determine if this was conversion of tritium gas to tritiated water in the plants or conversion in the soil and uptake by the roots. In either case, it was obvious that much of the tritium was converted to tritiated water in a few hours.

It is interesting to speculate on the mechanism for this conversion. There is little information in the literature about the metabolism of gaseous hydrogen. Krogmann[10] reports that the plant enzyme ferredoxin from spinach could be reduced using gaseous hydrogen. This would enable the gaseous hydrogen or any of its isotopes to enter into the photosynthetic process and be incorporated into carbohydrates which could be further metabolized to water. Thus the biochemical paths and the enzymes exist to allow the incorporation of tritium in higher plants.

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TABLE 1

Uptake of Tritium Activity by *Pinus elliotti* Engelm Needles

	Dark[a]		*Light*[a]	
Time, hr	1	2	1	2
Surface Area, cm^2	8707	11453	6182	9267
Leaf Activity, pCi/ml	102.9	78.6	115.7	77.9
Final Water Activity,[b] pCi/ml	13984	8252	11540	5123
Adjusted Leaf Activity, pCi/ml	0.00714	0.00928	0.00999	0.0143
Stomatal Resistance, sec/cm	31.9	14.8	6.5	2.6

a. Living branches enclosed in sealed pigmented (<1% light transmission) and clear polyethylene bags.

b. Initial water activity: 15.7 μCi/ml.

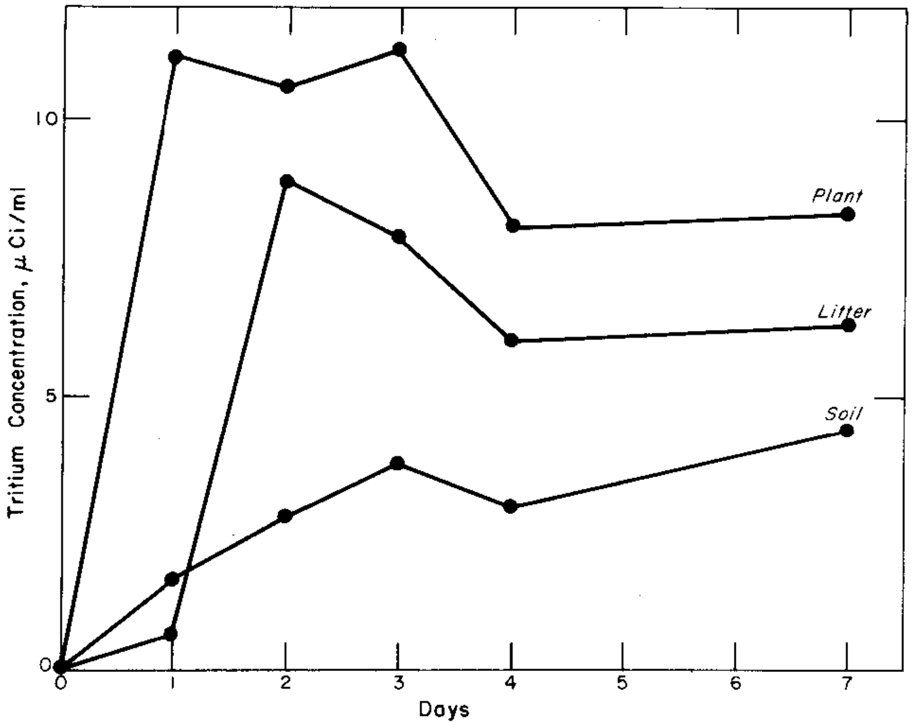

FIGURE 1. HTO in Freeze-Dried Water from Pine Seedlings

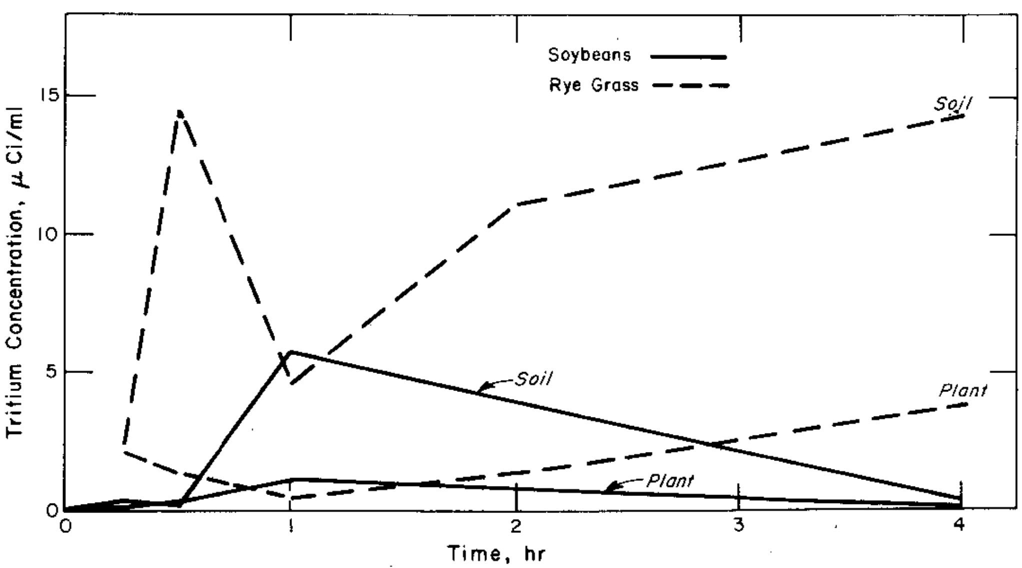

FIGURE 2. HTO in Freeze-Dried Water from Soybeans and Rye Grass

14. USE OF MICROAUTORADIOGRAPHS TO DETERMINE THE ABILITY OF SOIL MICROORGANISMS TO INCORPORATE TRITIUM †

INTRODUCTION

Tritium cycling occurs through biological systems as demonstrated by tritium uptake in higher plants.[1] In terrestrial ecosystems, microorganisms play an important role in the mineralization of compounds and the cycling of nutrients for biological metabolism. This is particularly true for the environment under the influence of plant roots (rhizosphere).[2] Studies were undertaken to determine whether microorganisms associated with the rhizosphere of higher plants were able to fix gaseous tritium into biological compounds. Microorganismal incorporation of tritiated hydrogen was measured by microautoradiographs,[3] which distinguished between radioactive microorganisms and non-radioactive ones. If the fixation of tritiated gas into biological compounds by microorganisms occurs, then the biological half-life of tritium in a terrestrial ecosystem may be longer than previously thought. Preliminary experimental results indicate that microorganisms incorporate tritium gas into their cell structures, and that the microorganismal uptake of tritium decreases with increasing soil depth.

MATERIAL AND METHODS

Soil Jar Preparation and Incubations

Glass jars were partially filled with approximately 2 kg of sandy soil typical of that found at SRP. Glass microscope slides (2.5 cm x 7.5 cm) were washed with alcohol and inserted vertically in replicates of four into the soil profile. Seeds of rye, *Lolium perenne;* soybean, *Glycine max;* and loblolly pine, *Pinus taeda,* were planted separately in individual jars. The glass slides and seeds were placed in juxtaposition to one another so that plant roots and the rhizosphere were in close relationship to the slides. All seeds were germinated and the plants were grown under greenhouse conditions. At the end of the growth period, the jars were sealed and a dilute tritium-air mixture was injected at a concentration of 10 μCi/cc of air space in the chambers. After designated incubation periods the slides were removed from the soil-plant ecosystems and stored at -20°C until processed.

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† Work done by C. B. Fliermans.

Microautoradiography of Microorganisms

The glass slides, which provided an attachment surface for microorganisms (bacteria, algae, fungi, and actinomycetes), were heat-fixed, washed in phosphate-buffered saline solution, and stained with fluorescein isothiocyanate (FITC) as previously described.[3]

Four replicate glass microscope slides with the heat-fixed and washed bacteria were dipped in *Kodak* NTB-2 nuclear track emulsion (Eastman Kodak Co., Rochester, New York) and diluted to a final concentration of 1:3 with filtered, sterilized, distilled water. All manipulations involving NTB-2 emulsion were performed in total darkness in an isotope-free darkroom. The emulsion was heated to 43°C in a constant temperature water bath 30 minutes prior to dipping and freed of air bubbles.[4] Slides were immersed in the emulsion in a reproducible manner and immediately placed horizontally on a cold metal tray in order to gel the molten emulsion prior to drying. The metal tray was held in a light-tight chamber kept at 45% relative humidity,[5] and the slides were allowed to dry for 45 minutes. Dry slides were placed in black plastic slide boxes containing an indicator desiccant. The boxes were sealed with black electrical tape and stored at room temperature for 2 to 10 days. After appropriate exposure times, the slides were developed for 30 seconds at 23°C in *Kodak* D-19 developer diluted to a final concentration of 1:3 with tap water, fixed in 30% sodium thiosulfate for two minutes, washed in running tap water for 15 minutes, and air dried.

Microorganisms stained with the FITC and silver grains developed in the radiographic emulsion by tritium radiation were viewed simultaneously using a *Zeiss* Universal Photomicroscope with a combination of epifluorescence and transmitted dark-field illumination.

RESULTS AND DISCUSSION

The combination of fluorescent staining and microautoradiographic techniques permitted the assessment of the role of microorganisms in fixing tritiated gas in the rhizosphere of various higher plants. Microscopic examination of the autoradiograms demonstrated the uptake of tritiated compounds by the microbial community. Each radiogram had a number of silver grains in juxtaposition with the microorganisms. The concentration of the silver grains was in direct proportion to the levels of tritium incorporated into the cells. Thus, the levels of tritium incorporation could be determined. Generally, microorganisms incorporate greater levels of tritium near the soil surface than in deeper profiles. Such differentiation may have been due to limited gaseous diffusion.

Preliminary results indicate that most of the activity of tritiated compounds, as measured by developed silver grains, was associated with algal cells, fungi, and detrital material rather than with actinomycetes or bacteria. Further studies will determine the extent of tritium fixation in relation to depth and type of rhizosphere.

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3. C. B. Fliermans and E. L. Schmidt. "Fluorescence Microscopy: Direct detection, enumeration and spatial distribution of bacteria in aquatic systems." *Archives Hydrobiologie 76*, 33-38 (1975).

4. A. W. Rogers. *Techniques in Autoradiography.* P. 372, Elsevier Scientific Publishing Co., New York (1973).

5. R. H. Stokes and R. A. Robinson. "Standard Solutions for Humidity Control at 25°C." *Ind. Eng. Chem. 41*, 2013 (1949).

15. OIL BIODEGRADATION STUDIES †

INTRODUCTION

Waste oil is produced at the Savannah River Plant (SRP) as a consequence of industrial practices and automotive maintenance. The majority of the waste oil is burned in the onsite coal burning power plants as a supplemental energy source. The remainder is unsuitable for burning because of elevated trace metal contents or the hazards associated with combustion of low flash point solvents. This program was undertaken to examine the potential for using biodegradation of oil placed on the soil to dispose of the oil safely and with a minimum effect on the environment. Of interest in the study are the effects of aeration and fertilizer addition on biodegradation rate. The study, begun in June, 1975, has already provided significant preliminary observations. Some of these preliminary observations are: no vegetation is growing on the plots that have had oil added; however, vegetation is growing on the control plots; soil temperatures at 1:00 PM on sunny days are approximately 10°C above those of the non-oiled plots; and approximately 20 g of oil/m^2 of surface/day is volatilized from an open pan containing oil.

EXPERIMENTAL SITE

The field disposal test site consists of six strips (Figure 1). Each strip contains four plots, each 3.66-m wide and 10-m long separated by a 5-m long buffer zone. The variables examined by this experimental design were aeration rate (monthly, bimonthly, and none), and fertilizer addition (carbon/nitrogen rates of 156/1, 60/1, 36/1, and 0). Aeration was accomplished by rotatilling the plot. To achieve the appropriate carbon/nitrogen ratios, the plots received 200 pounds each of 5-10-15 fertilizer plus 0, 50, or 100 pounds of 33-0-0 fertilizer. The plots are being sampled monthly and analyzed for nitrogen, phosphorus, potassium, and oil at depth layers of 0-15 cm, 15-30 cm, and 30-45 cm.

PRELIMINARY OBSERVATIONS

The oil was somewhat aromatic, which suggested a certain volatility. To estimate the magnitude of oil loss through

† Work done by S. E. Kane (Undergraduate Research Trainee, Vanderbilt University, Nashville, Tennessee) and J. C. Corey.

evaporation, oil was placed in open pans either with or without soil (5% oil by weight). Evaporation of oil from pans (0.05 m^2) placed in the sun averaged the equivalent of 20 g/m^2 of surface/day. The pans with soil and oil showed no detectable losses. Soil temperatures on the surface of the oil plots averaged 10°C above those of the non-oil plots at 1:00 PM when the sun was shining. Soil temperatures as high as 54°C were recorded on the oil plots.

To fully utilize the site, the U. S. Forest Service decided to make it a demonstration location for their ground cover mixtures for minimizing erosion on forest roads and borrow pits, song bird habitat development, pecan grove restoration activities, and forest road preparation and maintenance. Visiting groups can now examine these aspects of the site's environmental activities in addition to the biodegradation study.

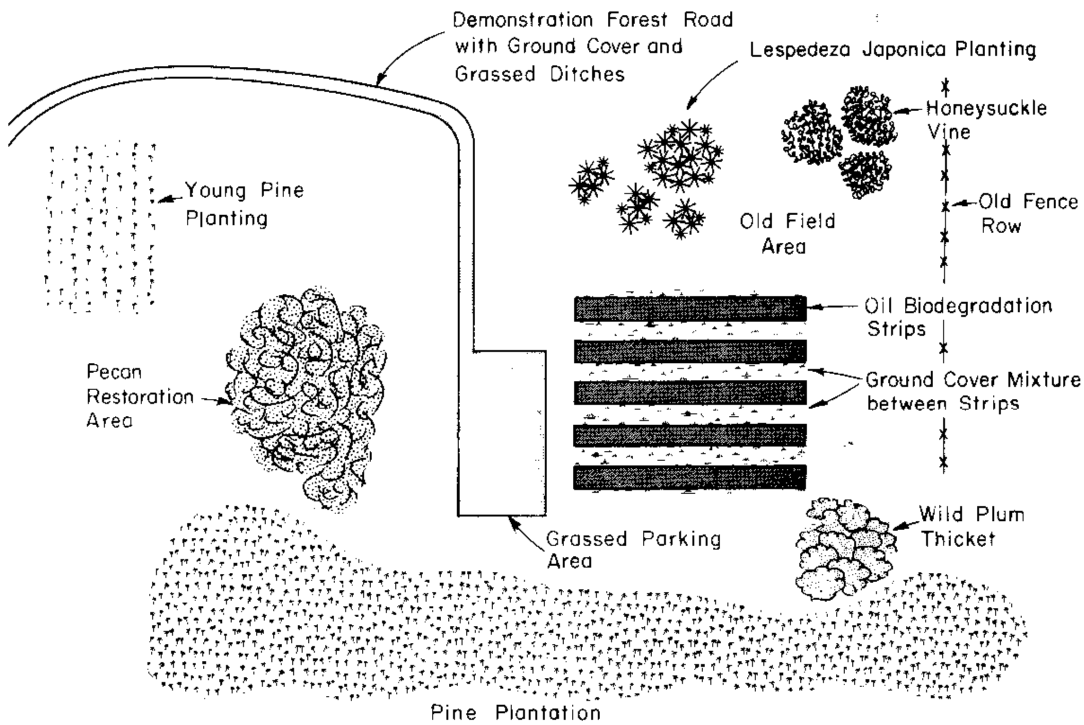

FIGURE 1. Oil Biodegradation Study Site

16. ISOLATION AND ANALYSIS TECHNIQUES OF AEROSOLS FROM A NUCLEAR FUEL REPROCESSING PLANT †

INTRODUCTION

The Savannah River Plant (SRP) since its inception in 1950 has routinely and continuously monitored the local environment. Environmental studies of plutonium (Article 20 of this report) indicate that the offgas particulates do not affect offsite plutonium concentrations. As part of this intensive monitoring program, a technique was developed to characterize microaerosols containing plutonium which might be vented from a nuclear fuel reprocessing facility. The small quantities of plutonium released from the offgas system (7.68 mCi in 1974) have required the development of very sensitive techniques.

Samples are being collected throughout the exhaust system including the stack effluent to the atmosphere. Aerosol samples collected at the source provide information about plutonium-bearing particles which may be released. Samples collected before and after the exhaust air is filtered indicate what could be released should the filter system accidentally fail. This study intends to provide information that can be used to determine the source and possible cause for release of plutonium-bearing particles found in the environment.

ISOLATION AND ANALYSIS TECHNIQUES

Particles from air exhausted from the reprocessing plant are collected on 47-mm-diameter, commercially available, polycarbonate membrane filters having pores 0.1 μm in diameter. Each filter is placed in a small glass vial and dissolved in 3/4 ml of chloroform, and the solution is evaporated on a glass plate to form a clear polycarbonate film. The films are fused to acrylic resin frames for support and stripped from the glass plates using water. To locate those particles which contain plutonium, the films are irradiated with 3.72×10^{13} thermal neutrons/cm^2. Fission fragments from plutonium in the particles sensitize the polycarbonate resin along paths leading from the particles. To reveal fission fragment tracks, the sensitized film is etched

† Work done by S. M. Sanders, A. L. Boni, and R. W. Taylor.

for 10 minutes in 6N NaOH at 50°C. Polycarbonate squares (10 x 10 μm), that contain particles with tracks, are excised from the film with an ultra microknife with the aid of a 210X stereomicroscope. A tungsten needle is used to lift the polycarbonate squares onto a 1-in.-diameter, polished-beryllium, sample mounting block scribed with a grid of numbered 1-mm squares. The tracks in each polycarbonate square are photographed at 400X magnification (Figure 1). The beryllium block is placed in a low-temperature asher, where the polycarbonate is oxidized in an oxygen plasma containing 10% carbon tetrafluoride. A second photograph is then made at the same magnification to identify the location of particles containing plutonium (Figure 2).

For particles greater than 1 μm, information about their color, refractive index, opacity, and birefringence is obtained using a light microscope. Information about particle size, shape, surface texture, and topography is obtained using a high-resolution scanning electron microscope (SEM). Some information about agglomeration and purity is also obtained by direct observation with the SEM. Elemental composition and distribution are obtained by wavelength and energy dispersive analyses of the x-ray spectrum produced by bombarding the particles with the energetic electron beam of an electron microprobe analyzer (EMA).

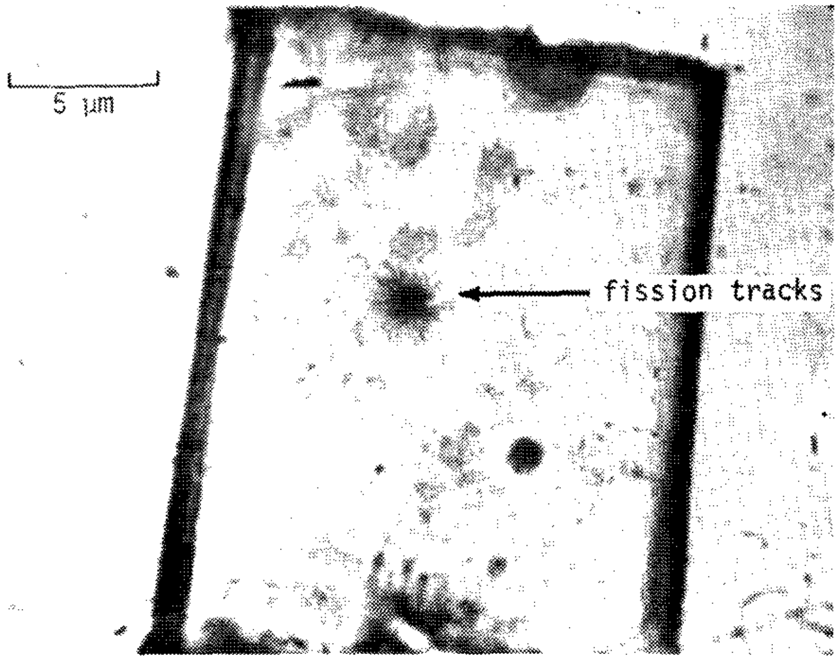

FIGURE 1. Fission Fragment Tracks in Polycarbonate

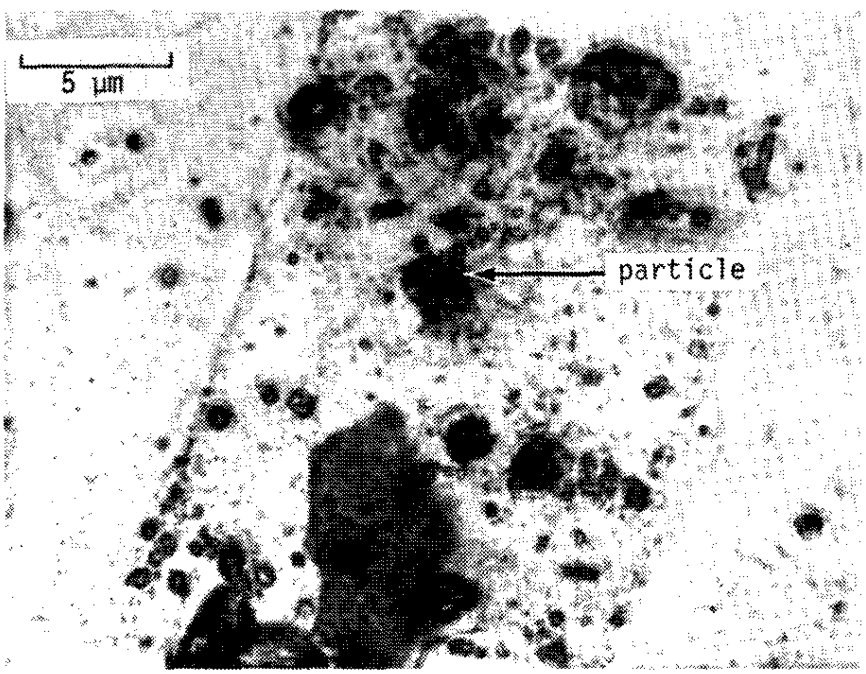

FIGURE 2. Mounted Radioactive Particle

17. A FIELD STUDY TO OBTAIN PLUTONIUM CONTENTS OF OLD FIELD VEGETATION AND SOIL UNDER HUMID CLIMATE CONDITIONS †

INTRODUCTION

A field study was conducted in the fall of 1974 using very sensitive analytical methods to determine the spatial variation of plutonium in the soil and in the old field vegetation in a 250- x 30-m field adjacent to one of the nuclear fuel reprocessing plants on the Savannah River Plant (SRP). This location was used subsequently for determining plutonium contents of wheat (Article 19 of this report) and resuspension of plutonium during agricultural operations (Article 18 of this report). The field was selected since it has the highest plutonium concentrations on SRP (Article 20 of this report). The highest plutonium concentrations were at the soil surface. Resuspension and stack releases of plutonium were the principal contributors to the plutonium concentration in unwashed vegetation samples. The ^{238}Pu/total plutonium ratios were more closely aligned to source term values than to soil values. Plutonium uptake studies in the laboratory may underestimate the plutonium content of vegetation grown under field conditions adjacent to a fuel reprocessing facility where resuspension and stack emissions are both operable.

METHODS

The field was segmented into 30 plots (Figure 1). At each location, four soil samples were taken: a vacuumed sample that removed resuspendibles and soil cores from each of these depths: 0-5, 5-15, and 15-30 cm. The vegetation was segmented into annual-biennial or perennial. The principal plants were *Andropogan virginicus* (broom sedge), *Lespedeza cuneata* (sericea lespedeza), *Ambrosia artemisiifolia* (ragweed), *Prunus augustifolia* (chickasaw plum) and *Pinus taeda* (loblolly pine). Both soil and vegetation were analyzed for plutonium using the method shown in Figure 2.

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† Work done by J. E. Pinder, III and M. H. Smith (SREL), H. R. McLendon (SRP), and A. L. Boni, J. H. Horton, and J. C. Corey (SRL). Presented at the *Radioecology Symposium*, Corvallis, Oregon, May 12-16, 1975.

RESULTS AND DISCUSSION

Total biomass of the field was estimated to be 237.5 g (dry weight)/m^2. Plutonium analyses of vegetation and soil are shown in Tables 1 and 2. Table 3 summarizes plutonium distribution in the vegetation and soil. Examination of the plutonium composition of the plants and soil of Table 1 indicates that the plants have a significantly higher ^{238}Pu/total Pu* ratio than the soil indicating the source of the ^{238}Pu is other than uptake by plant roots. Stack emissions have been measured and have a ^{238}Pu/total Pu ratio similar to that of the plants (approximately 0.70). The elevated ratio of the resuspendibles indicates that the stack material is also depositing on the soil surface where it can be blown around and deposited on vegetation. The plutonium content of the vegetation (Table 2) is much higher than laboratory uptake studies suggest. Laboratory results usually show the plutonium content of the vegetation to be 10^{-4} -10^{-6} that of the soil. This elevated content supports the theory that deposition of stack emissions and resuspension of surface particulates on the vegetation is contributing to the elevated ratios observed. The plutonium content in the vegetation of the field only represents 0.2% of the total plutonium content of the field. The distribution in the soil is abnormal because this field was ploughed in 1968. Other work at SRP[a] has shown that in a 30-cm soil core, removed from undisturbed ground, approximately 90% of the plutonium is found in the top 15 cm of soil. Of the 90%, 84% is found within the top 5 cm.

