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SAVANNAH RIVER LABORATORY ENVIRONMENTAL TRANSPORT AND EFFECTS RESEARCH

ANNUAL REPORT - 1976

SAVANNAH RIVER LABORATORY
AIKEN, SOUTH CAROLINA 29801

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ABSTRACT

Research in the environmental sciences by the Savannah River Laboratory has a general objective of improving our understanding of transport through ecosystems and functional processes within ecosystems. With improved understanding, the basis for environmental assessments can be improved for releases from the Savannah River Plant (SRP) or from the power industry of the southeastern United States.

This report, for the calendar year 1976 and the last half of 1975, is organized into several discipline-specific sections, each of which includes a series of short summary articles on individual studies. The subjects are:

- *Soil and terrestrial ecology studies* focused on characterization of transuranic element emissions from an SRP reprocessing plant; uptake of transuranics by deer, corn, and bee pollen; conversion processes for molecular tritium to oxidized tritium in soil-plant systems, and the resulting effect on dose calculations caused by cycling tritium through forest ecosystems; the biodegradation of waste oil in soil-plant systems; the effect of operating an SRP powerhouse for over 20 years on trace element concentrations in surrounding terrestrial ecosystems; the use of an old coal ash basin for agriculture; and a radiological survey of the Savannah River marine region.

- *Geologic studies* focused on developing a conceptual geohydrological model, collecting hydraulic conductivity data for the shallow geologic formations in the vicinity of the SRP reprocessing plants, and installing an SRP seismograph network.

- *Aquatic transport studies* focused on modeling the transport of sediments in reactor effluent streams, understanding the heat loss in a small cooling pond, instrumenting a navigational light tower off the Savannah River estuary, measuring the movement of tritium in the Savannah River estuary, and attempts to develop a physical oceanographic data set for the southeastern United States Continental Shelf.

- *Aquatic ecology studies* focused on determining the responses of periphyton productivity and composition, and shifts in temperature optima caused by thermal stresses in streams and cooling-reservoir ecosystems; determining the effects of cooling systems on zooplankton populations and aquatic macrophytes in a cooling reservoir; and the effect of cooling systems on the survivability and distribution of *Aeromonas hydrophila* and *E. coli* in a cooling reservoir.

- *Atmospheric transport studies* focused on wind and turbulence statistics as applicable to diffusion calculations; comparing different methods of calculating transport and dispersion with each other and with environmental measurements of ^{85}Kr, special releases of deuterated methane and sulfur hexafluoride, and smoke from a controlled fire in logging debris; and summarizing current knowledge of diffusion velocities appropriate for developing parameters to determine the uptake of gaseous pollutants by vegetation.

- *Emergency response studies* focused on developing rapid methods for calculating and communicating information to assess the possible consequences of accidental releases to the atmosphere and to SRP streams.

- *Computer methods development* for environmental transport studies focused on developing an environmental data base extraction and graphical display system, developing a software system to link environmental data bases with various atmospheric calculational modules, improving numerical techniques for solving atmospheric diffusion equations, and developing three-dimensional models of atmospheric diffusion using strong and implicit techniques.

FOREWORD

This report is the third 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 calendar year 1976 and the last six months of calendar year 1975. From this point onward, the reports in this annual series will be on a calendar year instead of a fiscal year basis. 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 U. S. Energy Research and Development Administration divisions supporting that operation. During calendar year 1976, principal funding was by the Division of Nuclear Fuel Cycle and Production (DNFCP). That part of the effort which has general applicability to the energy industry of the southeastern United States was funded by the Division of Biomedical and Environmental Research (DBER).

An example of a major process development effort funded in support of the operation of SRP is the entire section on Geologic Studies in this report. Other specific studies in support of the SRP operation are sprinkled throughout the report.

During this report period, DBER directly funded seven separate environmental science programs at SRL, and administered the funding of one additional project on Environmental Protection Agency (EPA) pass-through funds at SRL. Most of the research reviewed in this report was accomplished in support of DBER programs.

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 with 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 SRL research on transuranics in terrestrial ecosystems was in collaboration with a separately funded program at the Savannah River Ecology Laboratory

(operated by the University of Georgia), the Environmental Monitoring Group of the Health Physics Section of SRP, the U. S. Forest Service group on the Savannah River site, and the Argonne National Laboratory. Marine science programs are in collaboration with the Skidaway Institute of Oceanography, with the National Oceanic and Atmospheric Administration (NOAA) marine laboratories at Beaufort, North Carolina, and other ERDA-funded oceanographic groups in the southeastern United States. The Atmospheric Release Advisory Capability (ARAC) program has involved direct interaction with SRP personnel and joint research with the Lawrence Livermore Laboratory. Measurements of environmental ^{85}Kr are being interpreted in collaboration with the Air Resources Laboratory of NOAA at Silver Spring, Maryland. The ^{85}Kr was analyzed at the Argonne National Laboratory.

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

This report was prepared principally by the ETD of SRL, with contributions in the environmental sciences by other SRL divisions, and with other collaborators from both on and off the plant site. The author credits show that many of the collaborators are people from universities of the southeastern United States.

Other environmental efforts performed by Du Pont personnel at the site, such as the large effort of the Savannah River Plant Health Physics Section in environmental monitoring, the portion of the National Uranium Resource Evaluation (NURE) program being conducted by SRL, the environmental effects effort being done in support of the closing of the fuel cycle for the light water reactor industry, and beginning geologic efforts in support of the National Waste Terminal Storage program, are reported elsewhere.

Todd V. Crawford, Research Manager
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CONTENTS

III. AQUATIC TRANSPORT STUDIES

IV. AQUATIC ECOLOGY STUDIES

I. SOIL AND TERRESTRIAL ECOLOGY STUDIES

The soil and terrestrial ecology studies use real source terms from SRP's nuclear complex to quantify the effects of these materials on the surrounding ecosystem (including man) and to produce information of general applicability to the energy industry of the southeastern United States. The research in the current year was focused on plutonium, tritium, waste oil, trace elements, and coal ash. The following articles (1 through 10) summarize the progress in these areas.

1. SOURCE-TERM STUDY OF PLUTONIUM-BEARING PARTICLES FROM A NUCLEAR FUEL REPROCESSING PLANT†

INTRODUCTION

Fuel reprocessing facilities at the Savannah River Plant (SRP) occasionally release small quantities of ^{239}Pu in particulate form. The total accumulated release of such particles has never exceeded 1 mCi/yr. A program to determine the origin and subsequent environmental behavior of this long-lived radionuclide was undertaken. As part of this study, airborne particles bearing plutonium were isolated from two exhaust systems in the plutonium finishing operation (JB-Line) in Building 221-F and their elemental compositions were determined.

METHODS

Particles were collected from air in both exhaust systems in JB-Line. One system takes room air from work areas and from inside wet cabinets (where plutonium is in solution) and transfers it to the JB-Line exhaust stack. The other system takes air from the mechanical line, air dryer, process vacuum, and furnace off-gas units and transfers it to the Building 291-F exhaust stack. Air was sampled almost continuously from five locations in the first system during June 1975 and from four locations in the second system during October 1975.

Exhaust air was filtered at 100 ml/sec through 47-mm-diameter polycarbonate membrane filters having 0.1-μm-diameter pores. Each filter was dissolved in 0.75 ml of 40 vol % 1,2-dichloroethane in dichloromethane. This solution was evaporated on a 2-in.-square glass plate to form a clear polycarbonate film containing the particles. Particles bearing plutonium were identified by irradiating the film with 4×10^{13} thermal neutrons/cm^2. Fission fragments from ^{239}Pu sensitized the polycarbonate resin along paths leading from these particles. The sensitized film was etched for ten minutes in 6N NaOH solution at 50°C to reveal fission-fragment tracks. Microscopic squares of the polycarbonate film containing a single particle with fission-fragment tracks were excised from the film and placed on a polished beryllium

† Work done by S. M. Sanders. Reported in: *Compositions of Airborne Plutonium-Bearing Particles from a Plutonium Finishing Operation*, S. M. Sanders. USERDA Report DP-1445, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, SC (1976).

sample-mounting block. Polycarbonate resin was washed from each particle with the 1,2-dichloroethane-dichloromethane mixture using microscopic techniques. Photomicrographs were made of each particle before and after washing to aid in analysis.

The elemental composition of the particles was determined at Arizona State University with a Cameca MS46 electron microprobe. Measured x-ray intensities for elements with atomic numbers greater than 10, together with estimates of particle size, shape, and density, were processed with the FRAME program[1] as modified for particle work by Armstrong,[2] and the elemental compositions were calculated.

RESULTS

A total of 279 particles were collected for analysis: 121 from the wet cabinets and 158 from the mechanical line unit by sampling the exhaust streams to the JB-Line and 291-F exhaust stacks, respectively. The distributions of minerals and oxides in 111 of the wet-cabinet particles are given in Tables 1 and 2. The size distributions for these particles are given in Table 3. Data from the remaining 168 particles are being evaluated.

Of 111 wet-cabinet particles, 105 contained element ratios commonly found in minerals in the SRP region, i.e. silica, kaolin clay, mica, and feldspar. Only six small iron particles, about 2 μm in diameter, contained no minerals. These findings indicate that most of these particles were crustal in origin. The particles also contained elements not found in appreciable quantities in the earth's crust: zinc was found in 73 of the particles, 64 particles contained nickel, chromium was found in 59, and copper was found in 39 particles. A total of 20 different elements were detected. Thus, these plutonium-bearing particles can be described as dust composed of polymineralic aggregates containing anthropogenic material.

All 279 particles selected contained plutonium, but the level of this element was too low to be detected by microprobe analysis in all but one particle. This lone particle was 1-μm in diameter and contained 73 wt % PuO_2, 14% Fe_2O_3, and 6% mica. Thus, most plutonium-bearing particles from these sources contain only trace quantities of ^{239}Pu.

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TABLE 1

Distribution of Clay, Quartz, Feldspar, and Mica in the Microprobe Analyzed Particles

Mineral in Particles, wt %	*Number of Particles Containing*			
	Clay	*Quartz*	*Feldspar*	*Mica*
0.05 - 4.99	20	14	20	5
5.00 - 9.99	11	7	10	7
10.00 - 14.99	8	3	7	5
15.00 - 19.99	8	11	3	10
20.00 - 24.99	3	5	4	5
25.00 - 29.99	3	5	4	4
30.00 - 34.99	3	-	-	1
35.00 - 39.99	3	2	1	2
40.00 - 44.99	3	4	-	-
45.00 - 49.99	2	3	-	-
50.00 - 54.99	-	1	1	-
55.00 - 59.99	1	1	-	2
60.00 - 64.99	-	-	1	-
65.00 - 69.99				
70.00 - 74.99				
75.00 - 79.99				
80.00 - 84.99				
85.00 - 89.99				
90.00 - 94.99				
95.00 - 100.00		6		
Total Number	65	62	51	41
Median, %	11.0	17.1	8.2	16.3

TABLE 2

Distribution of the Minerals and Constituent Oxides in the Microprobe Analyzed Particles

Material in Particles, wt %	*Number of Particles Containing*															
	Minerals	Fe_2O_3	TiO_2	*ZnO*	*CaO*	*NiO*	Cr_2O_3	*MgO*	*CuO*	Al_2O_3	K_2O	SO_3	*MnO*	*Cl*	WO_3	PuO_2
0.50- 4.99	4	7	53	33	42	43	44	23	26	9	27	10	3	3	1	
5.00- 9.99	7	17	14	20	15	7	7	11	7	8	1		3			
10.00- 14.99	9	17	1	10	7	2	5	5	4	2	3	1	2			
15.00- 19.99	10	6	2	2	2	3	1	5	1	4		1	1			
20.00- 24.99	4	12	1	6	1	3	1	2		1						
25.00- 29.99	9	12	1		1					1						
30.00- 34.99	8	5				1				4						
35.00- 39.99	14	6	2	1	1	1		1								
40.00- 44.99	2	5	1		1	1			1	2						
45.00- 49.99	6	2		1												
50.00- 54.99	4	3						1		1						
55.00- 59.99	6	2				2										
60.00- 64.99	9															
65.00- 69.99	4	3						1		1						
70.00- 74.99		1														1
75.00- 79.99		1														
80.00- 84.99	1	1														
85.00- 89.99	1	1														
90.00- 94.99	1															
95.00-100.00	6	6	—	—	—	1	—	—	—	—	—	—	—	—	—	—
Total Number	105	106	76	73	70	64	59	49	39	33	31	12	9	3	1	1
Median, %	35.1	22.7	2.1	5.7	3.3	3.0	2.2	5.8	1.9	9.2	1.8	1.2	8.5	3.4	1.2	73.4

TABLE 3

Size Distribution of Analyzed Particles

Particle Diameter, μm	*Number of Particles*
0.4 - 1.9	34
2.0 - 3.9	30
4.0 - 5.9	11
6.0 - 7.9	6
8.0 - 9.9	8
10.0 - 11.9	5
12.0 - 13.9	2
14.0 - 15.9	2
16.0 - 17.9	4
18.0 - 19.9	4
20.0 - 21.9	1
22.0 - 23.9	0
24.0 - 25.9	1
26.0 - 27.9	1
28.0 - 29.9	0
30.0 - 31.9	0
32.0 - 33.9	0
34.0 - 35.9	1
36.0 - 37.9	1
Total	111

2. PLUTONIUM CONTENT IN DEER IN THE SOUTHEASTERN UNITED STATES†

INTRODUCTION AND SUMMARY

The objective of this study was to determine the distribution of plutonium in tissues of deer foraging on natural vegetation in the southeastern United States. The deer were obtained from North Carolina, Georgia, Alabama, and the Savannah River Plant (SRP) in South Carolina. Nuclear fuel reprocessing plants and global fallout are the primary sources of plutonium at SRP. Plutonium analyses of deer indicate that the plutonium content of onsite deer muscle is similar to values in offsite deer.

METHOD

Three native white-tailed deer *(Odocoileus hemionus)* were collected in August 1975 at SRP. Two of the deer were obtained 1 km from the SRP nuclear fuel reprocessing plants, and the third deer, approximately 5 km from the plants. A single deer was obtained from each of the following southeastern states: Alabama, Georgia, and North Carolina. Samples of the bone, muscle, liver, and lung were oven-dried, ashed, and analyzed for plutonium content.

RESULTS AND DISCUSSION

Table 1 summarizes the plutonium concentrations in selected portions of the deer. There were no significant differences in plutonium concentrations between the lung and muscle from the onsite and offsite deer. The bulk of the plutonium in an onsite deer resides in the bone (Table 2). Bones of deer at SRP contained a significantly higher concentration of plutonium than those in bones of offsite deer. Even though the plutonium concentrations of bone of deer from SRP were significantly higher than those of deer from neighboring states, plutonium content of bone of deer from Mississippi[1] had plutonium concentrations similar to SRP values. Plutonium concentrations of muscle are similar to published values for meat, cattle, and reindeer (Table 3).[2,3,4] Therefore, there is no apparent increase in plutonium content of edible flesh in deer that have foraged adjacent to a large nuclear fuel reprocessing plant.

† Work done by M. B. Kirkham, Faculty Research Participant (University of Massachusetts, Amherst, Massachusetts), and J. C. Corey.

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TABLE 1

Plutonium Concentrations of Deer

Location	*Pu Concentration, fCi/g dry weight*			
	Bone	*Liver*	*Muscle*	*Lung*
Onsite:[a]				
Mean	0.70	0.59	0.05	0.29
Range	(0.67-0.76)	(0.25-1.01)	(0.01-0.12)	(0.22-0.36)
Offsite:[b]				
Mean	0.14	0.21	0.06	0.20
Range	(0.09-0.16)	(0.20-0.23)	(0.03-0.08)	(0.14-0.30)

a. 3 deer from SRP.

b. 1 deer each from Alabama, Georgia, and North Carolina.

TABLE 2

Plutonium in Onsite Deer

Organ	*Mass, kg*[a]	*Pu Concentration*[a]	
		pCi/kg[a]	*pCi*
Bone	9	0.70	6.30
Liver	1	0.15	0.15
Muscle	30	0.01	0.30
Lung	1	0.03	0.03

a. Wet weight.

TABLE 3

Comparisons of Plutonium Contents of Muscle

Muscle Source	*Concentration, fCi/g muscle*[a]	*Reference*
Meat	0.01	2
Cattle (in Western U.S.)	0.02	3
Deer (SRP)	0.05	
Deer (Southeastern U.S.)	0.06	
Reindeer (Sweden)	0.04	4

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a. Dry weight.

3. UPTAKE OF THREE ISOTOPES OF PLUTONIUM FROM SOIL BY SWEET CORN GROWN IN A GROWTH CHAMBER†

INTRODUCTION

A gamma-emitting isotope of plutonium for simulating ^{238}Pu and ^{239}Pu behavior in the environment would eliminate the high cost of sample preparation necessary for detecting alpha particles. To date, selected tracers for this purpose have not been satisfactory; however, the availability of ^{237}Pu has provided an additional candidate tracer. ^{237}Pu has been used to trace ^{239}Pu in metabolic studies of plutonium distribution in, and excretion by, dogs and rats[1] and to determine the distribution coefficient of plutonium between sediment and sea water.[2] The suitability of ^{237}Pu as a tracer for ^{238}Pu and ^{239}Pu in environmental systems was determined using a plant-soil system. These three isotopes were compared by measuring their uptakes by sweet corn. A nitrate solution containing all three isotopes was added to the soil. The apparent availability of the three isotopes differed: ^{237}Pu was more available than ^{238}Pu, which was more available than ^{239}Pu. The quantity of ^{237}Pu in the standing crop, on a mass basis, closely approximated that of ^{238}Pu.

METHOD

Soil, collected from a depth of 0 to 15 cm from an area northeast of the Savannah River Plant, was spiked using a modified form of the layering technique described by Cummings.[3] For each of 20 pots, 2 ml portions of the plutonium solution were mixed with 40 g of soil and placed uniformly in a pot. This step was repeated until each pot contained 2 kg of soil spiked with 0.5 μCi of ^{237}Pu, 0.03 μCi ^{238}Pu and 0.066 μCi of ^{239}Pu. Resuspension of plutonium was prevented by the addition of 3 cm of unspiked soil to the surface in each pot. Fertilizer was added to the soil surface of each pot at an N-P-K ratio of 160-100-160 mg in the form of ammonium nitrate, potassium nitrate, and monobasic potassium phosphate.

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† Work done by L. W. Hersloff (graduate student, University of Georgia, Savannah River Ecology Laboratory, Aiken, South Carolina) and J. C. Corey.

Two sweet corn seeds, *Zea mays L.* var. Silver Queen, were planted in the unspiked soil layer of each pot. The pots were placed in a controlled temperature chamber which was maintained at 30°C during the day and 20°C at night and had a 12-hour photoperiod. Watering replaced water losses from evapotranspiration. Thirty days after seedling emergence, 10 pots were randomly harvested and sampled for standing biomass and soil. The remaining 10 pots were sampled 50 days after seedling emergence.

The standing crop samples were ashed at 500°C, then counted directly using a dual NaI(Tl) detector-counting system for ^{237}Pu content. Ten oven-dried soil samples from each pot were counted in the same manner. On the basis of ^{237}Pu content in the soil samples, the coefficient of variation for plutonium distribution within pots was estimated to be 33%. The standing biomass samples were analyzed for ^{238}Pu and ^{239}Pu by alpha spectrometry following the separation of plutonium by solvent extraction. The concentrations of ^{238}Pu and ^{239}Pu in the soil were determined by combining the results of the above spiking solution additions and the coefficient of variation as determined for ^{237}Pu.

RESULTS AND DISCUSSION

The plutonium contents of the soil and standing vegetation for the 30- and 50-day sampling periods are shown in Table 1. The mean concentrations of all three isotopes in the standing crop decreased significantly ($p < 0.05$) from 30 to 50 days. The mean activity content of each isotope in the standing crop after 50 days was twice the content after 30 days, because the mean vegetation biomass increased from 4.4 g to 22.5 g between the two sampling periods.

The effect of time on the concentration of plutonium in vegetation is considered to be a result of biological dilution. This dilution is also reflected in a significant decrease in the concentration ratios [(pCi/g of vegetation)/(pCi/g of soil)] of the three isotopes over time. Although the decrease in the concentration ratios does not result in "order-of-magnitude" differences, it is an important consideration when comparing studies of plutonium uptake.

At both sampling times, the concentration ratios of ^{237}Pu were significantly greater than those of ^{238}Pu, which were greater than those of ^{239}Pu ($p<0.05$). Converting the values in Table 1 to a mass basis, expressed in picograms (pg), the ratio (^{239}Pu pg/g)/ ^{238}Pu pg/g) in the soils after 30 days of growth was 617; the ratio for vegetation was 244. The ratios for the same time

period for (^{238}Pu pg/g)/(^{237}Pu pg/g) were 42.5 and 2.6 for soil and vegetation, respectively. The isotopic ratios in vegetation for those plants grown for 50 days were 300 for (^{239}Pu pg/g)/^{238}Pu pg/g) and 2.2 for (^{238}Pu pg/g)/^{237}Pu pg/g). These results indicate differences in availability between plutonium isotopes. Similar variations in availability have been noted for ^{238}Pu and ^{239}Pu in environmental systems[4,5] and in physiological systems.[6] Hypotheses concerning mechanisms responsible for the observed isotopic differences include (a) a chemical explanation related to chelation, and (b) variations in physical properties, such as specific activity and energy of major radiations, which are expected to influence particle size.

The methods used in this experiment provided a thoroughly mixed solution of the three isotopes. An ion exchange technique determined that approximately 95% of each isotope was in the tetravalent state prior to spiking the soil. Given homogeneity of plutonium in the spiking solution and that the three isotopes were applied to the soil simultaneously, there is no basis in this experiment on which to suspect a chemical explanation for differential behavior of the plutonium isotopes.

The most apparent physical differences between the three isotopes of plutonium considered in this study are specific activity, type of major radiation, and energy of those radiations. The greater alpha energies of ^{238}Pu, which produce greater recoil energies, may partially explain differences in availability of these two isotopes.[4] ^{237}Pu decays primarily by electron capture, however, with negligible recoil energy to the nucleus. Subsequent radiations include neptunium L and K x-rays in the KeV energy range. The type and energy of major radiations of ^{237}Pu, therefore, cannot adequately explain the greater availability of ^{237}Pu as seen in this study.

A direct relationship was found between specific activity and plant uptake of plutonium. In this study, ^{237}Pu was more available for plant uptake than ^{238}Pu, which was more available than ^{239}Pu. The specific activities of these isotopes are 12075 Ci/g ^{237}Pu, 17.4 Ci/g ^{238}Pu and 0.061 Ci/g ^{239}Pu. Although the extent and exact mechanisms are as yet unknown, differences in specific activity offer a potential explanation for the differential behavior of the plutonium isotopes.

The greater availability of ^{237}Pu resulted in only a two-fold difference in the mass concentrations of ^{237}Pu and ^{238}Pu in the standing vegetation. This is encouraging for using ^{237}Pu for a tracer of ^{238}Pu. However, the close correspondence is only applicable for the levels of each isotope used in this study. Further studies are presently under way, encompassing a variety of activity levels and interactions of these plutonium isotopes, to establish clear relationships among them. These studies are particularly needed in light of the apparent differential behavior of ^{237}Pu, ^{238}Pu, and ^{239}Pu.

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TABLE 1

Summary of Soil and Standing Crop Data for ^{237}Pu, ^{238}Pu, and ^{239}Pu

Time of Harvest, days	*Plutonium Isotope*	*Activity*		*Concentration Ratio (CR)[d] (× 10^{-3})*
		Soil, pCi[a]/g[b]	*Standing Vegetation, pCi[a]/g[b,c]*	
30	^{237}Pu	237±78	1.7±0.4	7.2±3.7
	^{238}Pu	14.3±4.7	(6.4±2.3)×10^{-3}	0.45±0.16
	^{239}Pu	32.2±10	(5.4±3.8)×10^{-3}	0.17±0.11
50	^{237}Pu	246±81	0.7±0.1	2.8±0.5
	^{239}Pu	14.8±4.9	(2.2±0.82)×10^{-3}	0.15±0.056
	^{239}Pu	33.4±11	(2.4±0.72)×10^{-3}	0.072±0.022

a. pCi = activity in soil and standing crop corrected to time zero, ±1 σ.

b. Dry weight, in grams.

c. There were 5 samples taken of the standing vegetation.

d. CR = [(pCi/g of dry weight vegetation)/(pCi/g of dry weight soil)].

4. POLLEN AS A MONITORING TOOL†

INTRODUCTION

The purpose of this study was to evaluate the suitability of bee pollen as a biological indicator of trace metal levels in the environment. Tong[1] reported honey produced by bees in the vicinity of the New York State Thruway contained elevated levels of elements emitted by automobiles. Lasceve and Gonnet[2] showed a relation between mineral composition of a honey and its geographical origin. Hakonson, et al.[3] found that honeybees could be indicators of environmental tritium contamination. Even though pollen has been analyzed to study the effect of irradiation on plants[4] and pollen-collecting habits of irradiated bees,[5] it apparently had not previously been studied as a possible indicator of trace metal levels.

Pollen was collected and analyzed at the Savannah River Plant (SRP) to determine possible concentration of environmental trace metals by honeybees. The pollen was analyzed with neutron activation, spark source mass spectrometry, and gamma spectroscopy techniques. Pollen was found to be a sensitive indicator of radioactive contaminants, particularly cesium (Table 1). The data also indicate higher concentrations of trace elements exist downstream of SRP facilities.

METHODS

In April 1975, bee hives were placed at four places on the SRP site. One set of hives was placed beside Upper Three Runs Creek, a control site located upstream of any nuclear activities. A second set of hives was placed beside Steel Creek, a stream that received reactor effluent until 1967 and is known to have elevated levels of cesium. A third set of hives was placed beside Four Mile Creek, a stream that receives aqueous effluent from H-Area, a nuclear fuel reprocessing plant. A fourth set of hives was also placed on Four Mile Creek, downstream of the effluent from the two reprocessing plants at SRP. The pollen from foraging bees was removed with a pollen trap upon their return to the entrance of the hive. Pollen within each individual bee's pollen baskets was from a single plant species; however, different bees brought

† Work done by M. B. Kirkham, Faculty Research Participant (University of Massachusetts, Amherst, Mass.), K. W. MacMurdo, and J. C. Corey.

different pollens to the hive at the same time. The pollen was dried and analyzed.

RESULTS

Concentrations of stable elements were determined by spark source mass spectrometry and neutron activation analysis of the pollens, suspended solids in transport in Upper Three Runs Creek, and of a National Bureau of Standards fly-ash sample (Table 2). The iron, manganese, nickel, and zinc contents in the field pollens were significantly greater than in the pollens from the control area; although, in general, the stable element content of the pollen from locations downstream of plant facilities was higher than pollen from the Upper Three Runs Creek location. The stable element content of the pollen did not correlate with the stable element content of suspended solids in transport or fly-ash, which suggests that dust and fly-ash accumulation by the exposed flower is not affecting the elemental content of the collected pollen.

A number of fission products and naturally occurring radioactive elements were determined by gamma spectroscopy (Table 1). Elevated levels of cesium were found in the pollen, as expected, at locations of elevated cesium content in the soil. The relationship between ^{137}Cs and ^{134}Cs is dependent upon the burnup of the fuel and the time since the fuel left the reactor. As the material ages, the $^{137}Cs/^{134}Cs$ ratio increases because of the relative half-lives of ^{137}Cs and ^{134}Cs (30 and 2 years, respectively). At SRP, the ratio is usually 10 to 20. Ratios of 50 and 100 indicate the material is old. The trace quantities of ^{60}Co and ^{65}Zn are expected from operational activities. The increased concentrations of ^{40}K, ^{212}Pb, and ^{226}Ra (naturally occurring radioisotopes in the soil), in the vicinity of the production areas was unexpected and the reason is unknown.

This pollen research project confirmed that honeybees are excellent random samplers of relatively defined areas. The sampling can be temporal if the pollen sacs are stripped according to a time schedule and the pollen samples are classified. Vegetated areas that are difficult to sample by human collectors (bogs, steep slopes, etc.) can be routinely surveyed by analyzing collected pollen during flowering seasons.

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TABLE 1

Radionuclide Concentrations of Pollen at Different Locations on the Savannah River Plant Site

	Radionuclide Concentration, pCi/g			
			Four Mile Creek[c]	
Element	*Upper Three Runs Creek*[a]	*Steel Creek*[b]	*Near H-Area*	*Below F- & H-Areas*
A. Fission Products and Induced Activity				
^{137}Cs	0.34 ± 0.02	20.70 ± 0.19	20.60 ± 0.24	89.60 ± 0.36
^{134}Cs	ND[d]	0.37 ± 0.04	0.44 ± 0.05	0.90 ± 0.06
^{60}Co	ND	ND	0.15 ± 0.04	ND
^{65}Zn	ND	1.02 ± 0.11	ND	ND
B. Naturally Occurring Radioactive Elements				
^{40}K	2.26 ± 0.23	4.23 ± 0.54	4.70 ± 0.52	10.30 ± 0.63
^{212}Pb	0.16 ± 0.02	ND	ND	0.40 ± 0.06
^{226}Ra	0.45 ± 0.14	ND	ND	3.93 ± 0.65

a. Control area; located upstream of SRP manufacturing facilities.

b. Contains reactor effluent from production nuclear reactors.

c. Sampling areas located downstream from nuclear fuel processing areas.

d. ND = not determined.

TABLE 2

Stable Element Content of Pollen at Different Locations on SRP, Suspended Solids in Transport in Upper Three Runs Creek, and an NBS Standard Fly Ash

	Elemental Concentrations, ppm					
			Four Mile Creek[c]			
Element	*Upper Three Runs Creek*[a]	*Steel Creek*[b]	*Near H-Area*	*Below F- & H-Areas*	*Suspended Solids in Transport in Upper Three Runs Creek*	*NBS Fly Ash*
As	ND[d]	0.33	ND	ND	3	58
Ba	ND	0.84	ND	ND	ND	2700
Br	7.0	18.0	12.0	9.2	22	12
Cl	1100	2500	1400	1600	ND	42
Co	ND	0.3	0.38	0.4	14	42
Cr	1.3	4.3	4.0	3.6	ND	127
Cs	0.16	ND	ND	0.85	ND	8.6
Fe	79	300	215	220	14000	62000
K	2700	8500	8500	8800	1400	16100
La	0.06	ND	ND	0.2	40	82
Mg	ND	ND	2800	ND	ND	18000
Mn	7.9	44	115	135	110	49.6
Na	20	90	54	68	1200	3200
Ni	ND	0.26	0.35	0.65	ND	98
Sb	ND	0.26	0.2	6.5	ND	6.9
Sc	0.01	0.06	ND	0.02	3.0	27
Sm	ND	ND	ND	0.05	8	12
Zn	120	5500	5000	1600	ND	216

a. Control area; located upstream of SRP manufacturing facilities.

b. Contains reactor effluent from production nuclear reactors.

c. Sampling areas located downstream from nuclear fuel processing areas.

d. ND = not determined.

5. THE CONVERSION OF GASEOUS MOLECULAR TRITIUM TO TRITIATED WATER IN PINE NEEDLES†

INTRODUCTION AND SUMMARY

Molecular tritium, as well as other isotopes of hydrogen in the molecular form, is reported to be metabolized by soil microorganisms. Some of the metabolized hydrogen isotope is eventually incorporated into the free water of the soil matrix.[1,2] Much less work has been done on the hydrogen metabolism of higher plants. Cline[3] found tritiated water in the free water of beans exposed to molecular tritium gas.

Vegetation near nuclear facilities which release tritium to the atmosphere has elevated concentrations of tritiated water (HTO) in the free water when compared with HTO concentrations in free water in vegetation grown at some distance from the facilities. Because some of the tritium released from these facilities is in the form of HTO vapor, it has been assumed that the elevated concentrations were due to direct exchange of vegetation water with HTO in the atmosphere. However, in some cases the tritium concentration in the free water did not seem to be in equilibrium with the tritium concentration in the atmosphere.[4,5]

Exposures of pine needles show that absorption of molecular tritium takes place in the needles. The absorbed tritium is incorporated both in the tritiated water and in the dry fraction of the needles.

EXPERIMENTAL EXPOSURES OF PINE NEEDLES

Since exposures to a closed plant-soil system suggested that there might be conversion of molecular tritium to tritiated water in plants,[2] a series of exposures were conducted on the needles of loblolly pine under field conditions. A three-year-old sapling from a pine plantation was selected, and groups of needles were enclosed in a chamber. The chamber was constructed from a glass test tube and a split, two-hole stopper. Ambient air was pulled through the test tube with a pump connected to one of the holes

† Work done by C. E. Murphy, Jr.

in the stopper. The flow was held at a constant 1.5 liter/min. This allowed a turnover of air every 2 seconds. The high turnover rate kept the air in the chamber close to ambient conditions.

The needles (still attached to the living tree) were put in the chamber through the slit in the split stopper. The slit was sealed with a spongy plastic strip on either half of the stopper. Once in place, the chamber was supported by a test tube clamp on a laboratory stand. The exposures were made by introducing molecular tritium to the incoming air stream with a gas syringe. The pulse of the gas was of one minute duration in each case. The volumes of gas added were 5, 10, 25, and 50 cm^3, corresponding to 50, 100, 250, and 500 μCi of tritium activity. Ten replicates were made at each volume; except at 50 cm^3, when only six replicates were made.

After exposure, the needles were removed from the chamber, stripped from the branch, placed in sealed glass containers, and frozen in dry ice to stop leaf metabolism. The period between the end of an exposure and freezing was less than one minute to limit the loss of tritiated water vapor to the atmosphere. Later, the water in the needles was removed by freeze-drying and analyzed for tritium by the liquid scintillation technique. The dry material left after freeze-drying was combusted, and the water of combustion was collected and analyzed for tritium by the liquid scintillation technique.

RESULTS

The results of the experiment are illustrated in Figure 1. There is a measurable amount of tritium in both the freeze-dried water and in the water of combustion. While there is a great deal of variability within replicates for each of the exposure volumes, there is a trend toward increased tritium content at higher exposure rates. The relationship does not appear to be linear and suggests that the mechanism of tritium incorporation approaches saturation at the higher rates.

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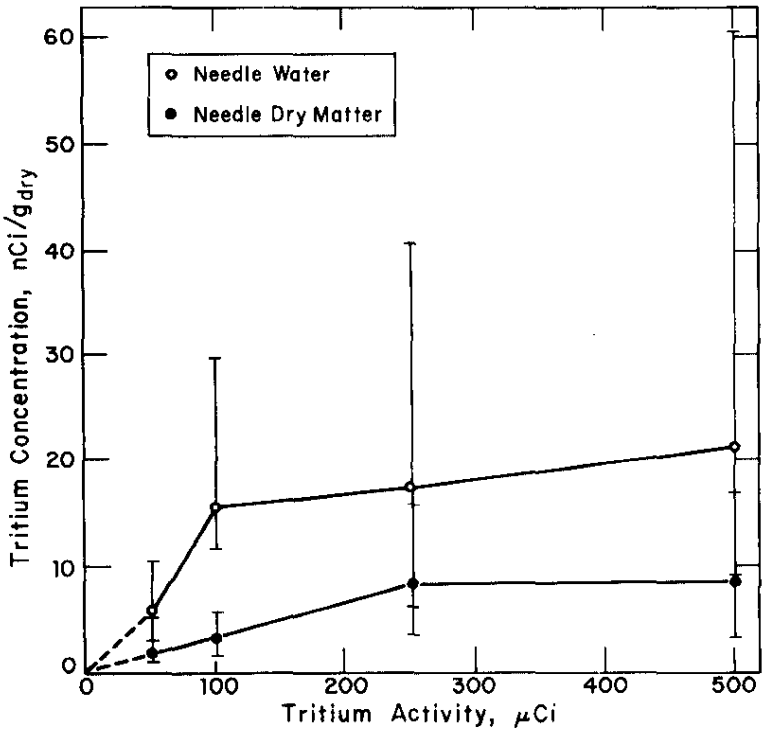

FIGURE 1. Activity of Tritium in Water and Dry Matter After Exposure to Gaseous Molecular Tritium

6. ASSESSMENT OF POTENTIAL RADIATION DOSE FROM AN ACUTE TRITIUM RELEASE INTO A FOREST ECOSYSTEM†

INTRODUCTION

An accidental release of 479,000 curies of tritium gas occurred at the Savannah River Plant (SRP) on May 2, 1974.[1] Environmental monitoring data confirmed that the release first touched the ground at the plant boundary, approximately 15 km from the release point. Standard meteorological methods calculated that the cloud would pass the contact point in approximately one hour.