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* See page 2, Article 18 of this report.

a. H. R. McLendon. "Soil Monitoring for Plutonium at the Savannah River Plant." *Health Physics 28*, 347 (1975).

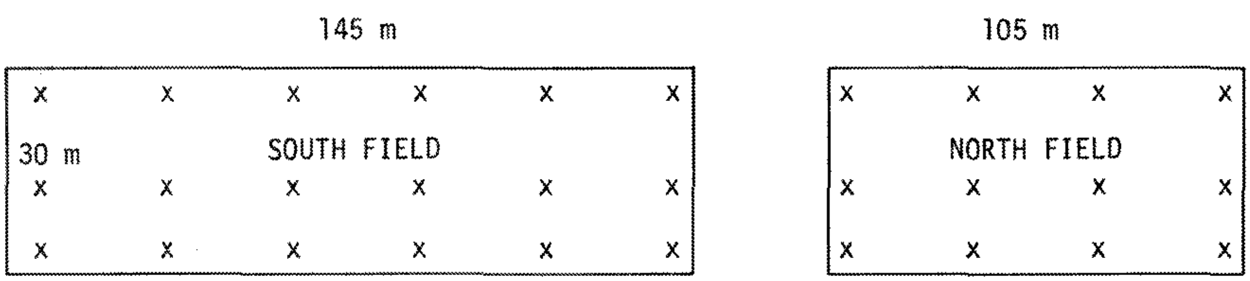

FIGURE 1. Sampling Locations

TABLE 1

Plutonium Analysis of Soil and Vegetation

	Alpha Percent ^{238}Pu[a]		
	South Field	*North Field*	*Both Fields*
Plants			
Perennials	61.5 ±6.0	66.6 ±5.7	63.4 ±6.3
Annuals-Biennials	61.4 ±5.9	66.8[b]	62.1 ±5.8
Soil			
Resuspendibles	51.1 ±9.1	49.2 ±9.3	50.4 ±9.1
0 to 5-cm cores	27.6 ±8.7	19.9 ±8.7	24.5 ±9.4
5 to 15-cm cores	30.4 ±10.3	20.0 ±8.2	25.7 ±11.4
15 to 30-cm cores	28.2 ±11.0	29.6 ±8.6	28.8 ±10.0

a. Alpha Percent ^{238}Pu = $\dfrac{\text{alpha disintegrations from } ^{238}\text{Pu}}{\text{alpha disintegrations from } ^{238,239,240}\text{Pu}} \times 100$

b. Single value.

TABLE 2

Plutonium Analysis of Soil and Vegetation

	Concentration, pCi/g dry weight		
	South Field	*North Field*	*Both Fields*
Plants			
Perennials	0.89 ±0.43	0.16 ±0.07	0.60 ±0.49
Annuals-Biennials	1.68 ±0.47	0.09[a]	1.48 ±0.71
Soil			
Resuspendibles	12.90 ±16.01	1.61 ±0.88	8.32 ±13.50
0 to 5-cm cores	1.62 ±1.51	0.60 ±0.48	1.21 ±1.32
5 to 15-cm cores	0.12 ±0.12	0.094 ±0.063	0.11 ±0.10
15 to 30-cm cores	0.20 ±0.26	0.035 ±0.024	0.13 ±0.22

a. Single value.

TABLE 3

Distribution of Plutonium in Field

Sample	*Pu Distrib., %*
Vegetation	0.2
0 to 0.1-cm cores	9.0
0.1 to 5-cm cores	57.3
5 to 15-cm cores	12.1
15 to 30 cm cores	21.4

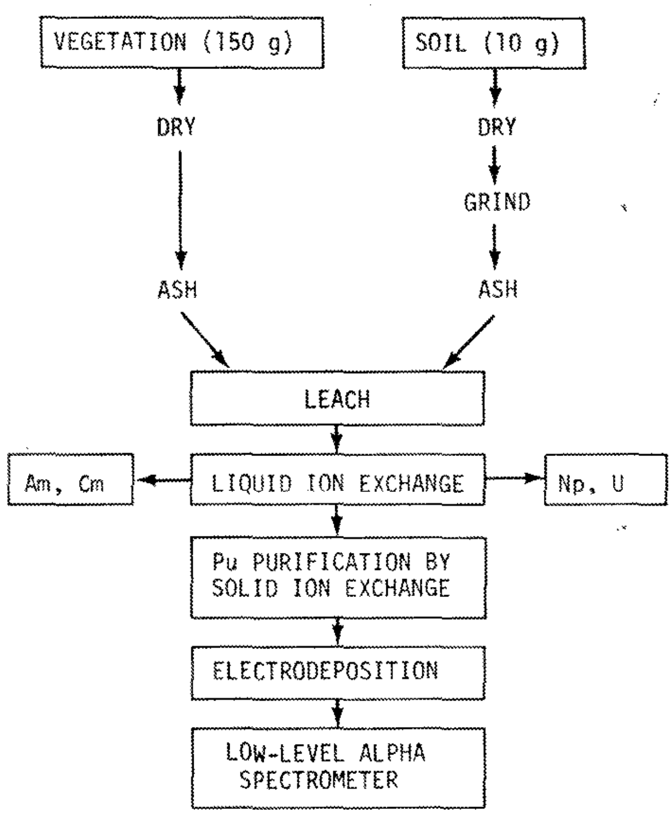

FIGURE 2. Flow Chart of Plutonium Analysis Procedure

18. MEASUREMENTS OF RESUSPENDED PLUTONIUM DURING AGRICULTURAL OPERATIONS ON AN OLD FIELD AT THE SAVANNAH RIVER PLANT †

INTRODUCTION

Air sampling was conducted upwind, downwind, and on the tractor during land preparation (bush-hogging, disking, and fertilizing) and wheat planting of an old field area (Figures 1 and 2) at the Savannah River Plant (SRP). The field contained elevated levels of plutonium as described in the preceding article. The sampling program described in this article was done to determine the effect of agricultural practices on the resuspension of plutonium under southeastern United States conditions. The air concentrations of plutonium measured as a result of the agricultural operations in this particular field study are higher than would be found elsewhere on or offsite but the resuspension factor should be typical for southeastern United states conditions. The results from the wheat grown as a consequence of the agricultural activities are summarized in Article 19 of this report.

SAMPLING PROCEDURES AND RESULTS

Plutonium contents of soil were determined in the field at 30 locations chosen on a uniform grid on the 0.75 hectare field (Table 1). Before and after agricultural operations, resuspendible particulates on the soil surface were sampled using a vacuum sampling system. During the bush-hogging, disking, and subsoiling operations necessary before planting, airborne particulates at eight locations (upwind, downwind, and on the tractor pulling the agricultural implements) were collected using high-volume air samplers. Filters were changed between agricultural practices to permit assessment of the relative effects of different practices.

Potential resuspendible plutonium was present in the first millimeter of the soil surface and probably associated with soil particles and/or organic matter. A portable vacuum cleaner and

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† Work done by R. C. Milham, J. F. Schubert, J. R. Watts, A. L. Boni, and J. C. Corey. Presented at the *Symposium on Transuranium Nuclides in the Environment*, San Francisco, California, November 17-21, 1975.

its suction head were modified to pick up the potential resuspendible material at a known velocity. The suspended materials were collected in filter bags, and each sample was prepared for analysis. Resuspendible plutonium content of the old field soil averaged 8.3 pCi/g. Following cultivation, the value decreased to 3.3 pCi/g as the surface suspendibles became mixed with the average soil concentration of 1.2 pCi/g for the 0 to 5-cm depth.

During the cultivation period, the prevailing wind was perpendicular to the cultivation direction (cross-wind) and ranged from 0 to 6.2 m/sec. The plutonium content upwind (Table 2) averaged a consistent 1.7×10^{-15} Ci/m^3. The concentration downwind of the field during cultivation and planting operations varied from 1.4 to 200×10^{-15} Ci/m^3. The average air concentration was 21×10^{-15} Ci/m^3 at 7.62 m and 12×10^{-15} Ci/m^3 at 30.5 m downwind from the field. The wide variations measured are attributed to inhomogeneity of the plutonium content in the suspended material and shifting of the resuspended material plume due to unstable wind conditions.

Table 1 shows the initially high ^{238}Pu concentration gradient (26 to 50 alpha % ^{238}Pu)* observed between the 0 to 5 cm layer of soil and the resuspendible layer. This steep concentration gradient provided an excellent tracer for determining transport modes.

CONCLUSIONS

^{238}Pu alpha % values observed in the air samples downwind from the cultivation operations generally reflect the average value observed in the soil (26%) and not that in the resuspendible soil surface (50%). The higher ^{238}Pu alpha % values observed at greater distances may indicate a mixture of subsurface and surface resuspended material.

Assuming all the plutonium in the top 5 cm of soil is resuspendible, it was possible to calculate resuspension factors of 25×10^{-8} at the tractor, 103×10^{-8} at 7.6 m downwind from the field edge, and 5×10^{-8} at 30.5 m downwind from the field edge during these agricultural operations.

Additional resuspension studies are in progress to determine more precisely the parameters governing surface transport of plutonium and potential impact on the environment.

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* alpha % ^{238}Pu = (^{238}Pu/Total Pu) x 100.

TABLE 1

Old Field Soil Plutonium Data Summary

	Total Pu Concentration, pCi/g		
	North Field	*South Field*	*Both Fields*
Resuspendibles			
Pre-cultivation	1.6 ±0.9	13 ±16	8.3 ±14
Post-cultivation	0.9 ±0.4	4.8 ±2.4	3.3 ±2.7
Soil 0-5 cm			
Pre-cultivation	0.6 ±0.5	1.6 ±1.5	1.2 ±1.3
Post-cultivation	0.9 ±0.7	4.6 ±2.5	3.1 ±2.7

	^{238}Pu, α %		
	North Field	*South Field*	*Both Fields*
Resuspendibles			
Pre-cultivation	49 ±9	51 ±9	50 ±9
Post-cultivation	27 ±8	28 ±5	28 ±6
Soil 0-5 cm			
Pre-cultivation	20 ±9	28 ±8	25 ±9
Post-cultivation	26 ±8	23 ±8	24 ±8

TABLE 2

Agricultural Resuspension Data Summary

Sample Location	*Sampling Distance, m*	*Concentration, fCi/m³* North Field	South Field	Both Fields
Upwind Background	7.6	1.4 ±0.3	2.0 ±0.6	1.7 ±0.6
Tractor	0	7.4 ±8.6	91 ±81	49 ±69
Agricultural Operations (Downwind)	7.6	192 ±462.9	233 ±739.5	209.9 ±589.3
Agricultural Operations (Downwind)	30.5	11.2 ±18.5	9.1 ±13.3	10.3 ±16.1
		^{238}Pu, α % North Field	South Field	Both Fields
Upper Background	7.6	12 ±4	18 ±3	15 ±4
Tractor	0	27 ±15	25 ±27	26 ±20
Agriculutral Operations (Downwind)	7.6	15 ±14	18 ±11	17 ±13
Agricultural Operations (Downwind)	30.5	32 ±19	38 ±20	35 ±19

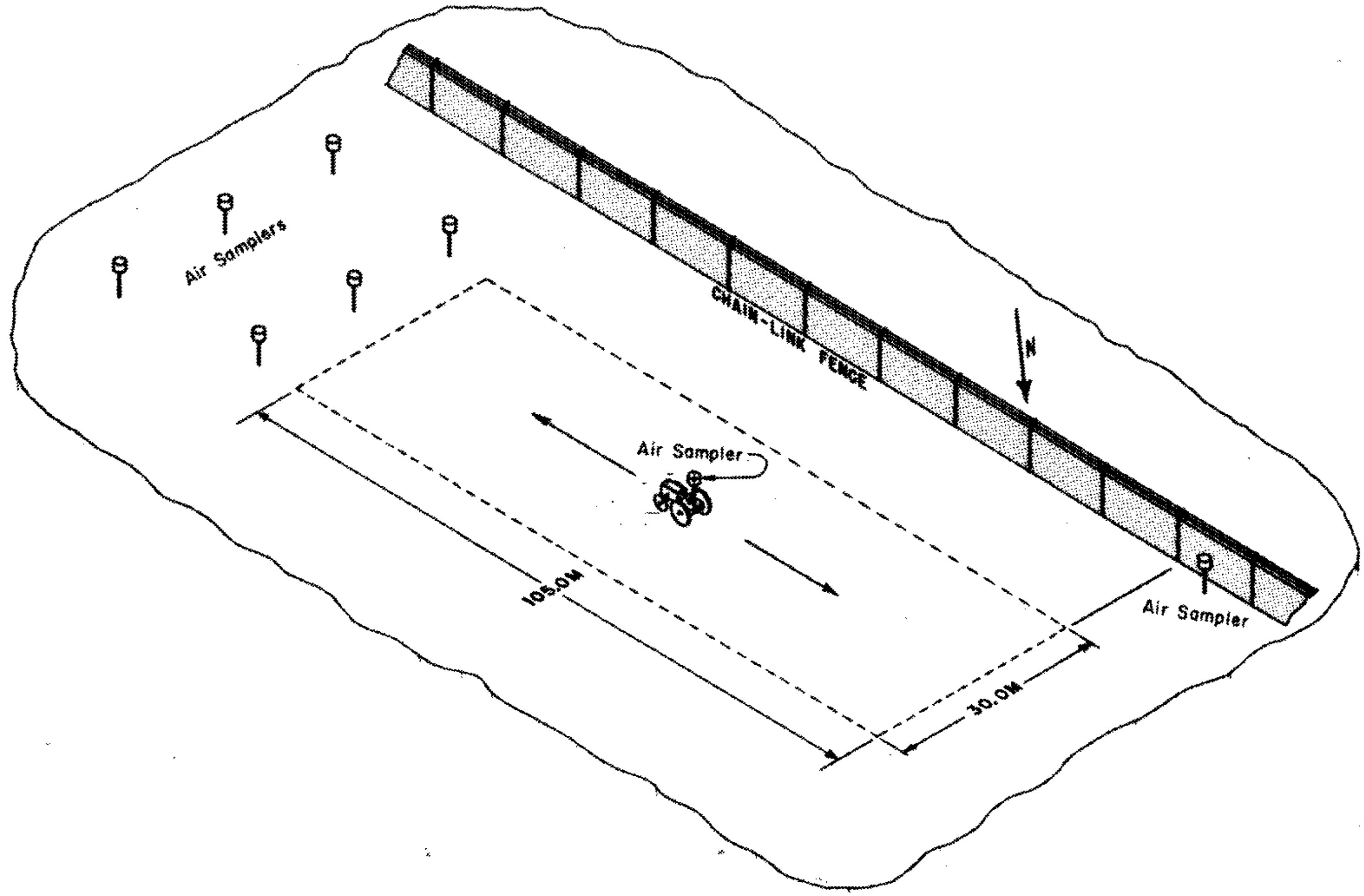

FIGURE 1. Sampling Locations

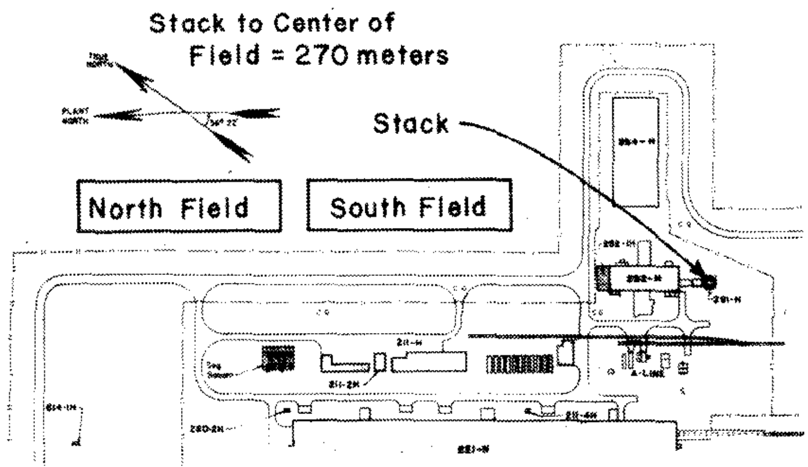

FIGURE 2. Location of Tilled Fields in Relation to Reprocessing Facilities

19. A FIELD STUDY TO DETERMINE PLUTONIUM CONTENTS OF WHEAT AND SOIL AT SRP †

INTRODUCTION

A field study was initiated in the fall of 1974 to determine the distribution of plutonium between the soil, straw and grain of wheat grown on the 250- x 30-m field adjacent to one of the nuclear fuel reprocessing plants on the Savannah River Plant (SRP). Resuspension studies of plutonium (Article 18 of this report) were conducted during the agricultural activities required to produce the wheat crop. The plutonium content of the wheat field was low ($\sim$2.0 fCi/g of grain) and the dose to a person eating 3×10^5 g (667 lb) of grain per year would result in a 70-year bone dose of 0.5 mrem to an individual. The ^{238}Pu/total Pu ratio of the grain is closely aligned to source values (stack emissions from the reprocessing facility) and considerably greater than the ratio present in the soil, indicating much of the plutonium present reaches the grain by deposition rather than uptake by the growing wheat plant.

METHOD

The old field (Article 17 of this report), 30-m x 250-m, was bushhogged, subsoiled, disked, fertilized, and planted to wheat in the fall of 1974. The field was divided into thirty plots of equal size.* From each plot, the following samples were taken for plutonium analyses: resuspendible materials on ground surfaces were collected by suction of a vacuum cleaner; soil cores were taken at depth increments of 0 to 5, 5 to 15, and 15 to 30 cm (as described in Articles 17 and 18 of this report). The wheat plants were sampled at 3-week intervals during their growth cycle. At harvest (June 1975), plant parts were separated into grain and straw.

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† Work done by D. C. Adriano, K. W. McLeod, J. E. Pinder, III, and M. H. Smith (SREL), and A. L. Boni, J. C. Corey, and J. R. Watts (SRL). Presented at the *Annual Meeting of the American Society of Agronomy*, Knoxville, Tennessee, August 24-29, 1975.

* Figure 1, Article 17 of this report.

RESULTS AND DISCUSSION

Total biomass of the field was estimated to be approximately 3600 kg per hectare (∿1.5 tons/acre). Plutonium analyses of vegetation and soil are shown in Table 1 and 2. Table 3 summarizes plutonium distribution in the vegetation and soil. The data show 99.9% of the plutonium on the field (approximately 3 mCi) is in the soil; the plutonium content of the wheat is about 2 fCi/g of grain; and the ^{238}Pu/total Pu ratio of the grain is closely aligned to the source values and not to the soil, which indicates that most of the plutonium in the wheat came from deposition and not root uptake.

The dose to a person from ingesting the wheat grain directly can be obtained using the nomograph in Figure 1. If a person ate 3×10^5 g (667 lb) of wheat per year containing 2 fCi of plutonium/g of wheat grain, the 70-year bone dose would be 0.5 mrem.

TABLE 1

Plutonium Analysis of Soil and Vegetation

	^{238}Pu, α %[a]		
	South Field	*North Field*	*Both Fields*
Wheat			
Straw	58 ±9	55 ±9	57 ±9
Grain	56 ±11	55 ±11	56 ±11
Soil (prior to cultivation)			
Resuspendibles (0 to 0.1 cm)	51 ±9	49 ±9	50 ±9
0.1 to 5 cm cores	28 ±8	20 ±9	25 ±9
5 to 15 cm cores	30 ±10	20 ±8	26 ±11
15 to 30 cm cores	28 ±11	30 ±9	29 ±10
Soil (following initial cultivation)			
Resuspendibles	28 ±5	27 ±8	28 ±6
0.1 to 5 cm cores	23 ±8	26 ±8	24 ±8
5 to 15 cm cores	22 ±9	25 ±13	23 ±11

a. $\alpha \% \, ^{238}Pu = \frac{\text{alpha distintegrations from } ^{238}Pu}{\text{alpha distintegrations from } ^{238,239,240}Pu} \times 100.$

TABLE 2

PLUTONIUM ANALYSIS OF SOIL AND VEGETATION

	Total Pu Concentration, pCi/g		
	South Field	North Field	Both Fields
Wheat	0.088 ± 0.065	0.039 ± 0.064	0.068 ± 0.068
Straw	0.002 ± 0.002	0.001 ± 0.001	0.002 ± 0.001
Soil (prior to cultivation)			
Resuspendibles (0 to 0.1 cm)	12.90 ± 16.01	1.61 ± 0.88	8.32 ± 13.50
0.1 to 5-cm cores	1.62 ± 1.51	0.60 ± 0.48	1.21 ± 1.32
5 to 15-cm cores	0.12 ± 0.12	0.094 ± 0.063	0.11 ± 0.10
15 to 30-cm cores	0.20 ± 0.26	0.035 ± 0.024	0.13 ± 0.22
Soil (following initial cultivation)			
Resuspendibles (0 to 0.1 cm)	4.83 ± 2.37	0.85 ± 0.37	3.31 ± 2.71
0.1 to 5-cm cores	4.59 ± 2.49	0.87 ± 0.69	3.12 ± 2.70
5 to 15-cm cores	0.92 ± 1.46	0.17 ± 0.14	0.62 ± 1.18

TABLE 3

DISTRIBUTION OF PLUTONIUM IN THE FIELD BEFORE AND AFTER INITIAL CULTIVATION (BASED AT HARVEST TIME OF THE WHEAT CROP).

	Plutonium Distribution, %	
Sample	*Before Cultivation*	*After Cultivation*
Vegetation	0.2	0.005
Resuspendible (0 to 0.1 cm)	9.0	1.4
0.1 to 5-cm cores	57.3	64.3
5 to 15-cm cores	12.1	26.1
15 to 30-cm cores	21.4	8.2

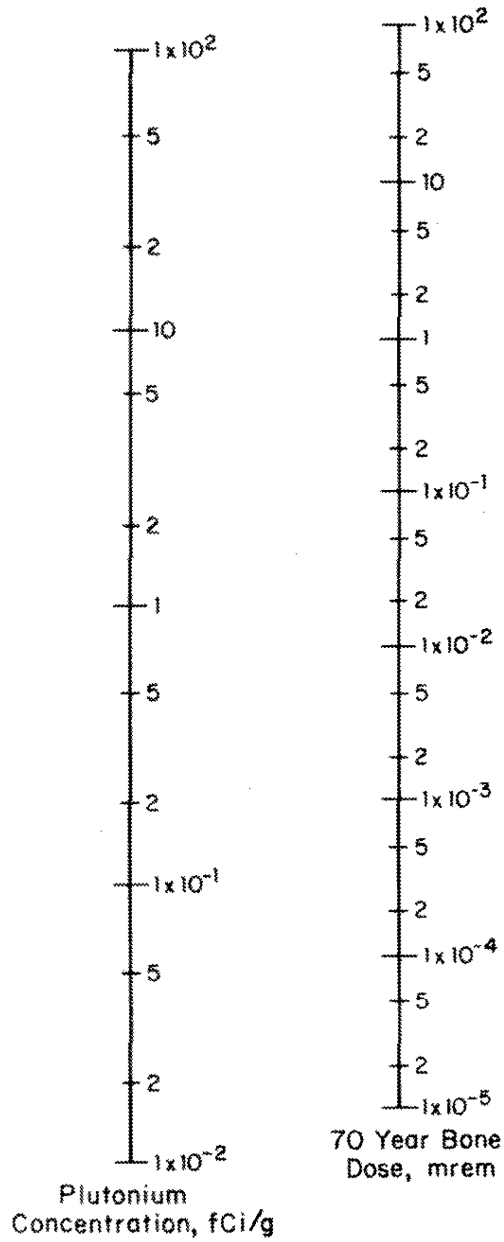

FIGURE 1. Nomograph to Calculate Dose-to-Bone from Consumption of Plutonium-Containing Wheat. The dose is that which will be received by the bone during a 70-year lifespan. Dose calculations use the following assumptions from ICRP Publications: ICRP 2 (effective absorbed energy per disintegration = 270 Mev); ICRP 19 (fraction from gastrointestinal tract to blood = 3×10^{-5}; fraction from blood to bone = 0.45, half-life in bone = 100 yr); ICRP 20 (mass of bone = 5×10^{3} g).

20. RELATIONSHIPS AMONG PLUTONIUM CONTENTS OF SOIL, VEGETATION, AND ANIMALS COLLECTED ON AND ADJACENT TO SRP†

INTRODUCTION

As a consequence of an extensive environmental monitoring program at the Savannah River Plant (SRP), detailed information on the plutonium content of soil has been documented.[1] This particular monitoring program has established a background level for plutonium in this area of the southeastern U.S. at approximately 2 mCi/km^2 and has provided information needed to assess the plutonium content of the SRP environment. Idealized isopleths showing plutonium deposition starting at the chemical separations areas and decreasing toward the plant perimeter were drawn based on data from the monitoring program (Figure 1). These isopleths represent soil concentrations ranging from the background level of approximately 0.009 pCi/g to a high of 2.74 pCi/g adjacent to one of the nuclear fuel reprocessing facilities on the site. These data have been used to select study sites (Article 18 and 19 of this report) for research on plutonium behavior in the environment. Preliminary analyses indicate the quantity of plutonium in vegetation is proportional to that in soil. The relationship between plutonium contents in animals to that in the soil is not as sharply defined.