The monitoring data showed that less than 1% of the release was tritiated water (HTO). Some of the HTO was assimilated directly into the forest ecosystem by diffusion and by direct exchange. The patterns of uptake suggest that some molecular tritium was converted to HTO by soil microorganisms and plants.[2] The HTO diffused and/or exchanged between soil and plants, maintaining an elevated air concentration after the initial puff had passed. Tritium was also observed in pine needles for 70 days.[3]

A model was developed which simulated the absorption of molecular tritium by forests and the subsequent release of HTO into the atmosphere. The predicted concentrations by the model are in agreement with the values of soil, leaf, and air concentrations of HTO found following the release of May 1974. The model predicts a diurnal cycle of tritiated water vapor with higher concentrations at night when air movement under the canopy is slow.

DOSE MODELS

Models used to describe tritium uptake by man assume that the tritium inhaled as HTO is exchanged in the respiratory tract and is retained in the body. Exposure to an atmosphere containing HTO results in an assimilation equal to inhalation.[4] Molecular tritium contributes no internal dose.

The internal dosimetry model for tritium for environmental dose evaluation at the SRP was proposed in the International Commission of Radiological Protection (ICRP) Publication 2.[5] The model has a single compartment of body water with an effective half-life of 12 days.

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† Work done by J. R. Watts and C. E. Murphy, Jr.

Long-term tritium uptake studies show tritium body retention is described by a three-compartment model: body water and two bound compartments. Available data suggest a model with elimination halftimes of 9, 30, and 450 days for the three compartments.[6]

DOSE COMPARISONS

The maximum potential dose to an individual was calculated three ways: 1) the single-compartment, body-water model (ICRP) predicts a potential dose of 0.14 mrem for tritium uptake only during passage of the cloud; 2) the same dose model predicts a potential dose of 0.80 mrem for tritium uptake from atmospheric concentrations that were calculated using the model which simulated the release of HTO into the atmosphere; 3) the three-compartment dose model, when combined with the model which simulated the release of HTO into the atmosphere, predicts a potential dose of 0.89 mrem.

CONCLUSION

The potential dose commitment from a tritium release is significantly affected by the ecosystem into which the material is deposited. In our observation, the forest ecosystem increased maximum dose from 0.14 mrem to 0.80 mrem. The dose calculated from passage of the cloud is clearly inadequate for radioactive materials which interact with the ecosystem.

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7. OIL BIODEGRADATION STUDY AT THE SAVANNAH RIVER PLANT†

INTRODUCTION

Waste lubricants and other organic liquids are a byproduct of most large industrial complexes. They are discarded by two methods: ponding (biodegradation) or burning. Both techniques have environmental impact. Oak Ridge, Tennessee, and Deer Park, Texas, studies found soil biodegradation acceptable for routine oil disposal.[1,2] At the Savannah River Plant (SRP), the majority of the used oils are burned in an onsite power plant as a supplemental energy source to coal. However, some organic fluids are not acceptable for burning. In July 1975, SRL began investigating soil biodegradation as a method to dispose of nonburnable organic liquids. To be an acceptable method, biodegradation must restore the fertility and appearance of the land to the preapplication level, and must permit no oil migration to the water table or to surface streams during the degradation process.

METHOD

The field study consists of 24 individual plots. The treatment levels were no fertilizer and three elevated levels of commercial fertilizer with a maximum of 0.5 kg/m^2 nitrogen, 0.2 kg/m^2 phosphorus, and 0.4 kg/m^2 potassium. Each treatment was replicated three times.

The oil applied to twelve plots was primarily a machine cutting oil with a viscosity similar to heavy automobile engine oil. Each plot had an oil application of 21.3 l/m^2 mixed into the top 15 cm of the soil.

RESULTS

The plots were sampled by soil cores taken with a 5-cm-diameter corer. The cores were divided into depth segments of 10 to 15 cm, 15 to 30 cm, and 30 to 45 cm. Cores were obtained before and after

† Work done by J. R. Watts.

application of fertilizer and oil, and at one, four, seven, eleven, and fifteen months after the initial application. The cores were analyzed by a commercial laboratory.[3] Oil content was determined by a petroleum ether extraction method. The average oil content of the three segments as a function of time is shown in Figure 1. Fertilizer application had no measurable effect. Oil content did not significantly decrease with time in the 0 to 15 cm segment, and only a minimum transport of oil into the 15 to 30 cm segment was found.

The rate of oil biodegradation was measured by the rate of carbon dioxide liberated from the soil by microorganisms. Several factors may limit the release of carbon dioxide from the soil surface;[4] e.g., soil water may absorb carbon dioxide, or hydrocarbons may be degraded without carbon dioxide emission when degradation is incomplete or when hydrocarbons accumulate in microbe cells.

The rate of carbon dioxide emanation from the plots is shown in Table 1. The mean for oil plots of 162 ±26 mg $CO_2/(m^2\text{-hr})$ is six times higher than the mean for nonoil plots of 26 ±10 $mg/(m^2\text{-hr})$. Two plots (one with oil and one without oil) were wetted, and the measurement of carbon dioxide emanation was repeated. The carbon dioxide emanation did not increase with addition of water, thus showing that lack of water is not growth-limiting for the microbes.

The productivity of the areas was evaluated by planting corn on the test sites nine months after the oil applications. Germination was <10% on oil-treated sites. Growth was very slow with all plants appearing chlorotic. Two applications of ammonium nitrate did not alter this characteristic. By contrast, the corn planted on oil-free plots germinated and grew luxuriantly with the application of fertilizer as would be expected.

CONCLUSIONS

Oil biodegradation by soil microorganisms is an environmentally acceptable method for disposal of oil. The oil applied to the soil did not migrate to either the water table or surface streams. An unpleasant odor was not present after the oil was tilled into the soil. Fertility and appearance of the soil will probably be restored to original conditions existing before the oil application. However, with the present test conditions, biodegradation was slow at SRP.

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TABLE 1

Carbon Dioxide (CO_2) Emanation From Soil at the Oil Biodegradation Study Site

Soil Site[a]	*CO_2 Emanation, mg/(m^2-hr)* Mean	±1 σ
A. All Plots without oil	26	10
No oil, 0 fertilizer	23	9
No oil, 1 fertilizer	31	12
No oil, 2 fertilizer	25	15
No oil, 3 fertilizer	23	6
B. All plots with oil	162	26
Oil, 0 fertilizer	157	40
Oil, 1 fertilizer	162	16
Oil, 2 fertilizer	151	15
Oil, 3 fertilizer	179	30

a. Fertilizer levels:
0 - no fertilizer
1, 2 - intermediate fertilizer
3 - maximum fertilizer

8. EFFECT OF STACK RELEASES FROM A COAL-FIRED POWERHOUSE ON TRACE ELEMENT CONTENTS OF NEIGHBORING SOIL AND VEGETATION†

INTRODUCTION AND SUMMARY

The Savannah River Plant 400-D Area powerhouse has operated since 1952 and consumes about 360,000 kg of coal per year. From startup until late 1975, this powerhouse operated without electrostatic precipitators. The objective of this study is to estimate the quantities of trace elements released before electrostatic precipitators were installed and to determine the influence of these releases upon the trace element content of surrounding soils and vegetation which are typical for much of the Coastal Plains of the Southeastern United States. Results to date indicate that none of twenty-six trace elements which have been measured in fly ash have produced measurable effects on the concentrations in soil or vegetation; however, mercury (not normally associated with fly ash because of its volatility) concentration in surface soil does appear to be influenced by stack releases.

METHODS

1. Fly ash, soil, and vegetation samples were analyzed using neutron activation, flameless atomic absorption spectrometry, and inductively coupled plasma emission spectroscopy.

2. The total quantity of fly ash released was calculated. Using measured concentrations of the trace elements in fly ash, the total quantity of each element released was estimated.

3. The deposition of each trace element at each location where soil and vegetation were collected was calculated using several years meteorological data previously collected at the Savannah River Plant.

4. Three depths of soil, 0 to 7.5 cm, 7.5 to 15 cm, and 15 to 30 cm were collected at 15 locations on a line extending 12.7 km from the stack in one direction and 16.5 km in the opposite direction. The minimum distance from the stack to a sample location was 1.8 km.

† Work done by J. H. Horton.

5. Samples of broomsedge (*Andropogon virginicus*), dog fennel (*compositifolium*), and panic grass (*panicum aciculare*) were collected at the same 15 locations at which soil was collected.

RESULTS

Fly ash release (in g per kg of coal burned) ranged from 24 to 62 and averaged 40. The ash content of coal ranged from 10.1% to 13.7% and averaged 12.1% during the stack gas sampling tests. During the 23 years operation, a total of 3.6×10^8 kg of fly ash was estimated to be released, and total deposition at the soil and vegetation sampling locations was estimated to range from 2.75 kg/m^2 to 0.026 kg/m^2.

Twenty-six trace elements were measured in fly ash. These were: As, Ba, Be, Br, Ce, Co, Cr, Cs, Cu, Eu, Ga, La, Mn, Mo, Ni, Pb, Sc, Sb, Sm, Sr, Tb, Th, U, V, Yb, and Zn. There was no measurable effect of these deposited elements on the concentrations in soil or vegetation, as concentrations did not decrease with distance from the stack. The concentrations of mercury (not normally associated with fly ash because of its volatility) in the top 7.5 cm of soil did decrease as distance from the stack increased (Figure 1), thus indicating a measurable effect of stack releases. This relation did not exist in the 7.5 to 15 cm depth or the 15 to 30 cm depth of soil. Only three of the 45 soil samples contained mercury in concentrations exceeding the world average of 0.07 ppm for surface soil.[1]

Analyses for mercury in vegetation and selenium and cadmium in all samples is in progress but not complete. Analyses for trace metals in ground water are in progress, and plans have been made to collect harvester ants which forage over a large area collecting seed for food.

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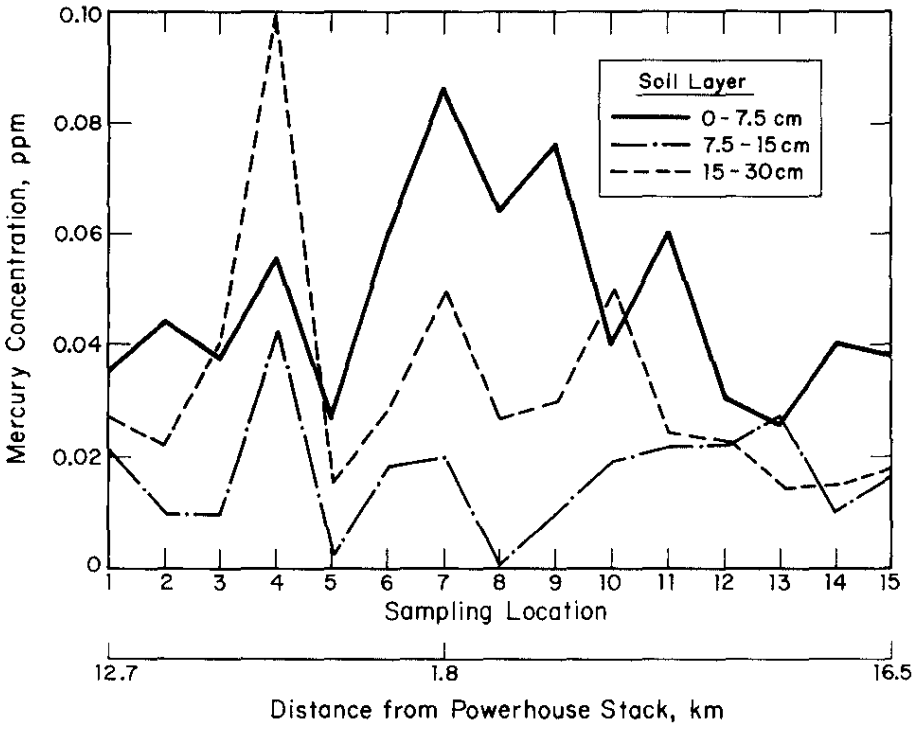

FIGURE 1. Mercury in Savannah River Plant Soil

9. ASH BASIN RECLAMATION FOR AGRICULTURAL USE†

INTRODUCTION AND SUMMARY

The disposal of coal ashes in the United States has consumed many hectares of land and removed it from production of food and fiber. Although ashes have possible economic value, their use has been very limited,[1] and the territory covered by them continues to grow. Because of the scarcity of arable land in England, reclamation studies were made two decades ago.[2] Those studies showed that some tolerant crops could be grown with a thin soil cover over the fly ash. One large Savannah River Plant ash basin filled with ashes from a stoker-fed boiler has been abandoned since 1964. During 1976, a study was begun to determine whether trees, grasses, or legumes could be grown on these ashes with only the fertilizer applications required on local agricultural soils. Loblolly pine, sweetgum, and sycamore seedlings have been successfully established, and survival and growth was much better on the ashes than on a local agricultural soil. Very unfavorable weather conditions caused a complete failure of grasses and legumes on both soil and ashes.

METHODS AND RESULTS

On January 26, 1976, seedlings of longleaf pine, loblolly pine, sweetgum, and sycamore were planted on both the ash basin and on a local agricultural soil. There were 4 replications with a plot containing 91 seedlings of each species in each replication. The data for survival of longleaf pine seedlings were disregarded, as these seedlings were improperly planted. Two droughts of long duration (one in February, March, and April, and the other in July and August) reduced survival and limited growth of all seedlings. Effects of the droughts were more severe on the seedlings planted in soil than on seedlings planted in ashes. As of August 24, 1976, the average number of trees surviving per plot were:

Species	*Soil*	*Ashes*
Loblolly pine	53	83
Sweetgum	34	71
Sycamore	55	82

† Work done by J. H. Horton.

To compare uptake of trace elements by the trees from soil and ashes, seven trees were harvested from each plot during the period August 30 and 31, and September 1, 1976. Soil and ashes were sampled as each tree was excavated. The trees were separated into leaves, stems, and roots. Trace metal analyses of all samples are in progress.

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10. AERIAL RADIOLOGICAL SURVEY OF THE SAVANNAH RIVER MARINE REGION†

SUMMARY

In December 1975, an airborne radiological survey of the Savannah River marine region was made to establish the present terrestrial exposure rate of this area and to determine if background radiation anomalies were present. Analyses of the survey data revealed over 80% of the area has an exposure rate of less than 4 μR/hr, and a small accumulation of ^{137}Cs has occurred in only one area, the dredge spoils on Hutchinson Island.

AREA SURVEYED

The survey of the local Savannah River marine area (Figure 1) included beaches, tidal creeks, open water, marshes (both fresh and salt), and bank areas adjacent to the Savannah River estuary. The survey was timed to roughly coincide with low water to minimize the shielding effect of water. The total area within the outside flight line, excluding the area north of Port Royal Sound, was 1340 km^2. About 12% of this area was surveyed by a flight pattern of 512 km in length and having a survey width of 305 m.

RESULTS

Exposure Rate

The exposure rate varied from about 1 μR/hr (overwater) to 9 μR/hr at one beach location on Wassaw Island. In general, the higher rates were over the beaches and are due to heavy minerals containing thorium and uranium. If water areas are excluded, the terrestrial exposure rate average is 3.3 (±1.1) μR/hr, which is comparable to other Coastal Plain rates of 1.5 to 3.1 μR/hr. This rate is about 1/2 the rate measured for the Savannah River Plant [6 (±2) μR/hr].[1] The Savannah River Plant (SRP) is situated in the Upper Coastal Plain area. The results of this survey and other related surveys of contiguous United States areas are compared in Figure 2. The Savannah River marine area exposure rate is similar to other Coastal Plain exposure rate patterns (Figure 2c and e) as expected.[2]

† Work done by D. W. Hayes.

Anomalies

A simple gamma ray spectrum substraction technique known as the Man-Made Gross Count (MMGC) was employed[1] to identify radiation anomalies. Positive MMGC counts indicated anomalies in gamma ray spectrum from man-made radionuclides or from natural Th-U-K deposits that differed from those of the area where gamma ray spectrum constants were determined. Only two areas (Figure 1) show the presence of anomalies: Area A, the dredge spoils on Hutchinson Island and on the north bank of the Savannah River estuary; and Area B, a marshy area on the west side (land side) of Daufuskie Island.

At least one component of a radiation anomaly on Hutchinson Island is ^{137}Cs. The average ^{137}Cs concentration in the spoils was determined to be 2.5 pCi/g (dry weight of soil). No other significant levels (>0.5 pCi/g) of man-made radionuclides were present. On the land side of Daufuskie Island, the anomaly apparently reflects a change in the natural Th-U-K deposits as compared to the background area for determining the constants for the MMGC subtraction routine. Samples have been taken in this area for radioisotopic analysis.

REFERENCES

1. P. K. Boyns. *Aerial Radiological Survey of the Savannah River Plant (Aiken, SC). Date of Survey: 2 thru 25 June 1974.* Report EGG-1183-1665, EG&G, Inc., Las Vegas, NV (1975).

2. D. T. Oakley. *Natural Radiation Exposure in the United States.* USEPA Report ORP/SID 72-1, Washington, DC (1972).

FIGURE 7. Measured Exposure Rates in the Savannah River Marine Region

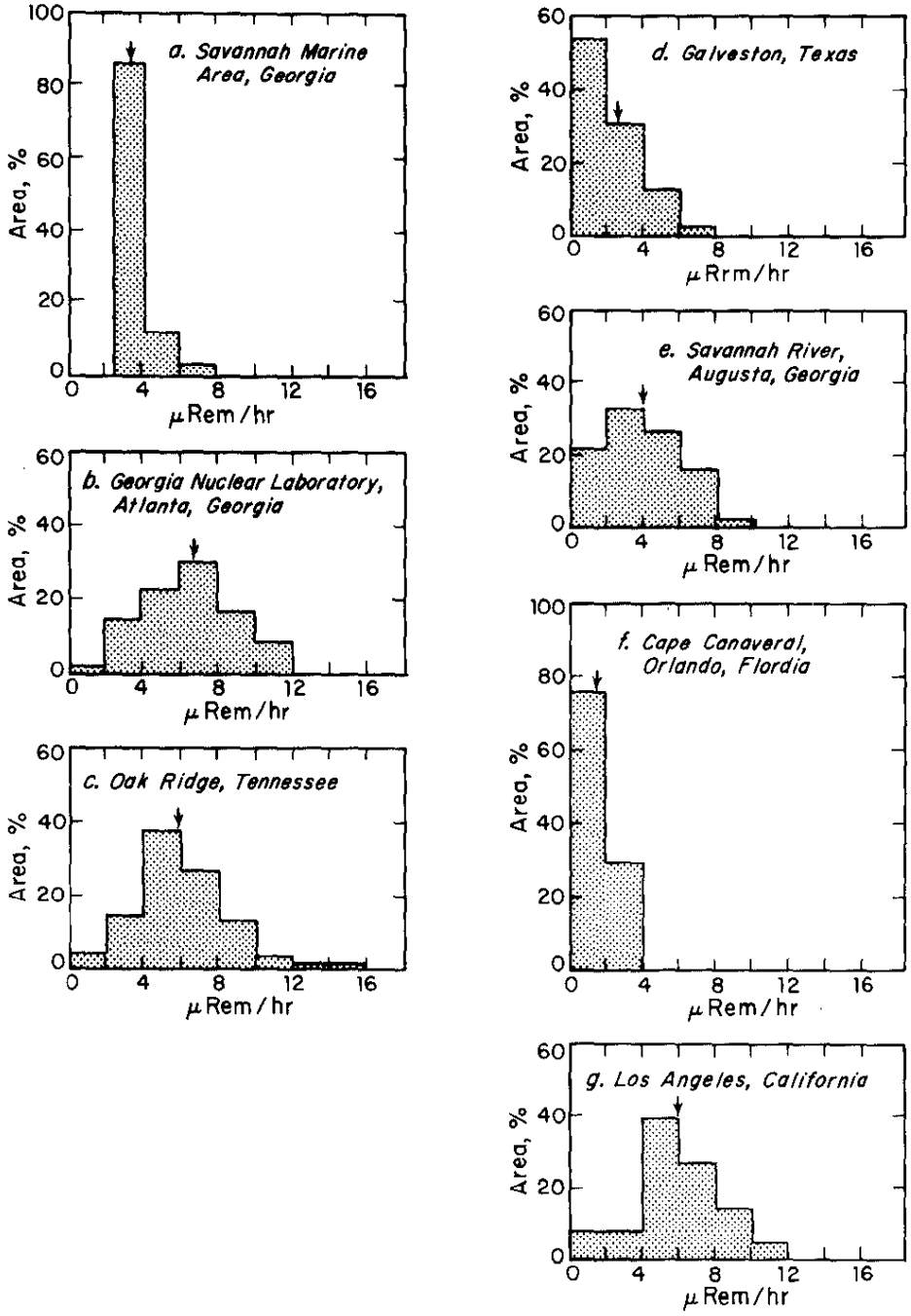

FIGURE 2. Dose Equivalent Rates in Several Areas of the United States (from Reference 2)

II. GEOLOGIC STUDIES

II

The objective of the geologic studies by the Environmental Transport Division is to characterize the forces operating within the solid earth that have or may have an effect on operations of the Savannah River Plant (SRP). Studies in two disciplines are currently being carried on: a) ground water/mass transport studies and b) seismic studies.

In the first of these studies, the ground-water flow in the separations areas of SRP is to be simulated by digital computer; later, the movements of dissolved ions in the ground water will also be simulated. The first three articles (11-13) report aspects of the ground-water studies. The first article presents a conceptual model of the framework through which the water passes, forming the basis for the quantitative numerical model. The second article presents the results of aquifer tests in part of the area being modeled to provide the numerical values that are to be input to the model. The third article presents an analytical shortcut for analyzing aquifer test data.

The last contribution describes the SRP seismograph system which was installed during the past year and its response to a local earthquake.

11. RESULTS OF PUMPING TESTS IN SHALLOW SEDIMENTS IN THE SEPARATIONS AREAS†

INTRODUCTION AND SUMMARY

Pumping tests in the shallow sediments were conducted in and around H-Area to determine values of hydraulic conductivity. These values were needed for a mathematical model to describe ground-water flow beneath the Separations Areas. The following median conductivities were measured:

Formation	*Conductivity, m/day*
Upper Barnwell	0.3
Middle Barnwell	0.04
Lower Barnwell	--
Upper McBean	0.13
Lower McBean	0.07
Congaree	1.5

TEST METHODS

Pumping tests were conducted by pumping water from a well at a constant rate and observing the drawdown of water levels with time in wells at a distance from the pumped well (called a drawdown test.)[1] Also, the rate of return of the water level to its original position in the pumped well after the pump was turned off was measured (called a recovery test).

The drawdown vs. time and recovery vs. time data may be analyzed by a variety of graphical techniques. Common to all these techniques are certain assumptions which must be met before the method can be strictly applied. These assumptions include:

1. The aquifer has an infinite areal extent but is of limited vertical extent.

2. The aquifer is homogeneous, isotropic, and uniform in thickness.

3. The pumped well is of infinitestimal diameter.

† Work done by R. W. Root.

4. There is no addition or subtraction of water from the aquifer except by the pumping well.

5. Water flow in the aquifer is horizontal.

The first assumption is approximately met because of the large areal extent of the shallow sediments underlying H-Area compared to the size of the drawdown cones. The second assumption is only approximate because of the variation of grain size and the distribution of clay in these unconsolidated Coastal Plain sediments. The third assumption may be met if the volume of water pumped is many times greater than the volume in storage in the well casing. Corrections may be made to the data using special techniques to satisfy Assumptions 4 and 5; i.e., when leakage to the formation occurs through confining layers (Assumption 4), or when the pumped well only partially penetrates the formation (Assumption 5).

Insofar as not all the assumptions were met by the conditions of the test, the results of pumping test analyses represent only approximations of the true hydraulic conductivities.

GEOLOGY

From the surface downward, the hydrologic units of interest are: (1) the Barnwell Formation, which consists of clays, sandy clays, and clayey sands about 30 meters thick; (2) a tan clay about 3 meters thick; (3) the McBean Formation, about 20 meters thick, which consists of an upper layer of clayey sand and a lower calcareous clay containing some small cavities; (4) a green clay about 3 meters thick; and (5) the Congaree Formation, consisting of layers of sand interbedded with layers of clay.

RESULTS

Drawdown and recovery tests have been conducted near the H-Area Waste Tank Farm with a few recovery tests at outlying sites. In cases where observation wells were available, values for both the drawdown test and the recovery test were determined. Many of the recovery data curves departed from a characteristic straight line associated with this type of analysis, perhaps indicating a violation of an assumption upon which the analysis was based. The drawdown tests conformed with "leaky" type curves as given by Walton.[2]

Instantaneous injection, or "slug," tests were also conducted. In a "slug" test, a volume of water is injected instantaneously into a well, and the rate of return of the water level to its original position is observed. "Slug" tests measure the hydraulic conductivity only in the immediate vicinity of the well and are strongly influenced by the construction features of the well. Therefore, the absolute value calculated from a "slug" test may not be a good estimate of the conductivity for a large segment of the formation. However, when compared to other "slug" tests, it is a means of defining relative conductivities of different parts of the formation.

All individual test values are plotted in Figure 1. Each individual data point represents a single well. A horizontal bar passing through a data point indicates a number of tests were conducted on one well. The length of the bar represents the range of values resulting from the different tests on that one well. Median values of hydraulic conductivity are also reported in Figure 1 for each test procedure.

The values of hydraulic conductivity (as measured by "slug" testing) for the different formations overlap; but generally, the Upper Barnwell Formation sand lens has higher conductivity than the Lower Barnwell Formation; which has, in turn, a higher conductivity than the Middle Barnwell Formation. Also, the Upper McBean Formation has a generally higher conductivity than the Lower McBean Formation. However, the values obtained from "slug" tests are generally higher than those obtained for the same formation by either of the two pumping test methods. The data from drawdown and recovery tests indicate that the conductivity of the sand lens in the Upper Barnwell Formation is higher than the conductivity of the Middle Barnwell Formation. Also, the Upper McBean Formation appears to have a higher conductivity than the Lower McBean Formation.

REFERENCES

1. E. E. Johnson. *Ground Water and Wells.* E. E. Johnson, Inc., Saint Paul, MN (1966).

2. W. C. Walton. *Selected Analytical Methods for Well and Aquifer Evaluation.* Bull. 49, Illinois State Water Survey (1962).

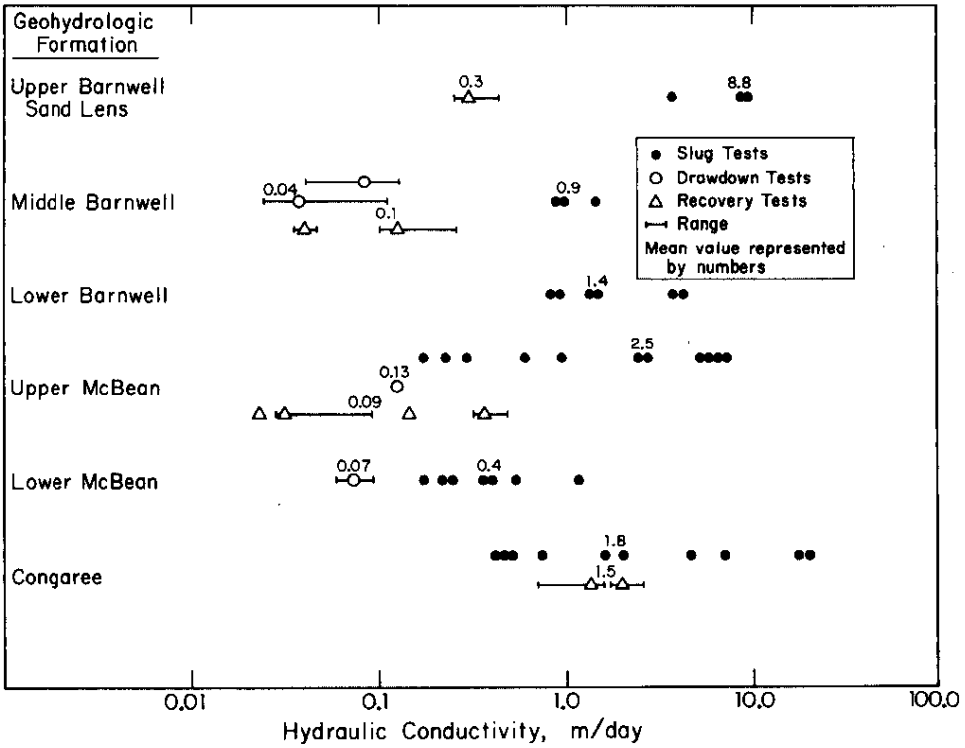

FIGURE 1. Hydraulic Conductivity Values from Different Wells

12. A COMPUTER PROGRAM TO ANALYZE AQUIFER TEST DATA†

SUMMARY

Aquifer test data were analyzed by a variety of curve-fitting and slope-measuring techniques to provide hydrologic information about water-bearing subsurface material. The curves are graphs of analytical functions, and these functions can be fitted to the field data by statistical techniques. A computer program was written for fitting field data by a nonlinear least squares technique. This method rapidly evaluates the hydraulic variables of the modeling equations for large data sets.

DISCUSSION

Pumping a well open to an aquifer (water-bearing formation) produces an inverted conical drawdown in fluid potential around the pumping well. The drawdown at an observation well may be described by an exponential integral function described by Equation 1:[1]

$$s = \left(\frac{Q}{4\pi T}\right)\left\{2\,K_o\,(r/B) - I_o\,(r/B)\,[-Ei\,(-\,r^2/4B^2u)] + [\exp\,(-\,r^2/4B^2u)]\left\{0.5772 + \ell n\,u + [-Ei\,(-u)] - u + u\,[I_o\,(r/B) - 1]\,/r^2/ \; - u^2 \sum_{n=1}^{\infty}\sum_{m=1}^{n} \frac{(-1)^{n+m}(n-m+1)!}{(n+2)!}\left(\frac{r^2}{4B^2}\right)^m u^{n-m}\right\}\right\}$$

where:

$$u = r^2 s/4Tt$$

and

$$r/B = r\,[T/(p'/m')]^{1/2} = \text{(a term proportional to the amount of leakage through the confining layer)}$$

† Work done by R. W. Root and C. E. Murphy, Jr.

s = drawdown in observation well, m

r = distance from pumped well to observation well, m

Q = pump discharge, m^3/day

t = time after pumping started, days

T = coefficient of transmissivity, m^2/day

S = coefficient of storage of aquifer (dimensionless)

p'= coefficient of vertical permeability of confining layer, m/day

m'= thickness of confining layer through which leakage occurs, m

K_o (r/B) = modified Bessel function of the second kind and zero order

I_o (r/B) = modified Bessel function of the first kind and zero order

E_i ( ) = exponential integral

The least squares routine for fitting the model equation minimizes the square of the difference between the observed and calculated drawdown by a direct search routine developed at the Savannah River Laboratory by L. M. Arnett.

Two separate subroutines are available depending on boundary conditions. The aquifer should be bounded above and below by confining layers. For the NONLEAKY case, these layers are taken as impervious; in the LEAKY subroutine, these layers allow water to pass through them. The LEAKY subroutine has more general application because, as leakage approaches zero, the LEAKY equation collapses to that of the NONLEAKY case.

Input to both subroutines includes r, Q, s, and t and initial guesses for T and S. In addition, for the LEAKY case, a value for m' and an initial guess p' must be made.

Fitting of the observed drawdown and time data to the theoretically generated curve may be done by minimizing either $\Sigma(s_c - s_o)^2$ or $\Sigma(\frac{s_c}{s_o} - 1)^2$, where subscript "o" denotes observed data and "c" denotes values calculated from the model. Minimizing $\Sigma(\frac{s_c}{s_o} - 1)^2$ gives a better fit for the rapidly varying earlier

period of the pumping test. The minimization of the function $\Sigma(s_c - s_o)^2$ weights the later data more than the earlier. Commonly in pumping tests, early data are not reliable due to such factors as adjustments to the discharge rate of the pump, which should be constant throughout the test. Weighting of later data may overcome this problem; therefore, the fit minimizing $\Sigma(s_c - s_o)^2$ is recommended.

Output of the program includes:

1. the initial guesses of T, S, and (when applicable) p'
2. a correlation matrix
3. calculated values of T, S, and p'
4. listing of the s and t data input and calculated s
5. several statistics, including the square of the multiple correlation coefficient

RESULTS

Several sample problems verified the accuracy of the program (Table 1). For the ideal cases, values of T, S, and p' were selected and substituted into Equation 1. The resulting calculated values of s at various t's were then input into the program, and final values of T, S, and p' were calculated. These final values generated by the computer were compared to the original input values. The Field Test data (Table 1) are from a workbook containing actual field pumping test data to illustrate different methods of analysis.[2]

The curve fitting of these data was done by the present authors. The differences between the curve fit and the computer results may be due to two factors. As seen in the differences in the ideal cases (Table 1), some error may be imposed by truncation error. For field tests, some error is caused by the departure of the field tests from the assumptions upon which the theoretical analyses are based, such as the homogeneity and isotropy of the porous medium and the infinitesimal diameter of the pumping well. The user must insure that the field tests do not violate the assumptions of the theory in order to minimize errors caused by departure from these assumptions.

REFERENCES

1. W. C. Walton, *Selected Analytical Methods for Well and Aquifer Evaluation.* Bull. 49, pp 4-5, Illinois State Water Survey, Urbana, IL (1962).

2. G. P. Kruseman and N. A. DeRidder. *Analysis and Evaluation of Pumping Test Data.* Bull. 11, pp 53-80, International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands (1970).

TABLE 1

Verification of Results

Computer Subroutine		*Curve Fit*	*Computer*	*Difference, %*
NONLEAKY:				
Ideal	T, m^2/d	1273	1242	2.4
	S	0.0002	0.0002	0
Field Test 1	T, m^2/d	489	499	2.0
	S	0.0002	0.0002	0
Field Test 2	T, m^2/d	450	481	6.5
	S	0.0001	0.0001	0
LEAKY:				
Ideal	T, m^2/d	1238	1239	0
	S	0.0001	0.0001	0
	p', m/d	0.101	0.099	2.0
Field Test	T, m^2/d	1688	1696	0.5
	S	0.00174	0.00175	0.6
	p', m/d	0.031	0.034	9.7

13. A CONCEPTUAL GEOHYDROLOGICAL MODEL OF THE SEPARATIONS AREA†

SUMMARY

Subsurface drilling in and around the Separations Areas (F-Area and H-Area of the Savannah River Plant) is providing detailed information for a conceptual model of the geology and hydrology underlying these areas. This conceptual model will provide the framework needed for a mathematical model of groundwater movement beneath these areas. Existing information substantiates the presence of two areally extensive clay layers and several discontinuous clay and sandy-clay layers. These layers occur in and between beds of clayey and silty sand that make up most of the subsurface material. Within these sand beds are geologic units of differing hydraulic conductivity. For the present scale of the model, the subsurface information is considered adequate in H-Area, but additional drilling is planned in F-Area.

GEOHYDROLOGIC UNITS

Figure 1 shows the locations of the two geologic cross sections given in Figures 2 and 3. Section A-A' (Figure 2) generally parallels the direction of dip of the subsurface materials, while Section B-B' (Figure 3) is approximately perpendicular to the direction of dip.

Each cross section is generally divided into five geohydrologic units. These are, from the surface downward: (1) the Barnwell Formation, consisting of sands, clayey sands, and sandy clays; (2) a tan clay; (3) the McBean Formation, consisting of an upper yellow clayey sand and a lower calcareous sandy clay, which has some small cavities caused by solution of disseminated calcareous material; (4) a green clay; and (5) the Congaree Formation consisting of fine sand layers interbedded with clay.