SAMPLING PROGRAM

The information provided by this monitoring program, particularly the established isopleths, was used to select 30 representative sampling locations for obtaining food chain information under southeastern U.S. environmental conditions. At each selected location, at least two types of samples for each sample grouping have been obtained. The material on the soil surface capable of resuspension and 10 soil cores, 30-cm deep, were taken 30-cm apart along a straight line to establish a baseline for the food chain mechanism. As representative vegetation samples, camphor weed and honeysuckle were selected. Honeysuckle was selected as one plant of importance because of its acknowledged dietary preference

† Work done by H. R. McLendon (SRP), O. M. Stewart (USFS), A. L. Boni and J. C. Corey (SRL), and K. W. McLeod and J. E. Pinder, III (SREL). Presented at the *Symposium on Transuranium Nuclides in the Environment*, San Francisco, California, November 17-21, 1975.

by deer during the summer months. Due to its abundance in the area, camphor weed was selected as the second type of vegetation. Cotton rats and grasshoppers are two abundant herbivores and were selected as representative of the expected concentration factors for the terrestrial environment. Therefore, deer, cotton rats, and grasshoppers were obtained for the animal and insect sampling.

CONCLUSIONS

The soil data for 23 of the selected locations are given in Table 1, and the selected locations are shown in Figure 2. Preliminary measurements of certain vegetation samples and small mammals are given in Tables 2 and 3.

Vegetation, grasshopper, and animal samples will be collected beginning July 1 to obtain sufficient vegetation and grasshopper samples in the immediate vicinity of the soil sampling locations. Following the collection of the cotton rats, the animals will be skinned, and the intestines removed to minimize external contamination possibilities in the analysis. The bone, liver, lung, and flesh of deer collected during supervised hunts will be analyzed separately to evaluate the importance of various organs as plutonium reservoirs.

REFERENCES

1. H. R. McLendon. "Soil Monitoring for Plutonium at the Savannah River Plant." *Health Phys. 28*, 4 (1975).

TABLE 1

Representative Soil Analyses for On-Site and Off-Site Locations (0-15 cm depth)

		Soil Cores (0-15 cm depth)		
Sample Location	*Distance from SRP Source, km*	*^{238}Pu, fCi/g dry wt.*	*^{239}Pu, fCi/g dry wt.*	*^{238}Pu,[c] α %*
Onplant[a]				
Inside 3 mCi/km^2 isopleth				
1	0.5	46.4 ±7.9	37.0 ± 6.8	56 ±12
2	0.5	7.2 ±5.0	163.8 ±21.8	4 ± 3
3	1.3	23.4 ±2.8	89.9 ± 5.8	21 ± 3
4	0.3	13.4 ±4.7	101.2 ±12.1	12 ± 4
5	1.0	2.9 ±1.9	33.6 ± 6.0	8 ± 5
Inside 2 mCi/km^2 isopleth				
6	3.8	4.0 ±1.8	6.9 ±2.3	37 ±19
7	8.4	0.8 ±0.8	9.5 ±1.8	8 ± 8
8	7.0	1.2 ±1.4	8.2 ±2.6	13 ±15
9	7.5	0.7 ±0.4	7.1 ±1.1	9 ± 5
10	4.0	0.5 ±0.4	5.8 ±1.1	8 ± 6
11	5.7	0.6 ±0.9	7.0 ±2.2	8 ±12
12	4.2	0.8 ±1.1	9.1 ±3.5	3 ±12
13	3.5	0.8 ±1.2	9.7 ±2.7	8 ±12
Offplant[b]				
At 40 km radius				
14	28	0.6 ±0.5	4.4 ±1.4	12 ±10
15	26	0.5 ±0.3	7.3 ±0.9	6 ± 4
16	38	0.2 ±0.2	1.3 ±0.4	14 ±11
17	38	0.8 ±0.8	7.1 ±1.7	10 ±10
18	45	0.4 ±0.2	6.2 ±0.8	6 ± 3
19	49	0.2 ±0.2	5.1 ±0.8	4 ± 4
20	41	0.4 ±0.4	5.5 ±1.0	7 ± 7
21	45	0.3 ±0.2	6.5 ±0.8	4 ± 3
22	40	0.5 ±0.4	8.6 ±1.2	6 ± 4
23	35	0.7 ±0.4	7.4 ±0.9	9 ± 5

a. Within the 3-mCi/km^2 isopleth (see Fig. 1).

b. 40-km radius from center of SRP (see Fig. 2).

c. $\alpha \% \; ^{238}Pu = \frac{\text{alpha disintegrations from } ^{238}Pu}{\text{alpha disintegrations from } ^{238,239,240}Pu} \times 100$

TABLE 2

Preliminary Data from Selected Vegetation Samples

Type[a]	$^{238,239,240}Pu$, *pCi/g Dry Weight*	^{238}Pu, α %
On-Site		
AB	2.112 ±0.011	62.7 ±0.5
AB	0.088 ±0.001	66.8 ±1.7
P	1.975 ±0.008	56.5 ±0.4
P	0.189 ±0.004	72.6 ±2.4
P	0.029 ±0.001	65.8 ±3.0
Off-Site		
P	0.002 ±0.001	18.0 ±3.0

a. AB, Annual-Biennial; P, Perennial.

TABLE 3

Preliminary Data from Selected Animal Samples

			Activity (Wet Weight)	
			$^{238,239,240}Pu$, *pCi/g*	^{238}Pu, α %
Bone	On-Site	Racoon	0.0071 ±0.0025	17.7 ±22.2
		Racoon	0.0407 ±0.0043	16.7 ± 5.0
		Fox	0.0073 ±0.0022	34.2 ±21.8
	Off-Site	Bobcat	0.0069 ±0.0018	26.1 ±18.7
		Racoon	0.0114 ±0.0030	7.9 ±13.3
Lung	On-Site	Racoon	0.0014 ±0.0006	35.7 ±32.4
		Racoon	0.0085 ±0.0034	91.8 ±52.6
		Fox	0.0014 ±0.0007	78.6 ±58.1
	Off-Site	Bobcat	0.0017 ±0.0003	29.4 ±12.9
		Racoon	0.0009 ±0.0003	33.3 ±24.8
Liver	On-Site	Racoon	0.0014 ±0.0001	71.4 ±64.5
		Fox	0.0009 ±0.0005	33.3 ±38.1
	Off-Site	Bobcat	0.0010 ±0.0001	30.0 ±10.4
		Racoon	0.0003 ±0.0001	33.3 ±35.1

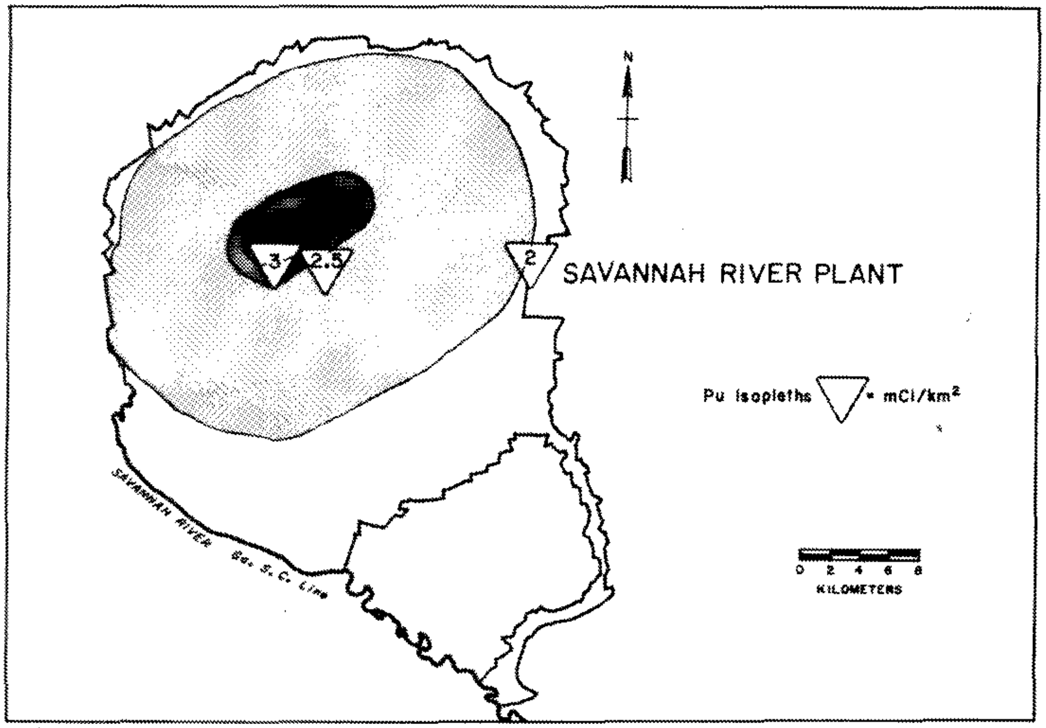

FIGURE 1. Plutonium Deposition on the Savannah River Plant

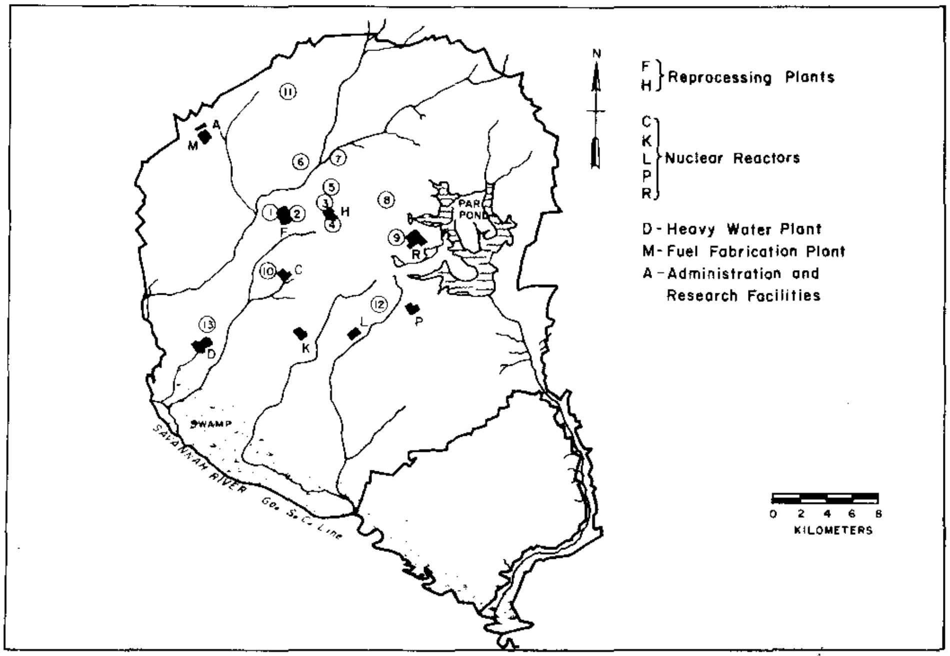

FIGURE 2a. Selected Soil Locations for Onplant

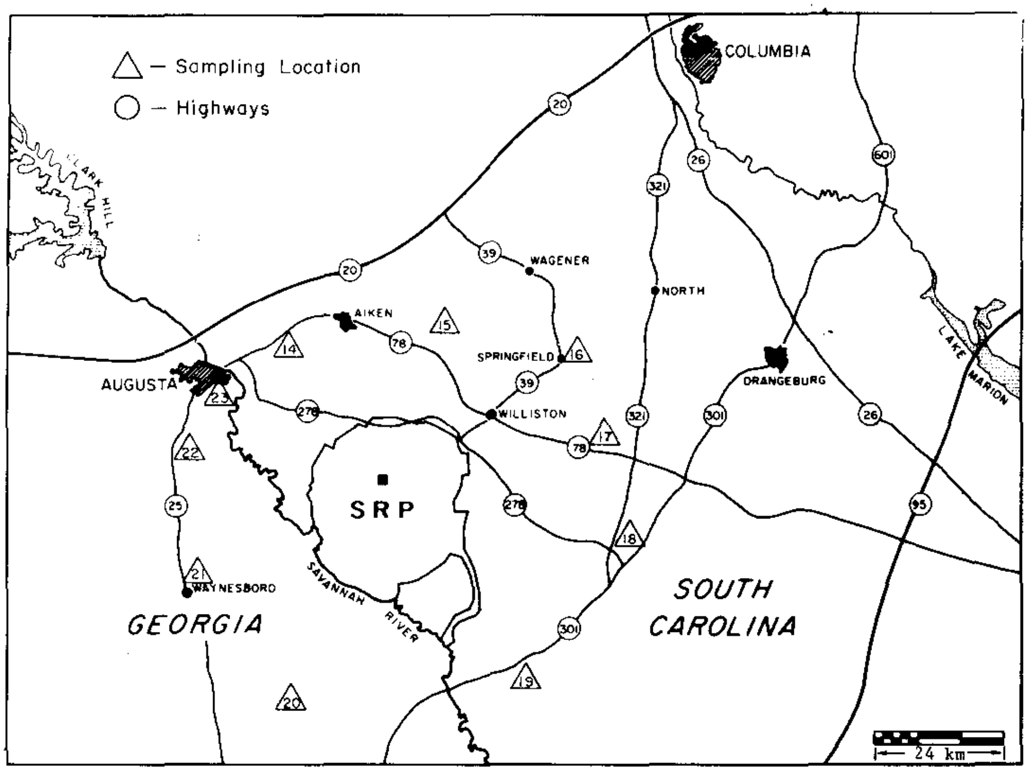

FIGURE 2b. Selected Soil Locations for Offplant

III. GEOLOGIC STUDIES

21. SUMMARY OF HYDRAULIC CONDUCTIVITY TESTS IN THE SRP SEPARATIONS AREAS†

INTRODUCTION

Hydraulic conductivity is of significance because, in conjunction with the hydraulic gradient and porosity, it determines the velocity with which water moves through the ground. In preparation for mathematically modeling the movement of water in the Separations Areas at the Savannah River Plant (SRP), hydraulic conductivities were calculated from existing data collected from laboratory tests of cores, pumping tests, water injection tests, injection-detection tracer tests, and point dilution tracer tests. The results of these calculations are reported below.

DISCUSSION

Five hydrologic units are of importance in the ground water model of SRP. From the surface downward, they are: (1) the Barnwell Formation, which commonly contains the water table and is made up of reddish-brown sands, clayey sands, and sandy clays; (2) the tan clay, which forms a leaky confining bed at the base of the Barnwell Formation; (3) the McBean Formation, which receives water by leakage through the tan clay and is made up of an upper yellow clayey sand and a lower calcareous clayey sand which has occasional cavities caused by the dissolution of disseminated calcareous material; (4) the Green Clay, which is a confining bed of very low permeability; and (5) the Congaree Formation which consists in its upper part of the fine sand layers interbedded with clay layers.

Hydraulic conductivity values for the Barnwell and McBean Formations are herein reported. If all of the hydraulic conductivity values were represented in series along the flow path, the low values would control the ground-water travel time, as most time would be spent traversing this type of material. However, if material of high and low hydraulic conductivity are in a parallel arrangement, the water will preferentially flow through the high conductivity material. Thus, the arrangement of high and low conductivity materials, which is not considered by laboratory

† Work done by I. W. Marine and R. W. Root, Jr.

determinations, is of such great importance that column tests for hydraulic conductivity are of little value unless the samples can be related to a known flow path of water.

As each geologic formation consists of lenses of clayey sand which are relatively permeable and lenses of sandy clay which are relatively impermeable, results of laboratory analyses for hydraulic conductivity, which are performed on a very small volume of sample, show a large range (Figure 1).

More reliable values of hydraulic conductivity can be determined in the field by methods that incorporate the effects of the arrangement of geologic materials. Pumping tests were made in the McBean Formation on two different pumping wells. One well was pumped at 38 m^3/day (7 gal/min) for 13 days, and the other well was pumped at 18 m^3/day (3.3 gal/min) for 36 days. Seven usable observation wells were available for the first test, and eight wells were available for the second test. It was apparent from the drawdown curves that vertical leakage of water was an important factor in supplying water to the drawdown cone, thus only methods of analysis that considered leakage were used.

Another hydraulic field test for conductivity consists of introducing a volume of water instantaneously into the well casing and measuring the return of the water level to its static position (known as a slug test). This type of test measures the hydraulic conductivity only in the immediate vicinity of the well.

Values for hydraulic conductivity can also be derived from the hydraulic gradient and the velocity, which were measured by means of tracer tests. At four locations in the Barnwell Formation, the natural ground-water velocity had been previously measured by injecting a tracer into one well or a closely spaced group of wells, and measuring the time of its arrival at one or more down-gradient wells.[1] These are shown by "I-D" (injection-detection) on Figure 1.

At these same wells and at many other locations, ground-water velocities were measured by the attenuation of the concentration of a tracer placed in a single well.[1] The results, converted to hydraulic conductivity by dividing by the applicable gradient and multiplying by the porosity, are plotted on Figure 1 as Point Dilution Tests A.

In an effort to determine the range of ground-water velocity in a small area, point dilution velocity tests were made on 53 wells drilled 22 feet apart in a crescent on the down-gradient side of the H Area tank farm. The hydraulic conductivities from these tests are shown on Figure 1 as Point Dilution Tests B.

RESULTS

The median of the values for hydraulic conductivity in the Barnwell Formation are nearly the same by all the methods used, i.e., about 0.5 m/day (1.8 ft/day). The median value for hydraulic conductivity in the McBean Formation determined by laboratory tests is about the same as those for the Barnwell Formation, but the analysis of pumping tests resulted in a median value of 0.18 m/day (0.6 ft/day) or about one-third lower than the laboratory tests.

PROGRAM

With the analysis of existing data as a base, additional values of hydraulic conductivity will be collected systematically from both formations over a wider geographic area for developing the computer model of ground-water movement beneath SRP.

REFERENCE

1. J. W. Fenimore. "Tracing Soil Moisture and Ground Water Flow at the Savannah River Plant." Presented at the *Conference on Hydrology in Water Resources Management* at Clemson University, Clemson, South Carolina, March 28-29, 1968. SRL Manuscript No. DP-MS-68-23.

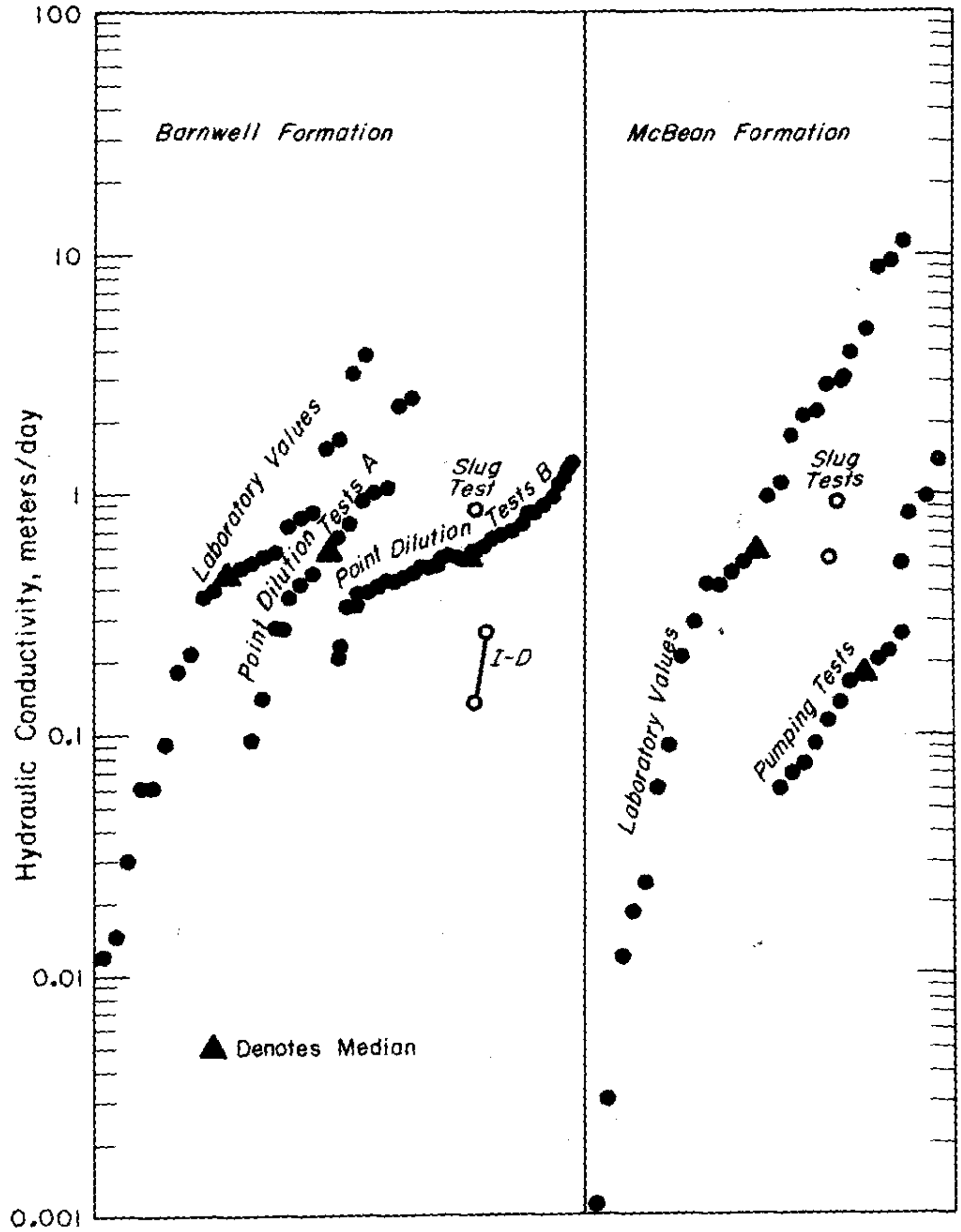

FIGURE 1. Horizontal Hydraulic Conductivities of the Barnwell and McBean Formations

22. SIMULATED SEEPAGE BASIN FLOW STUDIES WITH SOIL-FILLED COLUMNS†

INTRODUCTION

During 1974, the fluid level in H Area Seepage Basin Number 4 began to rise while inflow remained approximately constant indicating a decrease in seepage rate. To elucidate the causes and possible remedies for this undesirable situation, a series of soil column experiments were conducted using seepage basin soil and a variety of fluids.

DISCUSSION

Six soil columns were filled with soil from the H Area Seepage Basin Number 4 spoil pile. All columns were first conditioned by percolating calcium sulfate solution through them. The following solutions were then fed through the columns daily except on weekends and when manpower was unavailable.

Column No.	*Feed*	*pH*
1	Calcium Sulfate	6.3
2	Nitric Acid	2
3	Sodium Hydroxide	10.7
4	Sodium Hydroxide	10.7
5	H Area Seepage Basin Water	10.7
6	Calcium Hydroxide	10.8

Seepage rates were calculated as hydraulic conductivities, assuming the columns were constant head permeameters. No conclusions based on these experiments are drawn from the absolute hydraulic conductivity; all conclusions are relative and result from a comparison of one column with another or from the changes that took place in a column.

Figure 1 shows the change in hydraulic conductivity with the number of fluid additions in the various columns. All columns

† Work done by I. W. Marine and C. W. Krapp.

showed an initial decrease in hydraulic conductivity probably caused by settling and compaction of the soil in the column due to wetting. At the ninth fluid addition, the method of collecting the effluent was changed to be more representative of the actual effluent quantity that had passed through the columns during that individual run. This change in procedure resulted in an apparent increase in hydraulic conductivity, but is not indicative of an actual change.

By the 18th run, the columns with sodium ion and pH ∿10.7 (Columns 3, 4, and 5) had hydraulic conductivities 20 to 50 times lower than the calcium sulfate control column. The lowest hydraulic conductivity occurred in the basin water (Column 5). The hydraulic conductivities of the nitric acid and calcium hydroxide columns (Numbers 2 and 6) were only about two times less than that of the control column. All the columns that plugged had a pH of ∿10.7; but the calcium hydroxide column also had a pH of ∿10.7, thus pH alone was not a sufficient cause to bring about pluggage.

On Run 20, an attempt was made to repair the pluggage on the two sodium hydroxide (pH = 10.7) columns (Numbers 3 and 4) by feeding the two solutions that had not caused pluggage, i.e., nitric acid and calcium hydroxide. The calcium hydroxide solution (pH = 10.8) had no effect (Column 4). On the other hand, the addition of nitric acid, pH = 2 (Column 3) gradually increased the permeability, until by Run 60 it was as great as the column that had received a continuous feed of nitric acid, pH = 2 (Column 2). About 10 times more nitric acid solution (pH = 2) was required to repair the column than the volume of sodium hydroxide (pH = 10.7) which plugged the soil column.

An attempt was made to repair the seepage rate of Column 5, which had been plugged by basin water (pH = 10.7) by acidifying the basin water feed to a pH of 6. This addition started on Run 46 and by Run 139, there was no significant change in hydraulic conductivity.

Although a column plugged with sodium hydroxide solution (pH of 10.7) had been repaired by adding nitric acid, it was to be demonstrated that this could be done on a column plugged by basin water. On Run 66, feed for Column 2, which had been continually receiving nitric acid of pH = 2, was changed to basin water. This caused a 25-fold decrease in hydraulic conductivity in six runs. The decrease was less dramatic over the next eight runs; but by Run 80, the hydraulic conductivity was approximately that of the column that had received basin water continually (Column 5). The feed for Column 5 after Run 80 continued to be basin water, but was acidified to pH = 2. The hydraulic conductivity of this column increased, slowly at first, and by Run 139, it had recovered much of its original hydraulic conductivity.

CONCLUSIONS

The conclusions from the laboratory studies are: (1) for common solutions that may be going to the seepage basin, sodium ion is the most important contributor to pluggage; (2) sodium ion enhances pluggage when the pH is about 11; and (3) nitric acid or acidified basin water (both with a pH = 2) returns soil plugged with sodium ions to its unplugged rate, but return is much slower than initial plugging. Basin water of pH = 6 has no apparent effect on unplugging soil. Thus, the conclusion is reached that plugged seepage basins are repairable, but only by a massive acidification program.