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

HYDROLOGY OF THE STRATA

General Discussion

The clay layers are significant hydrologically because they retard the downward movement of ground water. Therefore, water levels in wells open above an extensive clay layer will stand higher than levels in a well open below the clay. Some clay layers are evident in only one well and cannot be correlated over a large area. They are indicated by small lenses (diamond-shaped features) on the cross sections. The lenses are probably not hydrologically significant at the scale of the present model. However, the major extensive layers must be considered in the mathematical model.

Grain-size distribution and clay content in the sand beds will influence the hydraulic conductivity of the material. Typically, silty sands allow more rapid movement of water than clayey sands. With this relationship and information from the subsurface drilling, the basic hydrologic units may be divided into sub-units of differing hydraulic conductivity.

The division of the Barnwell and McBean Formations into zones of different conductivity based on grain-size distribution and clay content is supported by the results of instantaneous injection (or "slug") tests (Table 1). These tests consist of injecting a volume of water into a well and measuring the rate of decline of the water level as it returns to its original level. The conductivity value resulting from a slug test may be influenced by factors other than hydraulic conductivity. However, when performed on similarly constructed wells, the results of slug tests are of value in defining areas of differing relative hydraulic conductivity.

Barnwell Formation

In Section A-A' on Figure 2, the Barnwell Formation appears to be divisible into three units: (1) a lower unit of silty sand, (2) a middle unit of clayey sand, and (3) an upper unit of clayey sand that includes several extensive clay beds and some discontinuous sand beds. The lower unit is separated from the middle unit by a dashed line on Figures 2 and 3. The hydraulic conductivity of the lower unit consisting of silty sand is about twice that of the middle clayey sand unit (Table 1). The clayey sands of the upper unit are probably of about the same hydraulic conductivities as those of the middle unit. However, the hydraulic conductivities of the clays in the upper unit are much less, whereas those of the sands are greater by about 5 times.

Along Section B-B' (Figure 3), slug test confirmation of the hypothesized conductivity distribution is lacking for the Barnwell Formation because much of the formation is above the water table.

McBean Formation

The McBean Formation is divisible into two parts on the bases of lithology and hydraulic conductivity (Table 1). The upper part is a silty sand or a clayey sand and has a conductivity that is generally higher than that of the lower part. The Lower McBean Formation is commonly a calcareous sandy clay or sandy silt; but in many locations, the calcareous material has been dissolved and removed, leaving the formation honeycombed with small openings. Where calcareous material has been removed, the formation will commonly not support the weight of drilling rods and will accept large quantities of water, drilling mud, or cement. However, these areas of small openings occur as pockets in a zone that otherwise has a low hydraulic conductivity. Thus, the overall hydraulic conductivity of the Lower McBean Formation is one of the lowest of the sandy sediments shown on Table 1.

Congaree Formation

The hydraulic conductivity of the Congaree Formation is characterized by a wide range depending on the nature of the material. However, it commonly has a hydraulic conductivity high enough to furnish small water-supply wells with water elsewhere on the Savannah River Plant Site.

TABLE 1

"Slug" Test Results

Geologic Unit	*"Slug" Test Hydraulic Conductivities, m/day*	
	Range	*Median*
Upper Barnwell (sand lens in clayey sand)	3.8 - 9.4	8.8
Middle Barnwell (clayey sand)	0.9 - 1.4	0.9
Lower Barnwell (silty sand)	0.8 - 4.1	1.4
Upper McBean (silty sand)	0.2 - 7.0	2.5
Lower McBean (calcareous sandy clay)	0.2 - 1.2	0.4
Congaree (sand layer interbedded with clay layers)	0.4 - 19	1.8

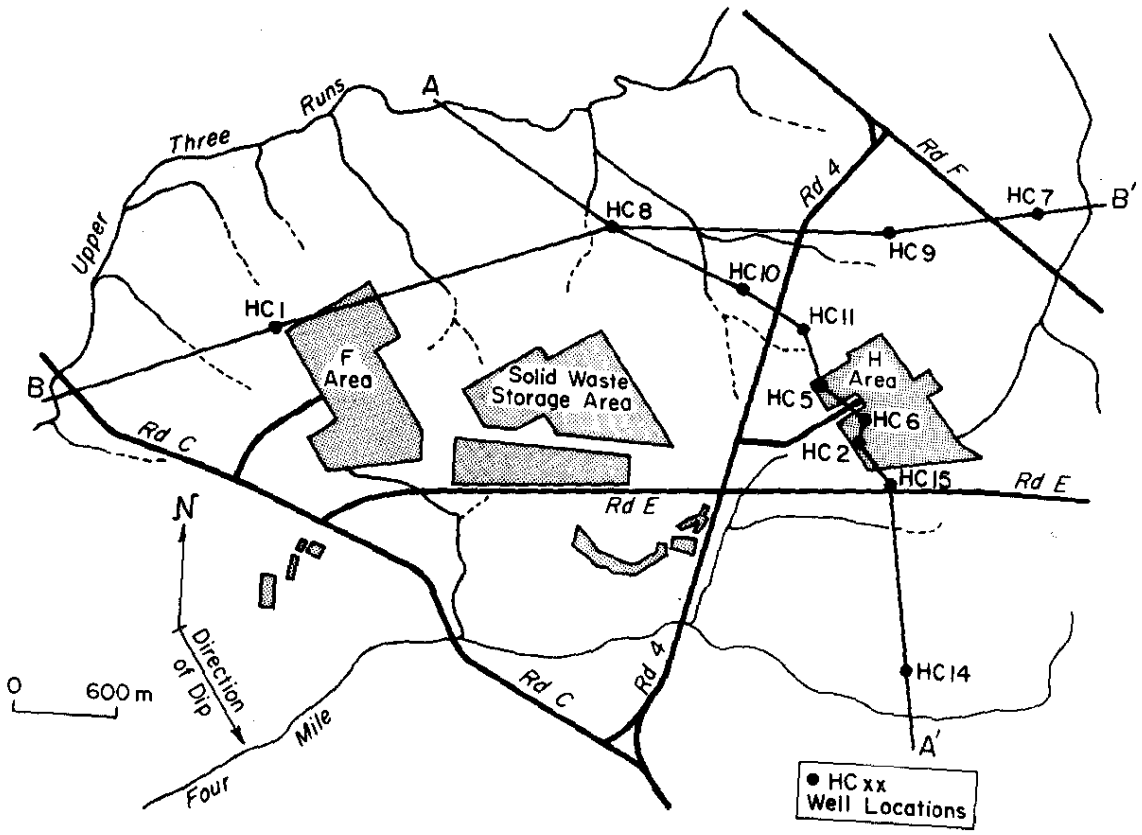

FIGURE 1. Areal Map and Cross-Section Locations

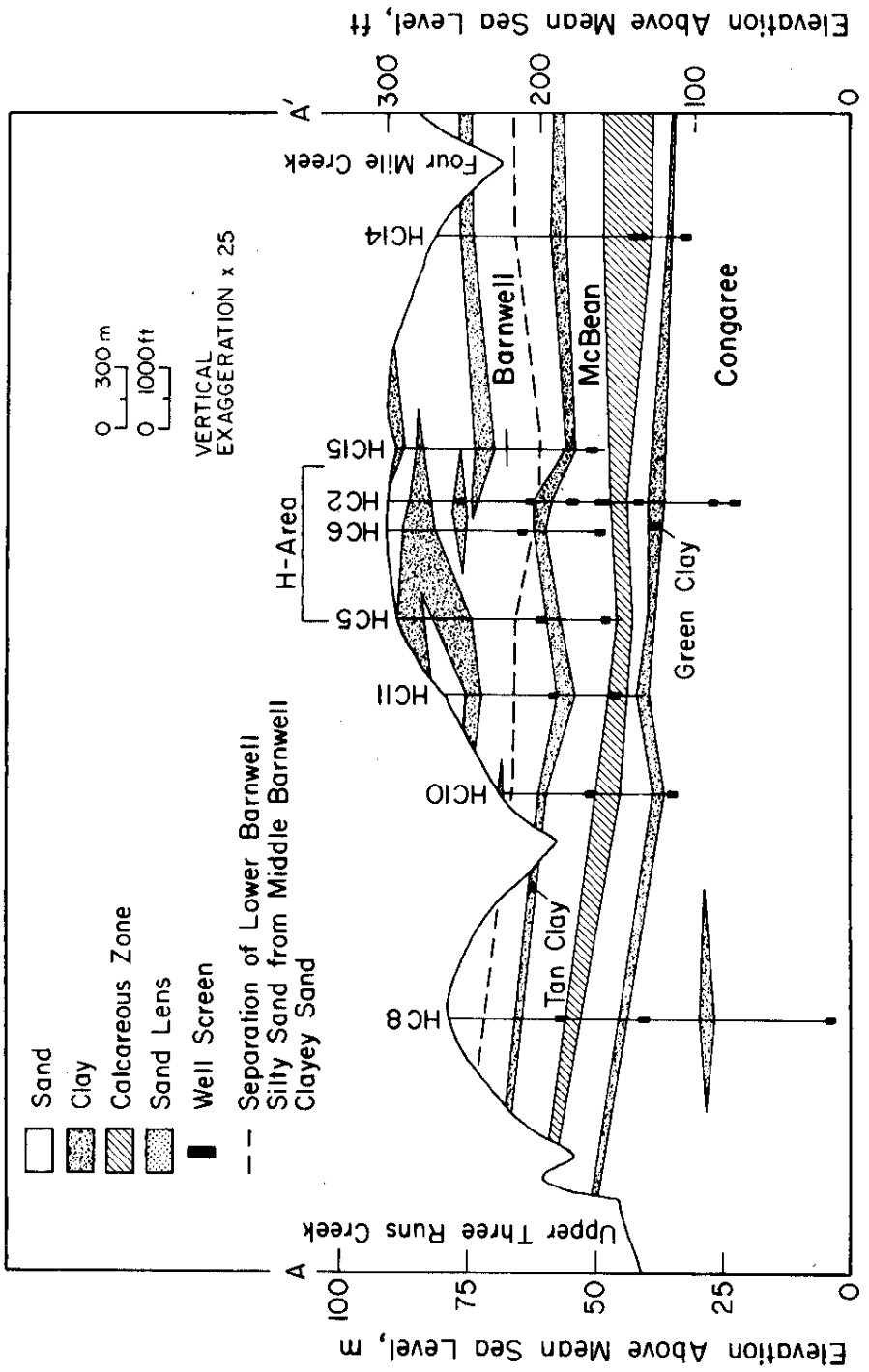

FIGURE 2. Hydrologic Section A-A'

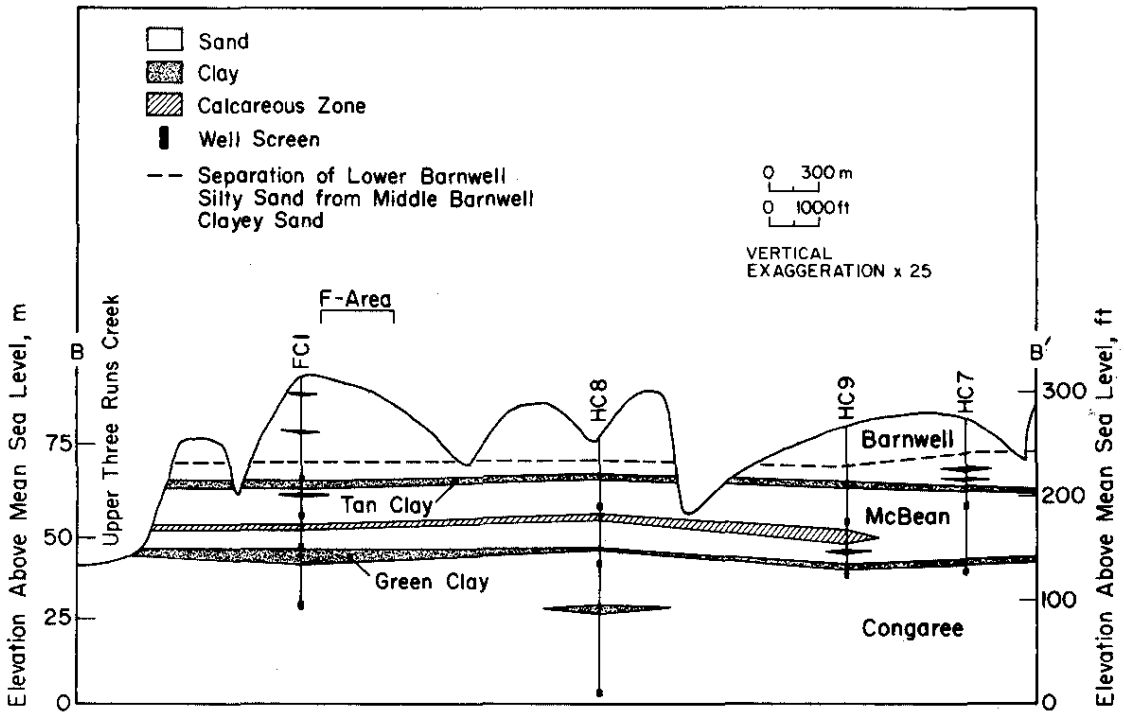

FIGURE 3. Hydrologic Section B-B'

14. SAVANNAH RIVER PLANT SEISMOGRAPH NETWORK†

INTRODUCTION AND SUMMARY

Although Charleston is the epicentral location of 92% of the earthquakes that occur in South Carolina, earthquakes do occur in other parts of South Carolina. No earthquakes have ever triggered the low-level alarms (acceleration >0.005 G) in the reactor buildings at the Savannah River Plant (SRP), nor have they triggered the strong motion recorders (acceleration >0.01 G). Thus, no useful seismic data have been collected at SRP on very small earthquakes that could have occurred in the general area. A project was authorized in late 1975 for the Savannah River Laboratory (SRL) to purchase, install, and operate a seismograph system at SRP.

The SRP Seismograph Network became fully operational on August 6, 1976. This network was designed to provide a continuous record of any local seismic activity. Parameters obtained from the network will be epicentral location and magnitude, and possibly, depth to focus of the earthquake.

NETWORK DESCRIPTION

The network consists of three field seismometer sites and one central recording station. The seismic activity at each field site is detected by a seismometer; a movable coil that induces a series of electric impulses when vibrated. These electrical impulses are amplified and sent over telephone lines to a central recording site, where the signals are again amplified and then recorded by a heated stylus on heat-sensitive paper. The locations of the three field seismometers and the central recording station are shown in Figure 1. A photograph of a seismometer in its small concrete vault is shown in Figure 2, and a photograph of the recording station is shown in Figure 3. The signals from Seismometer Amplifiers No. 1 (Navy site) and No. 3 (DRB-10 Well site) are fed directly to telephone lines, but the signal for Seismometer Amplifier No. 2 (D-Area) is first radio-telemetered to the D-Area powerhouse and then fed into a telephone line for transmission to the recording station. The signals from Seismometer Amplifier No. 1 (Navy site) are recorded at two different gains (high and medium) to permit different resolutions for earthquakes of different magnitudes.

† Work done by C. W. Krapp.

Timing accuracy is provided to within 0.050 seconds, and times are compared daily with the National Bureau of Standards time broadcast from radio station WWV. The time base for the network is Coordinated Universal Time (CUT), which is five hours later than Eastern Standard Time (EST) and four hours later than Eastern Daylight Time (EDT).

LOCAL EARTHQUAKE AND ANALYSIS

A local earthquake was detected on September 15, 1976, at 05:15 CUT (1:15 AM, EDT) by two of the field sites. The third site was not operational due to a tilted sensor. The term local earthquake refers to an event located not more than 1000 km (621 miles) from the seismometer.[1] Large earthquakes at greater distances (teleseisms) are recorded, but are of casual interest only.

The arrival of the compressional (P) wave and shear (S) wave were recorded at both sites. The seismograms (Figure 4) indicate that the DRB-10 site received the earliest response. The time interval between the arrival of S- and P-waves gives a measure of the distance to the epicenter of the earthquake. The arrival times and estimated distances to the epicenter from each site are listed on Table 1. Since only two sites were operating, a unique location cannot be found. The SRP locations for the earthquake would be in Burke County, Georgia, or Allendale County, South Carolina, 180° apart.

Discussions with the seismologist at the University of South Carolina, Columbia, South Carolina, confirmed the location of the epicenter in Allendale County, South Carolina, and indicated a magnitude of 2.5 on the Richter Scale. The SRP Seismograph Network gave a location near Martin, South Carolina, which correlated very well with the location determined by others using other seismographs.

REFERENCE

1. C. F. Richter. Page 16 in *Elementary Seismology*. W. H. Freeman, San Francisco, CA (1958).

TABLE 1

Analysis of September 15, 1976,
Earthquake Recorded on the SRP Seismograph Network

Site (Name)	*Arrival Times, CUT*		*S - P, sec*	*Distance to Epicenter, km*[a]
	P-Wave	*S-Wave*		
1 (Navy, High Gain)	05:15:40.0	05:15:43.5	3.5	29.8
(Navy, Medium Gain)	05:15:40.3	05:15:43.7		
2 (D-Area, Medium Gain)	Geophone tilted; seismograph inoperative			
3 (DRB-10, Medium Gain)	05:15:39.0	05:15:41.0	2.0	17.0

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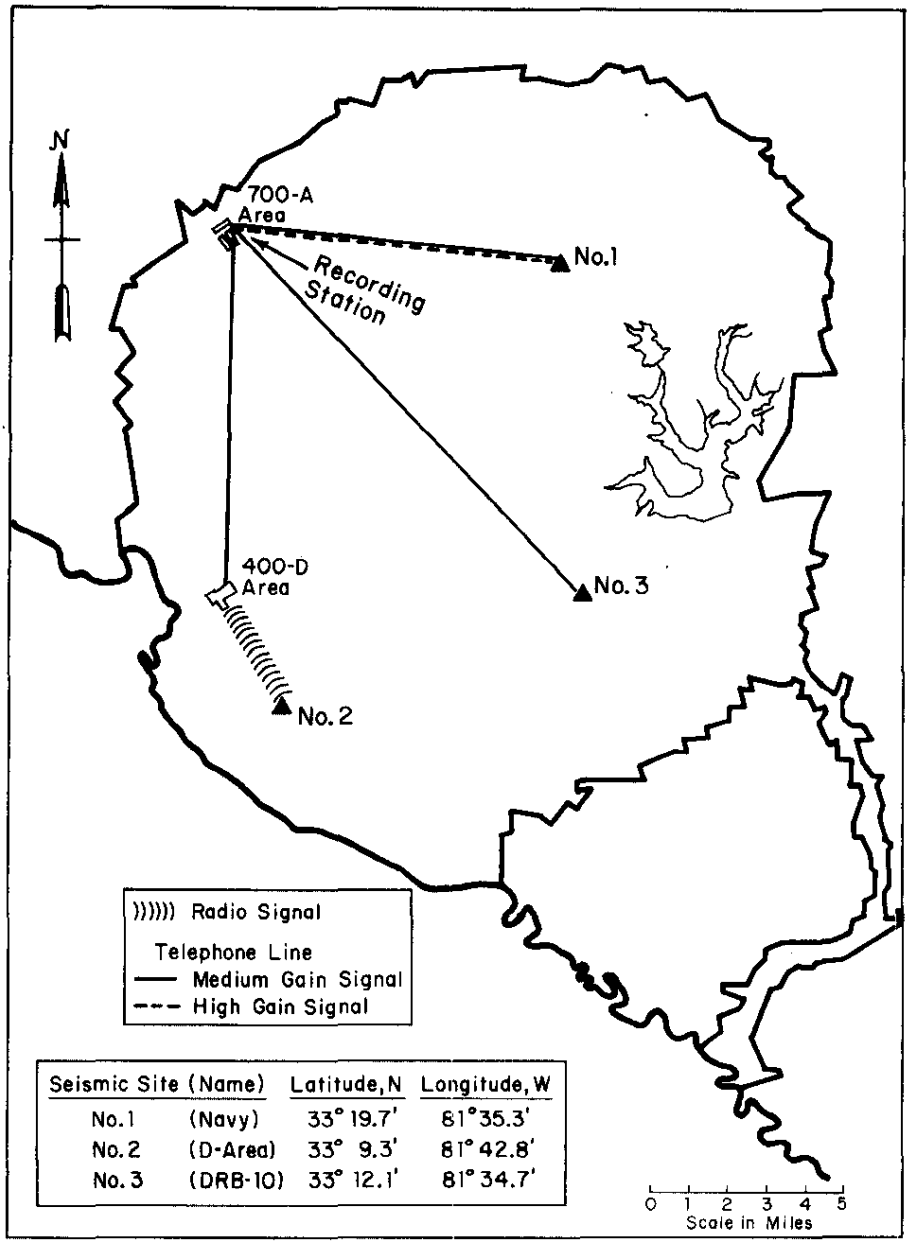
a. Dependent on crustal model used; assumed 8.5 km/sec between arrival of the S-wave and the P-wave.



Seismic Site (Name)		Latitude, N	Longitude, W
No. 1	(Navy)	33° 19.7'	81°35.3'
No. 2	(D-Area)	33° 9.3'	81° 42.8'
No. 3	(DRB-10)	33° 12.1'	81° 34.7'

FIGURE 1. SRP Seismograph Network

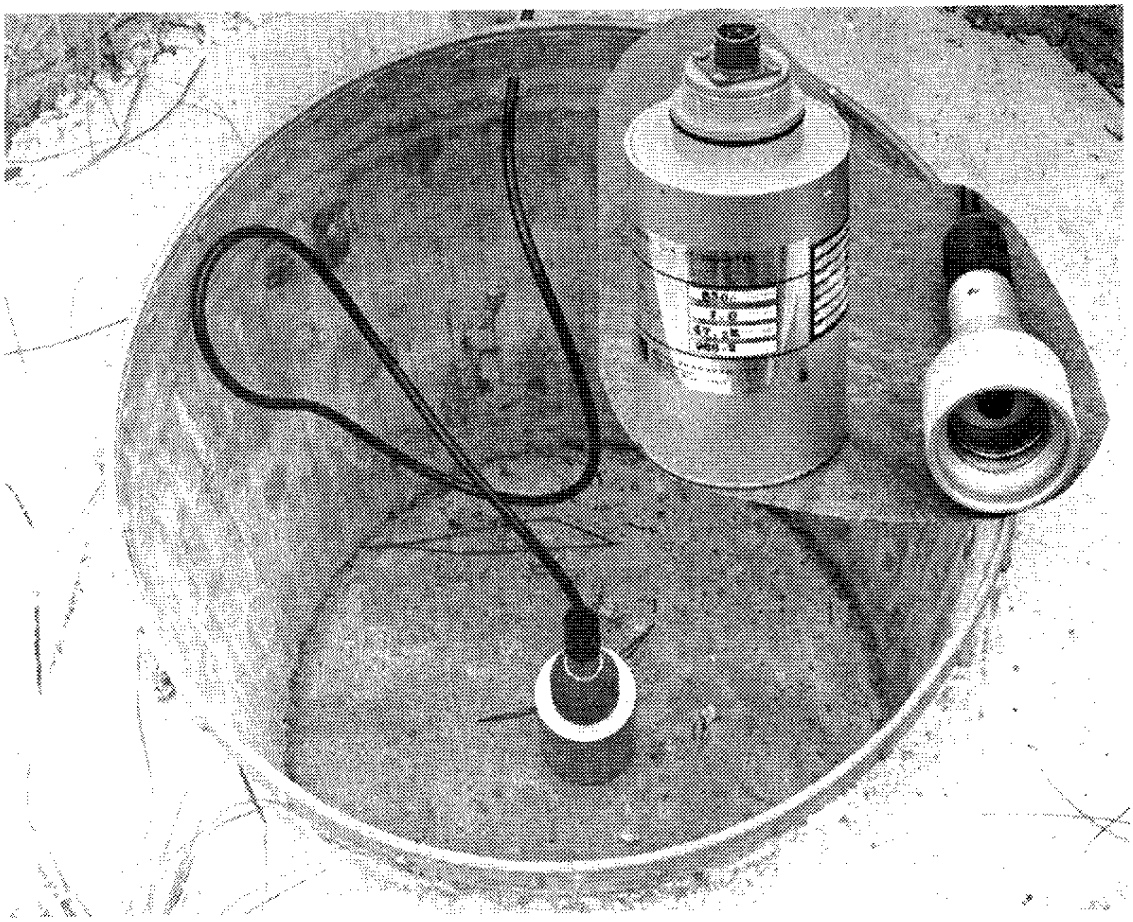


FIGURE 2. SRP Seismometer in Field Location

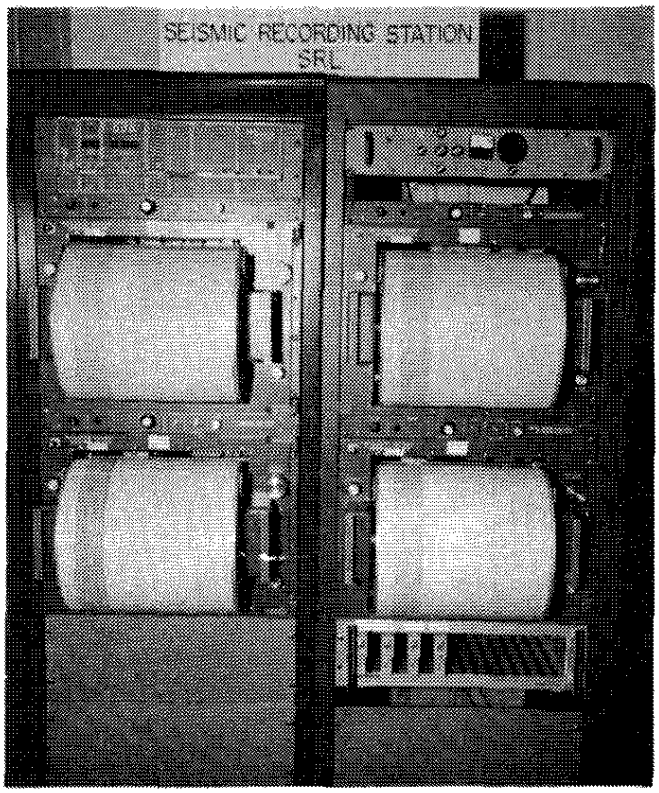


FIGURE 3. SRL Seismic Recording Station

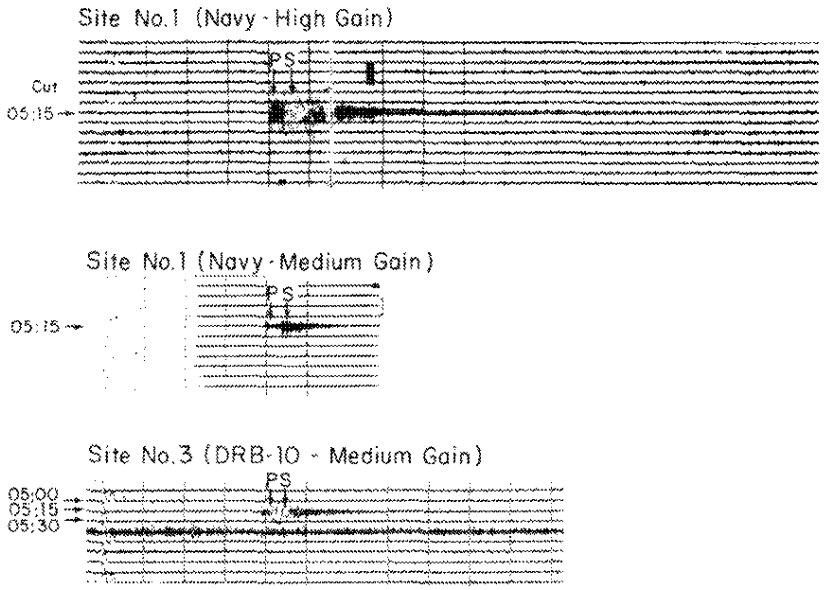
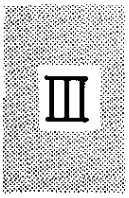


FIGURE 4. Seismic Tracings of September 1976 Earthquake

III. AQUATIC TRANSPORT STUDIES

The goal of the aquatic transport studies is to develop information to predict the concentrations of matter following releases into the Savannah River and transport to the coastal region of the southeastern United States. During the current year, a wide variety of studies were conducted; e.g., sediment transport measurements in a plant stream, and instrumenting a tower (located off the Savannah River Estuary) to obtain tidal current and meteorological information relevant to predicting pollution transport in the near-shore region. A paucity of information prevented the development of an evaluted reference data set to assist in interpreting marine environmental research in the South Atlantic Bight.



15. MODELING OF SEDIMENT TRANSPORT IN REACTOR EFFLUENT STREAMS†

INTRODUCTION

Sediments accumulate in the cooling water basins of the reactor areas and, if not removed, will significantly reduce the basin capacity. Flushing the sediments from the basins to the drainage stream is the most economical and least time-consuming method. Measurements of suspended solids and calculations of sediment transport were needed to determine the amount of sediment that could be flushed to the stream and remain within Environmental Protection Agency (EPA) guidelines.[1]

SUMMARY

Measurements were made of sediment transport on Four Mile Creek (C-Area stream) and Steel Creek (P-Area stream) during draining and/or flushing of cooling water basins in C Area and P Area, respectively. These measurements were used to determine transport coefficients for the Environmental Transport Division (ETD) models for Savannah River Plant (SRP) streams. The models predict sediment transport downstream after discharge of sediments from the basins.

Sediment release limitations were established by matching an EPA guideline to predicted concentration-time profiles. The daily maximum releases established are 765 m^3 of mud and 459 m^3 of mud for P Area and C Area, respectively.

MODELING THE SEDIMENT TRANSPORT

Stream mathematical models were developed to predict transport of pollutants or tracers in SRP streams. The one-dimensional equation describes the time change in concentration as a function of turbulent diffusion, longitudinal convective mass transfer, and source/sink effects within the streams. When source/sink effects within the streams do not need to be represented, the remaining equation is referred to as the bulk dispersion model. Transport coefficients for the bulk dispersion model using stream data were determined by an analysis code called TETRAD.[2] TETRAD uses an

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† Work done by D. L. Kiser.

analytical solution to the dispersion equation to route the movement of a tracer from one measurement station to another. The routing uses nonlinear least squares fitting to determine the coefficients and mean travel times that give the best agreement between each stream model and measured response at each station. The predictive transport was accomplished by a JOSHUA computer module called LODIPS (LOngitudinal DIspersion of a Pollutant in a Natural Stream).[2] In establishing limitations, the release profile of a time-varying function was specified for selected discharge quantities and time periods.

EXPERIMENTAL RESULTS

To obtain stream data for a stream model, the draining and/or flushing of a cooling water basin to the drainage streams in P-Area and C-Area were monitored.

During February 1976, No. 1 Basin in P-Area was drained to Steel Creek. Sampling stations were located at P-Area outfall, Road B, Road A-14, Road A, Road A-19, and the mouth of Steel Creek at the Savannah River (Figure 1). Figure 2 shows the data obtained and the model-fitting of the data. Transport coefficients developed by TETRAD are given in Table 1. During the draining of the basin, no measurable quantity of suspended solids was detected at the P-Area outfall. Suspended solids at Road B (Figure 2) resulted from the scouring of the creek bed in the reach between the P-Area outfall and Road B. This reach has an elevation drop of about 36.6 meters. The 4 to 5-fold increase in flow, about 1.29×10^5 liters/min (as measured at the USGS station at Road A-19) above normal, suspended the bed sediment. Samples collected at the mouth of Steel Creek at the Savannah River revealed no change in suspended solids for three days. Dye released at Road A arrived at the mouth of Steel Creek in about 13 hours.

Draining No. 3 Basin produced about 76.5 m^3 of mud. During the flushing of the basin to Steel Creek in March 1976, samples were collected at Road B and Road A-19. Samples were not collected at the other locations due to problems with the Universal Environmental Water Samplers. Using Road B data as the release profile, the model parameters developed previously predicted downstream concentrations (Figure 3). Peak concentrations predicted (15 to 17 mg/ℓ) for Road A-19 agreed with measured peak concentrations (20 to 23 mg/ℓ).

In May 1976, C-Area's No. 3 Basin, containing about 153 m^3 of mud, was flushed to Four Mile Creek. Monitoring stations were located at Road 3, Road A, and Road A-12.2 (Figure 1). Samples were not collected at the mouth of the creek at the Savannah River because the P-Area experimental results showed no elevation in suspended solids at

this location. Figure 4 shows the data obtained and the model fitting of the data. Transport coefficients developed by TETRAD are given in Table 1. Flow measured at the USGS station at Road A-12.2 was about 9.45×10^4 liters/minute.

ESTABLISHING THE LIMITATIONS

An EPA guideline on the discharge limitation for suspended solids is 100 mg/ℓ daily maximum (any 24-hr period).[1] The location of application of the limitation was implied as the last readily accessible sampling station on SRP. In the studies conducted, these locations are Road A-19 on Steel Creek, and Road A-12.2 on Four Mile Creek.

A parabolic release profile (Figure 5, Road B) was arbitrarily selected to characterize releases for LODIPS predictions. The time period for the specified release (720 minutes) was determined based on information from the Reactor Technology Department for the expected flushing interval. The time-integrated concentration at Road B (Figure 5) was made directly proportional to the time-integrated concentration at Road B from a release in P-Area to Steel Creek (Figure 3) and the mud volume flushed, e.g., flushing 76.5 m^3 of mud from No. 3 Basin resulted in 8.33×10^4 mg-min/ℓ at Road B (Figure 3). Hence, flushing 459 m^3 of mud from a basin would result in 49.98×10^4 mg-min/ℓ at Road B (Figure 5). The stream flow rate was assumed constant in developing the relationship. The time-integrated concentration value predicted at Road A-19 was 7.21×10^4 mg-min/ℓ, which was less than the EPA daily maximum limitation of 1.44×10^5 mg-min/ℓ. Selecting larger releases and following the above procedure, a quantity of 765 m^3 of mud was established as the daily maximum release for P-Area. With the same technique and C-Area data, the daily maximum release of mud from C-Area was calculated to be 459 m^3.

REFERENCES

1. "Federal Regulations - Effluent Standards (Section 135)." *Environment Reporter*, Bureau of National Affairs, Inc., Washington, DC (1976).

2. M. R. Buckner and D. W. Hayes. "Radionuclide Transport in Natural Streams." *Proc. Conf. Computational Methods Nucl. Eng., April 15-17, 1975, Charleston, S.C.* USERDA Report CONF-750413, American Nuclear Society; Oak Ridge Technical Information Center, Oak Ridge, TN.

TABLE 1

Stream Transport Properties Determined by *TETRAD*

Reach	*Distance, m*	*Dispersion Coefficient, m^2/min*	*Mean Travel Time, min*	*Mean Velocity, m/min*[a]	*Mass Accountability Factor*[b]
A. Stream: Steel Creek					
Rd B - Rd A-14	4,572	16,492.9	120.0	38.1	0.44
Rd A-14 - Rd A	3,380	209.0	399.9	8.4	0.28
Rd A - Rd A-19	3,251	3,895.7	223.2	14.6	0.61
B. Stream: Four Mile Creek					
Rd 3 - Rd A	5,842	899.1	467.7	12.5	0.35
Rd A - Rd A-12.2	2,536	55.7	455.4	5.6	0.68

a. Distance divided by the mean travel time.

b. The time-integrated concentration at the end station of reach divided by the time-integrated concentration at the beginning station of reach.