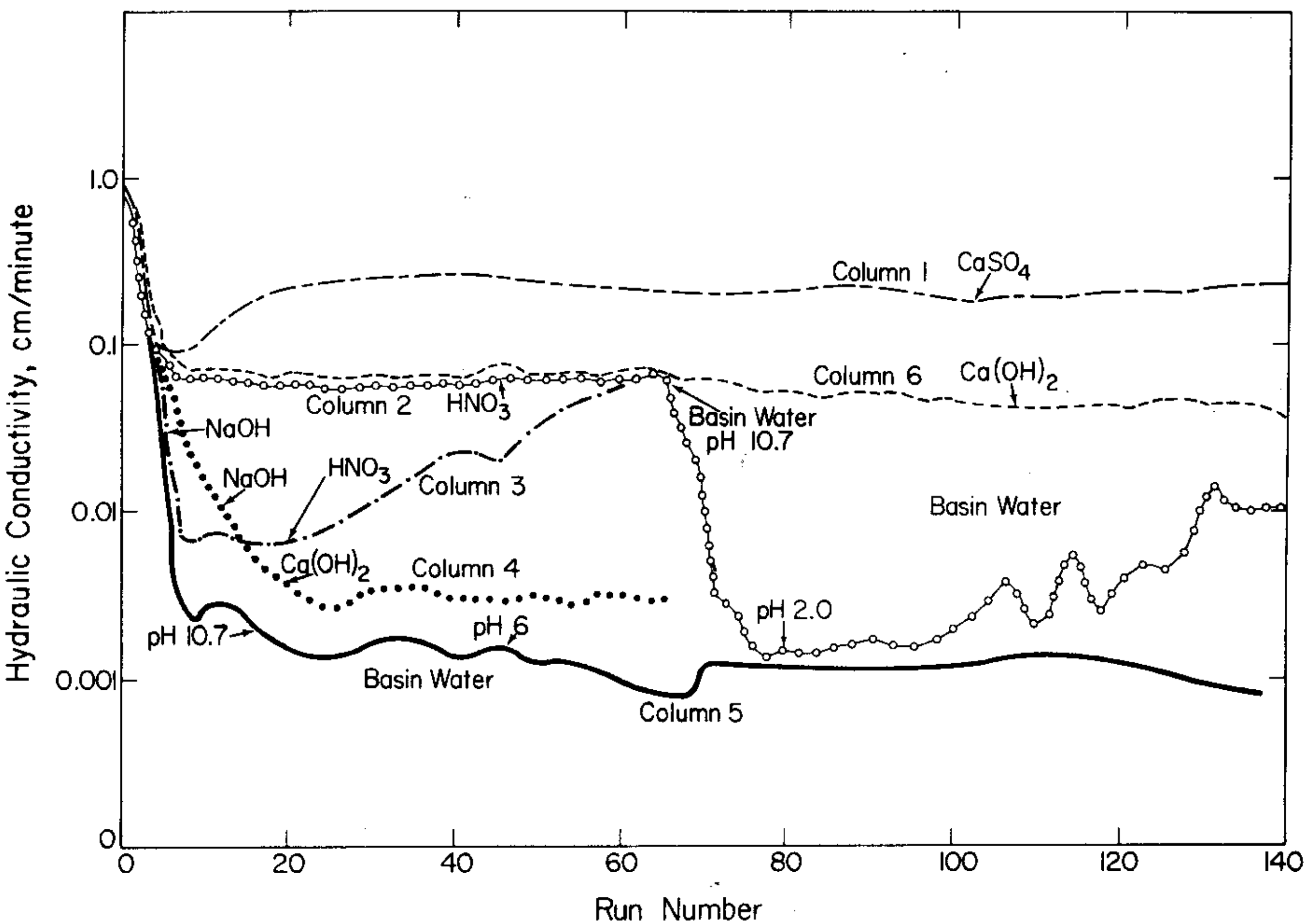

FIGURE 1. Hydraulic Conductivities of Treated SRP Soils as Measured in Experimental Soil Columns

IV. AQUATIC TRANSPORT STUDIES

23. COMPUTER MODELING OF STREAM AND RIVER SYSTEMS†

INTRODUCTION

Models describing pollutant transport in streams and rivers are being developed to predict the possible consequences of releases to the Savannah River and tributary streams on the Savannah River Plant (SRP). The models are employed to predict travel times, maximum concentrations, concentration distributions, and the duration of a concentration above a designated value. The models contain a parameter identification algorithm to estimate the transport coefficients based on stream-river studies using dye, tritium, sediment, and other tracers. The models handle both conservative (tritium, chloride, etc.) and nonconservative (cesium, iodide, acid, etc.) constituents. The conservative model employs bulk dispersion and dead-zone options. The non-conservative model employs sorption, ion exchange, and sediment deposition options.

RESULTS

The conservative model was applied to data collected using tracers in SRP streams. Dispersion coefficients and stream velocities estimated from the dye studies on all SRP streams ranged from 2.5 to 33.8 m^2/sec and 0.18 to 1.09 km/hr, respectively. The dispersion coefficients ranged from 3.5 to 33.8 m^2/sec over the length of one stream. The calculated stream parameters for each stream are stored and identified (as to stream location) on a permanent computer disk file for quick access in case of an accidental release. An example of a dye study is shown on Figure 1. The transport coefficients were calculated using the dye concentration curves and the parametric identification algorithm. The predicted curves were calculated using the predictive mode of the model with the calculated transport coefficients.

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† Work done by D. W. Hayes, M. R. Buckner, D. L. Kiser, and and J. R. Watts.

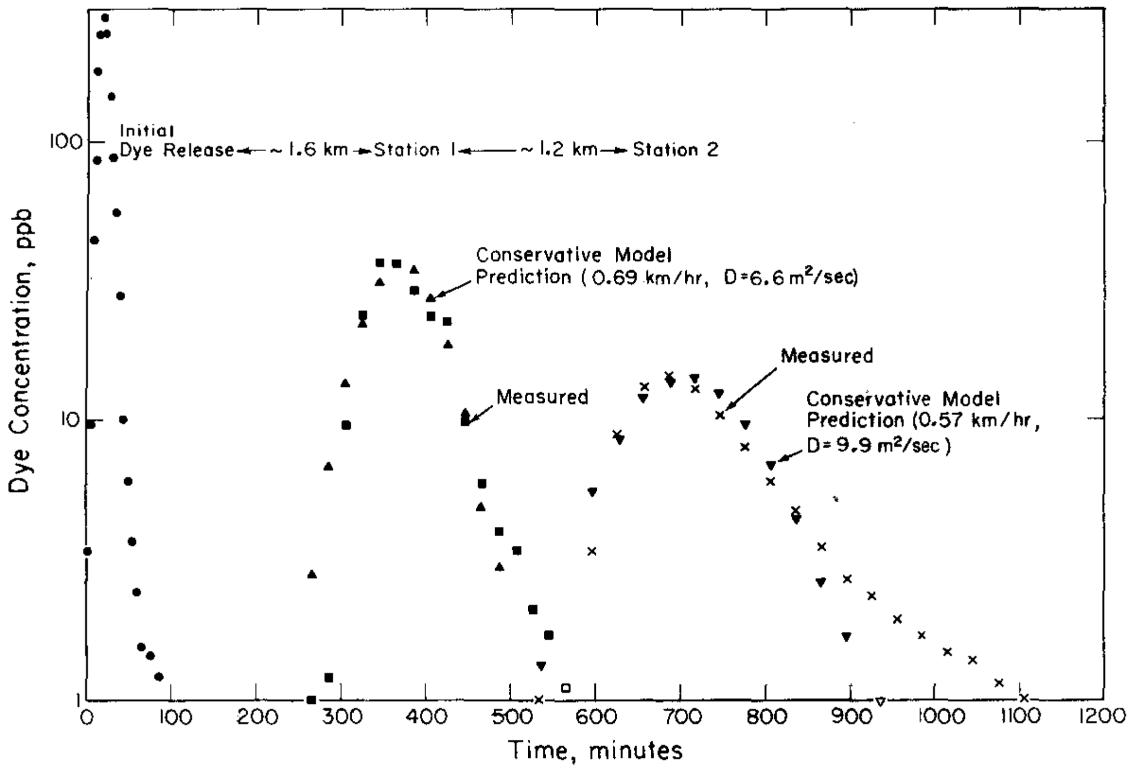

FIGURE 1. Comparison of Measured to Predicted Dye Concentration Curves

24. A WATER SAMPLER POWERED BY TIDAL FLOW †

INTRODUCTION AND SUMMARY

Water samplers that collect a composite sample are needed for coastal studies programs. The water samplers should operate in adverse environmental conditions, be independent of man-made power supplies, and require infrequent servicing. Currently available water samplers normally require either compressed gas or electrical power for operation and were considered marginal for this application. A simple water sampler was developed that did not require any source of power other than the energy available in the tides and could be constructed inexpensively from plastic parts. The sampler collects water on every flood tide and deposits it in a collection bottle on every ebb tide.

SAMPLER OPERATION

The sampler is placed in operation by lowering the suction, booster, and delivery tubes (Figure 1) into the water, assuring that the lengths of the booster and suction tubes are greater than the range of water level oscillation to assure proper operation. Optimum efficiency is obtained if the suction tube is completely submerged at high tide. The water sample is pumped into the collection bottle by the push-pull action of the suction and booster tubes. Starting at high tide, as the water recedes (water level falls), the pressure in the collection bottle is decreased by drop in water level in the suction tube. Pressure in the booster tube then forces water up the delivery tube and into the collection bottle. The pumping action is completed when the tide has ebbed; at this time both check valves are closed. As the tide comes in (water rises), the sample check valve opens, admitting water to the delivery tube and repressurizing the booster tube, and the check valve on the collection bottle opens, exhausting air.

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† Work done by D. W. Hayes.

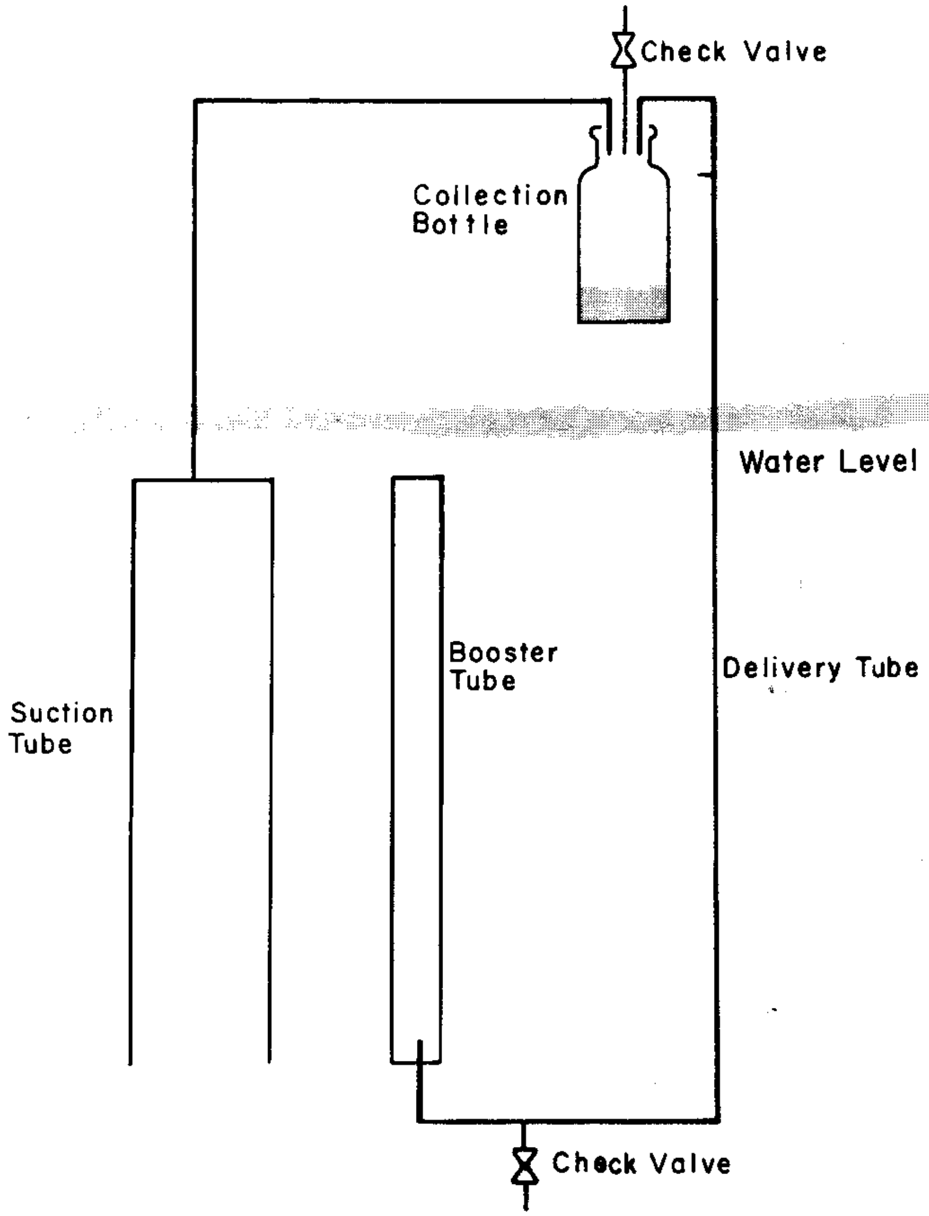

FIGURE 1. Tidal Sampler

25. PLUTONIUM IN ATLANTIC COASTAL ESTUARIES IN THE SOUTHEASTERN UNITED STATES†

INTRODUCTION

A number of power reactors and fuel reprocessing plants may be situated in the southeastern United States. Estuaries are a major geographic feature of this area and are important sinks of sediment containing associated radionuclides and trace elements. The distribution of plutonium is being measured in southeastern U.S. estuaries to establish the distribution and transport properties of this transuranic element. Of particular interest are the differences between the Savannah River estuary and other estuarine systems. The Savannah River estuary has received effluent for 20 years from the integrated nuclear production complex at the Savannah River Plant (SRP) of the U.S. Energy Research and Development Administration (ERDA), and from global fallout.

STUDY AREAS AND SOURCES

Sediment, marsh grass, and suspended particulate matter samples have been collected from the Savannah River estuary (Figure 1) and suspended particulate matter from the Neuse and Newport River estuaries (Figure 2). The Neuse and Savannah Rivers arise in the Piedmont region of the southeastern United States and have fairly large watersheds (14500 and 27000 km^2 respectively); whereas the Newport River is a small Coastal Plain river with a watershed of $\sim$350 km^2.

The Savannah River, in addition to fallout (55 Ci on its watershed), has received a small amount of additional plutonium from the estimated 0.3 Ci of plutonium released to SRP surface streams. Ratios of $^{238}Pu/^{238,239,240}Pu$ in the Savannah River ranged from 0.12 above the plant to 0.12 to 0.30 below SRP indicating the influence of SRP releases and the time-varying composition of the river. The concentration of plutonium in sediments and biota from the Savannah River is similar to values reported for other estuarine systems that receive only fallout.

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† Work done by D. W. Hayes, J. H. LeRoy, and F. A. Cross (National Marine Fisheries Service, NOAA). Presented at the *Symposium on Transuranium Nuclides in the Environment*, San Francisco, California, November 17-21, 1975.

EXPERIMENTAL RESULTS

Plutonium contents in surface marsh sediment from the Savannah River estuary (Table 1) are lower than those found in nearby bay sediments and similar to terrestrial values (see Article 19 of this report). In fact, total plutonium concentrations in sediments showed increases from the upper to lower portions of the estuary; however, higher ratios of $^{238}Pu/^{238,239,240}Pu$ in the upper portions indicate that releases from the Savannah River Plant do contribute plutonium to the Savannah River estuary. Estuarine sediment plutonium concentrations were roughly 1/3 the concentrations found in surrounding bay sediments. Plutonium concentrations in *Spartina* marsh grass were less than 10 fCi/g dry weight but are higher than plutonium contents of terrestrial plants (<1 fCi/g) from the same latitude. The higher plutonium concentration is attributed to surface sorption or attachment of suspended sediments rather than to root uptake, because no direct correlation was evident after comparing the contribution of ^{238}Pu to the total plutonium activities in the sediment and the *Spartina*.

The plutonium content of particulate matter from measured volumes of water was determined, but not the plutonium content of water itself. If plutonium is primarily associated with particulate matter, then the plutonium concentrations in the water of the estuaries are in the same concentration range as observed for other surface waters (Table 2). Plutonium concentrations were higher in the smaller size fraction (1 μm to 5 μm versus greater than 5 μm). Plutonium concentrations were about three times greater in the Newport River estuary than in the Neuse or Savannah Rivers. The Newport River estuary might be expected to have higher plutonium concentrations, since the particulate level is roughly twice that of the other two estuaries.

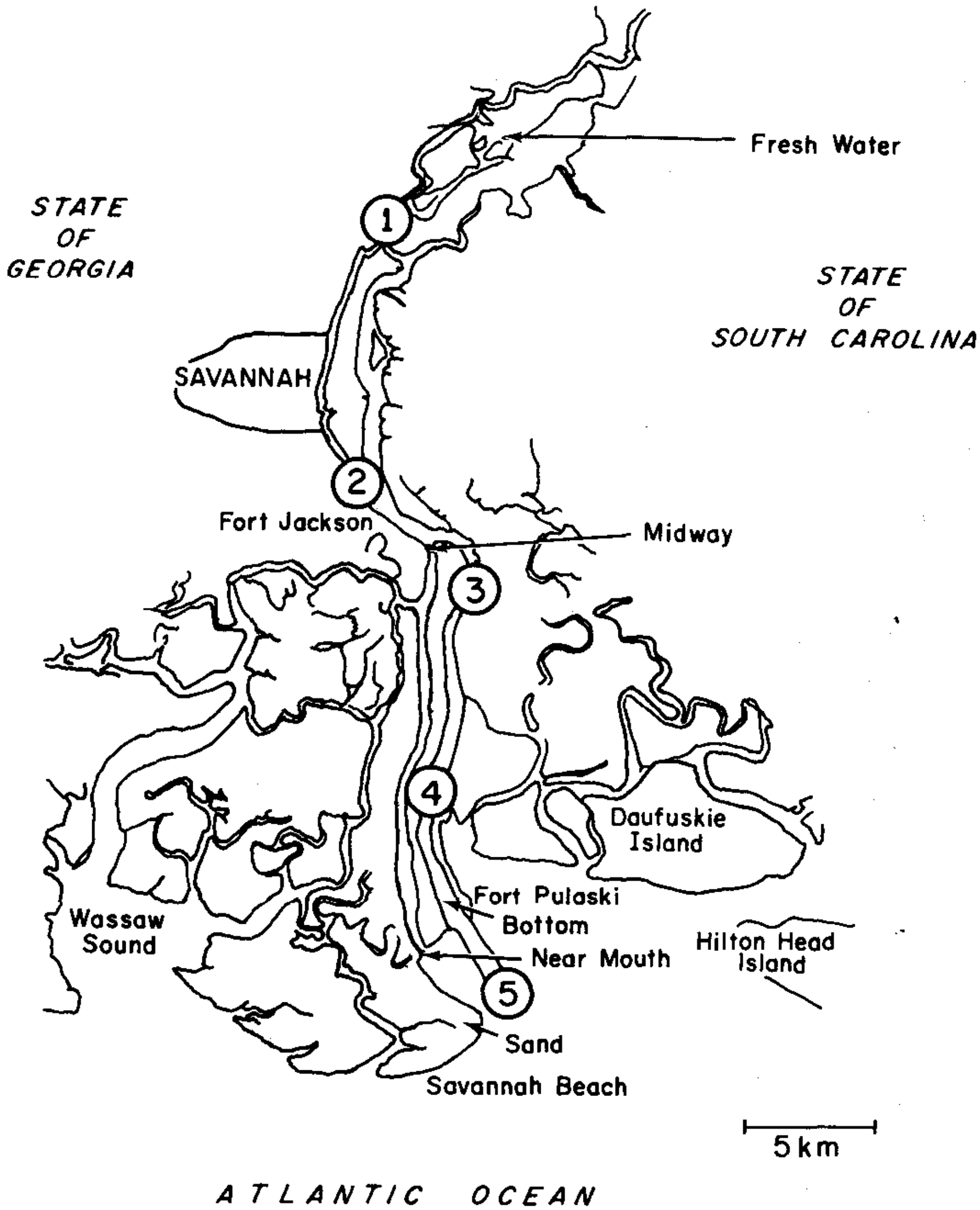

FIGURE 1. Sampling Locations in the Savannah River Estuary

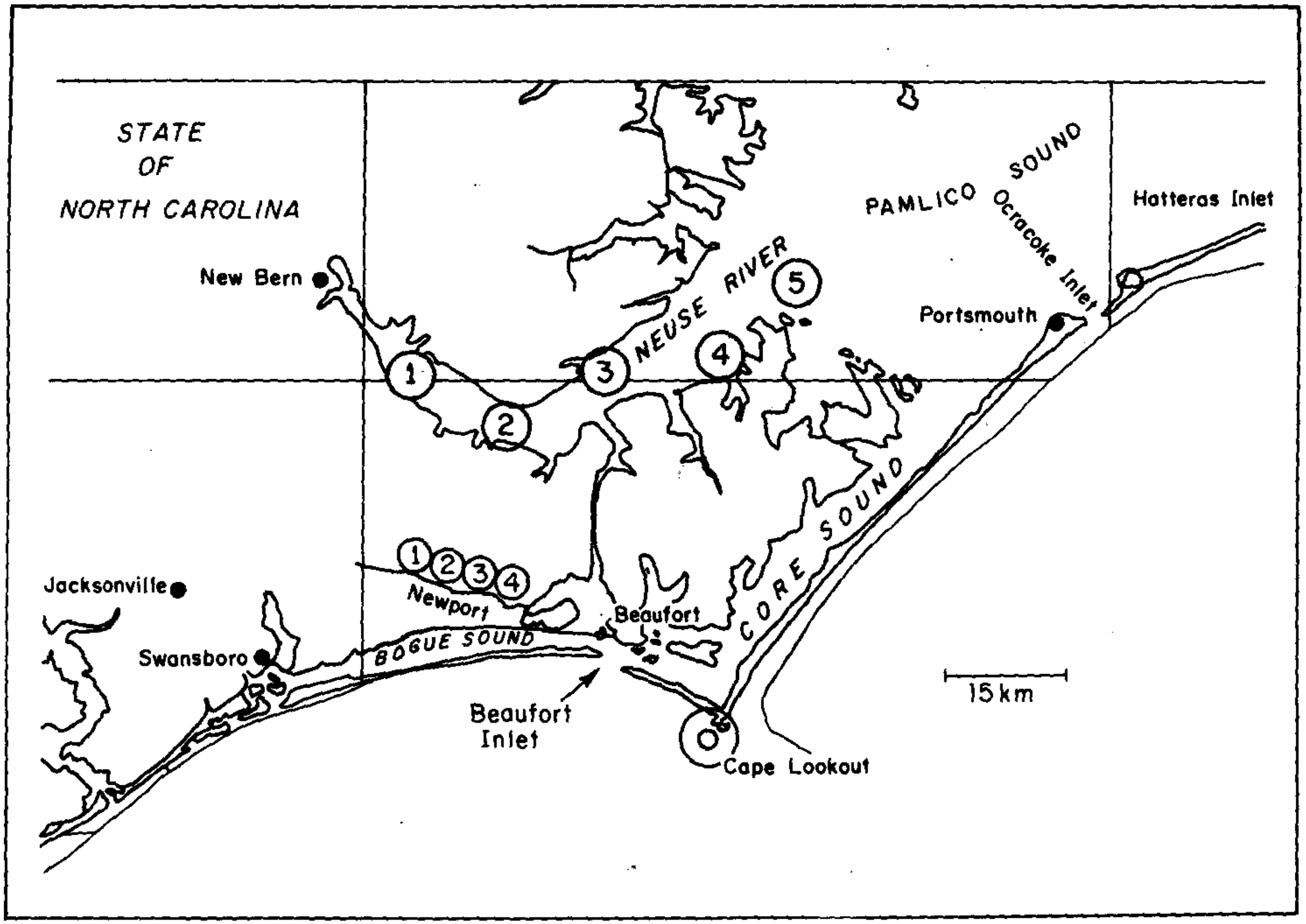

FIGURE 2. Sampling Locations in the Neuse and Newport River Estuaries

TABLE 1. PLUTONIUM CONCENTRATIONS IN SEDIMENT AND BIOTA IN SAVANNAH RIVER ESTUARY

		Sediment		*Live Spartina*		*Dead Spartina*	
Sampling Location	*Depth, cm*	*Total Pu, fCi/g of dry weight*	*^{238}Pu, alpha[a] %*	*Total Pu, fCi/g of dry weight*	*^{238}Pu, alpha[a] %*	*Total Pu, fCi/g of dry weight*	*^{238}Pu, alpha[a] %*
Fresh Water	0-2.5	4.6 ±0.4	43 ±7	1.7 ±0.1	30 ±4		
	2.5-5	3.3 ±1.1	56 ±31				
	28-30	0.4 ±0.2	-				
Midway	0-2.5	5.0 ±0.8	12 ±6	0.7 ±0.1	15 ±3	4.4 ±0.8	31 ±12
	28-30	1.5 ±0.3	62 ±20				
Near Mouth	0-2.5	11.1 ±1	11 ±2	9.3 ±0.4	50 ±3	6.2 ±0.9	11 ± 5
	0-2.5	9.6 ±1	13 ±3				
	28-30	0.1 ±0.1					
Recently Deposited (within 100 ft of near-mouth samples)	0-2.5	13.1 ±1	60 ±6				
Bay Sediments (within 10 miles of Savannah River estuary)[b]	grab	34	9				
		45	6				

a. $\frac{^{238}\text{Pu alpha activity}}{^{238,239,240}\text{Pu alpha activity}} \times 100$

b. See Figure 1.

TABLE 2. MEASUREMENTS OF $^{239,240}Pu$ IN ESTUARINE PARTICULATE MATTER

Sample Location (See Figs. 1 & 2)	*Salinity, Parts per Thousand*	*Activity in Particulates (>5-μm + >1-μm) fCi/l water[a]*	*Concentration of >5-μm Particulate Matter, mg/l water*	*Portion of Total Particulate Activity in 5-μm Fraction, %*	*>5-μm Particulate Activity, fCi/g ash*
Neuse River Estuary[b]					
Station 1	<0.1	0.42 ±0.08	2.5	30	
2	2.8	0.28 ±0.11	1.3	23	49
3	5.4	0.52 ±0.20	1.9	22	60
4	8.3	0.45 ±0.06	2.7	53	89
5	9.8	0.60 ±0.06	2.9	47	97
Beaufort Inlet	34.1	1.20 ±0.12	12.7	62	59
Newport River Estuary[c]					
Station 1	<0.1	0.24 ±0.08	0.8	22	66
2	1.4	1.83 ±0.24	8.1	29	66
3	4.8	2.13 ±0.31	9.5	35	79
4	9.8	1.56 ±0.21	3.9	23	92
5	13.1	2.53 ±0.40	9.5	18	48
		1.23 ±0.25	5.6	24	52
Savannah River Estuary[d]					
Station 1	<0.1	0.25 ±0.07	3.0	17	14
2	1.6	0.47 ±0.10	3.6	31	40
3	3.1	0.57 ±0.10	3.4	24	40
4	6.8	0.35 ±0.10	3.5	45	45
5	14.4	0.64 ±0.13	6.7	30	28
6	27.4	0.17 ±0.03	7.4	87	20

a. The drinking water standard for plutonium is 5×10^6 fCi/l [15].

b. $\frac{^{239,240}\text{Pu in the 5-μm particulates}}{^{239,240}\text{Pu in the (1-μm + 5-μm) particulates}} \times 100$

c. See Figure 1.

d. See Figure 2.

26. REMOVAL OF PLUTONIUM FROM DRINKING WATER BY COMMUNITY WATER TREATMENT FACILITIES †

ABSTRACT

Plutonium removal factors (RF) averaged 14 ±10 during a study of the effectiveness of three drinking-water treatment plants for removing plutonium from Savannah River water. Plutonium concentrations between 0.1 and 3.5 fCi/l were measured in raw and finished water samples. Volumes of water from 50 to 10000 liters were concentrated by ion exchange techniques and processed to determine the concentrations of plutonium-239,-240 and to derive plutonium RF's. The similarity between RF's observed for both plutonium and suspended solids suggests a colloidal behavior for plutonium. Plutonium RF's may be limited by low-level buildup on the treatment facility filters and subsequent bleeding into finished water, and thus may be higher during abnormal plutonium releases to the environment. Flocculation and filtration appear to be the primary factors in the water treatment process contributing to plutonium removal. The similarity between the plutonium contents of finished water from treatment facilities upstream and downstream of the Savannah River Plant (SRP) indicates that there is no measurable dose-to-man from SRP plutonium releases in the water. The 70-year bone dose commitment to an individual from consumption for one year of 1.65 liters per day of treated Savannah River water, based on the plutonium concentrations of finished waters from the three treatment facilities is 5×10^{-5} mrem.

† Work done by J. C. Corey and A. L. Boni. Presented at the *Symposium on Transuranium Nuclides in the Environment,* San Francisco, California, November 17-21, 1975.

V. AQUATIC BIOLOGY STUDIES

27. PRIMARY PRODUCTIVITY OF PERIPHYTON IN A REACTOR THERMAL EFFLUENT †

INTRODUCTION

Even casual visual comparisons of warm and cool stations in the reactor cooling impoundment, Par Pond, suggest that standing crops of periphyton are usually greater at the warmer stations. Hickman[1] made similar observations for a thermal effluent in Alberta, Canada. The greater standing crops associated with thermal inputs may be the result of increased primary productivity, decreased grazing, or both. Measurements of periphyton primary productivity were undertaken to help differentiate among these alternative responses.

Productivity, like biomass, directly followed temperature; but, whereas response per unit weight showed a similar trend, productivity per unit chlorophyll remained independent of temperature.

METHODS

Glass slides were exposed for two weeks of periphyton colonization using Catherwood diatometers[2] in surface waters along the thermal gradient. Colonized slides, in addition to being used for estimating the standing crop of periphyton, were incubated *in situ* in wide-mouthed, 130-ml reagent bottles for three-hour ^{14}C uptake determinations. The combination of measurements allowed comparisons of productivity per unit area and per unit biomass.

RESULTS AND DISCUSSION

Differences in standing crops accumulated at the different stations were obvious. The impression that biomass follows temperature was verified by the annual means summarized in Table 1. Dry weights (mg/m^2) differed more than fivefold for

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† Work done by L. J. Tilly. Presented at the *Annual Meeting of the American Society of Limnology and Oceanography*, Halifax, Nova Scotia, June 23-26, 1975.

samples from stations 5.5°C apart. Differences in chlorophyll (mg/m^2) were even greater (by a factor of 28) for the same stations because chlorophyll per unit weight of periphyton was 8 times higher at the warmest station (Station 2) compared with that at the ambient temperature station (Station 6).

Figure 1 shows the carbon uptake per unit area for the warmest and coolest stations for experiments during 1973-1974. In general, productivity was higher at warmer stations than at cold stations, and higher in warmer months than in cooler ones. Productivity per unit weight was higher at warm stations also, but productivity per unit chlorophyll did not differ significantly among stations. The productivity (P) per unit area and per unit dry weight both showed significant (<0.05) regressions on the average growing temperature (T_G), whereas productivity per unit chlorophyll did not. This suggests that the observed temperature enhancement involves the production of more photosynthetic material rather than a more-efficient utilization of existing pigments.

Productivity (mg/m^2) correlates less well with temperature than does biomass (measured as dry weight or chlorophyll); partially because the dates on which ^{14}C uptake experiments were performed were determined not by representativeness of ecological conditions, but by the number of days of prior exposure. Sunlight and temperature during the ^{14}C incubations could vary markedly from the mean conditions during the preceding exposure period. Nevertheless, ^{14}C uptake does provide a relative measure of the response of periphyton to conditions of growth.

^{14}C uptake was used in experiments (Article 28 of this report) to test the hypothesis that the observed differences in slopes of regression of biomass with temperature might in part be accounted for by water quality (especially nutrients) characteristics. Tilly[3] noted that Savannah River water additions as makeup water importantly influenced the productivity of Par Pond phytoplankton. It is likely that organisms living nearer the point of entry of the thermal effluent receive more nutrients than organisms more distant; however, differences in nutrient standing crop are difficult or impossible to measure.

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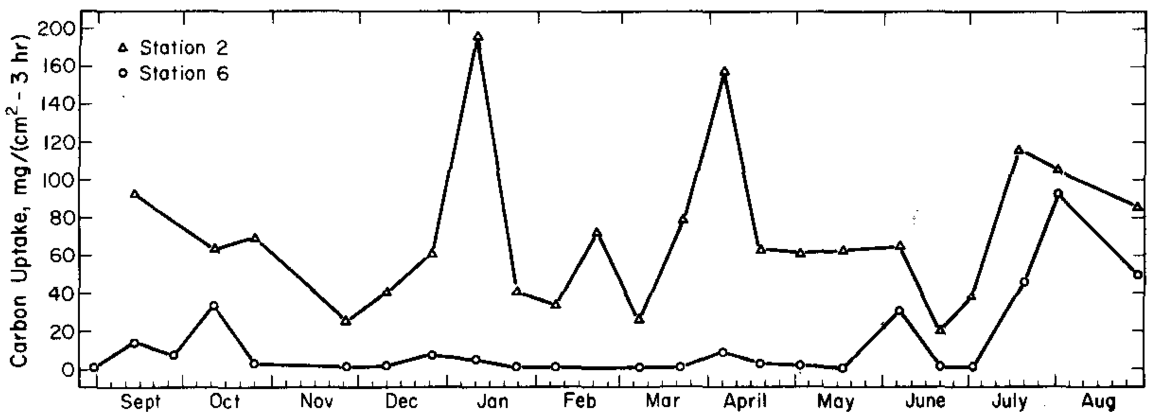

FIGURE 1. Carbon Uptake per Unit Area for 1973-1974

TABLE 1

Annual Periphyton Means, 1973-1974

Station	*Productivity, mg C/g/3 hr*	*Productivity, mg C/m²/3 hr*	*Productivity, mg C/mg chlorophyll/3 hr*	*Biomass, g dry wt/m²*	*Mean Growing Temperature, °C*
1	8.8 ±3.0	12.06 ±2.88	5.4 ±0.7	1.59 ±0.21	26.37 ±1.06
2	9.7 ±1.2	30.0 ±3.53	3.5 ±0.6	4.09 ±0.59	28.21 ±1.02
3	12.9 ±2.9	20.71 ±3.47	4.9 ±1.2	2.69 ±0.34	27.07 ±1.04
4	9.8 ±1.6	11.79 ±2.87	4.4 ±0.6	1.72 ±0.22	25.96 ±1.07
5	5.3 ±1.5	4.85 ±1.57	12.8 ±7.8	0.93 ±0.23	23.20 ±1.12
6	1.7 ±0.7	2.72 ±1.13	6.6 ±3.7	0.74 ±0.18	22.91 ±1.12
7	4.1 ±1.6	4.61 ±1.68	3.7 ±1.1	0.97 ±0.26	22.83 ±1.18

28. FACTORS OTHER THAN TEMPERATURE THAT STIMULATE PRIMARY PRODUCTIVITY IN A REACTOR EFFLUENT †

INTRODUCTION

Thermal effluents involve more than temperature elevation. Reactor effluent introduced into a reservoir may be expected to influence organisms by changing the regimes of flow and nutrients as well as temperatures to which they are exposed. After observing that consistent differences in periphyton standing crop and primary productivity were associated with sampling locations (stations) in the Par Pond thermal effluent, experiments were designed to separate a factor describable as "water quality" from temperature and other station effects. Results indicate that effluent water stimulates productivity independently of temperature.

METHODS

In this procedure, diatometer-grown periphyton from both a thermally hot or cool station was exposed to plankton-free water from the original station or the alternate station for 24 hours, and then incubated at the original or the alternate station for a three-hour ^{14}C productivity bioassay. The results from quadruplicate samples were tested for the effects of periphyton origin, water source, and incubation temperature.

RESULTS

Table 1 shows the results of a typical experiment. Analysis of variance shows significant effects of periphyton origin, water source, temperature elevation, and temperature decline upon weight-specific productivity. No effect of water source could be determined, however, for periphyton lowered in temperature or for periphyton grown near the effluent return point (hot station) but incubated in cool station water at the warm station. These results suggest that, independent of temperature, water quality near the effluent is better for periphyton productivity.

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† Work done by L. J. Tilly.

TABLE 1

Typical Translocation Results (1-9-75)

A. Hot Water Periphyton

Treatment	*Productivity, % control*	ΔT	*Nutrient Level*[b]	ΔP, %
HxHxH[a]	100	-		-
HxHxW	79.2	4.2		-20.8
HxHxC	60.8	-4.8	--	-39.2
HxWxH	98.4	0.0	-	- 1.6
HxWxW	70.4	-4.2	-	-29.6
HxWxC	65.9	-4.8	-	-34.1
HxCxH	100	0.0	--	0.0
HxCxW	74.3	-4.2	-	-25.7
HxCxC	66.7	-4.8	--	-33.3

B. Cold Water Periphyton

CxCxC	100	-		-
CxCxH	168.0	+4.8		+68
CxCxW	127.2	+0.6	+	+27.2
CxHxH	169.1	+4.8	++	+69.1
CxHxW	127.2	+0.6	++	+27.2
CxHxC	105.4	0.0	++	+ 5.4
CxHxC	192.3	+4.8	++	+12.3
CxWxC	125.3	0.0		+25.3
CxWxW	138.2	+0.6	+	+38.2

C. Warm Water Periphyton

WxWxW	100	-		-
WxWxH	156	+4.2		+56
WxWxC	89.9	-0.6		-10.1
WxCxH	98.1	+4.2	-N	- 1.9
WxCxW	77.6	0.0	-N	-22.4
WxHxW	115.6	0.0	+N	+15.6
WxHxC	105.0	-0.6	+N	+ 5.0
WxHxH	164.8	+4.2	+N	+64.8
WxCxC	84.2	-0.6	-N	-15.8

a. Position of capital letters denote: 1) source of periphyton, 2) source of water (from pond stations) in which periphyton was grown, and 3) station of incubation. H, hot; W, warm; C, cold (e.g., HxHxH = hot station periphyton, hot station water, and hot water incubation).

b. +, slight increase in nutrient level; ++, large increase in nutrient level; -, slight decrease in nutrient level; and --, large decrease in nutrient level

29. DISTRIBUTION AND ABUNDANCE OF SUBMERGED MACROPHYTES IN A REACTOR COOLING RESERVOIR†

INTRODUCTION

Submerged macrophytes play an important role in littoral zone dynamics by providing food, cover, and attachment for other organisms and by physically and chemically altering the aquatic habitat. This study is a preliminary attempt to examine the relationship between macrophyte distribution and conditions in a thermal gradient within the reactor effluent in Par Pond.

METHODS

Samples were removed for quantitative estimation of biomass by species from three stations (hot, warm, and cool) along the thermal gradient within the effluent return arm of Par Pond. Samples were taken randomly within each of four depth classes and within regions selected for equivalent orientation of shores. Samples were processed for fresh weight, dry weight, and percent ash as described by Westlake.[1]

RESULTS

The most conspicuous difference among the submerged plant communities was the biomass of the standing crops observed at the cold and warm stations (Table 1). As expressed by average biomass m^{-2}, *M. spicatum* was more than three times as abundant at the warm station than at the cold station and extended more abundantly into shallower depths. At the hot station, *M. spicatum* was greatly reduced at all rooting depths and maintained only moderate biomass at rooting depths of 2 to 3 m. Figure 1 shows a definite restriction of the maximum rooting depth at the hot as compared to the cooler stations. Although regular sampling extended no deeper than 4 m, field observations confirmed that the maximum rooting depth of *M. spicatum* was at least 1 m deeper at the cold than at the warm station. Standing crop was doubled at the warm

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† Work done by J. B. Grace (Laboratory Graduate Research Participant from Clemson University, Clemson, South Carolina) and L. J. Tilly.

station as compared to the cold station due to the enhancement of *Myriophyllum spicatum L.* However *M. spicatum* was least abundant at the hot station where *Najas guadalupensis (Spreng.) Morong.* predominated. Combining all species (Figure 1), standing crops of submerged macrophytes were highest at the warm station, lowest at the cold station, and intermediate at the hot station. Significant differences ($p < 0.01$) could be demonstrated between all stations. The relative proportion of biomass contributed by each species at each station is shown in Figure 1. *N. guadalupensis* trades position in biomass rank with *M. spicatum* when the hot station is compared with either the cold or the warm stations. Also, the warm station is overwhelmingly dominated by *M. spicatum.* The other stations show a more equitable distribution of biomass among species.

CONCLUSIONS

The data suggest that conditions for *M. spicatum* are most nearly optimal at the warm station, where at all depths but the shallowest it is the dominant biomass component. Temperature may be the most important single factor involved, but factors such as light, turbulence, nutrients, substrate, competition, and sociological features must be considered in explaining the condition of the submerged macrophyte community. All of the above factors may change in gradient fashion with distance from the "boil" in Par Pond. Although pH has been shown to be of importance in affecting distribution and abundance of *M. spicatum*,[2,3] it is not considered a variable in this study because the pH is near optimal for *M. spicatum* growth,[2] and because there are no significant pH differences between stations in Par Pond.

On the basis of the data, it appears that temperature plays an important role in regulating the aquatic macrophyte community in Par Pond. *Myriophyllum* achieves its maximum depth penetration at the cold station with restriction of growth at all depths occurring at the hot station. The growth of *Najas* is greatest at the hot station and probably also contributes to the restriction of *M. spicatum.*

The practical implications of this study lie in the fact that *Myriophyllum spicatum* has recently become a problem in the Southeastern United States due to its detrimental effects on reservoir usage.[4] In Par Pond, free-floating mats of *M. spicatum* have been observed to inhibit the withdrawal of reactor cooling water at the pump station. However, present levels of *M. spicatum* in Par Pond have only resulted in minor problems with respect to reservoir usage.

Further studies of *M. spicatum* in Par Pond are planned and should allow for a more complete consideration of its effects on reservoir usage.

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TABLE 1

Depth Distribution of Biomass in Relation to Station Temperature

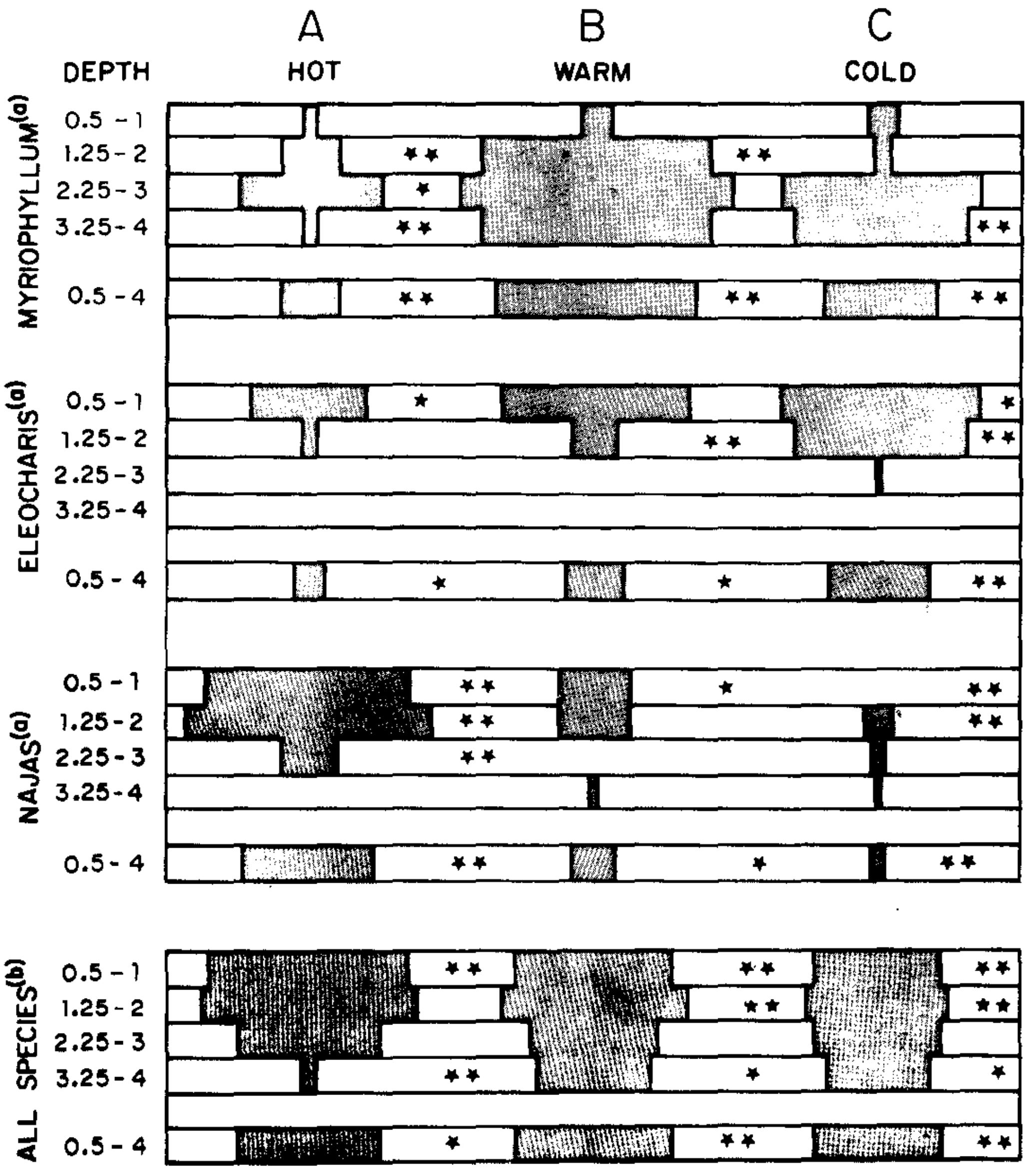
	Biomass of Species (Ash-Free Dry Weight), g/m²											
	Hot Station				*Warm Station*				*Cold Station*			
Depth stratum, m →	*0-1*	*1-2*	*2-3*	*3-4*	*0-1*	*1-2*	*2-3*	*3-4*	*0-1*	*1-2*	*2-3*	*3-4*
Myriophyllum spicatum	0.525	4.630	46.605	1.080	2.809	116.821	139.414	91.759	3.889	1.975	64.568	30.444
Eleocharis acicularis	20.370	4.815	0.000	0.000	29.506	10.123	0.000	0.000	49.630	24.074	0.123	0.000
Najas guadalupensis	47.840	85.710	4.383	0.000	7.130	15.247	0.000	0.154	0.000	1.543	0.556	0.093
TOTALS[a]	77.315	114.722	66.111	1.111	39.969	144.784	139.414	91.914	61.296	31.173	66.883	39.537

Temperature[b]	*Hot*	*Warm*	*Cold*
Avg. maximum, °C	33.4 ±0.9[c]	30.5 ±0.9	30.5 ±0.9
Avg. minimum, °C	26.3 ±1.1	23.8 ±1.0	21.1 ±1.7
Avg. difference, °C	7.1 ±0.4	6.7 ±0.3	8.4 ±0.5

a. *Myriophyllum spicatum* is important fraction of total in 0-2 meter depths at warm stations only. *Myriophyllum spicatum* is dominant fraction of total in 2-4 meter depths at all stations. *Other* species have important fraction of total only in shallows at cold and hot stations.

b. Previously unpublished data of J. W. Gibbons and R. R. Sharitz, Savannah River Ecology Laboratory, Aiken, South Carolina.

c. Average value ± one standard error; based on 25 replications.

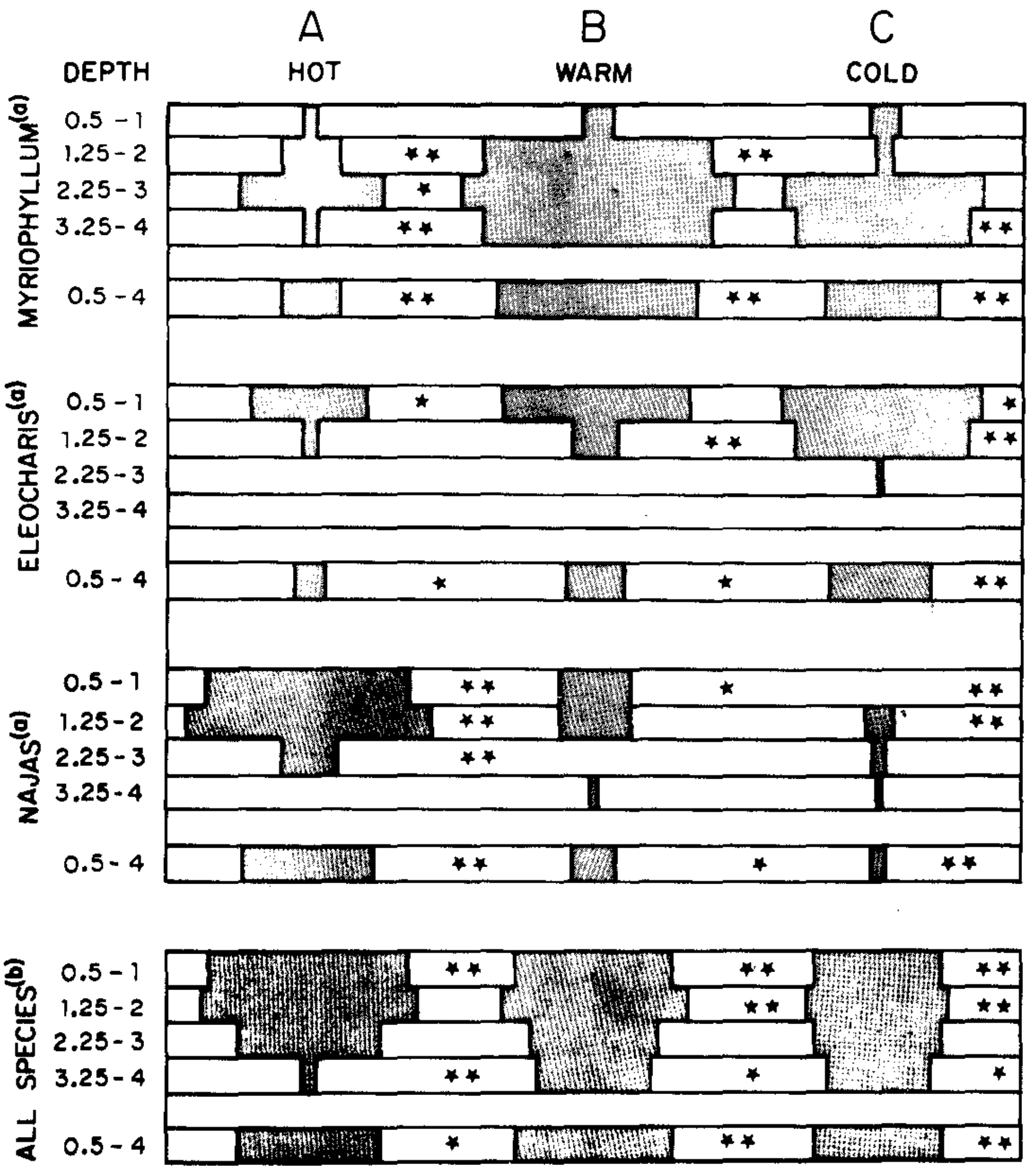


→| |← 5g organic weight

* The two averages on either side differ significantly at the 0.05 level of confidence with the Duncan's Multiple Range Test. If asterisk is at the right of Station C, it applies to Stations A and C.