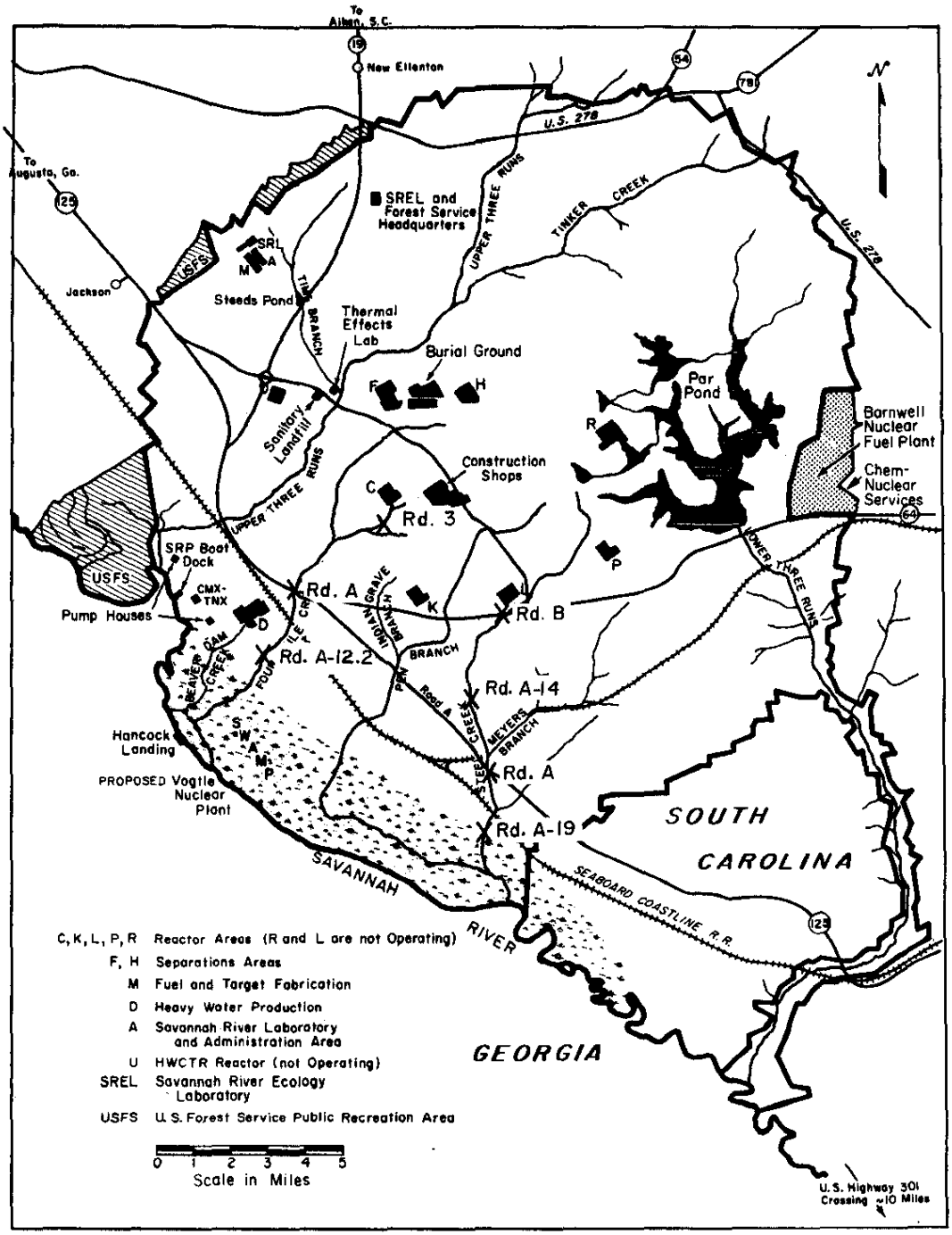

FIGURE 1. Four Mile Creek and Steel Creek Sampling Locations

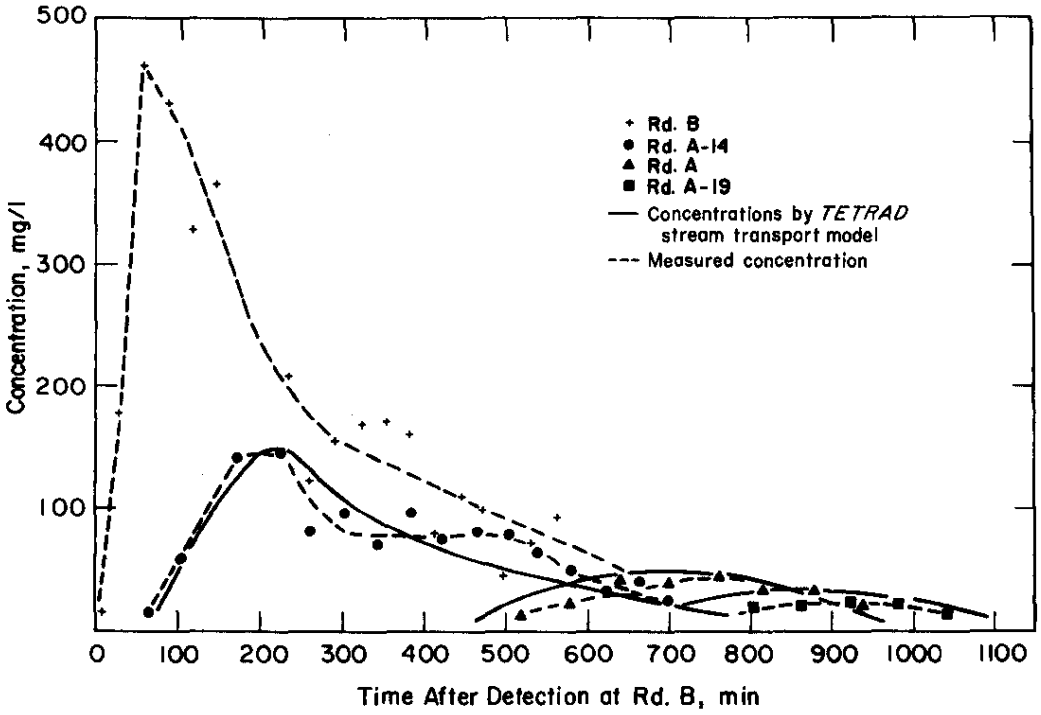

FIGURE 2. Concentrations of Suspended Solids in Steel Creek Following the Drainage of No. 1 Basin in P-Area

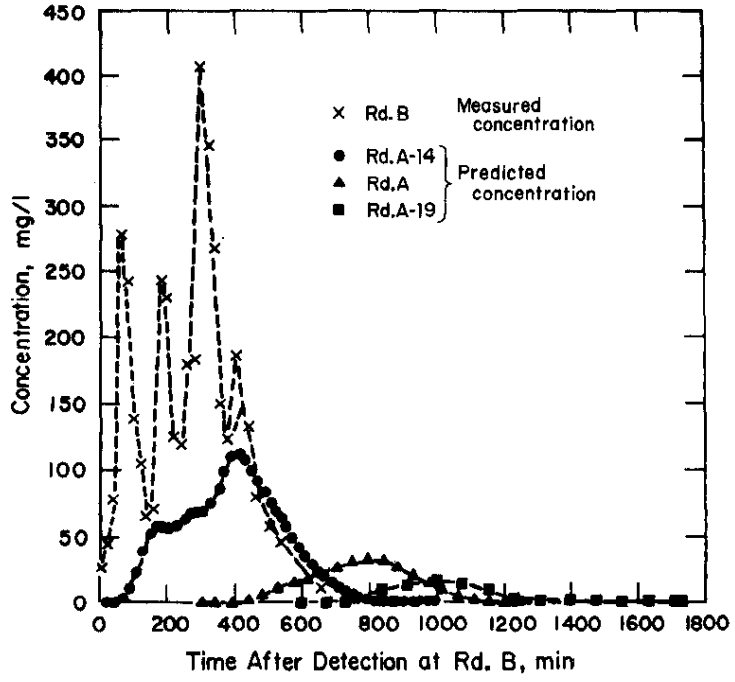

FIGURE 3. Predicted Concentrations of Suspended Solids in Steel Creek Following the Flushing of Sediments from No. 3 Basin in P-Area

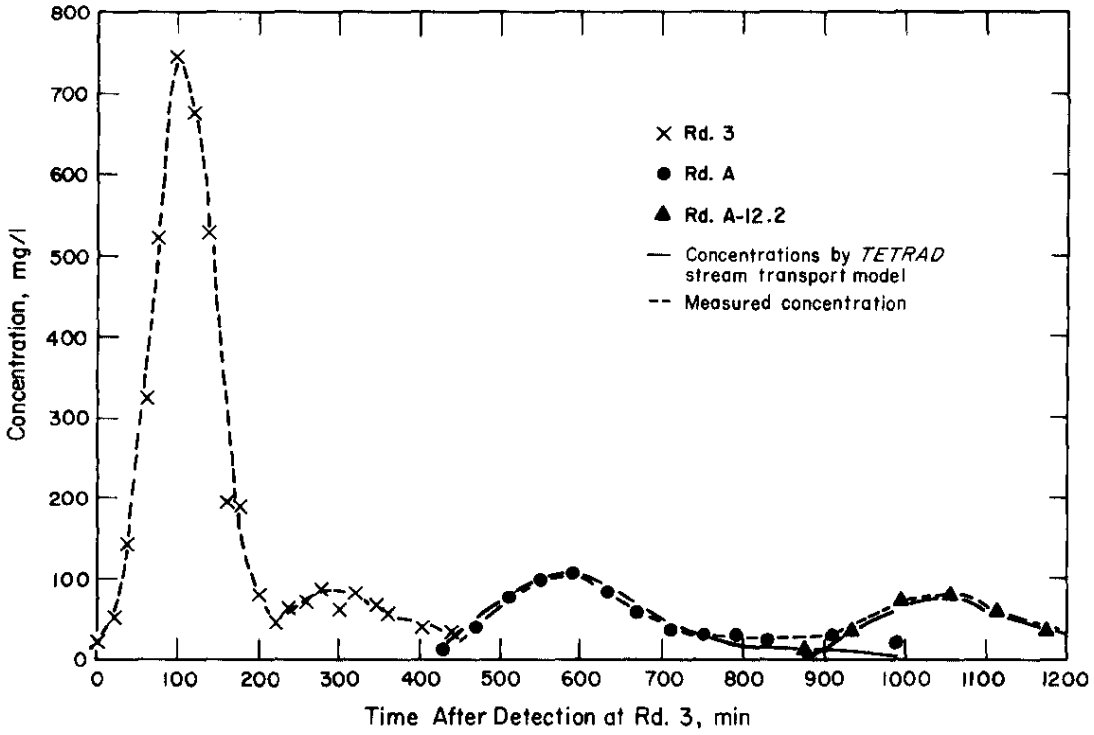

FIGURE 4. Concentrations of Suspended Solids in Four Mile Creek Following the Flushing of Sediments from No. 3 Basin in C-Area

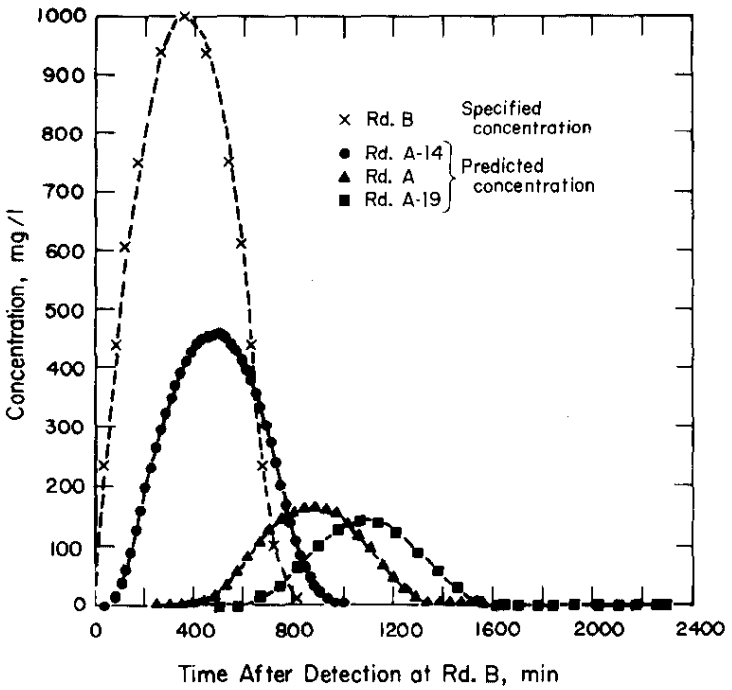

FIGURE 5. Suspended Solids Predicted in Steel Creek from a Specified Release in P-Area

16. HEAT LOSS IN A SMALL COOLING POND†

INTRODUCTION AND SUMMARY

Cooling ponds are designed employing conservative and/or simplified descriptions of heat loss and flow. Heat loss calculations are usually derived from formulae obtained from measuring natural water temperatures on lakes and reservoirs. Extrapolations using these coefficients tend to be conservative at higher temperatures. Therefore, for designing cooling ponds which receive heated waters, such as from a nuclear reactor, data are necessary to confirm the extrapolated values. Additional data are also needed on the importance of density currents on flow regimes within a cooling pond. Density currents are driven by pressure gradients due to density differences. These density differences can be generated by the cooling of water. The resulting currents transport water to unexpected parts of the cooling pond. Realistic examination of heat loss and flow at elevated temperatures under laboratory conditions is difficult; therefore, situations in the environment are needed to illustrate the importance of density currents in heat dissipation. A small cooling pond on the Savannah River Plant (SRP), Pond 2, has the twin features of elevated temperatures (~60°C) and density currents from the cooling of water. The energy loss in Pond 2 was found to be 11 ±8 MW total or 5.2 MW/hectare (2.1 MW/acre). Surface water temperatures were stable. Bottom water temperatures had a diurnal cycle.

POND AND INSTRUMENTATION DESCRIPTION

Pond 2 is an elevated temperature pond. It is connected to a hot-water, reactor effluent stream and pond system by a 1.8-m-diameter culvert underneath a road (Figure 1). The hot water enters Pond 2 in the upper part of the culvert, and the cooler water returns to the effluent stream in the lower part of the culvert. Pond 2 has a surface area of 2.0×10^4 m^2 and has a volume of 1.8×10^4 m^3.

The amount of heat and water entering Pond 2 was monitored by instrumenting the culvert opening on the Pond 2 side of the road. Instrumentation consisted of 18 thermocouples, a water-height gauge, and an electromagnetic flow meter. All sensors were

† Work done by D. W. Hayes (SRL-ETD) and R. Martinez (Undergraduate Research Participant, Cornell University, Ithaca, New York).

connected to a data acquisition and recording system. Meteorological conditions, wind speed, direction, and air temperature were recorded during the experiment.

A dye study was made to determine the residence time of water in the pond.

RESULTS AND CONCLUSIONS

A temperature and velocity flow-map typical of the culvert is shown in Figure 2. In general, flow into Pond 2 occurred in the upper 0.61 m, and return flow from the pond was in the lower 0.91 m. The upper 38 cm (TU1) was a zone of rapidly moving (22 cm/sec) water into the pond, the next 20 cm (TU2) was a zone of slowly moving water (5 cm/sec) into the pond, and the bottom 75 cm (TB) was a zone where water moved out of the pond with a speed of 6 cm/sec.

Measurement of the temperature in Pond 2 indicated that the surface water temperature drops 18°C in 30 m as the water moves out from the culvert and that the surface water is in a very thin layer, ∿5 to 10 cm. An estimate of the surface thickness from the dye study verified this observation. An average thickness for the surface water of ∿3 cm was calculated by dividing the volume flow travel time (to the pond edge from the culvert) by the surface area. Analysis of the dye data indicated that the residence time of the water in Pond 2 was 18 hours.

A 63-hour sequence of data was analyzed at one-hour intervals to determine the temperature, flow rates, and energy loss in Pond 2. The temperatures were very stable in each of the three zones of the culvert (TU1, TU2, and TB). The average temperature and standard deviation are, respectively, TU1 = 57.8°C ±1.3°C, TU2 = 45.5°C ±1.8°C, and TB = 38.5°C ±1.7°C, with a volume flow rate of 0.15 ±0.11 ft^3/sec in the lower layer.

The temperatures (TU1, TU2, and TB) versus time show that TB is cyclic with a period of 12 hours, peaking ∿5 to 6 PM, and bottoming at ∿6 AM. The temperature difference is ∿4°C and is probably caused by diurnal heating. Solar energy warms the thicker bottom layer which is isolated from the air by the thin upper layer, ∿3 cm thick. Using travel times and the solar input, the 4°C increase can be explained.

The energy loss from Pond 2 was calculated to be 11 ±8 MW. The pond had a cooling ratio of 5.2 MW/hectare (2.1 MW/acre). Heat loss calculations for thoroughly mixed ponds show that stratified ponds are at least as effective for cooling as non-stratified ponds.

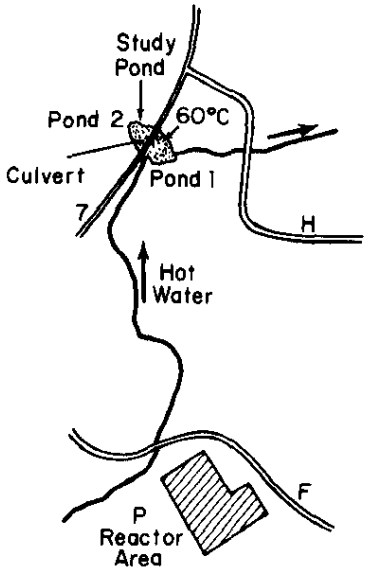

FIGURE 1. Pond 2 and P-Area Hot-Water Effluent System

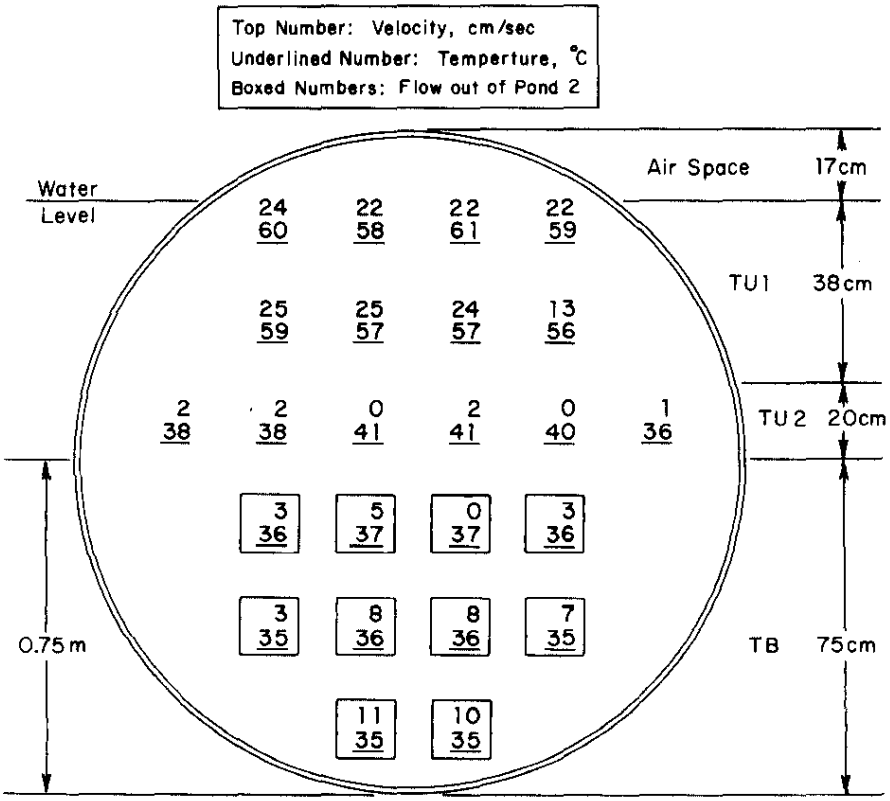

FIGURE 2. Velocity-Temperature Map in Mouth of Culvert, Pond 2

17. INSTRUMENTED NAVIGATIONAL LIGHT TOWER OFF THE SAVANNAH RIVER ESTUARY†

SUMMARY

An oceanographic and meteorological instrumentation system was installed on the Savannah Navigational Light Tower (November 1976). The instrumentation and recording system is providing synoptic information on ocean temperatures, currents, tides, salinity, and meteorological conditions. These data will aid in the interpretation of the processes governing pollutant transport in the Savannah River marine region and will support other ERDA-funded oceanographic programs in the southeastern United States.

SAVANNAH NAVIGATIONAL LIGHT TOWER

The Savannah Navigational Light Tower (unmanned), located about nine miles off Savannah Beach, Georgia (Figures 1 and 2), marks the approach to Savannah Harbor. It is operated by the U.S. Coast Guard, and Coast Guard personnel service it every 7 to 10 days. The tower is located in about 16 m of water, and the deckhouse is about 19 m above the water surface. The deckhouse has about 100 m^2 of floor space and contains adequate facilities to protect, power, and house the equipment.

SENSORS, INSTRUMENTATION, AND RECORDING SYSTEM

Sensors are installed in the tower to monitor water temperature, velocity, and height, as well as wind speed, direction, and temperature. Salinity and barometric sensors are also installed. The ocean water temperature is monitored at depths of 1.5, 3, 6.7, 10.4, 14, and 16 m. Water velocities are monitored at depths of 4.3 and 13.4 m. A bubbler gauge is employed for tide measurement. The wind speed, direction, and temperature are monitored at elevations of 17 and 27 m. Outputs from these sensors are recorded on magnetic tape every 10 minutes by a data acquisition system. The tape provides storage capacity for five weeks of information. The system can be programmed to accommodate up to 55 input channels and any desired recording frequency.

† Work done by D. W. Hayes.

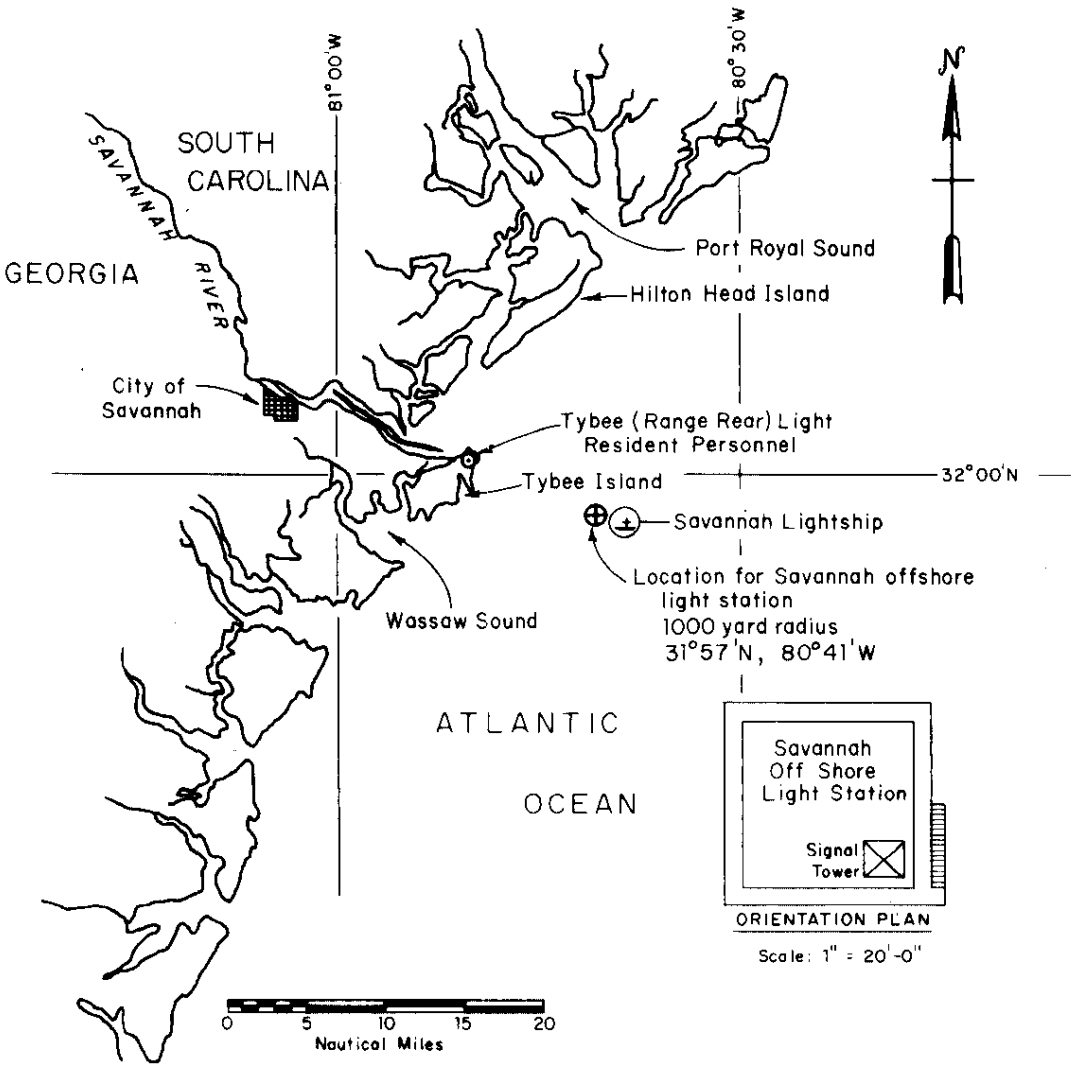

FIGURE 1. Location of Savannah Navigational Light Tower

FIGURE 2. Savannah Navigational Light Tower

18. TRITIUM IN THE SAVANNAH RIVER ESTUARY AND ADJACENT MARINE WATERS†

INTRODUCTION AND SUMMARY

The tritium distribution in the Savannah River estuary and adjacent marine waters was measured to provide information on the dilution, mixing, and movement of Savannah River water in this region. The Savannah River marine region was chosen for this study because the average tritium concentration in the Savannah River is 5 pCi/ml, whereas other rivers in the southeastern United States average less than 0.5 pCi/ml. Tritium measurements proved particularly effective in estimating the flushing time of the Savannah River estuary (2.4 days) and in delineating the relative river and sea water contributions to Ossabaw and Port Royal Sounds.

SAVANNAH RIVER ESTUARY

Tritium Levels

The tritium content was measured from the headwaters to the mouth of the estuary. Tritium levels decreased toward the mouth of the estuary, because the tritium content of sea water is less than that of the fresh water. The tritium concentration in the estuary is inversely proportional to the salinity (Figure 1) during steady-state tritium releases. If the curve is extrapolated to zero parts per thousand salinity, the fresh-water tritium concentration is 6.8 pCi/ml. Predictions of tritium concentrations in the estuary can be calculated from salinity and fresh-water tritium concentrations for steady-state releases. The minimum tritium dilution expected at the river mouth is 50% based on salinity data.

Flushing of the Estuary

The flushing time of an estuary is a crude estimate of how long a conservative pollutant will remain in an estuary. The flushing time, assuming the Savannah River estuary is nonstratified,

† Work done by D. W. Hayes.

was calculated from tritium data and from hydraulic data by three different methods: 1) the fraction fresh water method, 2) the tidal prism method, and 3) the fresh water method using tritium data. The calculated values by these methods were 2.1, 2.1, and 2.4 days, respectively. The three flushing times, in good agreement, would represent a minimum time a conservative pollutant would reside in the Savannah River estuary.

INLAND MARINE WATERS

Tritium content, together with salinity, is used to determine the direction and mixing ratios for water movement in inland marine waters such as the Savannah River estuary. This estuary and adjacent waters are shown in Figure 2. In general, higher tritium concentrations and lower salinities were found south of the Savannah River estuary. Salinity-tritium ratios show fresh water and sea water zones exist between 1) Savannah River and sea water, and 2) other nearby rivers and sea water.

A method for estimating the relative river and sea water contributions to water masses in this area was developed. An application of this method was the determination of the relative water source contributions in Port Royal and upper Ossabaw sounds. In Ossabaw Sound, the relative water contributions were 0.3 Savannah River, 0.1 Ogeechee River, and 0.6 sea water; in Port Royal Sound, the contributions were 0.1 Savannah River, 0.1 Coosawhatchie River, and 0.8 sea water. This method should prove useful in defining other river water/sea water mixtures in this area.

COASTAL WATERS

Tritium values about six miles off the mouth of the Savannah River varied widely: 22 TR (December), 115 TR (March), and 300 TR (July.)* These variations are caused by seasonal changes in coastal water structure.

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* TR = tritium ratio; 1 TR = (conc. of T atoms $\times 10^{18}$)/(conc. of H atoms). 1 TR = 0.0072 dpm/ml $\equiv$ 0.0032 pCi/ml (water).

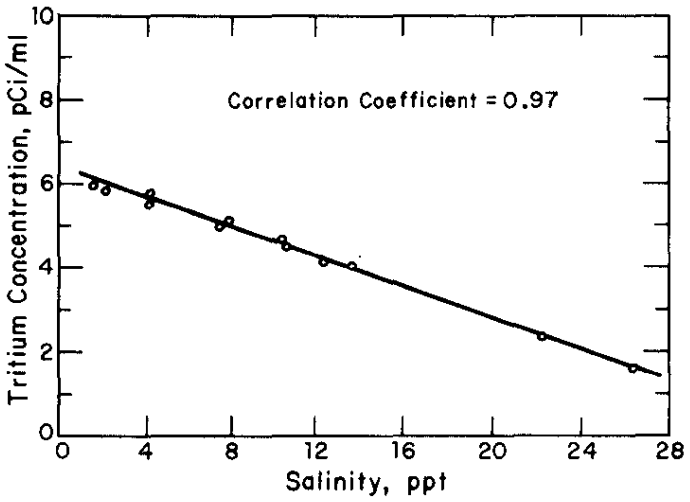


FIGURE 1. Tritium-Salinity Relationship of the Savannah Estuary and Adjacent Oceanwater

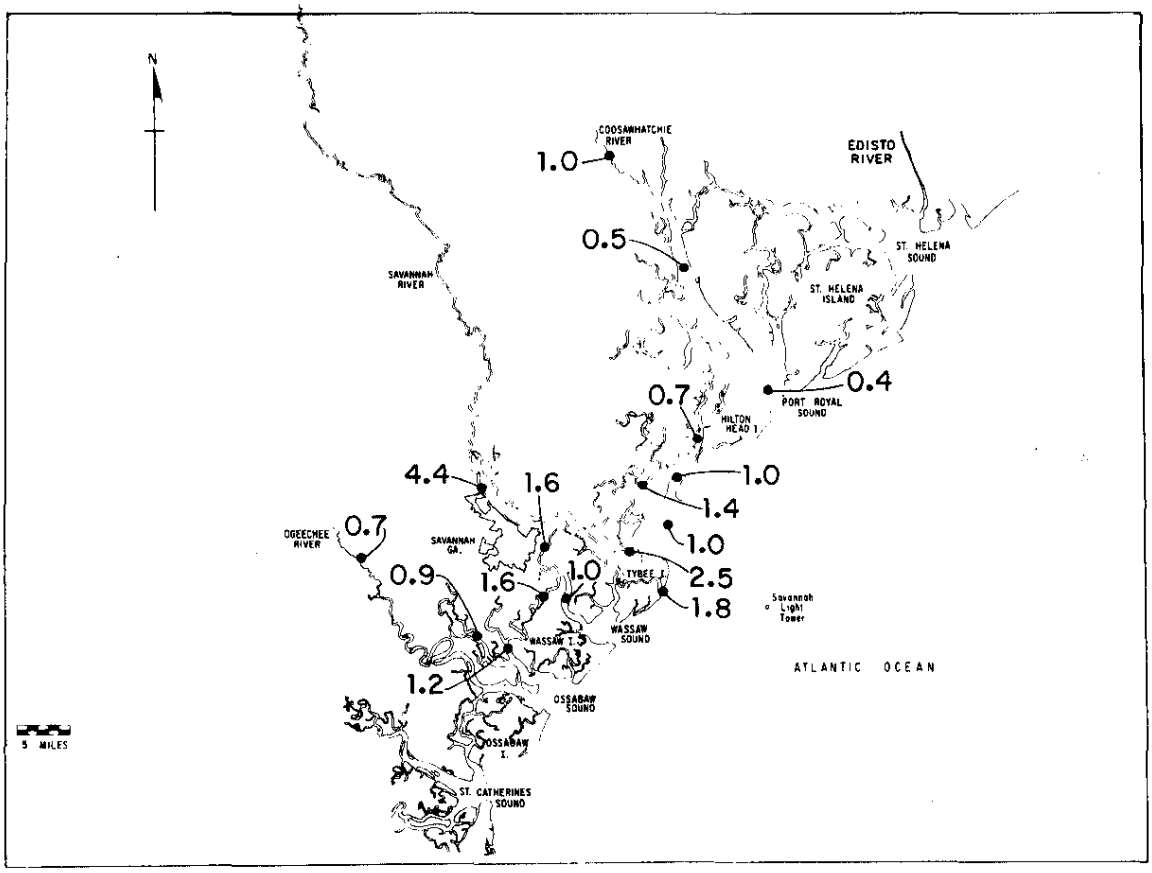


FIGURE 2. Tritium Concentration (pCi/ml) in Tidal Waters

19. DEVELOPMENT OF A PHYSICAL OCEANOGRAPHIC DATA SET FOR THE SOUTHEASTERN UNITED STATES CONTINENTAL SHELF†

SUMMARY

The Savannah River Laboratory has surveyed appropriate federal and state agencies and academic institutions to locate sources of physical oceanographic data relevant to the continental shelf of the southeastern United States. About 55 reference documents containing tabular or graphical data were found; however, much of the data in these documents were not appropriate for a reference data base.

By far the largest volume of data was retrieved from the computerized archives at the National Oceanographic Data Center and the National Climatological Center. While the amount of data retrieved was substantial, the coverage of the data is quite scattered in space and time.

By far the most comprehensive (but nonmachine readable) data set is that of the U.S. Coast Guard airborne radiation thermometer program. This data set yields sea-surface temperature to an accuracy of 1°C with good geographical coverage and a consistent time frame. However, the expense of digitizing several years of strip charts would be considerable, and could only be done at Coast Guard headquarters for security reasons.

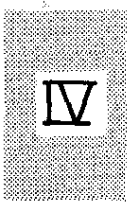
A series of FORTRAN computer programs were written to display the random geographic measurement locations and contours of sea-surface temperature observed by casual shipping vessels and archived at the National Climatological Center. Over a long period of record, spatial coverage of the oceans is quite dense at any point in time. However, specific coverage is sparse. The contours of sea-surface temperature are not readily displayed automatically owing to the considerable scatter of observed values with time and to the small sample size at any one time.

In general, despite our efforts to augment the existing archives, the reference data set is incomplete. Continued effort should be directed towards systematically consolidating new data (primarily from the baseline data collection program sponsored by the Bureau of Land Management) into an evaluated reference data set to assist in interpreting marine environmental research.

† Work done by J. E. Suich.

IV. AQUATIC ECOLOGY STUDIES

SRL aquatic ecology studies focus principally upon the interaction of industrial processes and aquatic ecosystems. The objective is to predict the influence of energy-related industrial processes on the function of representative systems from the southeastern United States. Studies currently are measuring the influence of cooling system operations on the lower food chain components of lakes and streams of SRP. A prominent and growing emphasis in these studies is the influence of such cooling system factors as elevated temperature, water movement, and nutrient translocation upon microbial survival with special attention to pathogens.



20. THE ESTABLISHMENT OF A FUNCTIONAL THERMAL STREAM LABORATORY FACILITY†

INTRODUCTION

The Flowing Streams Laboratory, on the banks of Upper Three Runs Creek on the Savannah River Plant, has six experimental streams for studying the long-term effects of low-level increases in water temperature on the ecology of aquatic organisms. Although the facility was completed in October 1971, thermal studies did not begin until April 1976 because of the time required for baseline studies and modifications to equipment.

STREAM FLOW AND TEMPERATURE CONTROL

After determining that the smallest differences likely to be statistically demonstrable for biological parameters in the experimental streams were of the order of 50%, a new experimental design for the application of temperature stress was adopted. Two streams now serve as controls; the remaining streams receive temperature elevations of 2.5, 5.0, 7.5, and 12.5°C, respectively.

Water heating and flow capabilities of the Flowing Streams Laboratory[1] were evaluated by the Reactor Engineering Division (RED) to determine the most effective and efficient mode of operation. RED recommended three options for recirculation of heated water to reduce power costs, improve maintenance, and achieve the desired temperatures for mixed water streams. The option that was selected recirculates 10 gpm within each stream to achieve a 30% decrease in power costs. New heaters, designed for more efficient operation, were also installed and protected from burnout by low-flow heater cutoff switches.

The experimental streams are colonized with plants and animals by a 35 gpm flow of Upper Three Runs water through each stream. Twenty-five gpm is fresh water, and 10 gpm is recirculated from the stream outlet into the stream inlet. There is no mixing of water between streams. Based on stream flow rates of 0.31 ft/sec, travel time for water in each stream is 84 seconds. With ∿30% of the flow recirculated, 97% of the recirculated water is replaced in 2.5 minutes.

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† Work done by R. S. Harvey.