** Significant at the 0.01 level of confidence.

FIGURE 1. Relative Biomass Histogram



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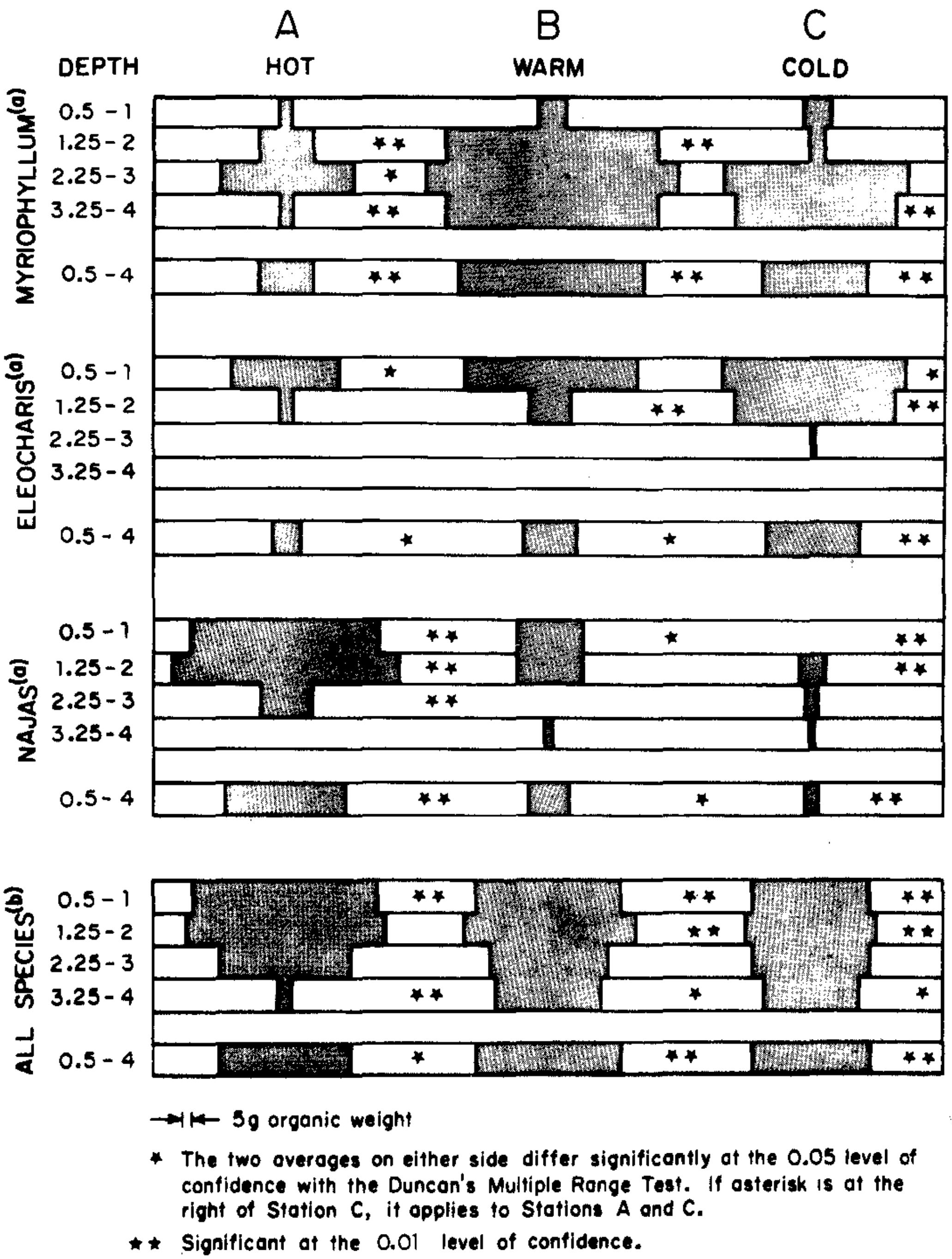

FIGURE 1. Relative Biomass Histogram

30. STUDIES OF CONTROL MEASURES FOR ASIATIC CLAM INFESTATIONS†

INTRODUCTION

The asiatic clam, *Corbicula manilensis*, reported as a nuisance species in Tennessee[1] and elsewhere[2] has invaded the Savannah River and has created problems by clogging heat exchangers at the Savannah River Plant (SRP). Mechanical removal of clam infestations allows normal operation of the heat exchangers, but a less-drastic and more inexpensive measure for routine control is being sought. Chlorine was added *in situ* to test acute chlorine treatment as a control measure. The findings suggest that neither acute nor low-level treatment with chlorine will be practicable under existing SRP conditions.

METHODS

Clam densities greater than 10^3 individuals/m^2 inhabiting a 5 x 10^5 gallon concrete suction well were subjected to chlorine concentrations greater than 10 and up to 40 ppm. The chlorination treatment was done with the existing gaseous chlorination system of C Reactor for a period of approximately 60 hours. The effects upon clams were monitored by periodically removing subsamples from minnow baskets in which they were exposed and comparing survivorship in recovery chambers with control samples from an adjacent unchlorinated basin.

Samples of populations remaining naturally in the mud within the suction well were removed for survivorship determinations at the end of the chlorine exposure. Small living clams attached to the suction well walls were examined microscopically to determine the proportions alive before and after exposure.

RESULTS

The survivorship of clams experiencing different exposure times and conditions is summarized in Figure 1. Progressively greater exposures produced successively higher mortality, but

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† Work done by L. J. Tilly.

much of the induced mortality was delayed several days. Animals exposed in the open water for the full period of the test (about 54 hours) experienced about 90% mortality within 7 days. Animals remaining in the mud during the entire exposure period experienced only about 35% mortality in the same time. Subsequent observations revealed no important further differences in death rates between control and exposed animals.

Microscope counts of small (<7 mm length) clams from the walls showed that chlorine exposure during this test caused 50% mortality. The smallest of these wall-living clams (<2 mm) appeared to suffer far less of this mortality than the larger ones. This may be because the smaller clams are more completely buried in and protected by the mud and worm (oligochaetes) tubes on the walls. Adding support to this idea is the fact that the microscopic worms living in the tubes appeared to be largely unaffected by the chlorine exposure although their bodies are delicate and readily attacked by free chlorine when the animals are outside their burrows.

The results of this test do not support the use of acute doses of chlorine as the procedure for controlling the invasion of suction wells by juvenile clams. Other possibilities to be considered include other biocides, chronic dosage with lower levels of chlorine, and periodic temperature shock. The effect of chlorine treatments upon larvae could not be considered here, but is being investigated in laboratory tests.

REFERENCES

1. R. M. Sinclair and B. G. Isom. "Further studies on the introduced asiatic clam *Corbicula* in Tennessee." *Tennessee Stream Pollution Control Board Mimeographed Report*, Tennessee Dept. of Public Health, Nashville, Tennessee (1963).

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METHODS

Clam densities greater than 10^3 individuals/m^2 inhabiting a 5×10^5 gallon concrete suction well were subjected to chlorine concentrations greater than 10 and up to 40 ppm. The chlorination treatment was done with the existing gaseous chlorination system of C Reactor for a period of approximately 60 hours. The effects upon clams were monitored by periodically removing subsamples from minnow baskets in which they were exposed and comparing survivorship in recovery chambers with control samples from an adjacent unchlorinated basin.

Samples of populations remaining naturally in the mud within the suction well were removed for survivorship determinations at the end of the chlorine exposure. Small living clams attached to the suction well walls were examined microscopically to determine the proportions alive before and after exposure.

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† Work done by L. J. Tilly.

much of the induced mortality was delayed several days. Animals exposed in the open water for the full period of the test (about 54 hours) experienced about 90% mortality within 7 days. Animals remaining in the mud during the entire exposure period experienced only about 35% mortality in the same time. Subsequent observations revealed no important further differences in death rates between control and exposed animals.

Microscope counts of small (<7 mm length) clams from the walls showed that chlorine exposure during this test caused 50% mortality. The smallest of these wall-living clams (<2 mm) appeared to suffer far less of this mortality than the larger ones. This may be because the smaller clams are more completely buried in and protected by the mud and worm (oligochaetes) tubes on the walls. Adding support to this idea is the fact that the microscopic worms living in the tubes appeared to be largely unaffected by the chlorine exposure although their bodies are delicate and readily attacked by free chlorine when the animals are outside their burrows.

The results of this test do not support the use of acute doses of chlorine as the procedure for controlling the invasion of suction wells by juvenile clams. Other possibilities to be considered include other biocides, chronic dosage with lower levels of chlorine, and periodic temperature shock. The effect of chlorine treatments upon larvae could not be considered here, but is being investigated in laboratory tests.

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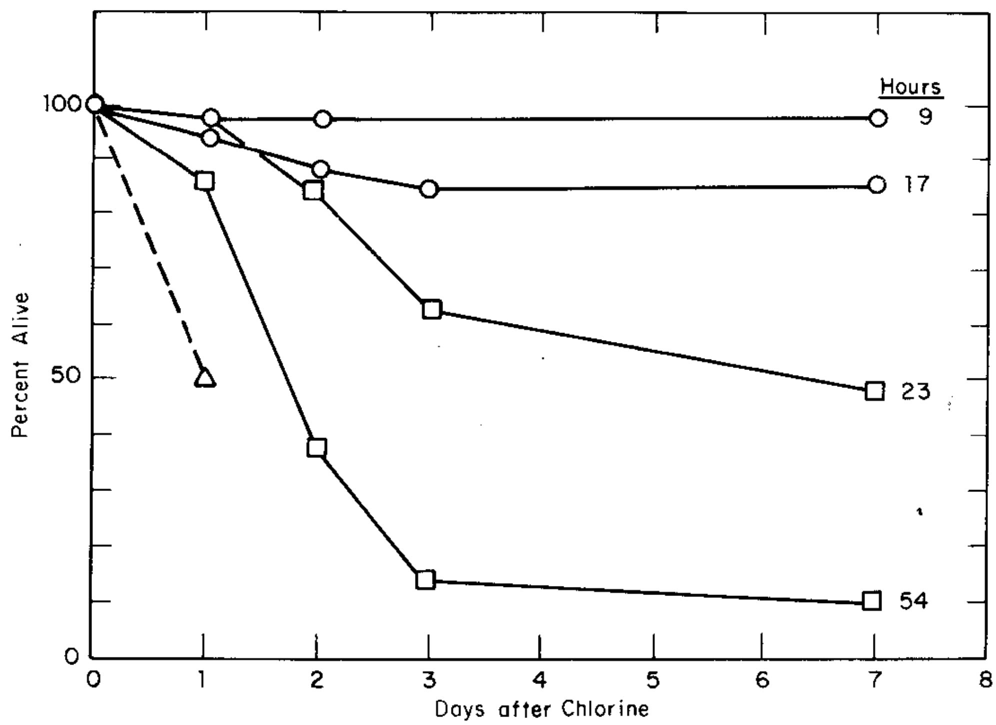

FIGURE 1. Clam Mortality as a Function of Exposure Time and Time Following Removal from Chlorine

31. THE IMPORTANCE OF WATER MOVEMENT IN STUDIES OF ZOOPLANKTON POPULATIONS ALONG A THERMAL GRADIENT †

INTRODUCTION

Investigations of the response of littoral zooplankton communities to the thermal effluent in Par Pond have resulted in observations which question the earlier conclusions of what is ecologically significant about thermal discharges both at Par Pond and elsewhere. Most previous efforts have focused upon the obvious phenomenon of temperature elevation. Recent sampling suggests that flow patterns and current velocities are critically important to the interpretation of ecological events, expecially in the littoral (near shore) zone.

Hot station populations are evidently greater than cool station populations and temporal changes in population make reasonable biological sense. However, reactor effluent flow is so strong that populations cannot be considered to be localized, and therefore the temperature histories of organisms are obscured in this and probably other reactor effluent situations.

SAMPLING METHODS

Zooplankton populations were sampled in relation to the thermal effluent in the hot arm of Par Pond during the summer of 1974 and again in 1975. Two 1.5 m vertical tows with a 13.5 cm diameter #10 plankton net were composited as a unit, and three units were taken per sample. Counts of *Bosmina longirostris*, and *Diaphansoma brachyurum* were made for each unit.

RESULTS

Variances among zooplankton counts were high, but it is clear from use of the Wilcoxon-Signed-Rank test[1] that abundances of *D. brachyurum* were significantly greater at the hot stations whereas *B. longirostris* was most frequently greater at the cool

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† Work done by T. J. Vigerstad (Laboratory Graduate Research Participant from the University of Rhode Island, Kingston, Rhode Island) and L. J. Tilly.

station in 1974 (Figures 1-3). Owing to the extreme abundance of *Ceriodaphnia* spp. zooplankton, standing crops were greater at the hot than at the cool station. This condition was also noted in the relative weights of net seston collected in previous years when species were not tabulated.

Based on the above observations from earlier years, three discrete sampling stations were established within the hot arm for purposes of examining the zooplankton population response to regions of differing temperatures (roughly +5, +4, and +2°C above ambient). We planned to make comparisons of population growth in relation to such statistics as the intrinsic rate of natural increase (r), the instantaneous birth rate (b), and the instantaneous death rate (d). Upon first inspection (Figure 3), population data seemed to follow reasonable biological trends with reasonable variances and appeared to bear some correspondence to reactor operations. However, surface currents not evident under a different flow regime during 1974 could be detected during sampling, and we decided to test whether the samples taken at the hottest station were from a discrete population reasonably confined to a limited area of the littoral zone. Three hundred replicate and sequential vertical tows were taken within 1/2 hour at this station to determine whether numbers in the area could be at least temporarily diminished. No reduction in density could be detected. Nets were then suspended at 1/2 and 1 m depths with mouths facing the point of effluent entry. In 1/2 hour or less, both collected hundreds to thousands of zooplankton. Velocities measured at the net depths of 1/2 and 1 meter were about 1 and 6 m per minute, respectively. Further quantification of this phenomenon is planned.

CONCLUSIONS

Several important conclusions result from these observations:

1. It is not safe to assume that the temperature (and other) conditions to which weakly swimming forms have been exposed are those measured at the points of collection.

2. A fairly detailed and generalized physical description of an effluent will be required if credible statements are to be made about the recent thermal history of small organisms in an effluent.

3. Work already done on small, mobile organisms needs to be reexamined in the light of the possibility that conclusions based on station sampling in an effluent have assumed minimal

movement of the organisms and relatively more constant physical and chemical conditions of the effluent than actually are involved.

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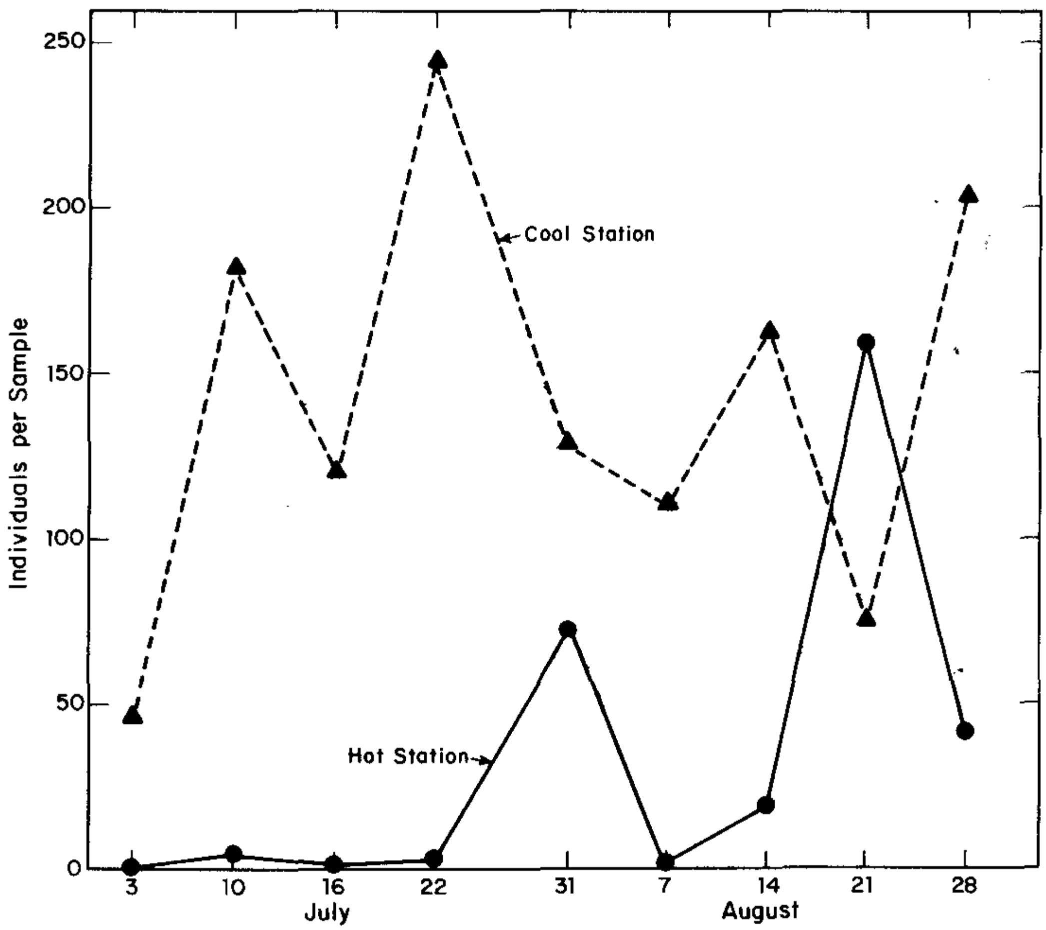

FIGURE 1. Total Numbers of *Bosmina longirostris* Sampled during July and August 1974 on a Weekly Basis

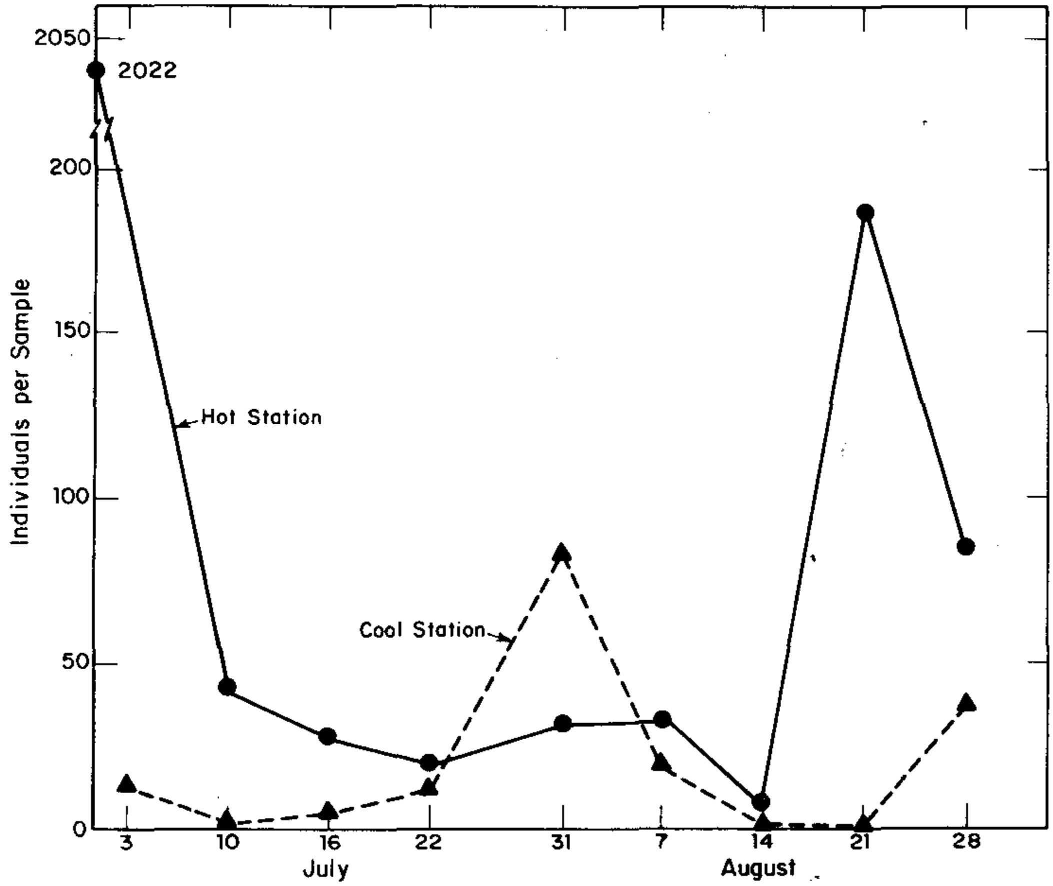

FIGURE 2. Total Numbers of *Diaphanosoma brachyurum* Sampled during July and August 1974 on a Weekly Basis

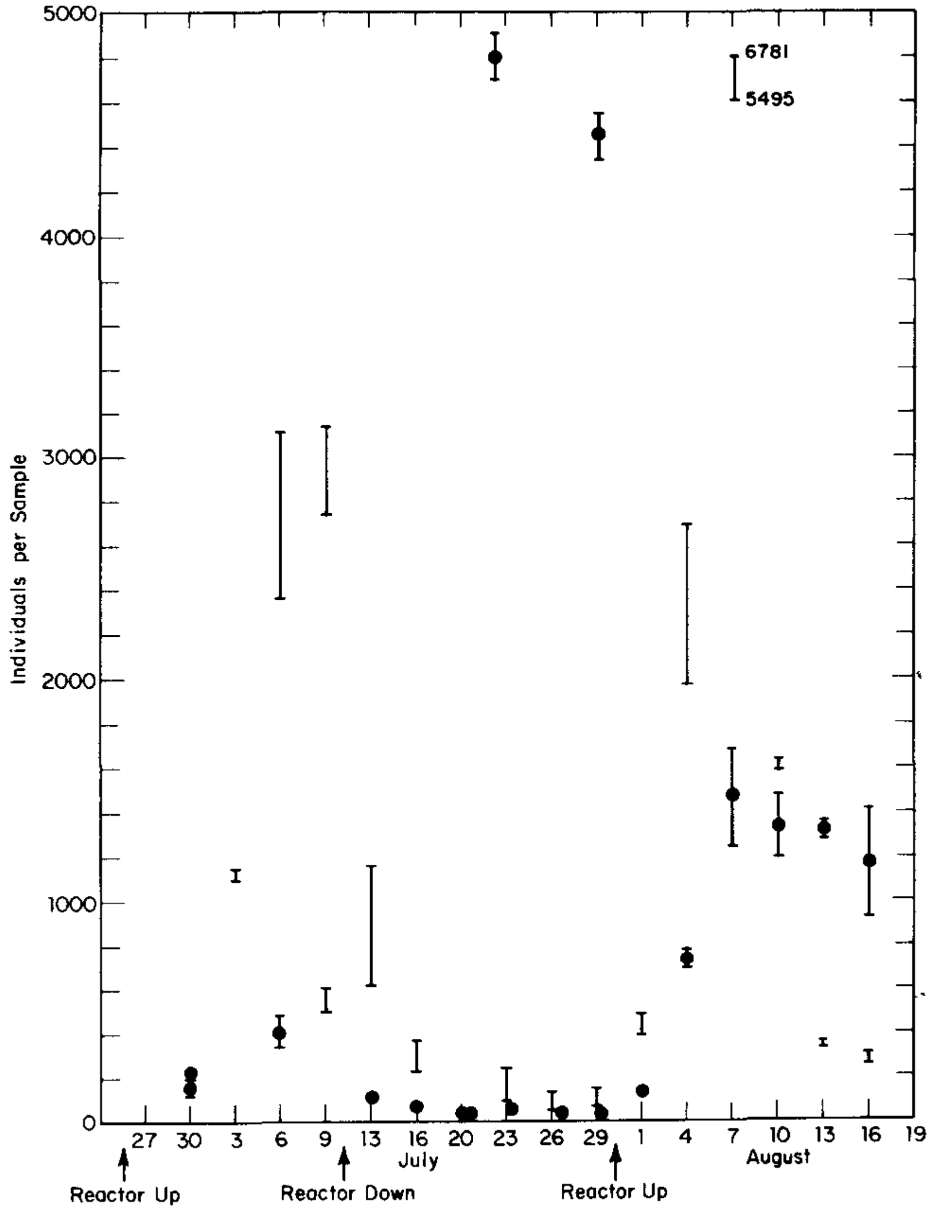

FIGURE 3. Abundance of *Bosmina longirostris* and *Diaphanosoma brachyurum* at the Hot Station during July and August 1975

32. BASELINE STUDIES OF UPPER THREE RUNS CREEK AND THE EXPERIMENTAL STREAMS OF THE FLOWING STREAMS LABORATORY †

INTRODUCTION

Upper Three Runs Creek on the Savannah River Plant (SRP) is the source of substrates water and organisms for the six experimental streams of the Flowing Streams Laboratory;[1] a facility for studying the effects of slight elevations in water temperature on the biota of a natural, blackwater stream. For the past three years, each experimental streambed has been continuously seeded with plants and animals by a once-through flow (50 gpm) of unheated creekwater. During this period, baseline studies were conducted to characterize the water and biota of the parent stream, and to establish the variance associated with the physical, chemical, and biological parameters for the six experimental streams before a heat stress was placed on the system. As a result of the baseline studies, the experimental design of the thermal studies was changed from two pairs of heated streams (2.5 and 5.0°C above ambient creekwater temperature) to four individually heated streams (5.0, 7.5, 10.0, and 12.5°C above ambient). The change was made because of wide variances associated with most of the biological parameters tested, and because laboratory studies showed that respiration rates of a native species of mayfly, *Dolania americana*, were little affected by water temperatures of 2.5 and 5.0°C above ambient.