OPERATION

The four test streams (2.5, 5.0, 7.5, and 12.5°C above ambient) were brought up to temperature on April 20, 1976. Except for one power outage of less than 2 hours, the facility has operated continuously. Mean Δt's and coefficients of variation for each stream are shown in Table 1. Data are based on 96 measurements in each stream.

TABLE 1

Water Temperatures in Experimental Streams

	Temperature Above Ambient, °C			
	2.5	*5.0*	*7.5*	*12.5*
Mean Δt	2.39 ±0.19	4.87 ±0.19	7.53 ±0.19	12.66 ±0.29
Coefficient of Variation	7.1%	3.9%	2.2%	2.3%

Interstream comparisons of water temperature, dissolved oxygen, and pH are placed on magnetic tape by means of a data acquisition system,which also compares the light intensity in control streams with that in Upper Three Runs Creek. Other water quality parameters and concentrations of trace elements in Upper Three Runs water are routinely determined from weekly, biweekly, or monthly water samples.

REFERENCE

1. R. S. Harvey. "A Flowing Stream Laboratory for Studying the Effects of Water Temperature on the Ecology of Stream Organisms." *Amer. Soc. Biol. Bull. 20(1)*, 3-7 (1973).

21. THE USE OF FLUORESCENCE MICROSCOPY IN ALGAL STUDIES†

SUMMARY

The identification and enumeration of phytoplankton and periphytic algae is aided at the Savannah River Laboratory (SRL) by the use of fluorescence microscopy. The ability of chlorophyll to emit fluorescent light is a phenomenon which has been utilized for many years in algal studies involving chlorophyll extraction, but has only recently been applied to studies involving microscopic examinations. Fluorescence microscopy has several advantages over conventional light microscopy. Distinctive exposure of chlorophyll pigments is helpful in differentiating between cells which were alive at the time of collection and those which were dead. Species identifications are facilitated by clear observations of the size and shape of chloroplasts in eucaryotic algae. The diffuse nature of the chlorophyll in blue-green algae can also be clearly observed. Sample analysis time can be greatly reduced, as only the chlorophyll-bearing cells appear bright in the field of view. Fluorescence microscopy is especially advantageous when samples containing substantial quantities of silt and detritus are analyzed, because obstructed specimens can be observed. However, chlorophyll-bearing diatoms which cannot be accurately identified during counting with the fluorescence technique require acid-cleaned hyrax preparations for species identification and diatom proportional counts.[1,2]

Preliminary observations indicate that fluorescence microscopy may have some additional applications in phycological work. Each algal division is characterized by cells which contain a distinct combination of pigments (chlorophylls, xanthophylls, carotenoids, etc.). Differentiation of these pigments by fluorescence microscopy could enable workers with little or no experience to count and identify accurately algae at the division level. The physiological condition of cells may possibly be evaluated by observing the relative amounts of chlorophyll *a* and its degradation product, pheophytin *a*, which fluoresces at a different wave length.

† Work done by E. W. Wilde.

Because it is seldom feasible to examine live cells in quantitative algal studies, a variety of preservation techniques are being evaluated at SRL for use with fluorescence microscopy. Freezing appears to be the best technique. However, chlorophyll fluorescence has been observed for samples preserved for a few days with 4% buffered formalin. Neutralized gluteraldehyde has been recommended by Coulon as a preservative,[3] but has not been tried yet at SRL.

REFERENCES

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22. CHARACTERIZATION OF ATTACHED ALGAL ASSEMBLAGES GROWING ON VARIOUS SUBSTRATES IN ARTIFICIAL STREAMS†

INTRODUCTION AND SUMMARY

Studies are currently being conducted at the Flowing Streams Laboratory[1] to gain a better understanding of the components of the attached community which colonize each of the major types of natural substrates. Preliminary results indicate that some taxa are very substrate-specific, while others develop abundant populations on several types of substrates. Glass slides (artificial substrates) appeared to best represent the algae attached to objects in the stream such as rocks, plants, and sticks. True benthic forms were poorly represented on the slides.

DATA COLLECTION AND INTERPRETATION

Approximately 140 natural substrate samples and 30 artificial substrate samples were analyzed during the second half of 1976. All natural substrate types in each of the six experimental streams were sampled on at least three occasions. Artificial substrate samples were obtained by submerging glass slides housed in diatometers[2] in the streams for two-week intervals. The artificial substrate samples represented five streams and six sampling dates.

Summarization of data from all samples enabled the distinction of several assemblages (microcommunities). These microcommunities are listed with their principal components in Table 1 and are discussed below.

Epilithon (Algae growing on rocks)

This assemblage appeared to be clearly subdivided into two groups, depending on the rate of water flow. Major components of the epilithon in rapid currents (where water enters the streams) were red algae *(Tuomeya fluviatilis* and *Andouinella violacea)*,

† Work done by E. W. Wilde.

yellow brown algae (*Vancheria* sp.), filamentous blue-green algae (*Schizothris* spp.), and filaments of the diatom *Eunotia*. The epilithon in other portions of the streams, where current was moderate, included *Eunotia* spp. and *Schizothris* spp., as well as substantial quantities of *Navicula* spp., *Spirogyra* sp., and coccoid blue-green spp.

Epiphyton (Algae growing on plant material)

Major substrates for this type of algae included the macroscopic algae, *Vancheria* and *Nitella*, and an aquatic plant, *Bacopa*. The epiphytic assemblages on all three kinds of plants were very similar and were dominated by *Eunotia* spp. Other abundant epiphytes included the filamentous green algae *Spirogyra* and *Stigeoclonium* sp.

Epipelon (Algae moving freely on the bottom sediments)

With the exception of the blue-green algae, *Schizothrix*, this assemblage consisted of a well-developed flora containing abundant quantities of taxa which were rare or absent from all other substrate types. These taxa included *Closterium* sp. #1, *Nitzschia* spp., *Pinnularia* spp., and *Cymbella cuspidata*. *Closterium* sp. #2 and *Oscillatoria princeps* were abundant on portions of the pool bottoms in three of the streams, but were never observed elsewhere.

Epipsammon (Algae firmly attached to sand grains)

From fluorescence microscopy,[3] this assemblage appeared to be an extremely abundant one. Several small (<20 μm) diatoms of the genera *Navicula* and *Achnanthes* were often observed on a single sand grain. Living diatoms were observed on more than half of the sand grains collected from the uppermost strata of sediment. The productivity contribution by this relatively unknown type of algae deserves future study.

Epidendron (Algae attached to submerged wood)

Relatively few algae were collected from the submerged sticks in the streams. Epidendric algal composition was similar to the epilithon (in moderate currents) and was dominated by *Eunotia* spp. and coccoid blue-green algae.

Glass Slide Assemblage

Major algal taxa collected from glass slides included *Eunotia* spp., *Navicula* spp., *Stigeoclonium* sp., and coccoid blue-green spp. The slides appeared to be fairly representative of the algae collected from rocks, sticks, and plants, but were apparently selective against true benthic algae such as *Nitelk, Vancheria, Schizothrix,* and many epipelic and epipsammic forms.

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3. E. W. Wilde. *The Use of Fluorescence Microscopy in Algal Studies.* Article No. 21 of this report.

TABLE 1

Major Algal Taxa Representing Various Habitats in the Artificial Streams at Flowing Streams Laboratory[a]

	Epilithon (in rapid current)	Epilithon (in moderate current)	Epiphyton	Epipelon (inlet and outlet channels)	Epipelon (pool bottoms)	Epipsammon	Epidendron	Macroscopic benthic algae	Glass slide assemblage
Tuomeya fluviatilis	x								
Andouinella violacea	x								
Vaucheria sp.	x							x	
Schizothrix spp.	x	x		x					
Eunotia spp.	x	x	x				x		x
Spirogyra sp.		x	x						
Navicula spp.		x				x			x
Coccoid blue-green spp.		x					x		x
Stigeoclonium sp.			x						x
Nitzschia spp.				x					
Cymbella cuspidata				x					
Pinnularia spp.				x					
Closterium sp. #1				x					
Oscillatonia princeps					x				
Closterium sp. #2					x				
Achnanthes spp.						x			
Nitella sp.								x	

a. x indicates taxon was relatively abundant in at least five samples of the assemblage.

23. COMPARISON OF GLASS AND ACRYLIC SUBSTRATES IN PERIPHYTON STUDIES†

INTRODUCTION AND SUMMARY

Most quantitative studies of periphytic algae have involved artificial substrates because natural substrates are very difficult to sample in a quantitative manner. Glass or acrylic* slides have been used extensively as substrates in diatometers.[1] The primary objectives of this experiment were to compare algal community development on glass and acrylic substrates, and to assess the variability between replicate slides and between diatometers. Significantly higher quantities of algae were collected from acrylic than from glass slides, whereas both substrates gave similar variation between replicates and displayed significant differences between diatometers.

METHODS

Two diatometers, each containing three glass slides alternately placed with three sandpaper-scratched acrylic slides, were submerged side-by-side in three artificial streams at the Flowing Streams Laboratory for a two-week period. Following collection, one side of each of the 36 slides was microscopically examined, and all chlorophyll-bearing algae observed in 100 random fields were identified and counted. Cells were counted for all algal groups, except the filamentous blue-green algae in which only the numbers of filaments were counted.

RESULTS AND DISCUSSION

The effect of substrate was evaluated with parametric and non-parametric statistical analyses of raw counts. Table 1 shows the means, standard errors, and statistical differences between substrates based on Student's t-tests.[2] Slides of acrylic resin yielded larger

† Work done by E. W. Wilde.

* Generic term for polymethylmethacrylate resin; *Plexiglas* (Rohm and Haas, Philadelphia, PA) was the acrylic material used in this study.

counts in every case. Populations of total periphyton, coccoid blue-green algae, and pennate diatoms were significantly higher on acrylic slides in all three streams. Sign tests,[3] comparing counts from each glass slide with those of the adjacent acrylic slide in the same diatometer gave the same significant differences ($p \leq 0.05$) as were shown by the t-tests for comparing means.

The coefficient of variation[2] was computed for counts of all major algal groups on each substrate type in each stream. Glass and acrylic did not differ significantly with regard to the amount of variability between slides of the same material. Statistical comparisons of these values showed no significant differences in variability between substrates.

An effect ascribed to diatometer difference was observed when counts from the slides from one of each pair of diatometers were compared with counts from the similarly positioned slides from the other diatometer. Statistically significant ($p \leq 0.05$) differences were detected by sign tests and t-tests (Table 2). Total counts, as well as those of all major algal groups except green algae, were significantly different in samples from two identical diatometers situated side-by-side in the same stream. The significant differences between diatometers were slightly more prevalent with acrylic slides than with glass slides.

Species composition was generally similar on glass and acrylic slides, and both substrates appeared to be about equally selective against filamentous blue-green algae, when results were compared with those of qualitative samples collected from natural substrates in the streams.

CONCLUSIONS

1. Valid quantitative comparisons cannot be made between periphyton studies involving glass slides and studies involving acrylic slides because significantly higher quantities of algae are collected from the latter substrate.

2. Glass slides are probably superior to acrylic slides for use in diatometers. Acrylic slides offer no apparent advantages. Glass slides are more convenient, less expensive, and have been used more frequently in prior studies.

3. Significant differences can occur between results from paired diatometers; hence, a need for substantial sample replication is indicated.

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TABLE 1

Comparisons of Mean Counts from Six Glass Slides and Six Acrylic Slides

Taxa/Substrate	*Stream 1*	*Stream 2*	*Stream 3*
Total Periphyton			
Glass	346 ±51	869 ±83	337 ±38
Acrylic	1203 ±186[a]	1735 ±214[a]	838 ±33[a]
Coccoid Blue-Greens			
Glass	163 ±31	226 ±50	39 ±9
Acrylic	605 ±70[a]	691 ±20[a]	140 ±24[a]
Pennate Diatoms			
Glass	126 ±24	455 ±29	240 ±31
Acrylic	462 ±108[a]	891 ±111[a]	547 ±152[a]
Filamentous Reds			
Glass	39 ±9	35 ±9	3 ±2
Acrylic	105 ±21[a]	56 ±27	7 ±6
Coccoid Greens			
Glass	12 ±4	14 ±4	7 ±2
Acrylic	20 ±4	30 ±6	13 ±6
Filamentous Greens			
Glass	2 ±1	17 ±7	38 ±16
Acrylic	4 ±3	58 ±17	115 ±32
Filamentous Blue-Greens			
Glass	3 ±1	6 ±1	9 ±3
Acrylic	6 ±2	9 ±3	17 ±4

a. Statistically significant difference ($p \leq 0.05$) according to Student's *t*-test.

TABLE 2

Summary of Statistical Comparisons of Algal Counts from Paired Diatometers

Taxa	*Glass Slides*		*Acrylic Slides*	
	Sign Tests	*t-Tests*	*Sign Tests*	*t-Tests*
Total Periphyton	NS[a]	NS	S[b]	S
Coccoid Blue-Greens	NS	S	S	S
Pennate Diatoms	S	S	S	NS
Filamentous Reds	NS	NS	S	S
Coccoid Greens	NS	NS	NS	NS
Filamentous Greens	NS	NS	NS	NS
Filamentous Blue-Greens	S	S	S	S

a. NS; not significant difference ($p > 0.05$).

b. S; significant difference ($p \leq 0.05$)

24. COMPARISONS OF THERMAL EFFECTS ON PERIPHYTON PRODUCTIVITY IN A STREAM *VS.* A LAKE ECOSYSTEM†

INTRODUCTION AND SUMMARY

The growth of attached algae in thermally altered experimental streams was compared with that in a man-made reservoir receiving thermal effluents from a nuclear reactor. The studies were made to determine whether the potential effects of thermal effluents were generally greater for streams or for lakes that presently receive thermal discharges from industrial power plants. The choice of which system to use (stream or lake) may depend primarily upon the environmental costs of the alternatives. Data are seldom available which enable direct comparisons of the effects to be expected from equivalent stresses upon the different systems.

The present studies were designed to use relative productivity measurements to compare the responses of a Coastal Plain reservoir (Par Pond) and a representative Coastal Plain stream (Upper Three Runs Creek) to the introduction of equivalent ranges of a thermal effluent. Measurement of ^{14}C uptake provided the basis for the comparison. Earlier studies[1] revealed that productivity and standing crop of attached algae correlated positively with habitat temperature along the thermal gradient to the reservoir system; that is, temperature increase above habitat temperature further enhanced ^{14}C uptake. Such observations suggested that in the Coastal Plain region, temperature elevations might be generally expected to increase algae growth rates and influence the size of algal crops accumulating on solid surfaces in cooling systems.

In the present work, ^{14}C uptake by periphyton from Par Pond and from artificial streams in the Flowing Streams Laboratory (FSL) were simultaneously measured from May through November 1976. The data confirmed the earlier findings of temperature-enhanced algal growth in the lake for similar time periods.[1] However, algal growth in the FSL heated streams was not significantly different from that in the unheated streams. These studies are being continued to determine whether nutrient differences limit the response of stream algae to elevated temperature, and whether this pattern is altered under winter conditions.

† Work done by L. J. Tilly.

METHODS

To test whether productivity rates were more- or less-affected in streams than in the reservoir, colonies of periphyton were simultaneously incubated in Par Pond and in artificial streams at the Flowing Streams Laboratory.[2] ^{14}C uptake measurements were converted to productivity estimated and normalized on a dry weight basis or on a per unit area of substrate. The experimental procedure was identical to that described earlier,[3-5] except that in Par Pond periphyton-coated microscope slides from the FSL were suspended over magnetic stirrers set to produce a current equivalent to that in the streams.

RESULTS AND DISCUSSION

Representative results for determinations made during the spring, summer, and fall of 1976 are summarized in Figure 1. The data show that algal productivity is strongly influenced by temperature for Par Pond and less so for the FSL. The range of productivity values measured for the duplicate ambient temperature streams in the FSL overlaps the entire range of values associated with the elevated temperature streams for FSL. Generally, a positive correlation between temperature and productivity exists for Par Pond but not for FSL.

The overall range of temperatures spanned by the observations at the two sites was quite similar: 13.0 to 34.5°C for FSL; 11.0 to 34.7 °C for Par Pond. This observation, together with the fact that the span of temperatures on any single date was usually greater at FSL than at Par Pond, reinforced the conclusion that temperature elevations have less influence on algal growth in the FSL streams.

One preliminary conclusion is that differences in water quality (nutrient level) between the two systems account for the differences in algal growth response. Par Pond is continually receiving input from a potential nutrient source, the Savannah River. The relationship between plankton productivity in Par Pond and Savannah River water quality has been well-documented.[1] In contrast, Upper Three Runs Creek, the water source for FSL, is largely isolated from unusual nutrient inputs. One set of experiments involving enrichment of FSL water showed that productivity can be increased several-fold by adding nutrients, and that the degree of enhancement differs with different habitat temperatures.[5]

One somewhat unanticipated result suggests that the systems least likely to be radically altered in crop or productivity by thermal additions are the oligotrophic systems already limited by

lack of nutrients. The data suggest further that the sources of makeup waters need to be carefully chosen to ensure that their addition results only in desired alterations in productivity. These studies of the interactions between water quality and temperature elevation are continuing through the winter of 1976-1977.

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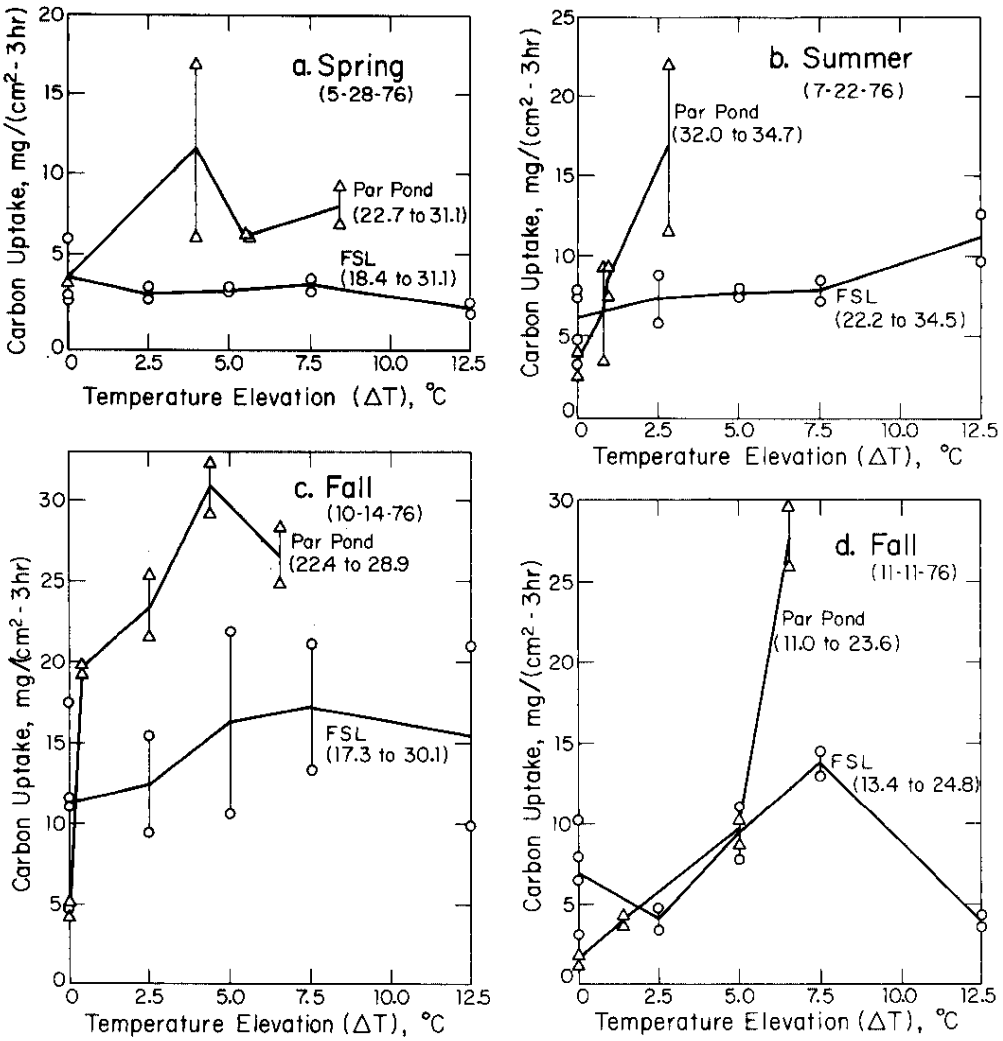

FIGURE 1. Periphyton Productivity; Par Pond *vs.* Flowing Streams Laboratory (FSL)

25. TEMPERATURE OPTIMA OF PERIPHYTIC COMMUNITIES IN THERMALLY ALTERED STREAMS†

INTRODUCTION AND SUMMARY

Stream communities in the Flowing Streams Laboratory at the Savannah River Plant are established in the six model streams. Stationary communities within the four heated streams are subjected to temperature perturbations of 2.5, 5.0, 7.5, and 12.5°C, respectively, above the ambient temperature of the parent stream, Upper Three Runs Creek. The communities have been subjected to these elevated temperatures since April 1976. The maximum temperature attained in the summer was 35.2°C. Subsequently, the minimum winter temperature observed in the ambient temperature streams was 7°C.

The present study determined that the response of the periphytic algal and bacterial communities was due primarily to temperature alterations and not to differences in nutrient concentrations. The optimum temperature for algal photosynthesis and bacterial respiration was determined to shift as seasonal and artificial heating temperatures changed. Such observations indicate that these periphytic communities can adapt to low-level thermal stresses. Adaptation is not uniform for all species, however, as species compositions within the communities were found to change with seasons and temperature.

MATERIAL AND METHODS

Algal and bacterial communities were allowed to colonize on either artificial substrates (glass coverslips) or natural rocks. After a given colonization period, the communities were removed from the substrates by a variety of techniques (grinding of coverslips, brushing, vortexing, sonication, etc.) and placed in filtered sterilized water taken from the artificial streams. Samples were homogenized, distributed into triplicate reaction bottles, capped, and incubated for 15 minutes at the appropriate temperature. Carbon-14 isotopes were then injected into the reaction bottles, and the incubations were continued. Algal responses were measured after ^{14}C-$NaHCO_3$ incorporation in the light, while heterotrophic bacterial populations were similarly assessed after ^{14}C-glucose, -acetate, and -glycine incorporations in the dark. All samples were incubated in baths ranging from

† Work done by C. B. Fliermans.

5 to 75°C, and isotope incorporation was terminated by the addition of 37% formaldehyde. Samples were filtered onto a 0.45 μm *Millipore* (Millipore Corp., Bedford, MA) membrane filter and combusted to $^{14}CO_2$, which was collected and counted by liquid scintillation.

RESULTS AND DISCUSSION

The data (Table 1) demonstrate that the temperature optima for isotopic uptake for both the heterotropic and autotrophic communities change with seasonal variation and with temperature. During the winter months when the water temperatures are cooler, the periphytic communities adapt to lower temperatures for both respiration and photosynthesis. Macroscopic and microscopic observations suggest that the species compositions of the algal communities shift dramatically under both seasonal and temperature changes. Such shifts in the community compositions are due primarily to temperature alterations rather than changes in nutrients. Table 2 substantiates these findings in that the data indicate that no significant differences in water quality occurs between the ambient water and water heated to 25°C above ambient.

TABLE 1

Temperature Optima of Bacterial and Algal Periphytic Communities at Various Habitat Temperatures

Community	*Season*	*Habitat Temp., °C*	*ΔT (°C) Above Ambient*	*Temp. Optima, °C*
Bacterial (heterotropic)	Winter	8.0	0	15
	Spring	14.5	0	25 to 30
	Summer	18.7	0	30
	Fall	17.5	0	30
	Winter	10.5	2.5	15
	Winter	13.0	5.0	25
	Winter	15.5	7.5	25
	Winter	20.5	12.5	30
Algal (autotropic)	Winter	8.0	0	25
	Spring	14.5	0	25
	Summer	18.7	0	25
	Fall	17.5	0	25
	Summer	21.2	2.5	25
	Summer	23.7	5.0	30
	Summer	26.2	7.5	30
	Summer	31.2	12.5	35

TABLE 2

Nutrient Concentration in Hot and Cold Water Flowing into the Flowing Streams Laboratory

Nutrient	*Nutrient Concentration, ppm*[a]	
	Hot water header[b]	*Cold water header*
$SO_4^=$	1.14 ± 0.25	0.88 ± 0.15
NH_4^+ (N)	0.021 ± 0.003	0.021 ± 0.002
NO_2^- (N)	0.0016 ± 0.0002	0.0010 ± 0.0005
NO_3^- (N)	0.111 ± 0.007	0.107 ± 0.009
PO_4^- (Total)	0.0223 ± 0.0038	0.0379 ± 0.0093
PO_4^- (Ortho)	0.023 ± 0.0011	0.023 ± 0.0033
Cl^-	2.36 ± 0.07	2.49 ± 0.17
HCO_3^-	4.63 ± 0.022	4.43 ± 0.15

a. n = 4; ± S.D.

b. Temperature in header was 25° above ambient.

26. PERIPHYTON COMPOSITION DIFFERENCES IN ARTIFICIAL STREAMS EXPOSED TO DIFFERENT TEMPERATURE REGIMES†

INTRODUCTION AND SUMMARY

Periphytic algae are of considerable ecological significance because they represent the major source of primary productivity in many aquatic ecosystems. Major changes in the abundance and species composition of these algae are usually indicative of, and contributory to, substantial changes in water quality. Studies to determine the impact on periphyton in artificial streams heated 2.5, 5, 7.5, and 12.5°C above ambient temperature are currently being conducted at the Flowing Streams Laboratory of the Savannah River Laboratory (SRL).[1]

Preliminary results from qualitative analyses of natural substrate samples indicated that temperature elevations up to 7.5°C caused only minor changes in community structure; whereas, a 12.5°C increase created a dramatic shift in species composition resulting in extreme dominance by filamentous blue-green algae.

METHODS

Approximately 20 samples were analyzed from each of the six artificial streams of the Flowing Streams Laboratory. Some samples were pipetted from various portions of the stream bottoms; others were collected by scraping submerged rocks, sticks, and plants. Each sample was examined by fluorescence microscopy[2] immediately following collection so that live specimens could be observed. Hyrax mounts were occasionally prepared to aid in the identification of diatoms. All taxa were identified to the lowest feasible taxonomic level and categorized as abundant, common, or rare. Water temperatures were measured daily with a mercury thermometer.

RESULTS AND DISCUSSION

A few weeks after the April 20, 1976, introduction of heated water to the Flowing Streams Laboratory, it became obvious from visual observations that natural substrates in the "hot" stream (+12.5°C) were being covered by mats of blue-green algae. Microscopic examinations, commencing in early July, revealed a pronounced

† Work done by E. W. Wilde.

domination of filamentous blue-green algae in this stream throughout the summer. Diatoms and green algae increased steadily in relative abundance during the fall, but filamentous blue-green algae were still the major algal group on many natural substrates in the "hot" stream at the end of the calendar year. Filamentous blue-green algae were common in the other five streams, particularly during the summer, but were never the dominant group on any of the natural substrates. Average daytime water temperatures for three of the streams are presented in Table 1. The average temperature of the "hot" stream during December (21.9°C) was slightly lower than the average temperature of the control streams in July (22.1°C); however, the relative abundance of filamentous blue-green algae in the "hot" stream during December was substantially greater than was observed in any of the other streams during any part of the year.

Although a direct relationship between water temperature and filamentous blue-green algal dominance was apparent, the relationship was not a linear one. Increasing water temperature up to 7.5°C caused only slight increases in relative abundance of blue-green algae, whereas the additional 5°C increase to that of the "hot" stream resulted in the group becoming very dominant. Other factors including light, nutrients, and predation are undoubtedly involved in this phenomenon. Experiments by Patrick, et al.[3] indicated that blue-green algae became dominant at temperatures above 35°C, and studies by Brock[4] suggested that 40°C was the critical temperature for blue-green algal dominance. A water temperature of about 30°C apparently caused blue-green algae to become dominant in the Flowing Streams Laboratory system, because dominance occurred in the "hot" stream when temperatures averaged slightly over 30°C; and the group did not become dominant in the second warmest stream where summer temperatures averaged slightly less than 30°C.

In addition to the filamentous blue-green algal dominance, several other substantial differences between periphyton composition in the "hot" stream and the other streams were noted. Several taxa were very abundant on some substrates in the ambient temperature control streams, successively less abundant in the streams heated 2.5, 5, and 7.5°C, and never observed in samples from the "hot" stream. These included a yellow-brown alga, *Vaucheria* sp.; the red algal species, *Tuomeya fluviatilis* and *Audouinella violacea*; a green alga, *Closterium* sp.; and a diatom, *Cymbella cuspidata*.

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TABLE 1

Average Daytime Water Temperatures (°C) of Three Artificial Streams at the Flowing Streams Laboratory (April 20 - December 31, 1976)

	Temperature, °C		
Date	*AS #2 (Control)*	*AS #1 (+7.5°C)*	*AS #6 (+12.5°C)*
April (20-30)	18.3	25.7	30.6
May	17.7	25.1	30.5
June	19.9	27.5	32.9
July	22.1	29.8	34.4
August	21.4	29.0	33.6
September	19.7	27.4	32.2
October	15.4	23.0	28.1
November	11.2	19.0	23.8
December	9.6	17.2	21.9

27. FIELD RESPONSES OF ZOOPLANKTON POPULATIONS TO TEMPERATURE CHANGES CAUSED BY REACTOR OPERATIONS†

INTRODUCTION

Field determinations of thermal tolerance limits for zooplankton have helped in the definition of experiments needed to evaluate the effects of reactor operations upon these animals. Currently, the rates of births and deaths for populations of Cladocera are being quantified in hyperthermal and nonhyperthermal areas of the reactor cooling reservoir, Par Pond.

The Par Pond cooling water system (Figure 1) passes through 7.1 kilometers of canals and six "precooler" ponds before entering Par Pond through a standpipe. Pond C, the last of the precooler ponds, may be as much as 20°C above ambient, while the upper 3 m of the thermally affected middle arm of Par Pond (avg depth, 6 m) may attain a maximum of 8°C above ambient. When the reactor is not operating for approximately one week, all limnetic Cladocera found in Par Pond can be found in Pond C. When the reactor is operating, hot water entering as a sheet across the surface of Pond C, heats the entire water column from above, sometimes in 3 to 4 days. This rapid heating of Pond C to high temperatures above ambient permits observations (in a field situation) which are similar to observations during laboratory studies of the critical thermal maxima of Cladocera. The effluent-receiving middle arm of Par Pond simulates more closely the thermal situation created by a power-generating plant.

METHODS

Studies of March 1976 are illustrative of how the cooling canal and pond system can serve as a field laboratory. The reactor was shutdown for a period of two weeks in the beginning of March 1976. As the reactor was started up, Cladocera were sampled at a station in Pond C and at two stations in Par Pond (Figure 1) by taking four vertical tows with a No. 10, 1/2-meter zooplankton net. One random subsample was counted from each tow and considered to be a nonparametric estimate of abundance.

† Work done by T. J. Vigerstad and L. J. Tilly.

Sampling sets were compared using a Mann-Whitney U-Test. In this comparison of four samples per station, significance at the 0.05 level was reached when no overlap of numbers occurred between sets of samples.

RESULTS

On March 15, all the cold station species were found in similar relative abundances in Pond C (Table 1). A trend of decrease in abundance of *Bosmina longirostris* and *Ceriodaphnia lacustris* began on March 18 as water column temperatures increased (Figure 2), and by March 21, both species were rare in the tows (Figure 3). In contrast, *Chydorus sphaericus* remained at approximately the same level of standing crops throughout the period sampled. The species which were rare on March 15 (Table 1) were still rare (less than 10% of the total Cladocera) on March 21.

Changes observed by March 28, the date on which the upper 3 m of the water columns reached maximum temperature (Figure 4) in the middle arm of Par Pond (Station MA), were a) significant drops in the standing crops of *Bosmina* and *Ceriodaphnia* and b) a significant increase of *Daphnia* (Figure 5); all other species remained at the same levels when compared to standing crops on March 15. In contrast, almost all species from the Cold Dam area (Station CD) remained at the same level of standing crop throughout the sampling period; only *Ceriodaphnia* decreased significantly in abundance.

DISCUSSION

The results illustrate the difficulty of using thermal tolerance data alone to predict the consequences of surface plume additions in the limnetic zone. On one hand, results from Pond C suggest that little or no short-term effect should be observed from the effluent additions. All species observed in Pond C were able to withstand changes in temperatures of 7°C per 24 hours and temperatures up to 35°C for several days. Neither condition occurred in Par Pond. On the other hand, if the results from Pond C are taken as a relative index of effect, *Bosmina* and *Ceriodaphnia* would be predicted to be affected to some extent by the heated waters, *Ceriodaphnia* being affected first (Figure 5), and the other species later or not at all. This latter prediction seems to describe more closely the series of events for the different species, which suggest that the species are more sensitive to changes in reactor operations than our Pond C observations indicate.

However, based upon the sampling data from Station CD, a decline in *Ceriodaphnia* by March 28 would be expected even without the addition of hyperthermal effluents. The events at Station MA are complex, and replication of the observations is required. Certainly, Pond C tolerance data are not useful for long-term prediction of consequences for existing thermal conditions at Station MA during reactor generations, as temperatures even within the surface plume are well below observed tolerance limits and below the 3 m isobath. Stations CD and MA are nearly identical in temperature. The extent of the effects of reactor operations on limnetic Cladocera of the middle arm will, therefore, depend upon the extent of the vertical migration of the Cladocera. The vertical migration, therefore, influences the thermal history of the Cladocera and thereby affects their birth rate, growth, metabolism, and vulnerability to predation.

TABLE 1

Relative Abundance of Cladocera Species in Par Pond

Species	*Relative Abundance, %*[a]	
	Cold Dam Station	*Pond C Station*
Bosmina longirostris	41-33.5	40.5-27.0
Ceriodaphnia lacustris	61.5-46.5	68.5-52
Other *(Chydorus sphaericus, Diaphanosoma brachyurum, Daphnia parvula, Eubosmina tabicen, Holopendium amozonicum)*	12.5-6.0	8.5-4.0

a. Range of Cladocera species collected in four replicate tows at each of the two stations on March 15, 1976.

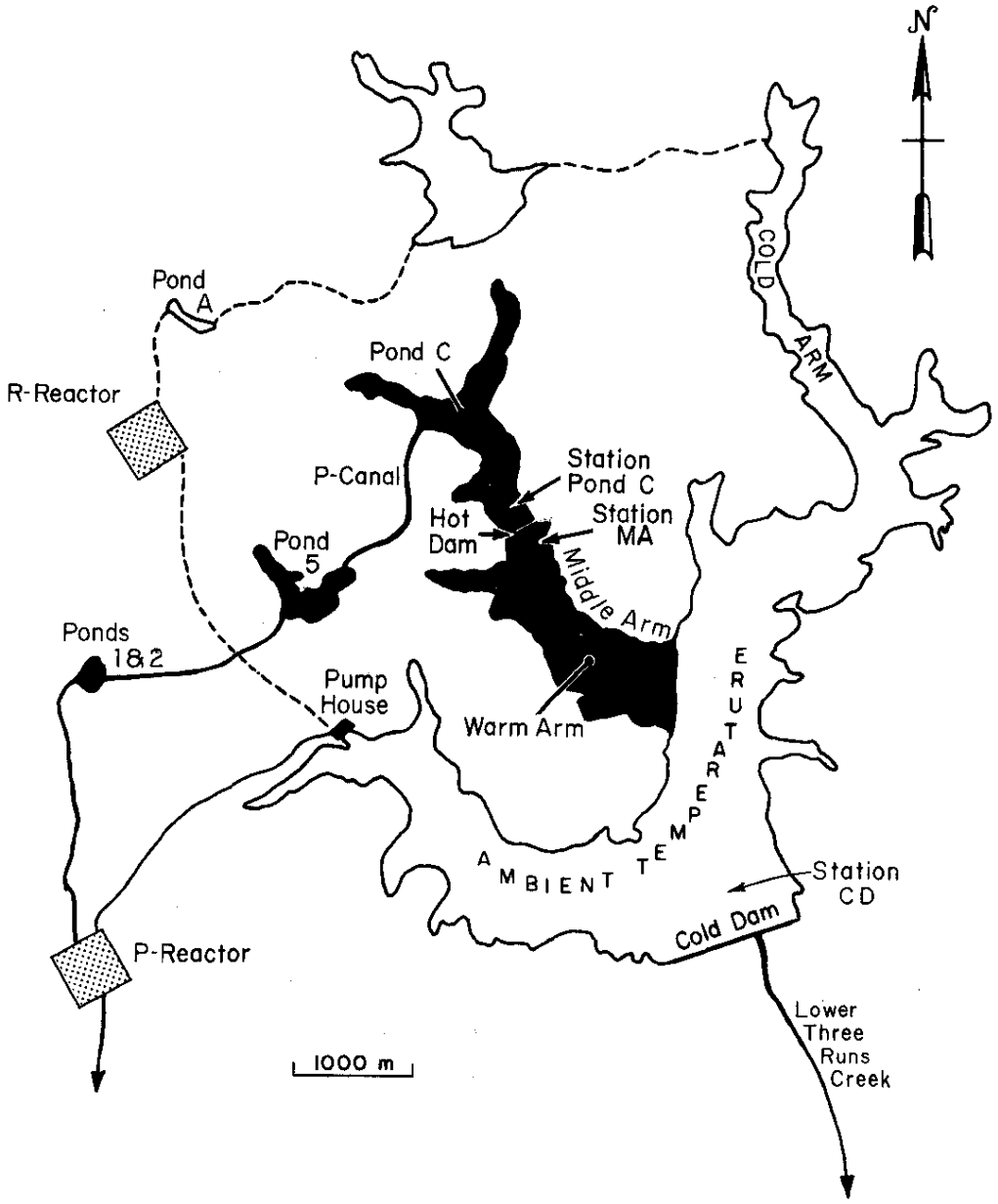

FIGURE 1. Par Pond Cooling System Showing Sampling Stations

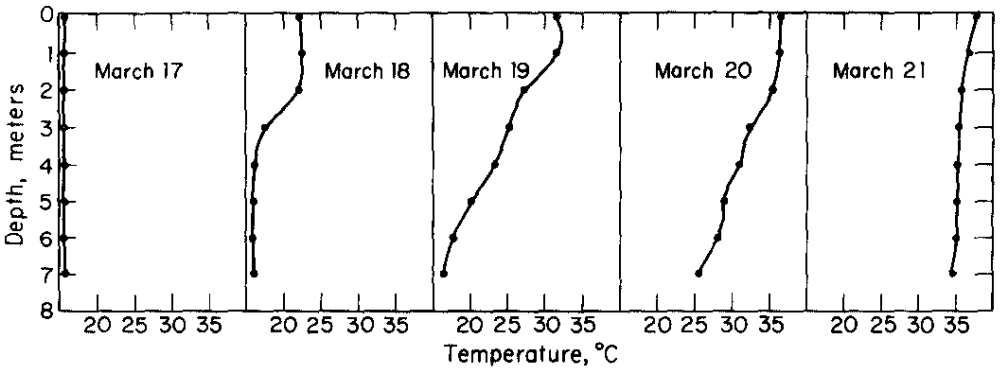

FIGURE 2. Temperature Changes in Water Column in Pond C (March 1976) after Reactor Startup

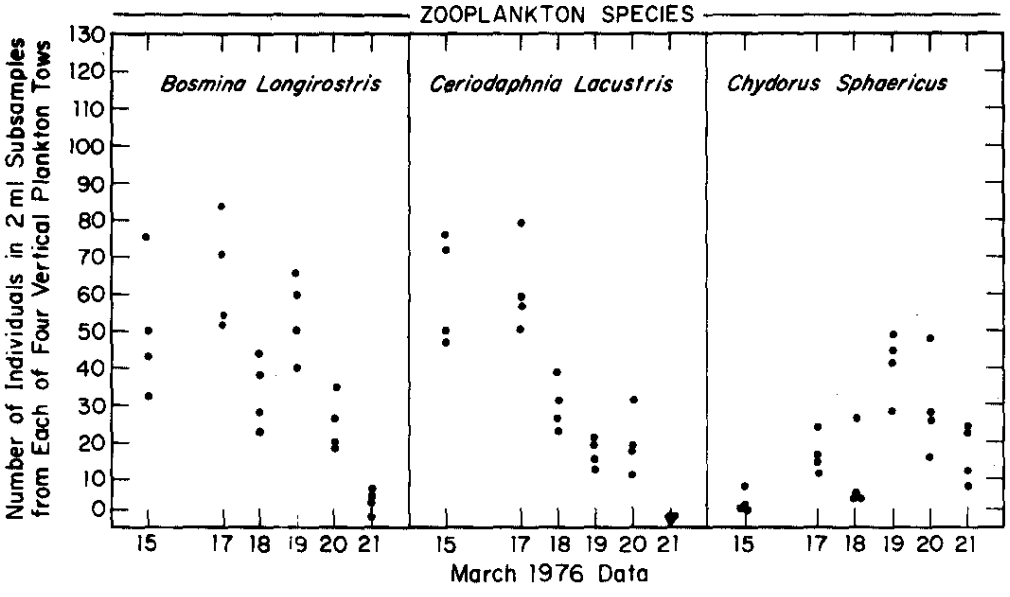

FIGURE 3. Dominant Zoological Species from Pond C

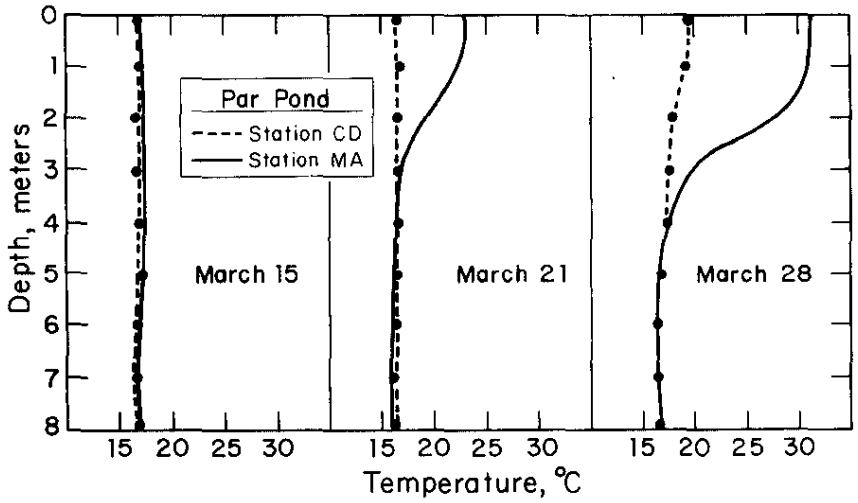

FIGURE 4. Temperature Changes in the Water Column in Par Pond (March 1976) after Reactor Startup

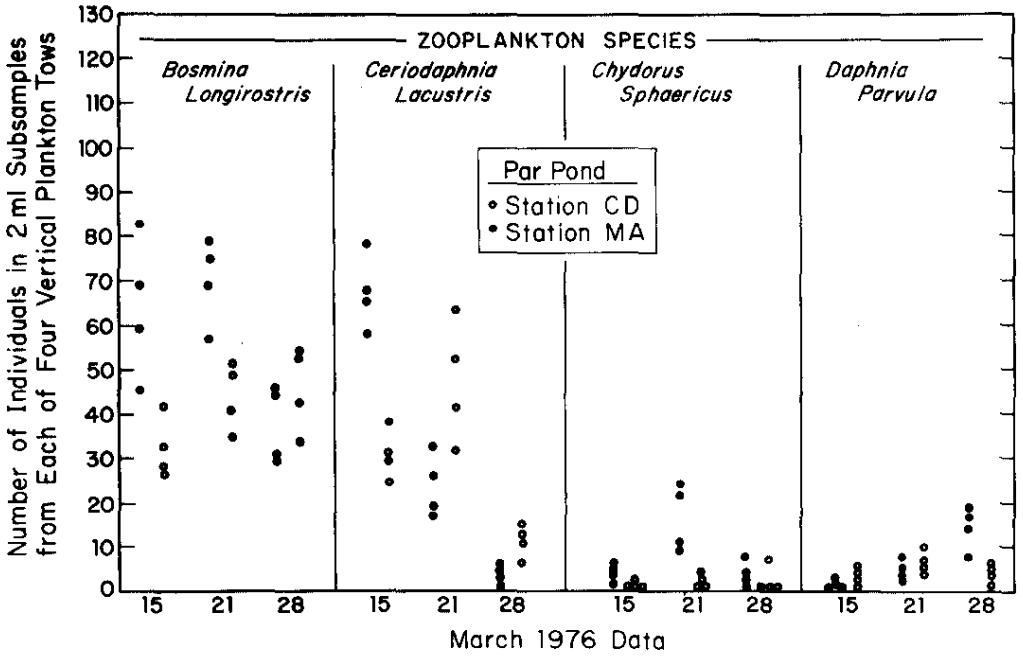

FIGURE 5. Dominant Zoological Species from Par Pond

28. DIRECT AND INDIRECT EFFECTS OF HYPERTHERMAL EFFLUENT ON AQUATIC MACROPHYTES IN PAR POND†

INTRODUCTION AND SUMMARY

Studies on rooted aquatic plants in a reactor cooling reservoir demonstrate that both direct and indirect effects result from the introduction of hyperthermal effluents into such aquatic systems.

Direct effects are generally effects mediated through the physiological response of the organisms to conditions of the effluent; indirect effects are influences mediated through interactions such as predation or competition. The 1975 observations of rooting depths of *Myriophyllum spicatum* and *Eleocharis acicularis* in relation to the thermal effluent in Par Pond illustrate this point.

METHODS

In July and October 1975, three stations at Par Pond were sampled to represent hot, warm, and unheated areas of the reservoir. These stations had similarly oriented shores, and thus were not subject to the confounding effects of differential solar radiation. Sampling was restricted to plants which were rooted at water depths ≥0.5 m to avoid emergent macrophytes. At each shore of each station, a total of 120 samples were collected for biomass determinations at water depths of 0.5, 1.5, 2.5, 3.5, and 4.5 meters along four randomly chosen transects. Samples were taken with a cylinder sampler described by Grace and Tilly.[1] "Rooting depth" means the depth below the water's surface at which plants are anchored to the bottom.

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

RESULTS AND DISCUSSION

Maximum Rooting Depth of *Myriophyllum spicatum*

Myriophyllum was found to water depths of 5.0 m in unheated areas of Par Pond (Table 1). However, at the warm station, the maximum water depth of rooting averaged 4.0 m; at the hot station, the maximum water depth averaged 3.0 m. If we assume that plant fragments were dispersed at depths of 5.0 m at all stations, then differences in environmental conditions must be responsible for the differences in the maximum water depths of rooting. Table 1 shows that representative light penetration differences between heated and unheated areas do not entirely explain the differences in rooting depth. The differences in light penetration could explain, at most, a 0.7 m decrease in rooting depth at the hot station, leaving a difference of 1.3 m unexplained (Table 1).

Another factor which could have been involved in the differences in depth of rooting was temperature. If decreased light penetration alone caused a 0.7 m reduction in the station average of the maximum depth of rooting at the hot station, this would limit the maximum water depth to 4.3 m. At a depth of 4.3 m at the hot station, water temperature was approximately 1°C warmer than at the unheated station at 5.0 m. Also, at the observed average maximum water depth of 3.0 m at the hot station, the water temperature was approximately 2°C warmer than at 5.0 m at the unheated station.

Very few plants were found at 4.5 m at the hot and warm stations, but those which did occur were quite tall (average = 1.6 m). This suggests that the cause of the low density of plants was a failure of plant fragments to establish themselves rather than an inability of established plants to grow well. If the low density were the result of an inability of established plants to grow, numerous short plants would be expected.

These observations are consistent with the prediction by Stanley[2] that the maximum water depth of rooting for *Myriophyllum spicatum* would be decreased at higher temperatures because of greater respiratory demands and, therefore, a higher light intensity would be required for the compensation point.

Maximum Rooting Depth of *Eleocharis acicularis*

The maximum depth of rooting of *Eleocharis* was the same as the minimum depth at which *Myriophyllum* was rooted in most of our observations. Therefore, Table 2 (which compares light penetration and *Eleocharis* maximum rooting depths) is equally valid as a

representation of the correlation between light penetration and the minimum water depth at which *Myriophyllum* rooted. However, in this case, there is no reason to suspect that light (or temperature) limited the establishment of *Myriophyllum*, because *Myriophyllum* was found between 0.5 and 1 m in the few cases when *Eleocharis* was absent from a transect. It is reasonable to suspect that the dense mats formed by *Eleocharis* can prevent the establishment of *Myriophyllum* in shallow waters. Osborn[3] has reported *Eleocharis* to be a very effective competitor against other species of macrophytes. Therefore, our observations strongly suggest that *Eleocharis* is the principal factor determining the minimum rooting depth of *Myriophyllum* in Par Pond.

In summary, we hypothesize that the maximum rooting depth of *Myriophyllum* is affected primarily by light and temperature, while its minimum rooting depth is determined by the presence of *Eleocharis*. Thus, the expected maximum rooting depth of *Myriophyllum* could be changed directly by changes in temperature from reactor operations; directly by light penetration, as a function of water quality; and indirectly by biological processes such as plankton productivity. The minimum expected rooting depth of *Myriophyllum* would be indirectly determined by reactor operations as these also affected *Eleocharis* populations.

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TABLE 1

Correlation Between Light Penetration and Maximum Depths of Rooting of *Myriophyllum*

	Station		
1974	*Hot*	*Warm*	*Unheated*
Maximum depth of rooting, m[a]	3.0	4.0	5.0
Surface light at max. depth, %[b]	4.42	-	0.78
Depths of equal light intensity, m[b]	4.7	-	5.0
1975			
Maximum depth of rooting, m[a]	3.0	4.0	5.0
Surface light at max. depth, %[b]	1.85	-	0.37
Depths of equal light intensity, m[b]	4.2	-	5.0

a. Determinations of maximum water depth of rooting were made by *in situ* measurements.

b. Average light penetration values from March through May were used because the growing tips of *Myriophyllum* shoots would begin growth in March and be 1 to 2 meters long by June. The Secchi averages for March through May were:

1974 — Station 1 = 2.875 and Station 4 = 3.092
1975 — Station 1 = 2.260 and Station 4 = 2.667.

TABLE 2

Correlation Between Light Penetration and Maximum Depths of Rooting of *Eleocharis*

	Station		
1974	*Hot*	*Warm*	*Unheated*
Maximum depth of rooting, m[a]	0.75	1.50	2.00
Surface light at max. depth, %	38.58	-	10.23
Depths of equal light intensity, m	1.80	-	2.00
1975			
Maximum depth of rooting, m[a]	1.00	1.50	2.00
Surface light at max. depth, %	26.18	-	10.86
Depths of equal light intensity, m	1.65	-	2.00

a. Determinations of maximum depth of rooting were made by *in situ* measurements.

29. MODIFICATION OF MEMBRANE DIFFUSION CHAMBERS FOR DEEP WATER STUDIES†

INTRODUCTION AND SUMMARY

Membrane diffusion chambers as designed and instrumented by McFeters and Stuart[1] have been widely used for the study of bacterial survival in surface waters of streams or in laboratory situations.[2,3] However, preliminary experiments in a thermally enriched, deep-water lake (Par Pond) demonstrated the need for modified chambers. The modified chambers, now routinely used in SRL studies, facilitate sampling and resist damage during exposure in the water column.

MATERIAL AND METHODS

Polycarbonate filters, 0.4 nm, (*Nuclepore*, Nuclepore Corp., Pleasanton, California), were substituted for cellulosic membrane filters, because the former are resistant to bacterial degradation. Enlarged and modified chambers, along with filters, were autoclaved and aseptically assembled as previously described.[1]

In order to determine diffusivity of the modified chambers, assembled chambers were placed in the lake at four different depths (1, 5, 10, and 15 meters). The external surfaces of the chambers including the polycarbonate membranes were colonized by periphytic microorganisms for periods of 0 to 14 days. At the end of the incubation period, a dilute solution of safranine, previously filtered through a 0.4 nm pore size polycarbonate filter, was injected into the chambers, and the chambers were returned to the appropriate depth. Samples were taken every 30 minutes, and the concentrations of the dye remaining in the chambers were determined using a Beckman Model 25 double beam spectrophotometer.

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

RESULTS AND DISCUSSION

The rate of diffusion for each depth and for each colonization time are plotted in Figure 1. The data indicate that the diffusion rates of these chambers are comparable to those of McFeters and Stuart.[1] The data further show that the deepest chambers have slower diffusivity than shallower chambers; this difference may be a reflection in part to the surface phenomena of wave action and wind turbulence. Although diffusion rates through the chambers increased with longer incubation times in Par Pond, the reason(s) for such changes are unclear. At the termination of the experiment, all membranes were intact and appeared in similar condition as evaluated by light microscopy.

Modified chambers containing equal densities of *Escherichia coli* were placed in triplicate in both epilimnetic and hypolimnetic waters at two thermally different stations in a thermally stressed lake. Surface waters at the thermal station of the lake are generally 10°C greater than the surface waters at the ambient temperature station. The data in Figures 2 and 3 show the close replication between triplicate chambers suspended at the same position in the water column during a three-week sampling period. The percent standard error among all the modified chambers ranged from 2.4 to 10.0, with a mean of 5.9 which further indicates the excellent reproducibility.

Membrane diffusion chambers are relatively inexpensive tools to study the response of known bacteria to a given aquatic system. These modified chambers provide ease in handling, freedom from external damage, long sampling life, good exchange capabilities, and excellent statistical reproducibility.

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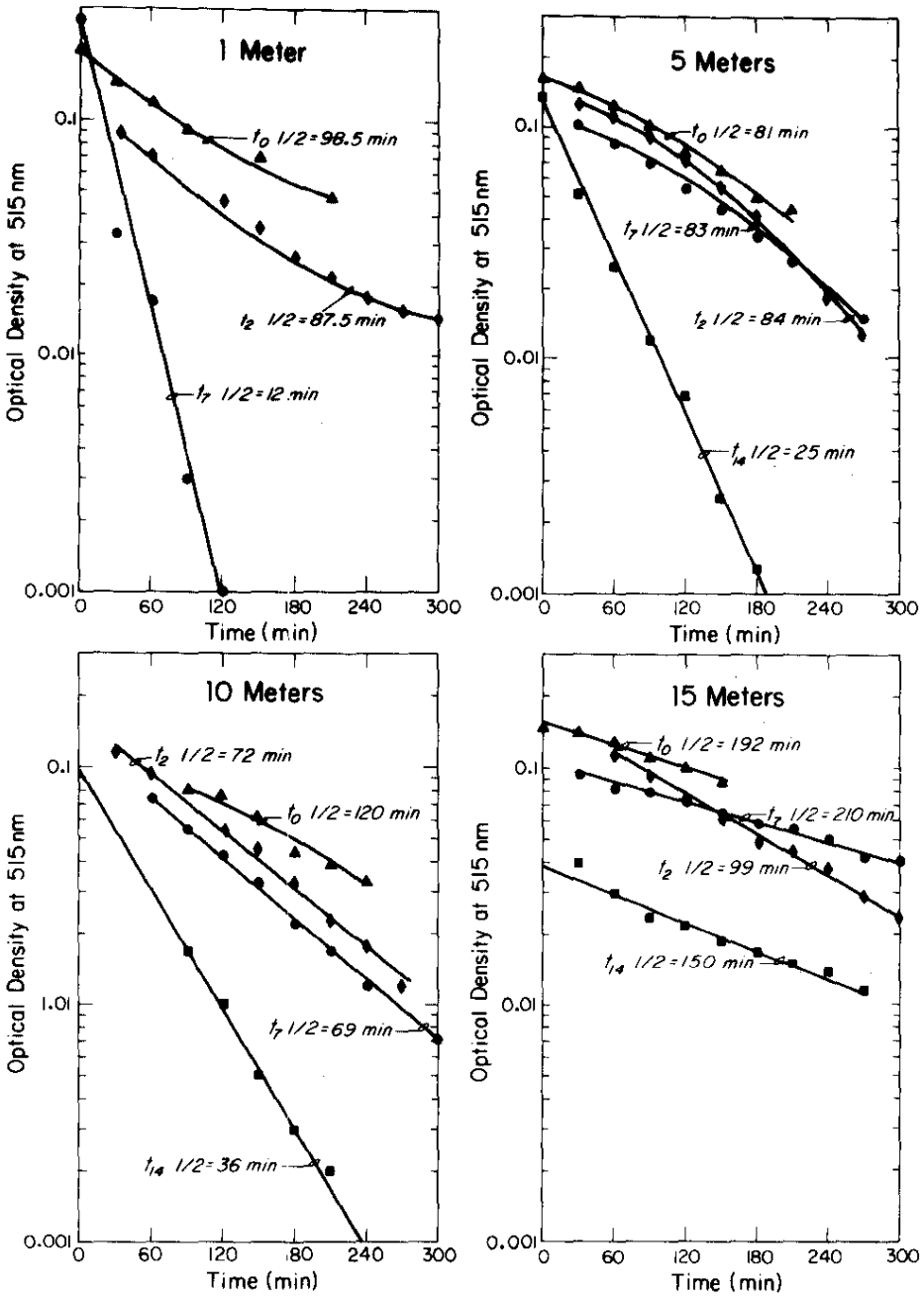

FIGURE 1. Diffusion of Dye from Modified Chambers. Chambers placed at various depths in the water column for several incubation periods; $t_n\frac{1}{2}$ = time necessary to empty half of the chamber after n days of incubation, ▲ No incubation, ◆ 2-day incubation, ● 7-day incubation, ■ 14-day incubation.

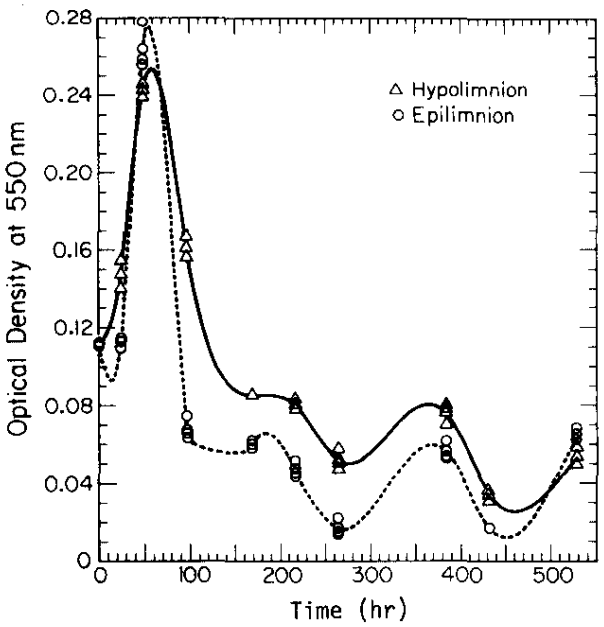

FIGURE 2. Densities of *E. coli* Cultures at the Thermal Station of Par Pond. Optical density measurements of *E. coli* culture placed in triplicate chambers suspended in both epilimnetic and hypolimnetic waters of a heated portion of a thermally stressed lake. The data are plotted through the mean of triplicate measurements.

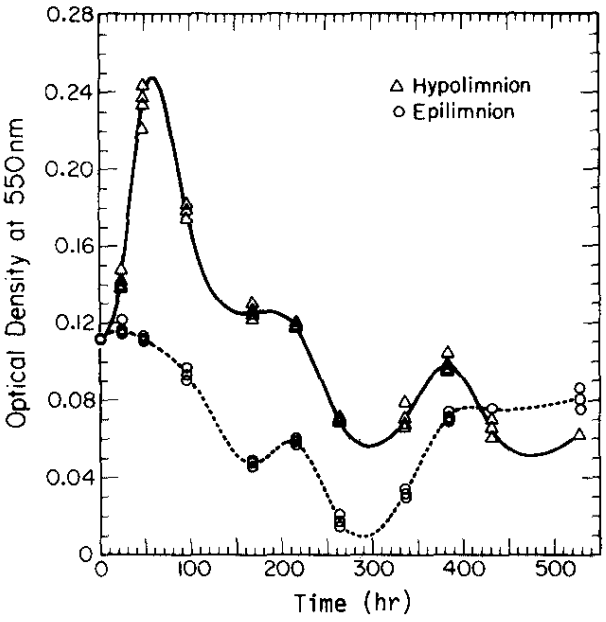

FIGURE 3. Densities of *E. coli* Cultures at the Ambient Temperature Station of Par Pond. Optical density measurements of *E. coli* culture placed in triplicate chambers suspended in both epilimnetic and hypolimnetic waters of an unheated portion of a thermally stressed lake. The data are plotted through the mean of triplicate measurements.

30. STRAIN SPECIFICITY OF *AEROMONAS HYDROPHILA*: AN IMMUNOFLUORESCENCE STUDY†

INTRODUCTION AND SUMMARY

Par Pond fish, particularly the largemouth bass, and alligator populations are infected with *A. hydrophila*, which causes "red sore disease." The bacterium has been shown to survive for extended periods of time in Par Pond,[1] but does not survive as well in Clark Hill, a nearby large reservoir on the Savannah River. The present study was initiated to characterize the various types of *A. hydrophila* in Par Pond and in the alligators and bass populations.

Strain-specific fluorescent antibodies were prepared for various strains of *A. hydrophila* isolated from water, largemouth bass, and alligators from Par Pond, a monomictic lake thermally altered by effluents from an SRP production nuclear reactor. Over 200 isolates obtained from water, bass, alligators, and human samples were characterized serologically and biochemically for drug sensitivity and were grouped. *A. hydrophila* associated with the infections of the largemouth bass and the alligators does not appear to be the serological strain dominant in the water column of Par Pond, nor in the strains examined from the American Type Culture Collection.

MATERIAL AND METHODS

Bacterial Isolates

A. hydrophila were isolated with RS medium[2] from a variety of habitats and from specimens obtained from the American Type Culture Collection (ATCC). Colonies characteristic of *Aeromonas hydrophila* were subjected to 23 different biochemical tests using the API system.[3] In addition, each of the 255 isolates were characterized as to their sensitivity or resistance to the following antibiotics: chloramphenicol, erythromycin, bacitracin, novobiocin, penicillin, streptomycin, vancomicin, furadantin, tetracycline, chloromycetin, ampicillin, nalidixic acid, and sulfathiazole.

† Work done by C. B. Fliermans.

Immunofluorescence Preparations

Cultures of *A. hydrophila* were isolated from Par Pond water, infected largemouth bass, and American alligators. The cultures were checked for purity and grown to a density of 10^8 cells/ml for the preparation of the individual fluorescent antibodies. Cells were harvested by centrifugation, washed, resuspended in phosphate buffered saline (pH 7.2) solution, and injected intravenously into rabbits. After injections were completed, test bleedings were made, and 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 previously described.[4]

Methods for preparation and staining of contact slides and for all fluorescence microscopy and photomicrography are detailed elsewhere.[5] Gelatin-rhodamine isothiocyanate conjugate was used to suppress nonspecific absorption of the fluorescent antibodies. The techniques for preparation of terrestrial and aquatic samples for immunofluorescence examination on membrane filters were as previously reported.[6]

RESULTS AND DISCUSSION

Each of the 255 cultures of *Aeromonas hydrophila* were analyzed for similarities in biochemical and nutritional requirements, drug sensitivity, and the degree of immunological similarity. The drug resistance data are summarized in Table 1. All isolates were resistant to high doses of penicillin, ampicillin, bacitracin, and novobiocin antibiotics. All the isolates were similar in their response to antibiotics regardless of where the isolates were obtained. In addition, all of the isolates appeared to be similar in their biochemical reactions and their utilization of various nutritional substrates as established by the API system.

The immunofluorescence data indicate that the isolates obtained from the ATCC are not serologically the same as the isolates obtained from Par Pond samples. Likewise, the isolates from the water are generally not the organisms causing the infections in the bass nor in the alligators. On the other hand, those isolates from infected bass appear to be serologically similar to isolates taken from internal tissues of the alligators.

Other data suggest that the various strains of *A. hydrophila* are similar in their biochemical, nutritional, and drug sensitivity requirements, but they are dissimilar in their serological reactions.

Thus it appears that given strains of *A. hydrophila* are more optimally adapted to the aquatic habitats, while others survive better in association with cold-blooded animals.

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TABLE 1

Percentages of Isolates Resistant to Tested Drugs

Antibiotics (conc., mcg)	*Furadantin (300)*	*Streptomycin (10)*	*Tetracycline (30)*	*Penicillin (10 units)*	*Ampicillin (10)*	*Nalidixic Acid (30)*	*Sulfathiazole (150)*	*Bacitracin (10)*	*Chloramphenicol (30)*	*Erythromycin (15)*	*Novobiocin (30)*	*Vancomicin (30)*	*Chloromycetin (30)*
Par Pond:													
Water n=115	14	4	1	100	100	0	45	86	14	48	100	19	0
Bass n=107	15	2	7.6	100	91	1	47	94	6	13	100	6	2
Alligator n=25	25	0	0	100	75	0	50	100	0	29	100	19	0
ATCC:													
14486	N.D.	+	N.D.	+	N.D.	N.D.	N.D.	+	+	+	+	+	N.D.
7966	-	+	-	+	+	-	+	+	-	+	-	-	-
15467				+	+			+	+	+	+		
13137	+	-	-	+	+	-	+	N.D.	-	-	+	-	-
15338	+	+	-	+	+	-	+	+	+	+	+	-	-
14715	-	+	-	+	+	-	+	+	+	+	+	+	-
19570	-	+	-	+	+	-	+	+	-	+	+	+	-
15468				+	+		+	+		+	+	+	

N.D. = Not Determined.

31. *AEROMONAS* SURVIVAL IN A THERMALLY ALTERED LAKE†

INTRODUCTION AND SUMMARY

Par Pond, a thermally enriched monomictic southeastern lake, has received considerable research attention due in part to the large populations of fish which are infected with the "red sore disease." The chief etiological agent of this disease is apparently the ubiquitous aquatic bacterium *Aeromonas hydrophila*.[1,2,3] Previous studies[4] have considered neither the survival nor the distribution of this bacterium *in situ*. This paper describes the survival of *Aeromonas hydrophila* in natural lake waters altered by thermal effluents discharged from a nuclear production reactor.

Survival of *A. hydrophila* under *in situ* conditions in both epilimnetic and hypolimnetic waters was determined with polycarbonate membrane diffusion chambers during two separate reactor operating conditions. Survival levels of pure cultures of *A. hydrophila* corresponded to the distribution patterns of the naturally occurring, *Aeromonas*-like populations. The greater survival of *A. hydrophila* during full reactor operation suggests that the fish populations may be exposed to high concentrations of this bacterium for relatively long time periods while the reactors are operating.

MATERIAL AND METHODS

Known cultures of *A. hydrophila* were checked for purity on *Aeromonas*-specific medium, transferred, and routinely grown in nutrient broth at 30°C. Cells were harvested during the logarithmic growth phase, washed three times in 0.01M phosphate-buffered saline solution (pH 7.2), centrifuged, and resuspended in 40.0 ml of phosphate-buffered saline solution to a final optical density of 0.150 at 550 nm. The cell suspension was placed into sterile membrane diffusion chambers as modified for deep water studies.[5] The chambers were immediately suspended from stainless steel chains and lowered to various depths in the water column at five permanent stations in Par Pond (Figure 1).

† Work done by C. B. Fliermans (SRL-ETD), R. W. Gorden (Faculty Research Participant, Southern Colorado State University, Pueblo, Colorado), and T. C. Hazen and G. W. Esch (Biology Department, Wake Forest University, Winston-Salem, North Carolina).

Previous studies with modified chambers[5] indicated that bacterial cultures inside triplicate chambers placed at the same depth in the water column had optical density readings within 10% of each other during a 2-week sampling period. Single chambers were placed at four different depths; two chambers in the epilimnetic waters, and two in the hypolimnetic waters at all five stations.

Sampling was irregular during the 3-week experiments; generally, initial samples were taken every 3 hours for 48 hours, then once every 24 hours through the remainder of the experiment. Samples, taken aseptically with sterile plastic syringes, were measured for optical density and tested for diffusion chamber purity by immunofluorescence (Fliermans, unpublished results) and/or plating on a selective medium.

RESULTS AND DISCUSSION

Initial population densities were measured, and survival of *A. hydrophila* was determined after the reactor had not been operating for 30 days. Subsequent measurements were conducted after the reactor had been operating for over 19 days, so that lake temperatures had stabilized.[6] All sampling was performed during normal lake stratification, and such stratification remained stable during both phases of reactor operations. Survival studies for *A. hydrophila* were conducted using sterile membrane diffusion chambers placed at various depths in the water column. The depth of each chamber depended on the station, the depth of thermal stratification, and the oxygen chemocline. Representative data for *A. hydrophila* survival, as measured by optical density, are plotted for various depths in the water column along the vertical oxygen gradient (Figure 2) and a surface temperature gradient (Figure 3).

The data demonstrate that regardless of the depth of the chambers, or the station, *A. hydrophila* survived longer when the reactor was in full operation than when it was not. Survival measurements at Station 5 (ambient control) indicated that similar results occurred, but less dramatically than in the stations closer to the thermal effluent.

Comparisons among stations demonstrated that when the reactor was not in operation, the percentage of initial optical density approached zero after 60 hours of *in situ* incubation in every chamber at all stations. The data are clear when a comparison is made of survival at the same station with two different reactor operations: survival and growth were always better when the reactor was in operation. This was true regardless of the depth, and even at depths in the water column where the influence of

reactor input could not be detected by the parameters measured. It is necessary to emphasize, however, that the sampling time between the two reactor operating conditions (and, thus, the experiments) was 19 days. Therefore, the natural stratification of Par Pond had advanced by nearly three weeks when survival and distribution experiments were undertaken for full reactor operations.

The greater survival of *A. hydrophila* during full reactor operation suggests that the fish populations may be exposed to *Aeromonas* for a longer period of time due to reactor operations. However, it is unclear whether the survival of aeromonads in Par Pond is due directly to thermal inputs or is indirectly related to changes in flow rates and/or nutrient distributions caused by reactor operations.

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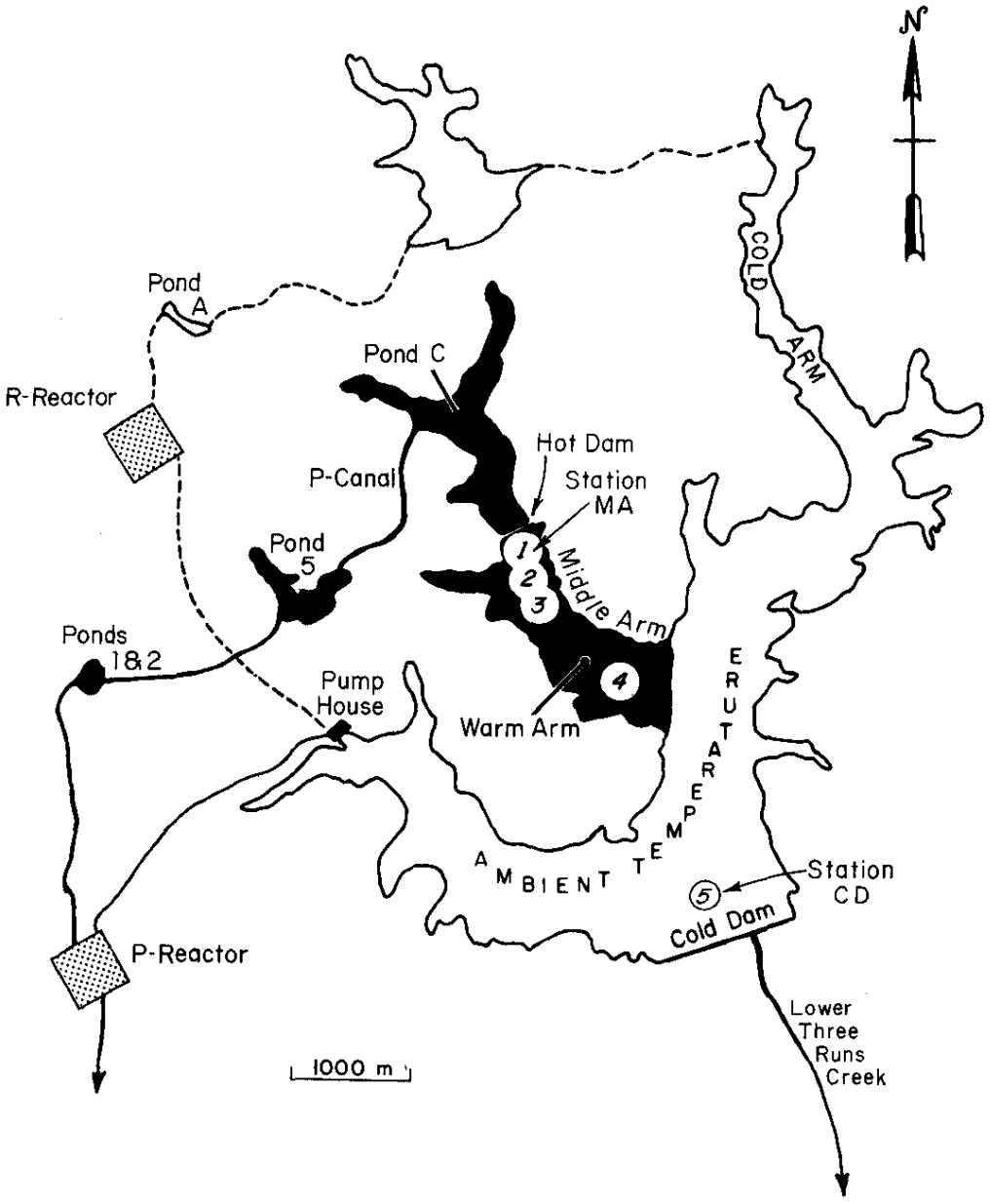

FIGURE 1. Par Pond Lake System. The ambient and thermal (shaded) temperature regions are shown; sampling stations are numbered.