RESULTS

The baseline data used to guide the decisions about experimental design are summarized in Tables 1-3. Seasonal variations in the chemical and physical characteristics of Upper Three Runs Creek have been published.[2] Water quality was not affected by the passage of stream water through the experimental streams.

Glass slides, mounted on diatometers,[3] were used to measure and compare the diversity and density of diatoms among the experimental streams. Diversity among the six streams did not differ (Table 1) but was significantly higher (0.01 level) in all

† Work done by R. S. Harvey. Presented at the *Annual Meeting of the Association of Southeastern Biologists*, VPI and State University, Blacksburg, Virginia, April 17, 1975.

streams than in Upper Three Runs Creek. Higher diversity on slides in the experimental streams may be due to their proximity (2 cm) to the bottom substrates compared to slide-substrate distances distances of about 1 meter in the parent stream. The observed number of species present (Table 1) was a much more stable biological parameter than the number of diatoms per mm^2 of slide surface (Table 2). Most biological parameters, including dry weight biomass, ash-free dry weight biomass, and percent diatom dominance, had ranges of variability similar to diatom density. Relative errors of percentage confidence limits[4] (Tables 1 and 2) show that the effects of added temperature could be detected at the 95% level by sampling two streams if the number of species changed as much as 10%, whereas diatom density would have to change from 38 to 70% to be detected at the 95% confidence level.

The total number of species of aquatic insects including mayflies, stoneflies, caddisflies, and dragonflies present in the streambed or collected in four-hour drift net (14 mesh) samples was judged to be a good index for interstream comparisons. Hand collections of immature specimens showed no significant differences among the six streams regardless of season. The movement of insects into and out of the experimental streams are shown in Table 3. All streams have essentially the same opportunity to be seeded with new insects. Drift-out data show the loss of insects from the streams with the influent (up-stream) nets in position and do not reflect those species that pass directly through the stream. The difference between drift-in and drift-out is presumably a measure of the flow-through drift. However, this estimate may reflect flow alterations caused by partial blockage of the streams by the influent nets.

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TABLE 1

Semi-Detailed Diatometer Readings for May 1973 - June 1974

	Observed Number of Species						
	AS1	*AS2*	*AS3*	*AS4*	*AS5*	*AS6*	*U3R*
Samples (N)	18	18	18	18	17	18	16
Mean ($\overline{x}$)	165	171	179	172	176	173	148
Std. Dev. (S)	20	19	25	20	16	16	15
Variance (S^2)	397	376	644	397	241	269	231
Std. Error (SE)	4.7	4.5	6.0	4.7	3.7	3.9	3.8
D[a]	9	8	10	8	6	7	-

a. D = Relative error of percentage confidence limits (based on above data when only 2 streams are sampled).

TABLE 2

Semi-Detailed Diatometer Readings for May 1973 - June 1974

	Density diatoms/mm²						
	AS1	*AS2*	*AS3*	*AS4*	*AS5*	*AS6*	*U3R*
Samples (N)	17	17	18	18	17	18	17
Mean ($\overline{x}$)	120	134	136	110	89	136	376
Std. Dev. (S)	100	71	133	91	66	108	236
Variance (S^2)	9940	5110	17800	8250	4340	11640	55920
Std. Error (SE)	24	17	31	21	16	25	57
D[a]	59	38	70	58	52	56	-

a. D = Relative error of percentage confidence limits (based on above data when only 2 streams are sampled).

TABLE 3

Number of Species from 4-hr Drifts of Aquatic Insects in Artificial Streams (5 Days, February 9 to February 14, 1974)

	AS1		*AS2*		*AS3*		*AS4*		*AS5*		*AS6*	
	In	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*
Samples	5	4	5	4	5	4	5	4	5	4	5	4
Mean ($\bar{x}$)	9.2	5.0	8.6	5.7	8.0	3.3	9.0	6.3	8.0	5.5	8.4	5
Std. Dev. (S)	5.1	1.0	3.5	0.5	2.0	0.9	2.0	2.1	3.5	1.3	2.9	3
Variance (S^2)	26	4.0	12	0.3	4.0	0.9	4.0	4.3	12	1.7	8.3	5
Std. Error (SE)	2.3	0.5	1.5	0.3	0.9	0.5	1.0	1.1	1.7	0.7	1.3	1.3
D[a]	39	28	28	7	18	20	16	23	31	17	49	29

a. D = Relative error of percentage confidence limits (based on above data when only 2 streams are sampled).

33. THERMAL EFFECTS ON GROWTH AND RESPIRATION RATES OF THE MAYFLY *DOLANIA AMERICANA* (EPHEMEROPTERA) †

INTRODUCTION

The mayfly *Dolania americana*,[1] common in the sand of Upper Three Runs Creek, was studied to determine the effects of seasonal changes in temperature on population growth rates and to determine the effects of slight elevations in water temperature on respiration rates of this benthic species.

Growth of the population increased with stream temperature until peak emergence of adults in June and July. There was a strong inverse correlation ($P < 0.01$) between body weight and respiration rates of immature nymphs. Respiration rates at 2.5, 5, and 10°C above ambient creekwater temperatures were not significantly higher than those measured at ambient creekwater temperatures.

RESULTS

The apparent population growth curves (Figure 1) show that mean dry weights for both males and females increased steadily from August through May as the second-year nymphs matured. Mean weights were reduced sharply in June and July as subimagoes of the second-year nymphs emerged from the stream leaving only first-year nymphs behind. Females generally attained larger size before emergence than males.

The first 940 specimens were studied at 0, 2.5, and 5°C above ambient stream temperature, because these temperatures were the planned mixed-water temperatures of the experimental streams in the Flowing Streams Laboratory.[2] An additional 400 specimens were studied at 0, 5, and 10°C above the ambient temperature to provide baseline data for planned experiments at even higher temperatures in the Flowing Streams Laboratory.

Analyses of variance, regression analyses, t-statistics for linear regression, and Student's t-test were employed to test the significance of experimental results.

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† Work done by R. S. Harvey. Paper presented at the *Annual Meeting of the American Institute of Biological Sciences*, Oregon State University, Corvallis, Oregon, August 18, 1975.

Sex had no significant effect ($P > 0.05$) on the respiration rates of *Dolania* when males and females of the same weight class were compared by paired t-tests. However, mature female nymphs are larger (up to 26 mg dry weight) than mature males (up to 15 mg dry weight) and consequently have lower respiration rates.

Combinations of dry weight and temperature, dry weight and sex, and dry weight, temperature, and sex had no significant effect on the respiration rates of *Dolania*.

Oxygen consumption rates for *Dolania* (Figure 2) increased for all weight classes as the seasonal water temperature in Upper Three Runs Creek increased from 7 to 21°C. Smaller nymphs generally consumed oxygen at higher rates than larger specimens, and water temperatures 5°C above ambient caused detectably higher respiration rates for most *Dolania* a significant portion of the time ($P < 0.01$). Edwards[3] also found a progressive decrease in oxygen consumption per unit weight as the size of chironomus larvae increased.

The effects of added heat stress on *Dolania* respiration are most apparent when examined for a single weight class. Oxygen consumption rates at 5°C above ambient were consistently higher than rates at ambient temperatures throughout the two-year baseline study (Figure 2). However, seasonal patterns of respiration were not altered by the higher temperature. Figure 2 also shows that only in 2 of 4 cases were respiration rates higher when the temperature stress was doubled to 10°C above ambient. There is no obvious explanation for the depressed respiration rate (involving 2 specimens) at 10°C above ambient for May 1975.

It is possible that chronic exposure of *Dolania* to water temperature of 5 and 10°C above ambient may affect biological rhythms; such as time of emergence and mating behavior. The continuing studies with experimental streams will address these questions.

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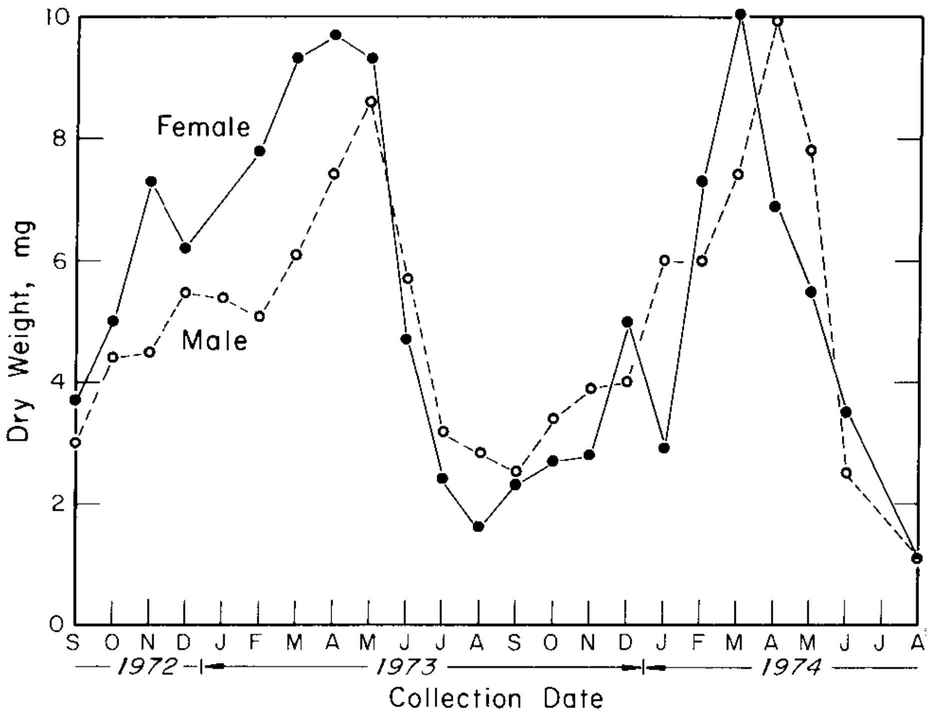

FIGURE 1. Growth of *Dolania americana* Nymphs in Upper Three Runs Creek

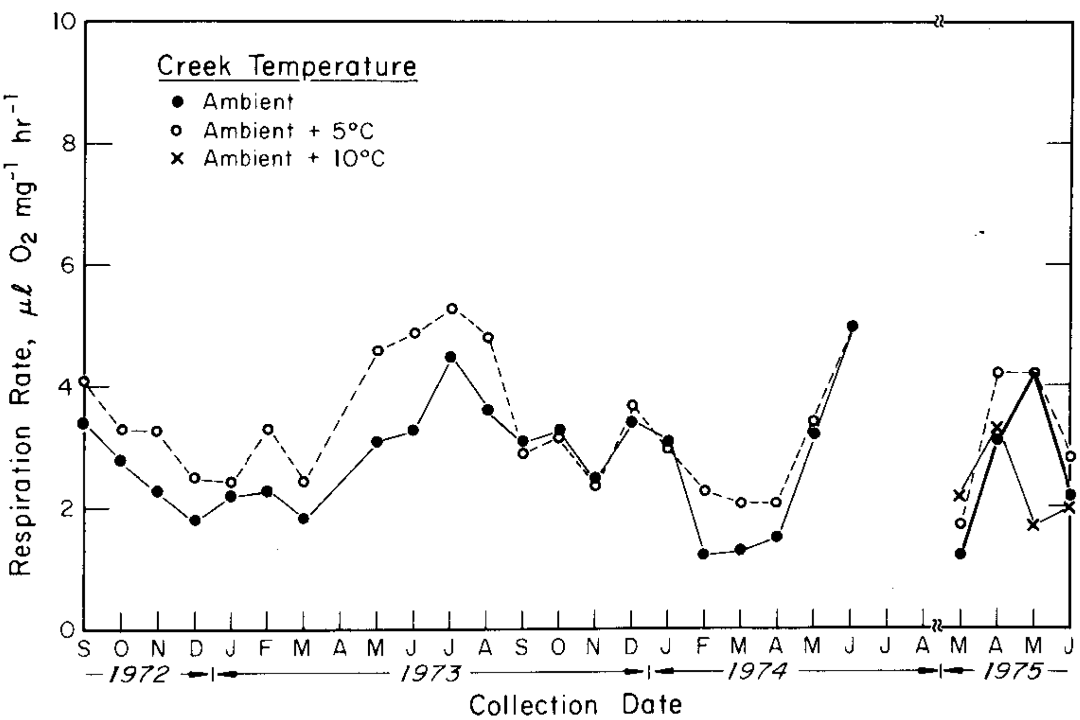

FIGURE 2. Respiration Rate vs Season for *Dolania americana* (4 to 6 mg dry weight)

34. ANAEROBIC METHANE PRODUCTION IN SRP STREAMS†

INTRODUCTION

Methane is a natural gas capable of being produced microbiologically under anaerobic conditions. Ambient concentrations of methane in the atmosphere are relatively low, 1.5 ppm,[1] while methane in lake sediments and submerged soils can range upwards to 700,000 ppm with 300,000 to 500,000 ppm being common.[2] Trace levels of tritiated methane have been found in ambient air samples taken at the Savannah River Plant (SRP); however, the origin of such methane is unclear. Methanogenic bacteria produce methane gas by fixing carbon dioxide from the air and using hydrogen gas as both an energy source and as an electron donor for the production of methane.[3] If the hydrogen is tritiated, then tritiated methane is readily produced.

The purpose of this study is to determine the distribution and concentration of methane gas in the sediments of several of the plant streams and Par Pond and to determine whether such methane gas is tritiated. The data indicate that high levels of methane gas are found in SRP sediments and that such gas is of biological origin.

MATERIAL AND METHODS

Sample Location and Collection

Gas samples were collected from the sediments at various points along P reactor canal, in Par Pond, Four Mile Creek, Beaver Dam Creek, Upper Three Runs Creek, and the artificial streams at the Flowing Streams Laboratory. Samples were taken by agitating the sediments to release the entrapped gas and then collecting the gas with an inverted funnel. Care was taken to ensure that no contamination by atmospheric concentration of air occurred. Gas samples were then transferred to vacuum-sealed bottles and the species of gases analyzed by gas chromatography.

Gas Chromatography Analysis

Gas samples were analyzed on a Hewlett-Packard Model 5756B Gas Chromatograph. Gas percentages were calculated from cali-

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† Work done by C. B. Fliermans.

bration curves (peak height) for oxygen, nitrogen, and methane on a volume percent basis with ±10 to 15% accuracy. Water vapor retained on the molecular sieve column was not detected, which may account for the samples having low total percentages. The percentage of carbon dioxide was calculated by measuring the peak area with a planimeter and ratioing to the area for 100% carbon dioxide.

RESULTS AND DISCUSSION

Methane levels detected in the sediments from plant streams ranged from 10.0 ppm to 688,000 ppm (Table 1). Pure culture studies using methanogenic bacteria indicated that methane produced from $^{12}CO_2$ and $^3H_2$ produced tritiated methane and tritiated water in accord with the overall formula:

$$CO_2 + 4\ {}^3H_2 \longrightarrow C^3H_4 + 2\ {}^3H_2O \quad (1)$$

where 1 mole of tritiated methane and 2 moles tritiated H_2O are produced from 4 moles of tritium. Nonbiological exchange between tritium and methane did not occur over a 48-hr period; therefore, the tritiated methane observed in pure culture experiments was due to the metabolism of methane-producing bacteria rather than to physical exchange.

Experiments conducted on Par Pond sediments indicated that the production of methane gas is a biological phenomenon. A sediment core was split; one half was sterilized by autoclaving, the other half was maintained intact under *in situ* conditions. No methane was produced in the sterilized sediment because the sterilization procedure killed the methane-producing bacteria.

Pure cultures of methane-producing bacteria incubated with gaseous tritium caused immediate production of tritiated methane (within 30 seconds) as predicted by the overall equation:

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O \quad (2)$$

The physical exchange of gaseous tritium with methane to produce tritiated methane did not occur during the duration of the experiments (72 hours).

The data indicate that methane is produced in high concentrations in the sediments of many SRP streams, and such production appears to be primarily biological.

Studies are in progress to evaluate further the levels of methane produced and the distribution of the gases in the sediments of SRP streams. Techniques are being developed to concentrate large volumes of pure methane gas collected from the sediments in order to evaluate the extent of tritiated methane occurring in SRP streams.

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TABLE 1

Gases in Sediments of SRP Streams

	Entrapped Gas, vol %				
Sampling Areas	*Oxygen*	*Nitrogen*	*Carbon Dioxide*	*Methane*	*Total*
Flowing Streams Laboratory	4.9	35.6	4.1	62.7	107.3
	7.0	53.5	1.0	34.0	95.5
	11.7	54.3	0.4	19.9	86.3
	17.2	62.8	0.2	7.5	87.7
	12.6	51.7	1.5	26.5	92.1
	8.3	47.1	1.6	35.3	92.3
Upper Three Runs Creek	8.4	48.4	1.2	34.0	92.0
P Reactor Canal[a]	20.1	75.5	0.3	0.07	96.1
	18.2	64.0	0.1	0.004	82.3
	10.8	64.8	1.2	1.7	78.5
	17.6	64.8	0.1	0.003	82.5
	16.9	65.3	0.2	0.3	80.7
	18.6	64.4	0.1	0.001	83.3
Pond C	4.6	47.0	2.9	48.0	102.5
Beaver Dam Creek	15.5	67.5	1.0	0.12	84.1
	9.4	49.0	0.7	18.8	77.9
	7.0	75.8	7.9	9.0	99.7
	5.8	32.2	2.6	50.8	91.4
Four Mile Creek	15.2	68.7	0.4	0.1	84.4
	9.7	45.0	2.7	36.6	94.0
	6.5	45.1	3.2	59.9	114.7
	9.1	68.8	1.8	5.2	84.9
Artificial Tubes with Par Pond Sediments[b]					
T_1	3.3	46.3	3.7	68.8	122.1
T_2 sterile	13.2	75.9	13.4	0.01	102.5
T_2 nonsterile	4.0	32.2	3.8	43.7	83.7

a. Samples taken after reactor had been down 6 weeks.

b. The T_1 sediment sample was freed of methane gas and the sediment split into two T_2 samples. One half was autoclaved, and both subsamples were placed in sterile acrylic tubes which were placed in an artificial stream. The evolved gas was measured after 30 days of incubation.

35. PREPARATION OF SPECIFIC FLUORESCENT ANTIBODIES AGAINST METHANOGENIC BACTERIA†

INTRODUCTION AND SUMMARY

Methane in sewage decomposition, heartwood of trees, ruminant and nonruminant digestive systems, submerged soils, and marine and freshwater sediments is produced by methanogenic (methane-producing) bacteria.[1] To evaluate the distribution and population densities of these bacteria, the methane-producing bacteria must be isolated and identified. Since the majority of bacteria can not be identified by morphological characteristics,[2] the use of species-specific fluorescent antibodies (immunofluorescence) has proven to be a valuable technique for the recognition and identification of bacteria in nature ecosystems.[3]

Five different strains of methane-producing bacteria were injected into separate rabbits to produce specific antibodies against each strain injected. These antibodies have been shown to be specific in that one and only one antibody reacts with its counterpart bacterium. These specific fluorescent antibodies determine how many methanogenic bacteria are in the sediments of Savannah River Plant (SRP) streams and where these bacteria are located.

MATERIAL AND METHODS

Bacterial Cultures.

Methanogenic bacteria were isolated from a variety of habitats in cooperation with Dr. J. G. Zeikus from the University of Wisconsin. The bacteria were grown under strict anaerobic conditions as previously described.[4] These organisms have been shown to be the primary producers of methane in each habitat from which they were isolated.

Fluorescent Antibody Preparation

Cloned isolates of the stock cultures of methane-producing bacteria were grown in pure culture to a density of about 10^8

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† Work done by C. B. Fliermans.

cells/ml for the preparation of individual antiserum. Cells were harvested by centrifugation, washed, resuspended in phosphate buffer (pH 7.2), and injected intravenously into rabbits. After injections were completed, test bleedings were made, and antibody levels were determined by tube agglutination. The antibody levels were shown to be greater than 1:5120 for each homologous system. Antisera were harvested by cardiac puncture, fractionated, and conjugated with a fluorochrome dye. All procedures were as described previously.[5]

Methods for preparation and staining of contact slides and for all fluorescence microscopy and photomicrography are detailed elsewhere.[5] Gelatin-rhodamine isothiocyanate (RhITC) conjugate (8 μg of RhITC per mg of gelatin) was used to suppress nonspecific adsorption of the fluorescent antibodies (FA).[6] The techniques for preparation of terrestrial and aquatic samples for immunofluorescence examination on membrane filters were as reported previously.[7]

RESULTS AND DISCUSSION

The data in Table I indicate the specificity of each one of the fluorescent antibody preparations. Each prepared antibody reacts specifically with its homologous antigen and not with any other methanogenic bacterium.

These antibodies constitute the major types of bacteria that are responsible for the biological production of methane in natural ecosystems. Thus, the data indicate that each of the methane-producing bacteria can be identified by immunofluorescence.

Preliminary studies on the distribution of methanogenic bacteria in SRP streams indicate that those bacteria that produce methane in high temperature situations, such as hot springs of Yellowstone National Park, also exist in Pond 1 of the P reactor canal.

In recent years, development of the FA technique for effective use in microbial ecology has greatly expanded the potential for autecological study of microorganisms. The unique, inherent advantages that this technique provide are particularly appropriate for study of the methanogenic bacteria. Refractory to ready culture, difficult to isolate, and of nondescript morphology, the methanogenic bacteria function in complex habitats characterized by great species diversity. The species-specific FA reported in this study make it possible for the first time to observe and recognize members of two methanogenic genera by direct microscopic examination of methane-producing habitats.

Immunofluorescence will continue to be used to locate and assess methanogenic bacteria in SRP streams and to determine their cell densities. Cell numbers of specific methanogenic bacteria will be correlated with concentrations of methane gas in the various habitats to determine the microbiological impact of methane production.

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TABLE 1

Immunofluorescence Staining of Methane-Producing Bacteria

Fluorescent Antibody	Methanogenic Bacteria Reactions[a]				
	Methanosarcina bakeri	*Methanosarcina sp. UBS*	*Methanobacterium thermoautotrophicum*	*Methanobacterium sp. YT*	*Methanobacterium arbophillicum*
Methanosarcina barkeri	4+	neg	neg	neg	neg
Methanosarcina sp. UBS	neg	3-4+	neg	neg	neg
Methanobacterium thermoautotrophicum	neg	neg	4+	neg	neg
Methanobacterium sp. YT	neg	neg	neg	4+	neg
Methanobacterium arbophillicum	neg	neg	neg	neg	3+

a. 4+ highly reactive; 3+, moderately reactive; 2+, reactive; 1+, ± marginal reactivity; neg, no immunofluorescence reaction.

36. REDUCTION OF PHYTOPLANKTON ACTIVITY BY PASSAGE THROUGH A PRODUCTION REACTOR†

INTRODUCTION

Heat from nuclear reactors at the Savannah River Plant (SRP) is dissipated by cooling water which returns to the environment. Cooling water taken from either natural rivers or artificial impoundments contain microorganisms which are adapted to the physical and chemical parameters of the parent water. Microorganisms in cooling water make significant contributions to the process of biological self-purification, a process which is defined as the entity of reactions due to organismal activity; which in turn, causes a concentration change of water components considered as pollution.[1] Reactor passage applies extensive thermal stress to these organisms.

The purposes of this study are to determine (a) the effects of the passage of cooling water through a heat exchanger of a nuclear reactor on the primary productivity of algae and (b) the utilization of organic compounds by the bacteria associated with the planktonic (free-floating) community.

The two-phase program was initiated with ^{14}C-tagged sodium bicarbonate incorporated in the organisms to determine the optimum temperature of the primary producers and the effect of reactor passage on these organisms. The data show the passage of the phytoplankton community through the heat exchangers of P reactor reduced the photosynthetic capabilities by 97%, while only a 30% reduction was seen in bacterial activity.

MATERIAL AND METHODS

Stations and Sampling

The effluents from P reactor were used exclusively in this study with seven sampling sites being established along the thermal effluent. Station 1 was in the mixing basin of P reactor, with the other six stations occurring in the P canal itself and Pond C. Temperatures ranged from ambient to 72°C.

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† Work done by C. B. Fliermans.

Sampling schedules varied depending on the research questions asked. Generally, samples were taken at the desired stations using an opaque Van Dorn sampling bottle. Seven subsamples were taken in replicates of four, which were divided among glass-stoppered reaction bottles for isotope studies. One-half of the reaction bottles were light-tight, while the remaining bottles were transparent. *In situ* temperatures of the reactor canal were measured before and after the 3-hour experiments, and all samples were equilibrated to the temperature of the habitat before experiments were begun. Each bottle containing the sample of plankton was injected with ^{14}C tagged sodium bicarbonate to a final concentration of 1.0 μCi/bottle. Incubations were carried out from 11 AM to 2 PM, and the ^{14}C isotope incorporations were stopped by placing the reaction bottles on ice. The total volume of the reaction bottle (130 ml) was filtered through a 0.45 μm filter, washed free of unincorporated isotope, placed in scintillation vials, and counted.