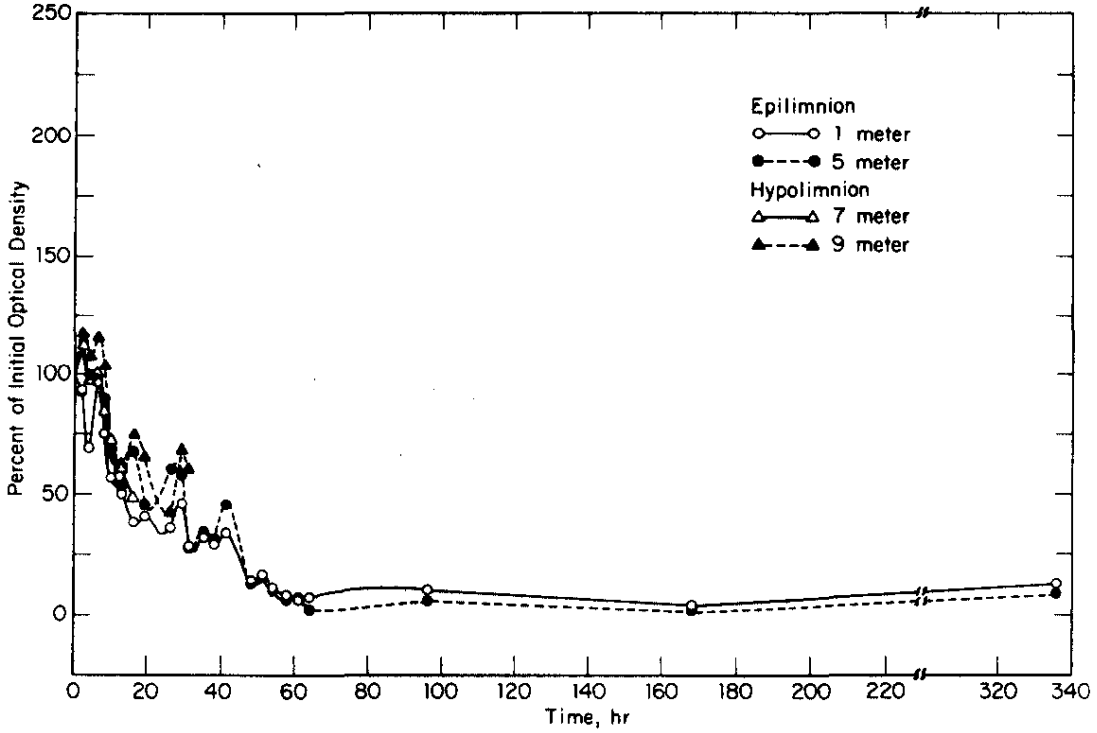

FIGURE 2. Survival of *A. hydrophila* at Station 3; Reactor not Operating.

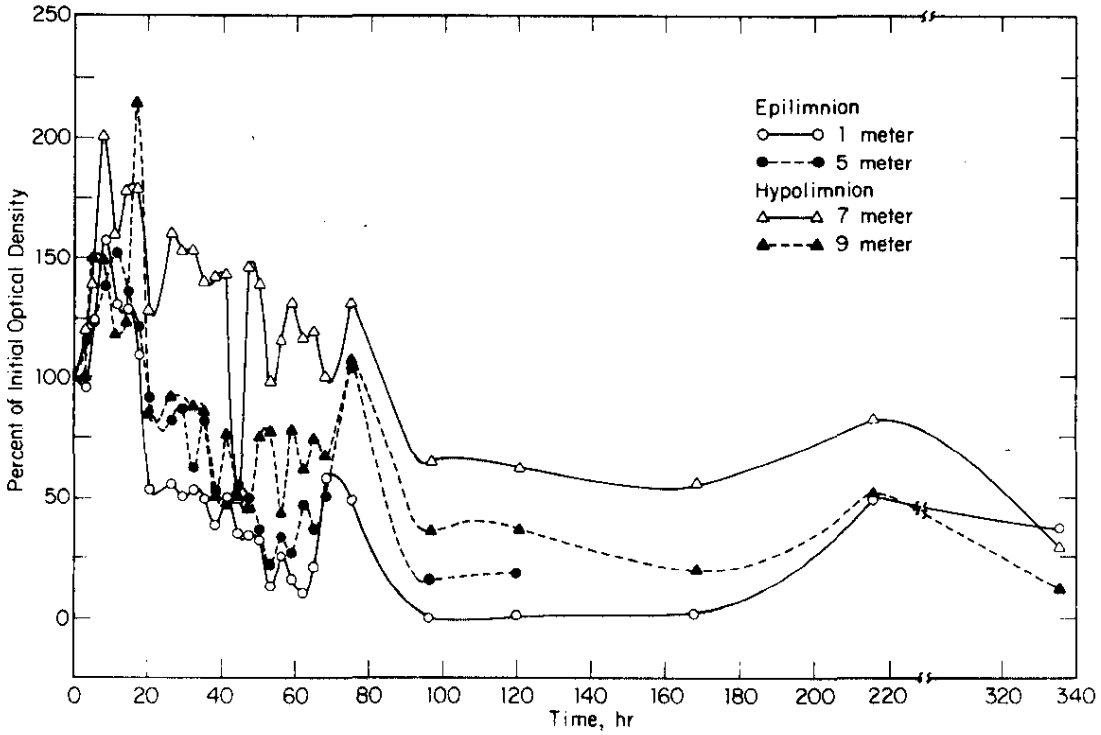

FIGURE 3. Survival of *A. hydrophila* at Station 3; Reactor Operating.

32. SEASONAL DISTRIBUTION OF *AEROMONAS HYDROPHILA* IN PAR POND†

INTRODUCTION AND SUMMARY

Par Pond is a thermally enriched, monomictic, southeastern lake which receives heated effluent from a production nuclear reactor. Fish populations in the lake have lesions from which the bacterium *Aeromonas hydrophila* is readily isolated. Distribution patterns and seasonal population densities of *Aeromonas* in the water column were measured. Greater population densities of *Aeromonas* occurred below the oxygen chemocline when the lake was stratified.

MATERIAL AND METHODS

Studies were conducted at Par Pond on the Savannah River Plant. Areas of the 1092-hectare lake are thermally altered from the input of cooling water from a nuclear production reactor, while other portions reflect ambient conditions common for southeastern lakes. Permanent sampling stations (Figure 1) were established throughout the lake at various distances from the thermal discharge. Physical and chemical water parameters (including temperature, dissolved oxygen, pH, conductivity, and redox potential) were measured weekly at each of the sampling stations.

Isolation and enumeration of *A. hydrophila* were determined by a membrane filter technique modified for *Aeromonas*. Water samples were taken at 1-m intervals throughout the water column in both the ambient and thermally altered portions of Par Pond. Triplicate water samples from each depth were taken with a Kemmerer bottle, which was rinsed with alcohol between samples. The samples were immediately placed in sterile Whirl-Pac polyethylene bags (Fisher Sci. Co., Pittsburgh, PA) and returned to the laboratory for processing. Known aliquots were filtered through 0.45 nm *Millipore* filters (Millipore Corp., Bedford, MA), placed on sterile pads saturated with R-S medium,[1] and incubated for 20 hr at 37°C. Filters were then examined for yellow-pigmented colonies, which are presumptive for *A. hydrophila*. These colonies were then tested for cytochrome oxidase,[2] and positive oxidase cultures were taken to be *A. hydrophila*.

† Work done by C. F. Fliermans and T. C. Hazen.

RESULTS AND DISCUSSION

The data in Table 1 represent the seasonal distribution of *A. hydrophila* in Par Pond for three specific locations. The number of *Aeromonas* is expressed as the mean number of bacteria/ml averaged throughout the water column. The distribution and densities of *Aeromonas hydrophila* for two stations during time of lake stratification are shown in Table 2.

The data indicate that the numbers of *A. hydrophila* are highest during the spring and summer of the year, and that the populations of *Aeromonas hydrophila* are highest in the hypolimnetic portions of the lake. Comparisons with similar distribution and density studies on other southeastern lakes suggest that Par Pond densities of *A. hydrophila* are 10 to 100 times higher (Fliermans and Gorden, unpublished results).

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TABLE 1

Seasonal Distribution of *Aeromonas hydrophila*-Like Bacteria at Selected Stations in Par Pond

	Station 5			*Station 3*			*Station 1*		
Month and Year	$\overline{X}$[a]	*SD*[b]	*N*[c]	$\overline{X}$	*SD*	*N*	$\overline{X}$	*SD*	*N*
August 1975[d]	0.39	0.54	114	0.24	0.38	72	ND[e]		
September[f]	1.51	1.42	56	3.01	1.06	33	ND		
October[g]	5.22	1.86	57	6.02	1.84	33	ND		
November[g]	3.14	1.93	50	14.62	7.96	39	9.58	3.78	30
December[g]	1.47	1.10	27	1.13	0.65	18	1.21	0.73	18
January 1976[g]	3.55	1.65	15	16.18	8.20	11	17.71	6.36	12
February[g]	2.54	1.07	33	5.20	3.56	26	3.22	2.71	26
March[g]	154.57	176.31	44	141.85	96.78	32	27.37	34.63	30
April[g]	32.83	14.76	18	147.80	71.25	15	99.20	67.74	15
May[g]	18.00	16.25	24	21.86	17.69	14	51.47	50.57	15
June[g]	300.09	147.01	27	20.25	30.42	15	0.44	1.37	27
July[g]	67.04	89.42	47	25.67	43.91	25	41.92	72.82	27
August[g]	7.94	6.19		18.33	8.89	15	12.67	9.96	15

a. Mean values of *A. hydrophila*-like bacteria per ml.

b. SD = Standard Deviation.

c. N = Number of determinations.

d. Experiments with reactor not operating.

e. ND = Not Determined

f. Experiments with reactor operating.

g. Data collected during both reactor operation and shutdown.

TABLE 2

Distribution and Population Densities of *Aeromonas hydrophila*-Like Bacteria in Par Pond

Depth, m[a]		*Aeromonas Concentration, per liter* — *Reactor Operating (8/18/75)* 1	2	3		*Reactor Not Operating (7/21/75)* 1	2	3
Station 3:								
0		350	400	ND[b]		20	0	0[c]
1		340	227	240		0	0	0
2		20	40	ND		0	5	20
3	($\bar{v}$ = 280)[d]	780	706	260	($\bar{v}$ = 4.3)[d]	0	8	20
4		60	220	540		0	0	0
5		60	74	160		0	0	5
6		600	724	840		0	2	20
7		800	867	780		40	8	20
8	($\bar{v}$ = 596)[d]	500	453	600	($\bar{v}$ = 226)[d]	500	323	420
9		740	667	660		380	500	500
10		200	227	280		ND		
Station 5:								
0		60	40	40		120	80	100
1		6	0	0		300	280	ND
2		0	0	0		400	233	260
3	($\bar{v}$ = 472)[d]	1200	1260	1300	($\bar{v}$ = 136)[d]	120	180	120
4		640	600	492		180	100	100
5		1780	1640	1860		60	40	60
6		1640	1120	ND		0	0	0
7		0	0	0		420	520	560
8		0	0	0		120	240	140
9		0	0	0		1640	800	960
10		0	0	0		1000	1180	1040
11		3000	3600	240		740	960	1120
12		>6000	4200	5000		580	400	ND
13		>6000	>6000	>6000		260	580	ND
14	($\bar{v}$ = 3969)[d]	5200	4800	2100	($\bar{v}$ = 894)[d]	840	720	840
15		>6000	>6000	ND		1400	1360	1380
16		>6000	>6000	ND		1440	2000	1800
17		>6000	>6000	ND		ND		

a. Dashed line denotes chemocline position.

b. Not Determined.

c. Actual numbers are less than 2 per liter.

d. $\bar{v}$ = mean of *Aeromonas* determinations for epilimnetic and hypolimnetic waters.

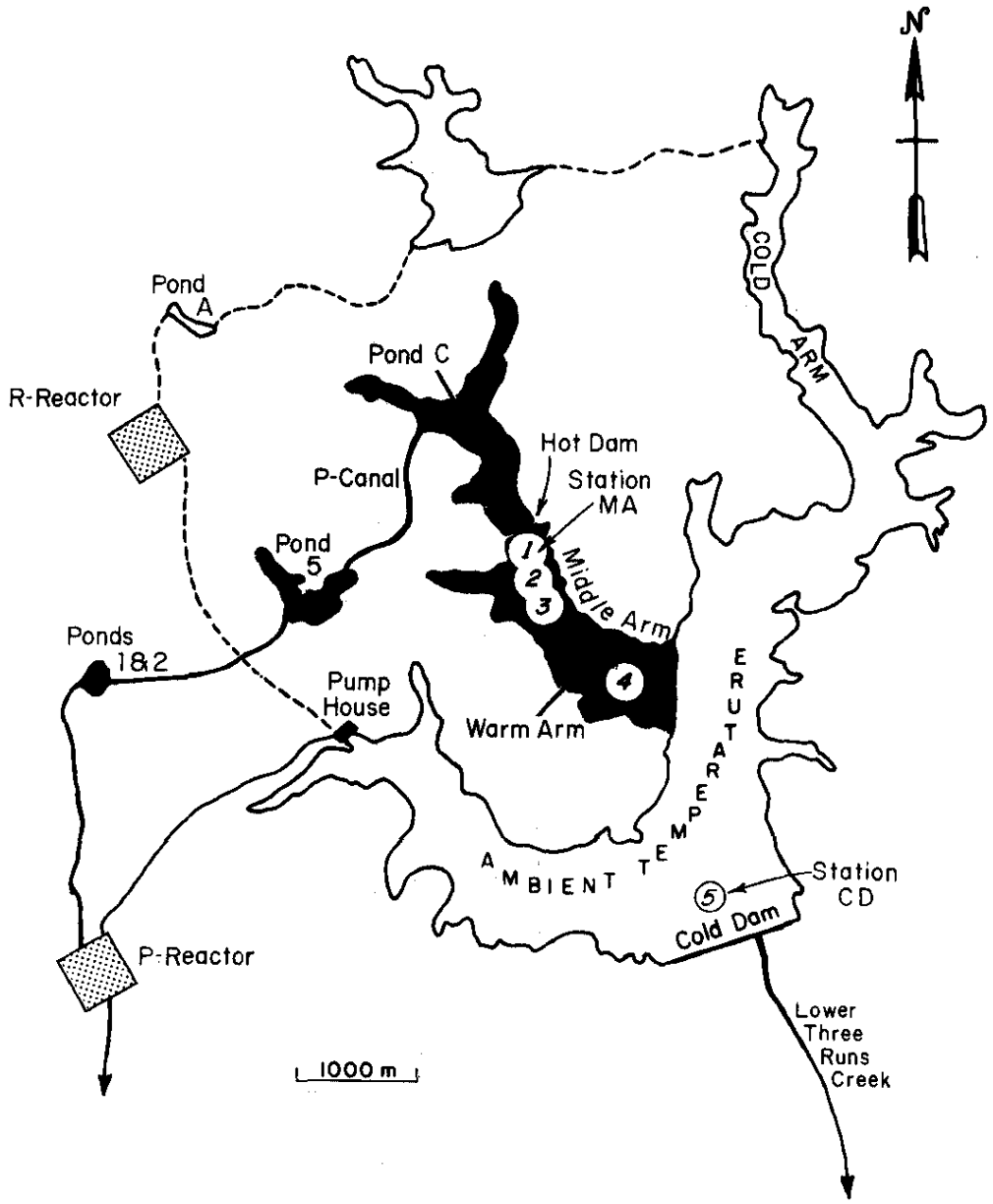

FIGURE 1. Par Pond Lake System. The ambient and thermal (shaded) temperature regions are shown; sampling stations are numbered.

33. EXAMINATION OF SRP EFFLUENTS FOR BACTERIAL VIRUSES SPECIFIC FOR *AEROMONAS HYDROPHILA*†

INTRODUCTION AND SUMMARY

Since high population densities of *Aeromonas hydrophila*, a fish pathogen, occur in Par Pond[1] and may represent a threat to the fish population, a means of biological control for the bacterium was sought. The purpose of this research was to survey Savannah River Plant (SRP) waters known to contain *A. hydrophila* for a virus that would specifically infect and kill *A. hydrophila*. Such viruses are called phage and may be useful as specific biological controls for a given bacterium. Over 65 water sources from SRP were sampled for specific phage without successfully isolating such a virus.

MATERIAL AND METHODS

Water samples were collected from effluent streams on SRP which had been previously shown to have a resident population of *A. hydrophila*. All samples were enriched for their viral components and specifically assayed according to the methodology described by Adams.[2] Strain B323L of *A. hydrophila*, which was isolated from a heavily infected largemouth bass, was used as the phage host and indicator organism.

RESULTS AND DISCUSSION

Viruses specific for another aeromonad, *A. salmonicida*, had been previously isolated.[3] The function of the virus is to invade its bacterial host, multiply, destroy its host, and then move on to other susceptible bacteria. Such viruses are termed "lytic" and are generally quite specific in their host relationships.

No virus specifically lytic for *A. hydrophila* are reported in the literature, but there is no *a priori* reason why such a virus does not exist. Host-virus relationships are highly temperature dependent, so that the host and virus optima are generally similar. Thus, the temperature gradient along the warm arm of Par Pond should provide proper temperatures where the virus could function at its optima.

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† Work done by C. B. Fliermans (SRL-ETD) and K. L. Kasweck (Faculty Research Participant, Florida Institute of Technology, Melbourne, FL).

In this study, 68 sites were extensively sampled for the presence of viruses specifically lytic to *A. hydrophila*. No such viruses were found. Over 200 strains of *A. hydrophila* have been isolated from Par Pond, and one of these strains may better serve as a host if a lytic virus for *A. hydrophila* is to be found.

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34. GENETIC VARIABILITY OF *E. COLI* IN PAR POND†

INTRODUCTION AND SUMMARY

Optimum growth temperature for many human pathogen bacteria is near body temperature, 37°C. Some pathogenic bacteria are able to survive for extended periods of time in habitats with nonoptimal temperatures, provided nutrients are available for growth. Previous survival studies of *E. coli* in Par Pond indicated that these bacteria became variable in a key diagnostic characteristic (lactose utilization) during the study period.[1] This study confirms previous findings of long-term viability and, in addition, demonstrates the genetic variability of this bacterial population in Par Pond. Because identification of fecal coliforms is based primarily on lactose utilization in a selective medium, the variability of this key diagnostic character could lead to serious errors in estimating fecal contamination.

MATERIAL AND METHODS

Bacterial strains of *E. coli* (1533-68) were obtained from the Center for Disease Control (CDC) in Atlanta, Georgia. The strain had previously and repeatedly been shown to be genetically stable for the key diagnostic characteristic, the utilization of lactose [lac (+)]. Genetic markers were incorporated into the genetic material of the strain using nalidixic acid, so that a derivative of the strain utilized lactose, but was resistant to nalidixic acid [lac (+), Nal R].

Sterilized membrane diffusion chambers[2] were fitted with double 0.4-μm polycarbonate filters. Two sized chambers (20 and 40 ml) were filled with thoroughly washed *E. coli* cells in phosphate buffer solution ($\sim 1 \times 10^9$ cells/ml). Chambers were then attached to stainless steel chains and lowered into the water at three stations along the thermal arm of Par Pond. At each station, diffusion chambers were located in the epilimnion (1-meter depth) and in the hypolimnion (1 meter from the lake bottom). These sites were chosen to represent the extreme conditions where genetic variation had been noted.[1] Thermal control chambers were maintained in the laboratory and in the artificial streams at the Flowing Streams Laboratory.

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† Work done by C. B. Fliermans (SRL-ETD) and K. L. Kasweck (Faculty Research Participant, Florida Institute of Technology, Melbourne, Florida).

Duplicate samples (0.5 ml) were taken with sterile syringes twice a day over the three-week study period for all chambers. One sample was frozen, while the other was diluted and plated to nutrient agar medium to assay for *E. coli* densities. Cultures were incubated for 24 hours at 37°C. Each culture was replicated as previously described.[3] Replication was onto media containing the sugar lactose and onto a separate media containing 100 µg/ml of nalidixic acid. Replicates were incubated at 37°C for 12 hours, and colonies were differentiated into 1 of the following 4 classes:

1) Lac (+) Nal - R

2) Lac (+) Nal - Sensitive

3) Lac (-) Nal - R

4) Lac (-) Nal - Sensitive

RESULTS AND DISCUSSION

The survival data indicate that neither the resistance nor the sensitivity to nalidixic acid affected the viability of *E. coli* in the habitats studied. Throughout the three-week experiment, the genetic characteristic of nalidixic acid remained stable. On the other hand, the lactose positive characteristic was not stable. After as little as three-day incubations in Par Pond, the *E. coli* populations began to change from lac (+) to lac (-). By the end of the experiment, all chambers (regardless of depth or position in the thermal gradient) were dominated by lactose negative *E. coli*. The "genetic" change occurred more rapidly in the warmer waters than the cool. None of the controls, which were incubated under the same temperature regimes, demonstrated any genetic variability.

The data suggest that lac (-) populations may be present within the tested *E. coli* population, and that these bacteria are selective and survive better than lac (+) *E. coli*. The data further suggest that temperature alone is not the controlling parameter for genetic variability in these bacteria.

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35. ENUMERATION AND IDENTIFICATION OF BACTERIAL POPULATIONS OF SURFACE MICROLAYERS IN PAR POND†

INTRODUCTION AND SUMMARY

Large elongated areas of quiet water or "slicks" are frequent on Par Pond and other southeastern reservoirs. Slick waters may contain greater amounts of organic nutrients than the surrounding waters.[1]

Previous studies[2] indicate that higher levels of coliform bacteria and fungi occurred at the surface of the slicks than in the remainder of the water column. The purpose of this research was to determine the distribution of bacterial populations, particularly *Aeromonas hydrophila*, in surface slicks on Par Pond. *Aeromonas hydrophila*, a fish pathogen causing "red sore disease," occurs in high numbers in Par Pond.[3] The data indicate that the concentration of *A. hydrophila* as well as the total bacterial population is greater in the microlayer of the slicks than those microlayers out of the slicks.

MATERIAL AND METHODS

During the summer of 1976, samples were taken in and out of the slicks along the thermally altered arm of Par Pond. Pre-sterilized, 47-mm-dia. membrane filters were placed on the surface of the water with sterile forceps. When completely wetted, the filters held 50 µℓ of sample.[4] The wet filters were then placed directly onto media specific for *Aeromonas hydrophila*[5] or on a non-selective media suited for growing a wide variety of bacteria. Samples were incubated at 37°C, and the bacterial colonies formed were counted.

RESULTS AND DISCUSSION

Regardless of the sampling site or the time of sampling, greater numbers of bacteria were found in the surfaces of the slicks. *A. hydrophila* densities were 3 to 6 times greater in

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† Work done by C. B. Fliermans (SRL-ETD) and K. L. Kasweck (Faculty Research Participant, Florida Institute of Technology, Melbourne, Florida).

the slicks than in immediately adjacent surface areas. Bacterial colonies forming on the non-selective nutrient were 2 to 10 times greater than the populations outside the slicks (Table 1).

The data indicate that a significant number of bacteria occur in the surface microlayer of slicks. The reason for such high numbers may be nutrient enrichment or concentration of organisms due to wave patterns. Regardless of the mechanisms of slick formation, large numbers of bacteria occur in these quiet waters. Such population densities may be significant if they are transported from the system by a skimming wall or if certain animals reside preferentially in these quiet waters.

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TABLE 1

Surface Microlayer Enumeration of Bacterial Populations

Sampling Location:	*Cold Dam*		*Warm Arm*		*Hot Dam*		*Clark Hill Reservoir*	
Population:	*In*[a]	*Out*[b]	*In*[a]	*Out*[b]	*In*[a]	*Out*[b]	*In*[a]	*Out*[b]
Bacteria Aeromonas[c]	768	222	564	88	668	186	280	48
n >45[d]								
Total Isolates	>2260	538	1052	384	>4276	388	N.D.[d]	N.D.
n = 30[d]								

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a. Sample taken in surface slick.

b. Sample taken on surface away from slick.

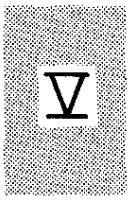
c. Organisms per ml of surface layer; arithmetic mean.

d. Number of samples taken to establish the mean value.

e. N.D. = not determined.

V. ATMOSPHERIC TRANSPORT STUDIES

The objectives of atmospheric transport studies are to develop and test models for predicting meteorological fields and for calculating the transport and dispersion of pollutants within the planetary boundary layer. The atmospheric planetary boundary layer is being studied over the Savannah River Plant site and the southeastern United States. Efforts have focused on enlarging the data input base, improving interpretations relative to diffusion within the planetary boundary layer, developing trajectory and dispersion calculational models, and testing these calculational methods against measurements of atmospheric pollutants.



36. POWER LAW PROFILES OF MEAN WINDS AND HORIZONTAL AND VERTICAL STANDARD DEVIATIONS OF WIND DIRECTION AT THE SAVANNAH RIVER PLANT†

INTRODUCTION

Downwind air concentrations from atmospheric pollutant releases are calculated with data from pollutant emissions and from a calculation of plume spread. Most calculational models use one of a number of empirically derived relationships which express plume spread as a function of downwind distance and atmospheric turbulence. The best plume spread relationships are based on direct measurements of atmospheric turbulence, i.e., the standard deviations of horizontal and vertical wind direction (σ_θ and σ_ϕ) and wind speed (u) at the height of the release.[1]

Often measurements of u, σ_θ, and σ_ϕ are not available at all heights of interest, and values must be interpolated from available data. This report presents results of an analysis of the applicability of the power law profile between 10 and 304 m at the WJBF-TV tower near the Savannah River Plant.

EMPIRICAL DATA TREATMENT METHODS

The power law profile, Equation 1, has been used extensively to describe the wind speed profile in the lower 1 km of the atmosphere.

$$u_z = u_h \left(\frac{z}{h}\right)^{p_u} \qquad (1)$$

where:

u_z is the wind speed at height z, u_h is the wind speed at height h, and p_u is an exponent depending on atmospheric stability and surface roughness. Observations have shown that σ_θ is inversely related to u in the lowest part of the mixed layer for all stability conditions.[2] This relationship makes it possible to express σ_θ in a power law similar to Equation 1, except the exponent is negative, i.e., $p_\theta = -p_u$:

† Work done by M. M. Pendergast.

$$\sigma_{\theta_z} = \sigma_{\theta_h}\left(\frac{z}{h}\right)^{-p_u} = \sigma_{\theta_h}\left(\frac{z}{h}\right)^{p_\theta} \qquad (2)$$

Fifteen-minute averaged values for u, σ_θ, and σ_ϕ were calculated from meteorological data collected from the WJBF-TV tower during 1975. Data for different stability conditions were fitted by a least squares method to Equations 1 or 2 to determine the exponents p_u, p_θ, and p_ϕ, respectively. When all tower data were available, this fitting involved 7 data points with valid heights ranging between 10 and 304 m. No fits were attempted when more than 3 data points were missing.

THEORETICAL DATA TREATMENT METHODS

Panofsky and Prasad[3] used Similarity Theory to relate p_u to universal functions of roughness (z/z_0) and stability (z/L) of Businger, et al.[4] to give Equation 3 for stable cases and Equation 4 for unstable cases.

$$p_u \equiv \frac{1 + \alpha\frac{z}{L}}{\ln\frac{z}{z_0} + \alpha\frac{(z-z_0)}{L}} \qquad (3)$$

$$p_u \equiv \frac{\gamma_1^{-1}}{\ln\left(\frac{(\gamma_1-1)(\gamma_2+1)}{(\gamma_1+1)(\gamma_2-1)}\right) + 2\,(\tan^{-1}\gamma_1 - \tan^{-1}\gamma_2)} \qquad (4)$$

where:

$$\gamma_1 = (1-15\,\frac{z}{L})^{\frac{1}{4}},\quad \gamma_2 = (1-15\,\frac{z_0}{L})^{\frac{1}{4}}$$

and z = height of observed wind, m

z_0 = surface roughness length, m

α = 4.7 (a dimensionless coefficient)

L is the Obukhov stability parameter

Theoretical estimates of p_u were determined from Equations 3 and 4 with values of L provided by Golder[5] for different stability categories for z_0 = 0.5 m and z = 62 m.

RESULTS AND CONCLUSIONS

Table 1 presents estimates of p_u, p_θ, and p_ϕ for all stability conditions. Theoretical values are also given for p_u and p_θ. Empirical estimates of p_u and p_θ agree with theory for neutral and unstable conditions. For stable conditions, the empirical values differ from the theoretical values by about 30%. The estimate of p_ϕ is as well correlated with 1/u as is σ_θ.

TABLE 1

Power Law Exponents Used to Describe the Vertical Variation of Turbulence and Wind Speed

	p_u		p_θ		p_ϕ
Stability	*Theory*	*Empirical Results*	*Theory*[a]	*Empirical Results*	*Empirical Results*
Extremely Unstable	0.11	0.08	-0.11	-0.06	0.02
Moderately Unstable	0.12	0.10	-0.12	-0.15	0.04
Slightly Unstable	0.14	0.11	-0.14	-0.17	0.01
Near Neutral	0.20	0.18	-0.20	-0.23	-0.14
Slightly Stable	0.62	0.31	-0.62	-0.38	-0.31
Moderately Stable	0.72	0.42	-0.72	-0.53	-0.49

a. If σ_θ is inversely proportional to u, then $p_\theta = -p_u$.

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37. TURBULENCE STATISTICS AS A FUNCTION OF SAMPLING PERIOD†

INTRODUCTION

In England during the 1930's and in the United States during the 1950's, atmospheric diffusion to distances of a few kilometers was studied in a large number of tracer experiments.[1] These experiments showed a strong correlation between the standard deviations of wind azimuth (σ_θ), elevation angle (σ_ϕ), and the spread of the tracer plume. The relevant time scales for these experiments were 3 to 10 min, which correspond to (1) the time period over which the turbulence data were tabulated, (2) the duration of the tracer release, and (3) the sampling time of the tracer. In recent years, results from these experiments have been applied to the diffusion calculation at travel distances greater than those for which the experiments applied. Yet, atmospheric turbulence extends over a wide spectrum of eddy sizes to scales associated with large weather systems. Consequently, the statistical properties of the turbulence depends on sampling period τ. This section presents results of an analysis of σ_θ and σ_ϕ as a function of τ over times ranging between 2.5 min and 3 hr.

Estimates of horizontal and vertical plume spread (σ_y and σ_z, respectively) from measurements of σ_θ and σ_ϕ have other limitations besides that caused by sampling period. The relationships developed for σ_y and σ_z as a function of σ_θ and σ_ϕ represent the ensemble average of a number of experiments. These relationships, therefore, are appropriate to obtain long-term average concentrations from many individual cases. When these relationships are used for a single case, a certain amount of variability is expected. This variability can be estimated by analyzing the variability of the original experimental data (i.e., σ_y or σ_z). The variability of the magnitude of the diffusion coefficients can also be estimated by the variability of σ_θ and σ_ϕ.

Data from the WJBF-TV tower between March and December 1974 were used to calculate $\bar{u}$, σ_θ, and σ_ϕ at 3-hr intervals beginning at 0000 GMT for each day. Single estimates for 36 sampling times

† Work done by M. M. Pendergast.

were calculated for a valid time at the center of each 3-hr interval. Linear trend was removed from wind azimuth and wind elevation data before σ_θ and σ_ϕ were calculated.

The variation of σ_θ and σ_ϕ and their standard deviations were analyzed as a function of stability. Stability category was assigned according to the magnitudes of σ_θ and σ_ϕ evaluated over the arbitrary sampling period of 12.5 min.[1] This sampling period is of the same order as that used in many experiments.

The variation of σ_θ and σ_ϕ with τ was expressed in terms of the product $u\tau$. This term has the dimensions of a distance and can be interpreted as a "sample length." Statistical properties of σ_θ and σ_ϕ for a particular sample length can be related to properties of eddies and pollutant clouds of similar dimensions.

RESULTS

Figure 1 shows the variation of σ_θ and σ_ϕ with sample length as a function of stability. The dashed line corresponds to the power law relationship

$$\sigma_1/\sigma_2 = (u_1\tau_1/u_2\tau_2)^{0.2}, \text{ assuming } u_1 = u_2 \qquad (1)$$

Equation 1 converts σ_θ to a sampling time different from the measured time.[2] The values of σ_θ and σ_ϕ are independent of sample length for unstable conditions (Curves A-C) and directly related to sample length for stable conditions (Curves E-G) in Figure 1.

Table 1 presents suggested exponents of power law relations that may be used for extrapolating estimates of σ_θ and σ_ϕ to other sampling periods. Equation 1 applies only to slightly stable cases in Curve E.

Figures 1b and 1d show the standard deviation of σ_θ and σ_ϕ as a function of stability category. An analysis of these data leads to the following conclusions about the variability of the diffusion coefficients σ_y and σ_z:

1. Largest errors occur for unstable conditions; least errors occur for stable conditions. An exception occurs for σ_y for sample lengths between 10^3 and 10^4 for which the error is nearly equal for all stabilities. The increased error is assumed to be the result of slow meandering of the wind direction occurring during stable conditions.

2. Errors in σ_y and σ_z are a function of sampling period (error in $\sigma_y \propto u\tau^{0.4}$ and error in $\sigma_z \propto \mu\tau^{0.2}$) for all stabilities except for very unstable conditions.

3. The error in σ_y is about 40% of the mean value of σ_θ; the error in σ_z is ~22% of the mean value of σ_ϕ.

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2. D. Slade. *Meteorology and Atomic Energy.* U.S. Atomic Energy Commission Office of Information Survey, Oak Ridge, TN, p 57 (1968).

TABLE 1

Variation of σ_θ and σ_ϕ with Sampling Period as a Function of Stability Categories

Variable	*Stability Category Based on* σ_θ *and* σ_ϕ	*Power Law Exponent,* B *in* $\frac{\sigma_1}{\sigma_2} = \frac{u\tau_1}{u\tau_2}^B$	*Applicability range of* $u\tau$, *m*	
σ_θ	A-D	0.0[a]	100	$<u\tau<3 \times 10^4$
σ_θ	E	0.22	100	$<u\tau<10^4$
σ_θ	F	0.71	1000	$<u\tau<10^4$
σ_ϕ	A-E	0.0[a]	100	$<u\tau<3 \times 10^4$
σ_ϕ	F	0.28	1000	$<u\tau<5 \times 10^3$
σ_ϕ	G	0.48	700	$<u\tau<10^4$

a. A value of B = 0.0 indicates that σ is constant for all sampling times.