Protein levels in the samples were analyzed by the biuret procedure to normalize the incorporation of ^{14}C to a single mg of protein.

RESULTS AND DISCUSSION

The activity of the primary producers is influenced by the temperature of the habitat (Figure 1). Samples taken from the mixing basin were placed at the various stations along the P reactor canal. The samples were incubated in both light and dark bottles when the reactor was not in operation but with water flowing in the canal. A 7°C increase in temperature was measured from the mixing basin (23.5°C) to the final station (30.5°C) due to solar insolation. While the bacterial incorporation of ^{14}C-tagged sodium bicarbonate in dark bottles showed no significant change with temperature or location of the incubation stations, the algal components of the planktonic community demonstrated a significant increase at the warmer temperatures. The data suggest that the plankton in the cooling water adapt to photosynthesize at a temperature warmer than those of their natural habitat. Such findings are in agreement with those of Brock[2] for microorganisms found in natural hot spring systems.

Once the reactor is in operation, the thermal stress on oxygen-evolving photosynthetic microorganisms is significant (Figure 2). The photosynthetic algae in the cooling water lose over 97% of their ability to fix $^{14}CO_2$. On the other hand, the bacteria, which are primarily fixers of more complex organic material, retain 70% of their activity, and in some cases recover to their initial activity levels.

Studies are in progress to corroborate such data, to define the temperature optima of the organisms in the cooling water, and to determine the effect of the heat stress on the heterotrophic members of the planktonic community.

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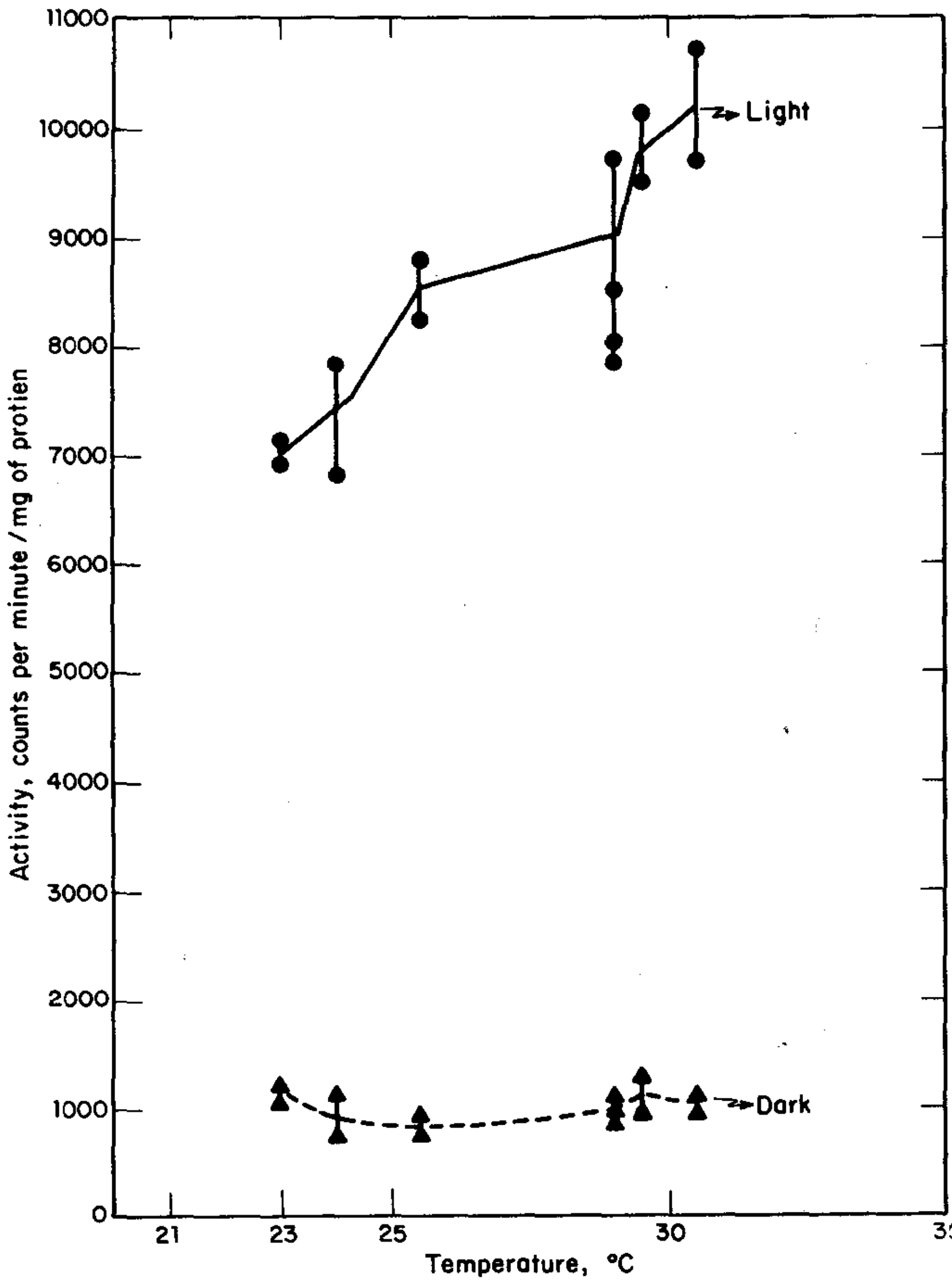

FIGURE 1. Primary Producer Activity in Plankton Samples. Samples were taken from the mixing basin in P reactor area and incubated in the P canal during a reactor shutdown.

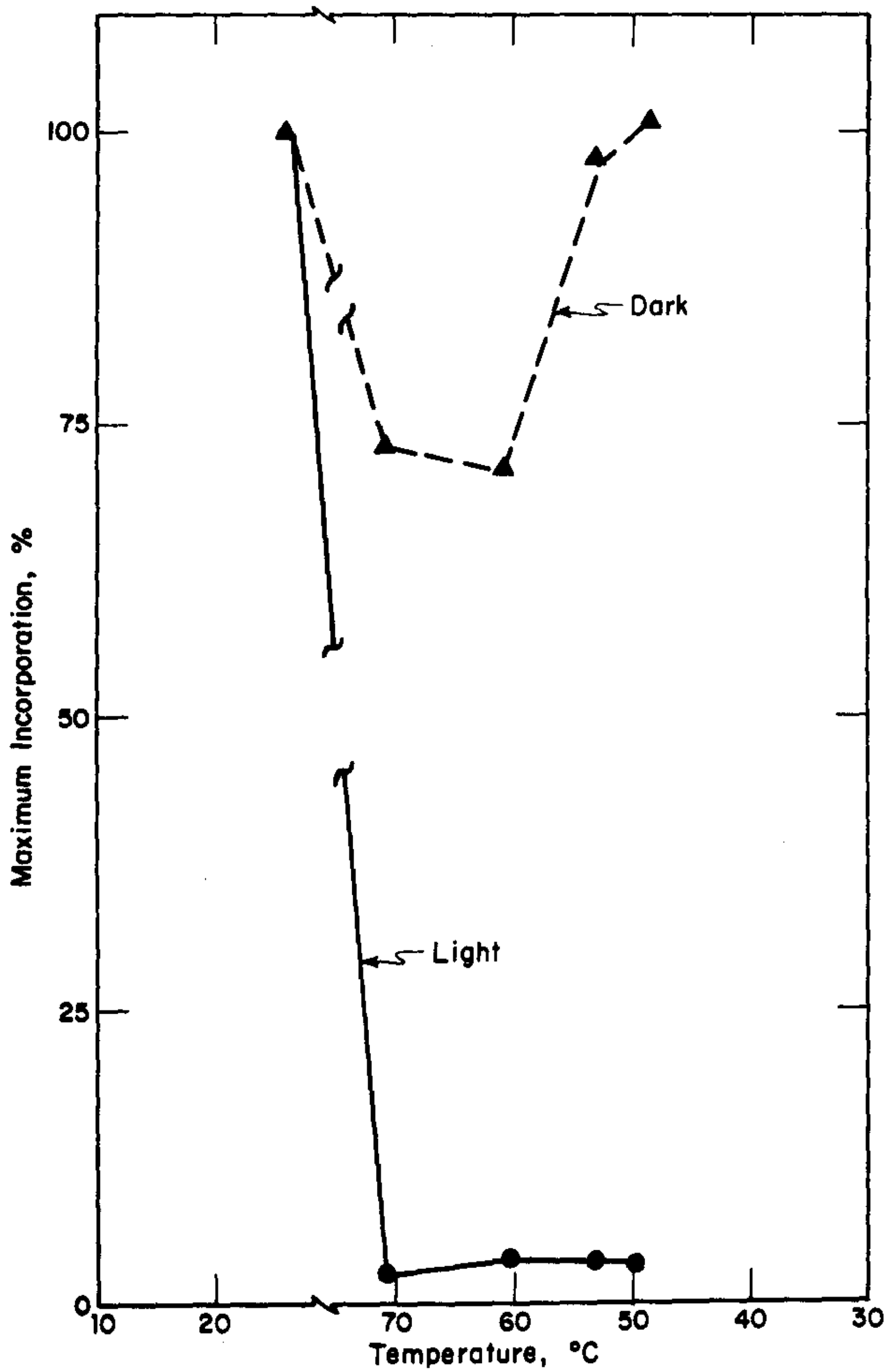

FIGURE 2. Primary Producer Activity in Plankton Samples. Samples were taken from the mixing basin in P reactor area and incubated in the P canal during maximum reactor operation. The data are normalized to the amount of incorporation in the basin samples.

37. MICROBIAL COLONIZATION OF ARTIFICIAL SUBSTRATES IN REACTOR EFFLUENTS†

INTRODUCTION

The cooling of nuclear reactors results in the dissipation of large quantities of heat, which are transferred primarily to cooling waters to create thermal effluents. As these thermal effluents cool, they provide habitats to a selected group of microorganisms, the thermophiles, which are capable of growing at temperatures above 55°C.[1] Selected thermophilic algae and bacteria are capable of becoming optimally adapted to these elevated temperatures, establish large populations, and eventually affect the water quality of downstream communities.

Studies were undertaken to determine the extent to which reactor streams support thermophilic microbial populations, how such communities colonize a natural substrate, the population response to reactor operations, and their nutritional effect on downstream communities. The data show that high levels of microbial biomass, protein, and chlorophyll occur in the reactor streams and grow rapidly on artificial substrates.

MATERIAL AND METHODS

Substrate Colonization

Marine plywood boards, 2500 cm^2, were sectioned into twenty 200 cm^2 areas (both sides of the board). Each section was numbered, and four such boards were weighted and lowered vertically into the reactor canal. Boards were placed in areas where the reactor effluent was 72°, 65°, 60° and 55°C, respectively. Current velocities were measured at the sites with a recording current meter. At the three cooler sites, thermally altered water was diverted at the rate of 10 to 12 liters/min. onto horizontal troughs to determine microbial colonization rates under lower current velocities.

Sampling

Samples were taken from both troughs and boards at weekly intervals using an alcohol flamed spatula. Samples from both the

† Work done by C. B. Fliermans and R. W. Gorden (Faculty Research Participant, Southern Colorado State University, Pueblo, Colorado).

boards and the troughs were taken in duplicate from different sections of the substrate (to minimize a position affect) and placed in sterile plastic bags.

Each sample was measured for biomass as determined gravimetrically by ash-free, dry-weight analysis; protein content was measured colorimetrically by the biuret procedures and algal chlorophyll was measured spectrophotometrically and calculated as described by Lorenzen.[2]

RESULTS AND DISCUSSION

The data for biomass (expressed as mg/cm^2) indicate that the highest levels were achieved after a four-week incubation period at the station where temperatures were near 60°C. Such data were confirmed by protein levels of 2.2 mg/cm^2, which were the highest after a four-week incubation period at this same station. Incubation periods greater or less than four weeks produced less growth. Lesser growth at longer incubation times is probably caused by sloughing off of the microbial mat once densities become too high to maintain attachment. Chlorophyll-*a* content in mg/cm^2 was also highest at this station; however, those levels were achieved after a three-week incubation rather than four weeks.

The data also indicate that P reactor canal effluents are capable of supporting large mats of highly proteinaceous material in the form of microorganisms. Time studies are in progress to confirm these preliminary findings and to determine rates of microbial colonization in the reactor streams.

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38. SURVIVAL OF HUMAN PATHOGENS IN REACTOR EFFLUENT WATERS†

INTRODUCTION

Human pathogenic bacteria are capable of growth at body temperatures with optimum growth near 39°C. Certain pathogens survive for several days in cool natural waters, although their capability for longer survival is undetermined.[1] The presence of human pathogens in thermally stressed aquatic ecosystems where temperatures reach or exceed 37°C may pose a health hazard, if such waters are used for both industrial cooling and recreational purposes. The present study was undertaken in order to study the growth and survival of *Escherichia coli*, an indicator of fecal pollution, in thermally-stressed and nutritionally-enriched Par Pond. Survival of these bacteria was measured at various stations along a thermal gradient and at various depths along an oxygen gradient in Par Pond.

The data suggest that fecal coliform bacteria can survive and adapt to the environmental conditions of Par Pond and that reactor operations do affect these organisms.

MATERIAL AND METHODS

Chambers

Membrane diffusion chambers[1] were fitted with 0.4 µm polycarbonate filters, filled with 20 ml of *E. coli* washed free of nutrients, and suspended in sterile phosphate buffer solutions at population densities of 1.5×10^6 cells/ml. The chambers were immediately attached to stainless steel chains and lowered to four designated depths at five stations along a thermal gradient in Par Pond. Station depths were carefully selected to obtain thermocline and oxygen depletion gradient levels between stations.

Sampling Procedures

Samples (1.0 ml) for optical density measurements were taken aseptically with 1.0 ml syringes. Each chamber was sampled every

† Work done by C. B. Fliermans and R. W. Gorden (Faculty Research Participant, Southern Colorado State University, Pueblo, Colorado).

three hours during a 96-hour period. Samples were placed in capped containers and immediately brought to the laboratory for analysis. The frequency of sampling was reduced to once every 24 hours for a total exposure time of 14 days. At each sampling interval, the optical density of each sample was measured using an ultraviolet spectrophotometer.

Less frequently, every 8 to 48 hours, the viability of the cells in the chambers was measured using microrespiration techniques. Cells which were incubated in the water columns at the various stations were placed in equal volumes of a nutrient broth solution and incubated in a Gilson respirometer to measure the levels of oxygen consumed by the bacteria. Such measurements provide information as to the effects of the *in situ* conditions of Par Pond on the bacterial populations suspended in the chambers.

Samples were taken during two different periods of reactor operations; first, when the reactor was not in operation, and second, when the reactor was in full operation.

RESULTS AND DISCUSSION

Optical Density and Respiration Measurements

Optical density (OD) was measured to determine the numbers of bacteria in a given sample. Significant numbers of *E. coli* survived for two weeks (336 hrs) at every station in Par Pond. During the first 16 hours, the number of *E. coli* increased, and then a period of die-off occurred. After 96 hrs, the number of bacteria at each depth at each station was very low; yet in every sampling chamber, the optical density was comparable to or higher after 336 hrs than readings taken at 96 hrs.

At established intervals, metabolic rates of *E. coli* were measured using a Gilson microrespirometer. The data indicate that the respiration rates of *E. coli* increase with time of exposure to the Par Pond ecosystem. Such an increase in metabolic activity may reflect an adaption of *E.coli* to the established habitat parameters in Par Pond.

The data suggest that *E. coli* can survive for at least two weeks in Par Pond. Such survival times are significantly greater than those reported for other aquatic systems.

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VI. DOSE-TO-MAN STUDIES

39. DOSE-TO-MAN PROGRAM IMPLEMENTATION ON THE JOSHUA SYSTEM †

The Savannah River Laboratory (SRL) Dose-To-Man Program[1] is part of an expanded program in environmental sciences that was begun in 1973. The objective of this program is to provide an estimate of the total environmental effects of Savannah River Plant (SRP) operations in terms of population exposure to radioactive effluents. A requirement for meeting this objective is an appropriate computational ability to model the transport and dispersion of various materials through environmental systems. Current state-of-the-art is such that the computational modeling capabilities are inadequate to describe satisfactorily the movement of material from release to ultimate uptake by man through various pathways. As a result, computational modules are being developed that utilize common and sometimes large data bases in a search for the most efficient method to determine environmental effects adequately. The Dose-To-Man Program includes a continuing effort of applying and testing computational modules, and data bases as they are developed and become available. These efforts are greatly facilitated through the use of a computational system called JOSHUA.[2]

JOSHUA was developed at SRL beginning in 1968 as a result of the great computational demands of nuclear reactor design, and the advent of advances in computer capabilities which made such a system feasible. The JOSHUA features that are of interest to the Dose-To-Man Program are its data management capabilities and the great flexibility allowed through modular structuring. The JOSHUA system provides efficient management of large volumes of data, while providing the flexibility to perform calculations over a wide range of complexity.

A JOSHUA configuration of a method currently in use at SRL to estimate environmental effects of atmospheric releases is shown in Figure 1. Although this operational system is currently simple in structure, it will become more complex as additional modules and data bases are included. The significant point to

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† Work done by R. E. Cooper.

be made applies to a configuration of any complexity; i.e., the data records (shown on the cylindrical symbols) exist as named data records, and the data communications are automatically established by JOSHUA through the various execution modules (rectangular symbols).

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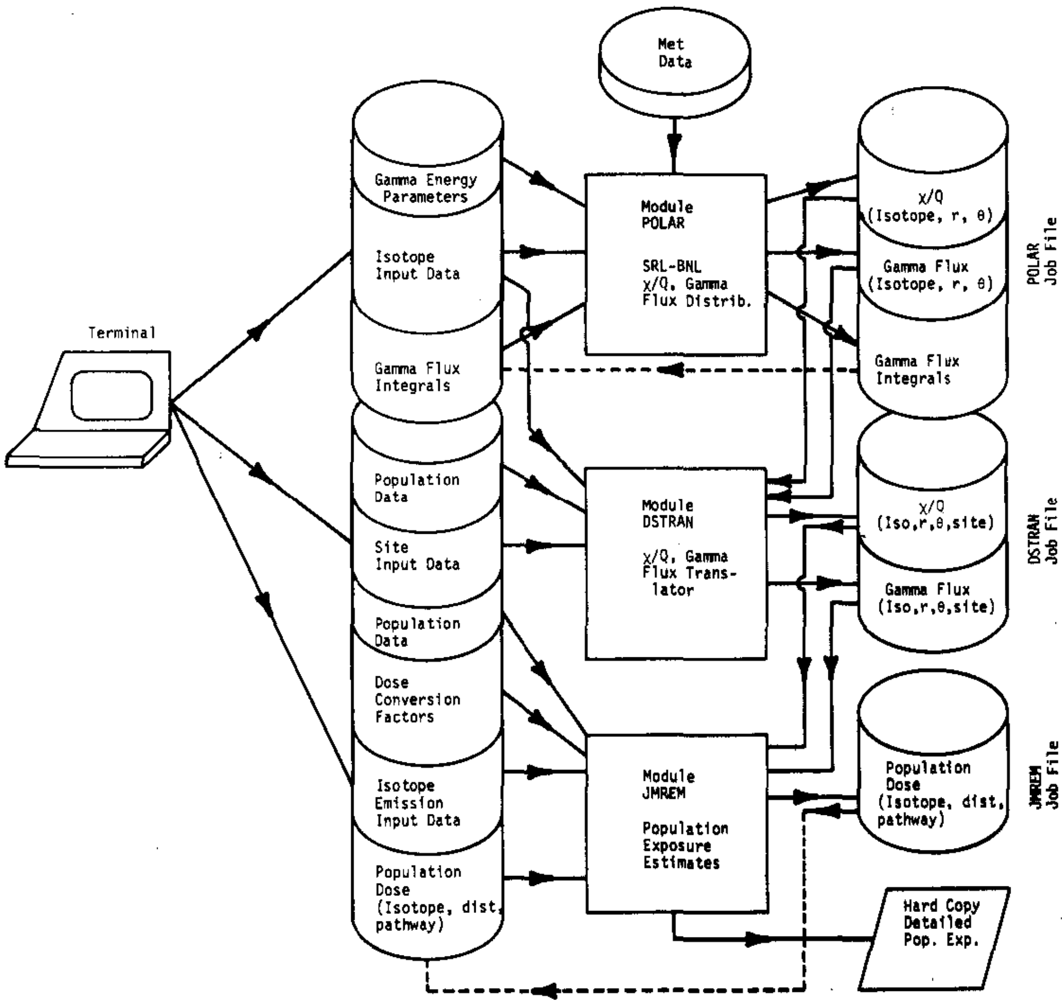

FIGURE 1. Dose-to-Man, SRL-BNL Polar Modules

40. A COMPUTER CODE TO PROVIDE EMERGENCY RESPONSE CAPABILITIES TO ESTIMATE WHOLE BODY GAMMA DOSE †

The Savannah River Plant (SRP) has several large reactors in routine operation for the production of various isotopes. The large inventory of radioactive materials contained in these reactors represents a possibility, although very remote, that radioactivity could be released to the environs in the event of an accident. Each reactor has an activity confinement system designed to remove almost all of the iodine fission products and particulates from the effluent stream. However, none of the noble gases (kryptons and xenons) would be removed. Therefore, the most significant radiological consequences of a reactor accident would be whole body dose from exposure to gamma radiations from a moving cloud or "puff" of radioactive gases. Due to the long mean-free path of gamma photons in the energy range of interest, the dose from a passing cloud of gamma emitters is not related to air concentrations at the receptor point. To estimate properly the whole body gamma dose, the gamma flux resulting from the total spatial distribution of gamma emitters must be integrated with respect to a receptor point.

A computer code, ERGAM, was written to estimate gamma dose efficiently in terms of input requirements necessary to initiate the job on the IBM 360/195 and in terms of computer time required to execute the job. The computer time requirement is less than 0.1 second per dose estimate as a function of downwind distance. Output from the code is immediately available at remote tube display terminals, so that no delay is incurred due to printing requirements. ERGAM, therefore, represents an extension of the capabilities already in effect to implement emergency response in accident situations.

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†Work done by R. E. Cooper.

41. COMPARISONS BETWEEN DOSE CALCULATIONS FROM ENIVRONMENTAL MONITORING DATA AND CARDOCC, A CHRONIC AQUEOUS RELEASE DOSE CODE †

INTRODUCTION

The primary aqueous releases from the Savannah River Plant (SRP) are by surface streams to the Savannah River. Any radioactive material reaching the river in these releases is available to the public from consumption of river water and foodstuffs and from direct radiation in proximity to the river. An extensive sampling program measures radioactivity in water, fish, and foodstuffs from offplant locations.

A computer code, CARDOCC, was developed to implement predictive dose models resulting from exposure to chronic aqueous releases from a nuclear facility, particularly from SRP. CARDOCC considers doses via internal pathways, such as consumption of water and fish, and external pathways, such as shoreline activities, boating, and swimming. The internal pathway dose is calculated for the whole body, gastrointestinal (GI) tract, bone, and six internal organs. The external pathway dose is calculated for whole body and skin. Comparison of results between calculated doses from CARDOCC and from environmental monitoring data show good agreement. This demonstrates the capability to calculate individual dose commitments from SRP aqueous releases using only stream release data with no downstream measurements.

METHOD

The model considers direct input to the river. The annual release is assumed uniform throughout the year and diluted by the river at the average annual flow rate. No deposition or radioactive decay is used in this calculation, although the model provides for entry of these factors. The fish pathway uses bioaccumulation factors to relate radioactivity levels in the fish to the levels in the water.

Dose calculational methods in CARDOCC are those recommended by the International Commission on Radiological Protection (ICRP).

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† Work done by J. R. Watts.

For each nuclide, CARDOCC calculates the dose commitment, i.e., the dose that the organs will receive in the 70-year period following the assimilation.

DISCUSSION AND RESULTS

The comparison between calculated doses from CARDOCC and from environmental monitoring data is shown in Table 1. The dose to the whole body via drinking water is 99% from tritium. Strontium contributes over 90% of the dose to the bone. The environmental monitoring dose calculations are from tritium measurements in potable water supplies. The model uses predicted tritium concentration from aqueous releases. Both systems, CARDOCC and environmental monitoring, use predicted strontium content because actual content is less than the detectable limit.

Table 2 shows a comparison of whole body dose from fish consumption. Eighty percent of the whole body dose is due to $^{134,137}Cs$. CARDOCC dose estimates are based on predicted water concentrations with resulting bioaccumulation in fish. Environmental monitoring data are radiometric analyses of fish from the river.

These comparisons document the adequacy of the model to predict individual radiation doses from SRP aqueous releases.

TABLE 1

Dose Commitment to an Individual from Consumption of Water from the Savannah River, mrem

	Whole Body		*Bone*	
Year	*Env. Mon.*	*CARDOCC*	*Env. Mon.*	*CARDOCC*
1973	0.45	0.61	0.08	0.12
1974	0.36	0.52	0.11	0.11

TABLE 2

Dose Commitment to an Individual from Consumption of Savannah River Fish, rmem

	Whole Body	
Year	*Env. Mon.*	*CARDOCC*
1973	0.20	0.14
1974	0.25	0.18