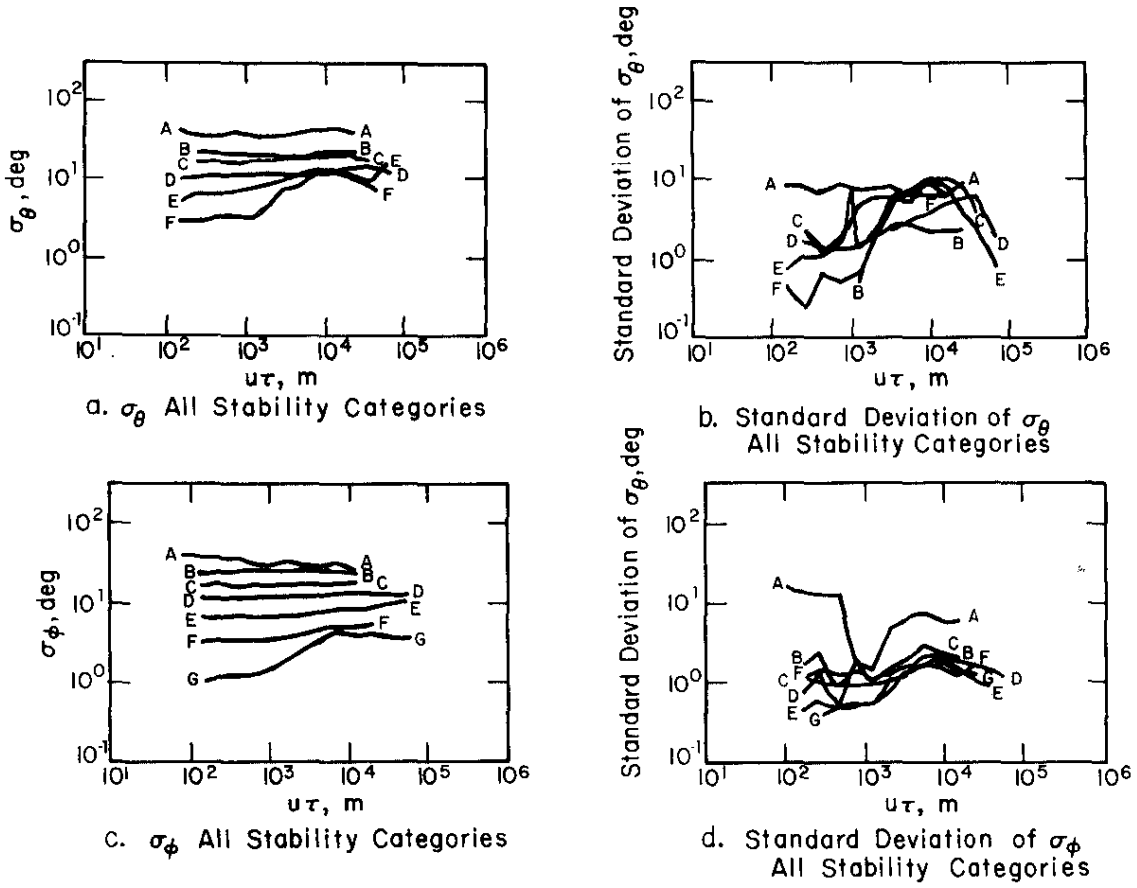

FIGURE 1. Variation of σ_θ and σ_ϕ with Sampling Time. Measured at the 10 m level of the WJBF-TV Tower near Beech Island, South Carolina. Stability categories for a and c were determined from σ_θ and for b and d were determined from σ_ϕ.

38. EVALUATION OF THE WIND ROSE METEOROLOGICAL MODEL USING KRYPTON-85 RECEPTOR DATA†

INTRODUCTION AND SUMMARY

The assessment of long-term environmental effects of industrial pollution is frequently obtained with a so-called stability wind rose model in combination with the Gaussian plume equation. Concentrations obtained with 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 for long-range application of the wind rose model by measuring ^{85}Kr concentrations at 13 sites. These sites were located 31 to 143 km from a point source at the Savannah River Plant (SRP). Comparisons are presented of annual averaged concentrations. The calculations use meteorological data from the WJBF-TV near Beech Island, South Carolina, located 16 km from the ^{85}Kr-emitting source.

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, $\bar{\chi}(x,\theta)$, for a particular direction (θ) and downwind distance (x) is given by

$$\bar{\chi}(x,\theta) = \sum_{SN} \frac{\Sigma\ Q\ f(\theta,S,N)}{L\left(u_N\right)\left(\frac{2\ x}{N_S}\right)}$$

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 for the wind speed Class N

† Work done by M. M. Pendergast.

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

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

RESULTS

Figure 1 presents the results of the evaluation of the wind rose model for 1975. The ordinate is the ratio of the calculated to the observed concentration. The 13 points are plotted as a function of increasing distance from the point of release. The ratios for the annual average concentration (open symbols) determined from the wind rose technique have an average value of 1.85 (standard deviation 0.81) and do not appear to be simple functions of distance.

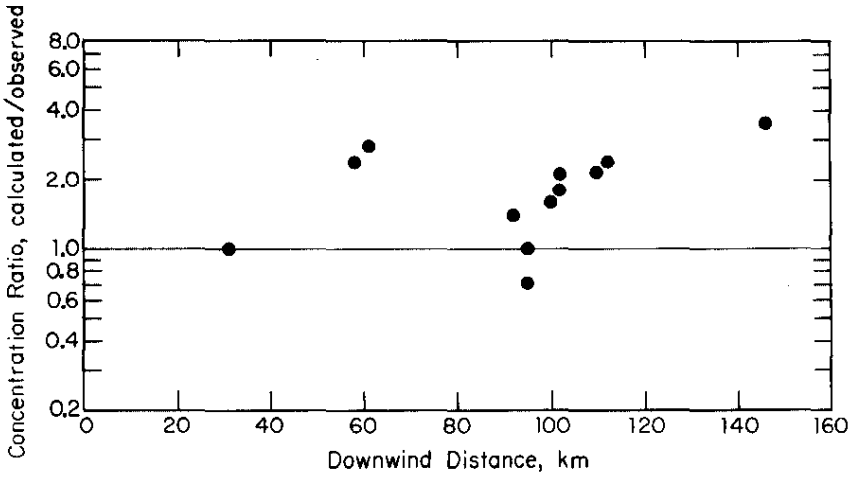

FIGURE 1. Ratio of Calculated-to-Observed Annual Average Concentrations for ^{85}Kr for 1975

REFERENCE

1. D. B. Turner. *Workbook of Atmospheric Dispersion Estimates.* USDHEW Public Health Service Publication No. 999-AP-26 (1969).

39. DIGITIZATION OF ACOUSTIC SOUNDER DATA†

A method of archiving acoustic sounder data in a format compatible with a computer is under development. The collected data will be used to compile a climatology of the atmospheric surface boundary layer to predict the transport and diffusion of atmospheric pollutants.

The acoustic sounder transmits a pulse of sound in a direction perpendicular to the surface of the earth. The energy is reflected back to the receiving antenna from inhomogeneties in the boundary layer caused by temperature-turbulence discontinuities.[1] The received signal is then digitized using a process simulator under control of a microcomputer developed by SRL. The signal is digitized at a rate sufficient to provide a data point for each meter of altitude on the 800-meter range. This information is then stored on magnetic tape.

Some smoothing is necessary to eliminate noise from the raw signal and to obtain a consistent, computer generated, graphical depiction of the data (Figure 1). The method averages 20 points for each height increment (bin) for a total of 40 bins (20 meters per bin); 20 scans are averaged to eliminate spurious signals and ground noise.

The large amplitude signal during the first 100 m in Figure 1 is caused by antenna "ringing." The peaks between 400 m and 600 m show an inversion at 500 m. The tall spikes at 200, 400, 600, and 800 m are the time-height markers, which are displayed each hour.

It is hoped that with the proper software development that the real-time mixed-layer height can be identified. This value can then be used directly in the transport and diffusion codes with the PDP-11/40 minicomputer.

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† Work done by J. F. Schubert.

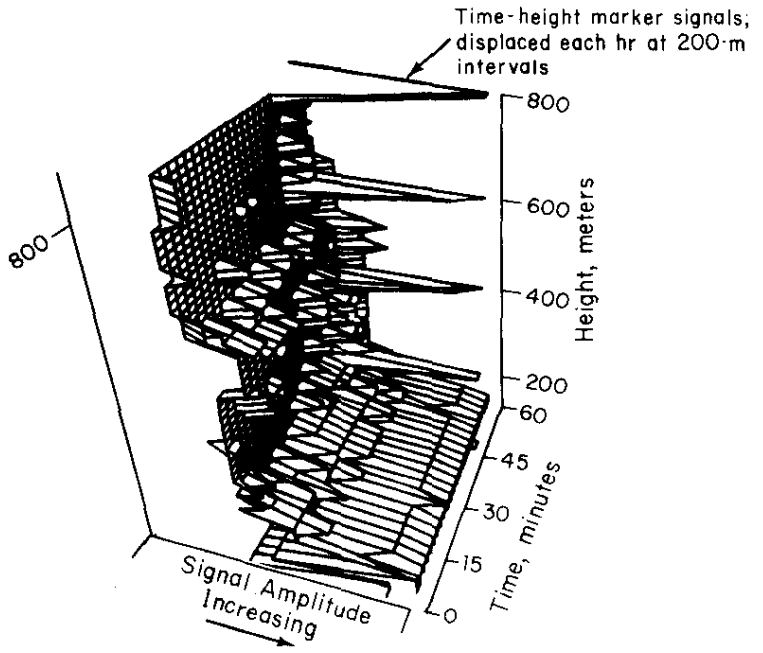

FIGURE 1. Computer Depiction of Acoustic Sounder Signals

40. TORNADOES ON THE SAVANNAH RIVER PLANT†

INTRODUCTION

Three small tornadoes struck the Savannah River Plant (SRP) in 1976. This is the first time in the 25-year history of the plant that tornadoes have been observed and confirmed within the 778 square kilometer area of the plant site.

The first tornado, which was observed at 1530 EDT on May 28, did minor damage to storage facilities, motor vehicles, and trees. No damage was done to production facilities, and there were no injuries. The second tornado occurred five hours later and did only minor damage to trees. The third tornado, which struck during the period July 2 to July 4, 1976, was not observed, but is presumed on the evidence of damage to trees. Preliminary investigations of the damage were made following each strike.

Funnels have been observed above SRP. However, tornado strikes in the SRP area since 1952 have been unconfirmed. Confirmation of a tornado long after the strike is impossible to make because of deterioration of the damaged area from ice storms, tree damage from thunderstorm downdrafts, and removal of downed or damaged trees by forestry cutting and cleanup.

THE TORNADOES OF MAY 28, 1976

Two tornadoes struck SRP on May 28, 1976. The first tornado touched ground at approximately 1530 EDT southeast of Central Shops and moved northwestward toward 200-F Area. The tornado reached 200-F Area at 1530 and lifted. The second tornado occurred at approximately 2030 EDT and moved in a westerly direction beginning 1/5 km west of Highway B on Highway 8-1. Figure 1 shows the direction and path length of both tornadoes.

The first tornado which struck SRP on May 28, 1976, was observed by personnel in the Central Shops area. Several large wooden pallets were seen to be lifted to 30 m above the ground by the vortex. A pine tree was seen in the vortex 25 m above the tops of the trees northwest of the Central Shops area. Windows were partially or totally broken out of 18 private automobiles. Buildings in the Central

† Work done by D. W. Pepper.

Shops Area suffered light damage. Eye-witness accounts of several Central Shops' personnel indicate that the width of maximum damage was approximately 20 m in the Central Shops Area.

Trees were either intermittently snapped off 2 m above the ground or uprooted in the path between 200-F Area and Central Shops. The damage width in the forest northwest of Central Shops reached a maximum of 300 feet. Medium-size hardwood trees were uprooted.

The 200-F Area suffered minor damage. Several large hardwood trees were uprooted and several pine trees were snapped 2 to 2.5 m above the ground. Corregated tin roofs of three small structures were blown off. A small section of one roof was found 90 m to the northwest of the structure.

Damage classification of the tornado using the Fujita-Pearson scale was undertaken by analyzing the damage to trees and debris adjacent to the structures in 200-F Area and Central Shops. The tornado was rated as an F1.

The damage path length was approximately 8 km long and its maximum width of damage was approximately 100 meters.*

The second tornado struck west of Highway B near Highway 8-1. The tornado was observed by Patrol but reported as a funnel aloft at 2043 EDT. The tornado was spawned from a thunderstorm cell east and north of the first tornado.

Damage was done only to the forest. Trees were found to be snapped 2 m above the ground, some trees were uprooted, and many were debarked. The path length was 0.8 km, and the width was approximately 120 m at the widest point. The tornado moved in a west-northwesterly direction. This tornado was also given a rating of F1.

TORNADO OF JULY 2, 1976

On July 2, 1976, synoptic weather reports indicated the likelihood of severe weather and possible tornado development in the Central Savannah River Area (CSRA) for July 2-4, 1976. Although there were no observations of tornadoes at SRP during this time, fresh damage to trees was noticed northeast of the Savannah River Ecology Laboratory (SREL) on July 5, 1976. An investigation of the damage was made the afternoon of July 5, 1976. Based on the appearance of the damage, a tornado track was confirmed 0.8 km northeast

* The Fujita-Pearson rating on this tornado was actually F1-P2-P2, where the first P2 denotes a path length between 5.1 and 15.9 km, and the second P2 denotes a damage width of 51 to 160 m.

of SREL. Later investigation of the damage near 700 Area suggested that the tornado originated west of A-Area and either skipped or lifted until striking near SREL. This tornado was given a rating of F1.

CONCLUSIONS

The two tornadoes of May 28, 1976, that struck SRP moved in an unusual direction. Nearly all tornadoes that have been observed and recorded in the Southeast have moved in a *northeasterly* direction. Both tornadoes that struck on May 28, 1976, moved in a *northwesterly* direction. The tornado that occurred during the period July 2-4, 1976, moved from west to east.

The tornadoes that struck SRP in 1976 were not of great consequence in themselves. However, they provided an opportunity to record data that may be useful in predicting trajectories and intensities of future storms. Timely warnings well in advance of a storm could alleviate the consequence of a severe tornado strike.

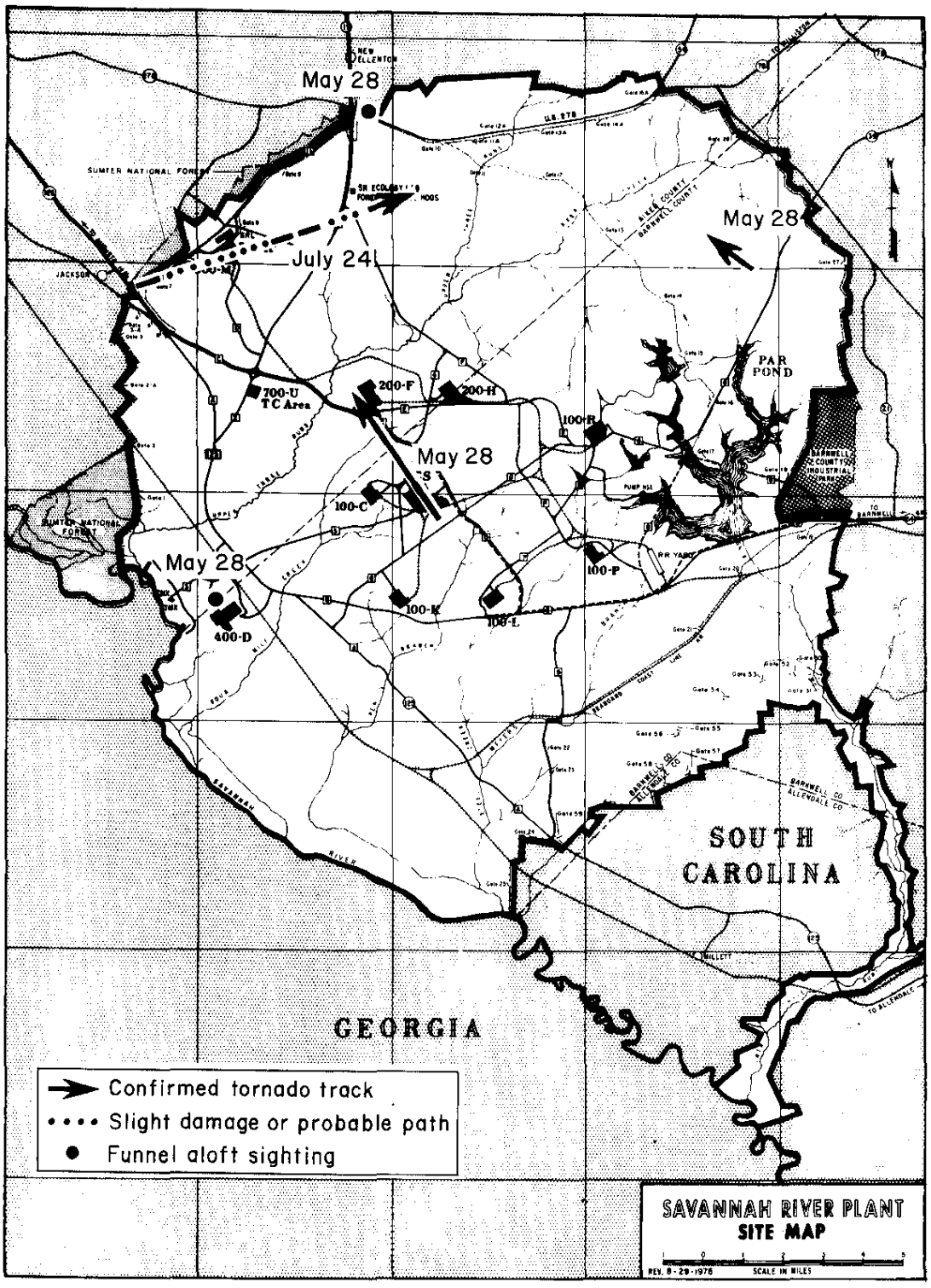

FIGURE 1. Confirmed Tornado Tracks at SRP

41. A COMPARISON OF CURVED TRAJECTORY ATMOSPHERIC TRANSPORT *VS.* ASSUMED STRAIGHT-LINE TRANSPORT†

INTRODUCTION

The Dose-To-Man[1] program as currently being implemented at the Savannah River Laboratory provides estimates of the environmental effects of Savannah River Plant operations. These estimates utilize a polar grid structure and assume straight-line transport of materials released to the atmosphere to distances beyond grid boundaries. The assumption of straight-line transport is standard for such estimates and greatly simplifies the computations involved in providing estimates of effects. Generally, the atmospheric transport trajectory will be curved; and, for distances out to 100 km or so, the assumption may lead to significant error. Therefore, a computer code was constructed to provide an estimate of the curved trajectory transport relative to straight-line transport over an extended time period.

DATA HANDLING

Computations were performed using two years of meteorological data consisting of 15-minute averages of wind speed and direction. Two basic assumptions were used in these computations: first, the population distribution was homogeneous, which made it unnecessary to account for crosswind dispersion as a function of time, and second, the differences in vertical dispersion for the two transport methods could be disregarded. As a result of these two assumptions, all released material was assumed to be concentrated in the line representing the centerline of the transport path. Comparisons were then made on the basis of total residence time of material within each grid area of a polar grid (Figure 1). A uniform release with time was also assumed for the two-year period.

When processing the meteorological data for the straight trajectory calculations, an instantaneous unit release of material was assumed to occur at each 15-minute interval. The material was then transported radially and at constant speed within a sector determined by the wind direction until the radial boundary of the grid was reached. The residence time within each grid area was determined and recorded accumulatively for each 15-minute interval.

† Work done by R. E. Cooper.

Curved trajectory calculations were much more complicated since the released material for each 15-minute interval was transported at a distance and direction dictated by the meteorological measurements for each interval. The material thus changed direction and wind speed at 15-minute intervals until it was transported beyond the radial boundary. Since a release occurred for each 15-minute interval, this also necessitated the tracking of several releases simultaneously. As in the straight trajectory case, the residence time within each grid area was determined for each release and accumulated for each grid area.

The ratio of curved-trajectory to straight-trajectory cumulative residence time for the two-year data base was then determined for each grid area (Table 1) for selected sectors of a polar grid out to a radius of 100 km. Since the curved trajectory estimates are considered to be the most accurate, these ratios are given as correction factors to be applied to the straight trajectory calculations over this period. As indicated, these factors are for a long-lived airborne isotope. The factors will vary as a function of isotope decay rate.

CONCLUSIONS

The factors range from 0.74 to 1.62 (Table 1). When the factor is less than 1.0, it seems to imply that (on the average) the curved trajectories cause less exposure in a grid area than the straight trajectories, which seems impossible. This implication follows from the analysis technique associated with the straight trajectory method. The assumption of a persisting wind speed for a time necessary to transport the material beyond the grid boundary always overestimates exposure when compared with the exposures derived from transporting the material according to actual measured speeds for each time increment, as is done for the curved trajectory analysis.

REFERENCE

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TABLE 1

Correction Factors for a Long-Lived Isotope

Radial Distance, km	*Sector* 1	6	11	16
5	1.09	1.04	1.07	1.05
10	1.13	1.07	1.08	1.10
15	1.16	1.04	1.07	1.16
20	1.13	1.06	1.11	1.08
25	1.14	1.09	1.12	1.09
30	1.11	1.06	1.10	1.13
35	1.22	1.02	1.07	1.25
40	1.56	1.00	1.04	1.54
45	1.61	1.02	1.03	1.62
50	1.26	1.03	1.03	1.21
55	1.14	1.01	1.04	1.06
60	1.12	0.96	0.98	1.03
65	1.07	0.92	1.01	1.03
70	1.09	0.95	1.02	1.04
75	1.09	0.88	1.00	1.05
80	1.09	0.83	0.96	1.07
85	1.08	0.80	0.95	1.08
90	1.14	0.83	0.92	1.10
95	1.05	0.77	0.89	1.05
100	1.05	0.77	0.84	1.01

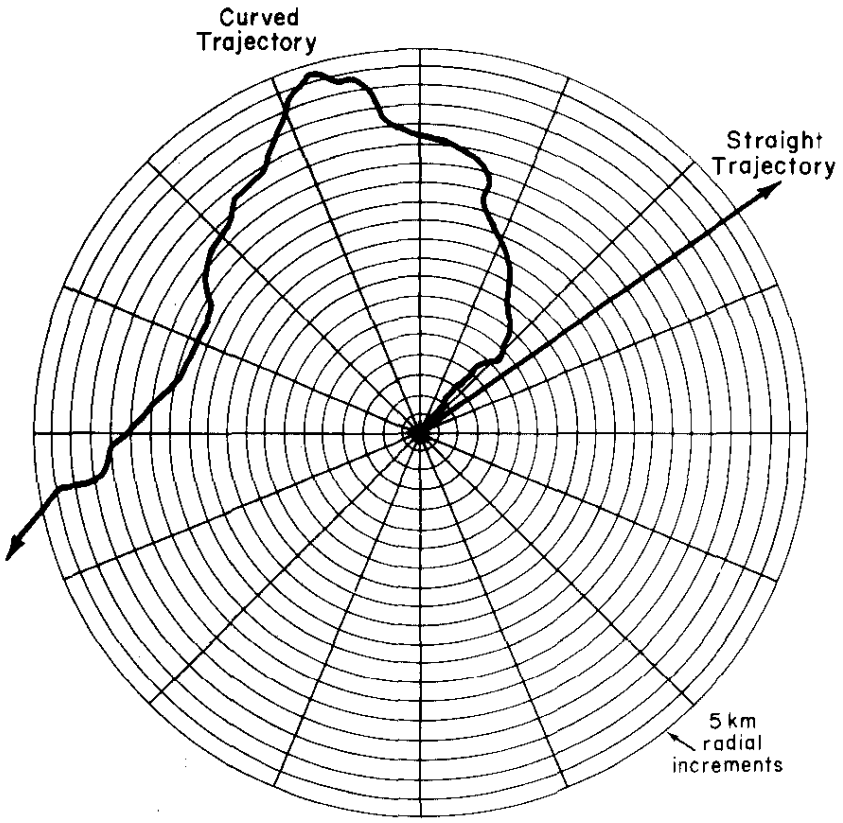

FIGURE 1. Polar Grid Structure

42. DEPOSITION VELOCITIES FOR ^{3}HHO, $^{14}CO_2$, $^{131}I_2$, AND $CH_3{}^{131}I$ ON SURFACES OF VEGETATION†

INTRODUCTION AND SUMMARY

The purpose of this study was to calculate deposition velocities of tritiated water, carbon dioxide, iodine, and methyl iodide gases on local vegetation adjacent to a reprocessing plant for spent reactor fuels. The information is required because an individual's potential dose from exposure to these airborne materials can be substantially reduced when removal processes are active, but the potential dose to man from ingestion and other pathways may increase. The calculated deposition velocities ranged from 0.10 to 2.04 cm/sec depending on the vegetation and the climatic conditions.

METHOD

In this report, deposition velocity is defined as:

$$V_d = \frac{F}{C} \tag{1}$$

where F = flux density of material to the surface, $g/(cm^2\text{-sec})$

C = concentration (g/cm^3) at a reference height near enough to surface that F = constant; i.e., $dF/dz \rightarrow 0$

Given a reference height above the vegetation, the deposition velocity can be related to the uptake processes at the surface using the resistance analogy

$$V_d = \frac{F}{C} = \frac{C - C_s}{RC} \tag{2}$$

where C_s = the concentration in equilibrium with the surface, g/cm^3

R = the total mass transfer resistance between the surface and the reference height, sec/cm

when $C_s \ll C$, then $V_d \simeq \frac{1}{R}$

† Work done by C. E. Murphy, Jr.

Equation 2 can often be applied to the initial period of exposure for radioactive gases that are readily absorbed at the external surface of the vegetation. If the material is absorbed inside the vegetation, by solution in the leaf water, and/or chemical reactions in the leaf, then the solubility and the form of the chemical reaction must be considered, and the deposition velocity can be written as

$$V_d = \frac{s(C - C_i)}{s(r_b + r_c) + \left[\frac{s(r_a + r_s) + r_i}{A}\right]} \qquad (3)$$

where:

s = Henry's law solubility ratio, C_{water}/C_{air}

C_i = the concentration in the leaf at the site of reaction, g/cm^3

r_b = mass transfer resistance through atmospheric surface boundary layer, sec/cm

r_c = mass transfer resistance through the canopy air space, sec/cm

r_a = mass transfer resistance through the boundary layer over the leaves, twigs, etc., sec/cm

r_s = mass transfer resistance through the leaf stoma, sec/cm

r_i = sum of mass transfer resistances to liquid diffusion and apparent diffusion at sink inside the leaves, sec/cm

A = leaf area per unit ground area, m^2_{leaf}/m^2_{ground}

Values of the diffusion resistances are taken from theory developed to estimate water vapor and carbon dioxide exchange between vegetation and the atmosphere.[1,2,3,4] The internal diffusion resistance for iodine was inferred from simultaneous measurements of water and molecular iodine uptake by leaves.[5] Experimentally determined ratios of methyl iodide versus molecular iodine were used to estimate the uptake of methyl iodide by vegetation.[6]

RESULTS

Deposition velocities were calculated for the five cases in Table 1a for a pine stand and a corn field. The stand characteristics are shown in Table 1b. These cases are representative of conditions during: (1) night with low winds; (2) an overcast day with moderate winds; (3) a sunny day with brisk winds; (4) Case 1 with the leaf stomates closed; and (5) Case 2 with leaf stomates closed.

The results (Table 2a) show that the deposition velocities are lower at night than during the day because of the combined effects of low turbulent transfer and closed leaf stomates. The effect of vegetation type is less than that of stomatal resistance or atmospheric conditions.

Table 2b shows the effect of the lower molecular diffusivities of $^{14}CO_2$, $^{131}I_2$, and $CH_3{}^{131}I$ on deposition. Molecular diffusion is dominant in the leaf boundary layer and the diffusion through the leaf stomates.

Tables 3 and 4 show the deposition velocites calculated for $^{14}CO_2$ and $CH_3{}^{131}I$ when the internal resistance is considered. Because of the high internal resistance (r_i/s), the effects of the atmospheric resistances are small ($r_b + r_c$). The deposition velocities for carbon dioxide will be much less than those given in Table 3 at low light values. These reductions are caused by the decrease in metabolic fixation of carbon dioxide (increasing r_i) and the closing of the leaf stomates (increasing r_s). The deposition velocity for methyl iodide will be affected very little by changes in stomatal resistance because the internal resistance is so much larger for methyl iodide than for carbon dioxide.

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TABLE 1

Atmospheric and Vegetative Characteristics Used for Calculations

a. Atmospheric Condition

Case	*Wind Velocity, cm/sec*	*Atmospheric Stability Class*
1	50	Stable
2	200	Neutral
3	400	Unstable
4	50	Stable
5	200	Neutral

b. Stand Characteristics for Pine and Corn

Vegetation	*Roughness Length, cm*	*Displacement Height, cm*	*Height, cm*	*Canopy Length, cm*	*Leaf Area (A), m^2*
Pine	30	912	1200	700	9
Corn	10	190	250	200	6

TABLE 2

Deposition Velocities as Limited by Diffusion

a. Resistances (sec/cm) and Deposition Velocities (cm/sec) of Tritiated Water for the 5 Cases in Table 1

Case	r_b	r_c	r_s	$(r_s + r_a)/A$	R	V_d
Pine						
1	2.01	0.69	3	0.35	3.06	0.33
2	0.38	0.13	3	0.35	0.86	1.15
3	0.10	0.04	3	0.35	0.49	2.04
4	2.01	0.69	35	5.1	7.80	0.13
5	0.38	0.13	35	5.1	4.4	0.23
Corn						
1	3.25	1.21	1	0.38	4.84	0.21
2	0.66	0.24	1	0.28	1.18	0.85
3	0.20	0.08	1	0.24	0.52	1.92
4	3.25	1.21	35	5.94	10.40	0.10
5	0.66	0.24	35	5.94	6.84	0.15

b. Influence of Molecular Diffusivity [$(r_s + r_a)/A$] on Deposition Velocities of Various Gases in the Pine Stand (Case 3)

Gas	$(r_s + r_a)/A$	V_d
^{3}HHO	0.35	2.04
$^{14}CO_2$	0.45	1.69
$^{131}I_2$	1.26	0.71
$CH_3{}^{131}I$	0.91	0.95

TABLE 3

Resistances and Deposition Velocities for Carbon Dioxide when Solubility and Internal Resistance Are Included

Case	$r_b + r_c$	r_i/s	$(r_a + r_s + r_i/s)/A$	R	V_d
Pine					
2	0.51	37.9	4.51	5.02	0.20
3	0.14	37.5	4.51	4.65	0.22
Corn					
2	0.90	12.6	2.34	3.24	0.31
3	0.28	12.6	2.34	2.62	0.38

TABLE 4

Resistances and Deposition Velocities for Methyl Iodide when Solubility and Internal Resistance Are Included

Case	$r_b + r_c$	r_i/s	$(r_a + r_s + r_i/s)/A$	R	V_d
Pine					
3	0.14	650	73	73	0.014
Corn					
3	0.28	650	108	108	0.009

43. MEASURING KRYPTON-85 CONCENTRATIONS AROUND A NUCLEAR FUEL REPROCESSING FACILITY†

INTRODUCTION

In the spring of 1974, Savannah River Laboratory (SRL) personnel began a cooperative research project to improve calculations of the transport and dispersion of materials released to the atmosphere. Krypton-85, a noble gas, is ideal for tracing the path of released materials because a) it does not react chemically with other substances in the air or on the ground, and b) it is radioactive and very small quantities can be measured with special instruments.

This report documents a small portion of the overall project: the collection of the samples, and an estimation of the individual exposure rates at the sample locations. Approximations of the dispersal of the ^{85}Kr is given in two diagrams. The exposure rates indicate that no significant individual doses are probable. Samples will continue to be collected through September of 1977.

SAMPLING

Equipment

A cryogenic air sampler developed by AIRCO[1] was adapted for use at SRL. The sampler is designed to concentrate the krypton in the atmosphere from an abundance of about one part per million in the ambient air to about one part per hundred in a sample bottle. This concentration is done by continuous liquifaction of the incoming air and allowing the more volatile atmospheric components to boil off. Liquid nitrogen is the cold source. The collected sample is further concentrated at Argonne National Laboratory (ANL) and assayed for ^{85}Kr, a radioactive isotope that constitutes a minute fraction of the total krypton collected.

Sites

The location of each sample station was chosen with several criteria:

- Security of the sampler.

† Work done by R. C. Craft and W. G. McMillan.

- Availability of power and heat so that the sampler could be kept above 70°C.

- Personnel able to operate the sampler.

With these criteria in mind, and wishing to keep the contracts for reimbursement for power to a minimum, satisfactory arrangements were made with governments of Georgia and South Carolina for the placement of samplers in highway maintenance shops, forestry service headquarters, and one police department's unused jail. In addition, one sampler was put in Du Pont's May Plant at Camden, South Carolina, and one at the Weather Bureau at Bush Field, Augusta, Georgia.

LOGISTICS

Each sampler consumes 160 liters of liquid nitrogen every 5 to 6 days. At the present schedule, a plant-operated delivery truck supplies nitrogen to three stations a day, four days a week, averaging 225 miles a day. At the May Plant at Camden, South Carolina, the Du Pont Company keeps the sampler supplied with liquid nitrogen. Krypton samples from the field are recorded and shipped to ANL approximately every two weeks for analysis. Sample results are returned to SRL for analysis and correlation with weather data.

MAJOR MECHANICAL PROBLEMS

Mechanical problems encountered with the samplers include:

- Drier saturation with carbon dioxide and water, resulting in blocking the heat exchanger, column, condenser, and foot with ice.

- Compressor failure and hose leaks.

- Circuit board malfunctions.

- Liquid nitrogen system leaks and defective photohelic gauges.

RESULTS

The ^{85}Kr concentrations measured at each of the sampling stations are listed in Table 1. Naturally occurring ^{85}Kr was not subtracted from the values. Exposure rates were calculated for both the arithmetic mean and the geometric mean by data in Reference 2, which gives the concentration resulting in 100 mrem per 168-hour week as $3 \times 10^{6} pCi/m^3$, based on the assumption that a body is surrounded by an infinite hemispherical cloud of radioactive material. The arithmetic mean is biased by very large and very small numbers, but the geometric mean is not. Both the geometric and the arithmetic means are given. The arithmetic mean, with the background subtracted, compares measured with calculated dispersion results, because the arithmetic means of weather data are used. For dose estimates, the geometric means should be used for this comparison, because single high numbers and very low numbers tend to bias the arithmetic mean.

A growing trend in Health Physics is the use of log-normal (geometric mean) values to describe not only aerosol particle size distribution, but also the concentrations of contaminants in the environs,[3] and film badge readings of employees.[4]

Figure 1 shows the isopleths of the ^{85}Kr activity (pCi/m^3, including a background of $\sim$14 pCi/m^3) using the arithmetic means.

Figure 2 shows the isopleths of the geometric means of the concentrations converted to mrem/year exposure rates.

CONCLUSIONS

Krypton-85 is a very useful nuclide for determining the actual patterns of dispersals from a nuclear fuel reprocessing plant. The actual patterns can be compared to release rates and weather data to verify dispersal computations.

The isopleths indicate a skewed distribution around the plant center, which may be as a result of either the dispersion parameters or the sample station locations. Dispersion parameters must be considered as predominate factors since the station at Millen, Georgia ($\sim$60 km), had about the same activity distribution as the station at Camden, South Carolina (125 km).

If either the arithmetic or geometric means are used to calculate the population dose, no health hazard is anticipated. The exposure rates are low compared to the 75 to 100 mrem/year dose received locally from naturally occurring nuclides.

REFERENCES

1. *Cryogenic Air Sampler - CAS-1, Installation & Maintenance Manual.* AIRCO, Inc., Corporate Research and Development Department, Murray Hill, New Providence, NJ (1973).

2. "Report of ICRP Committee II on Permissible Dose for Internal Radiation (1959),with Bibliography for Biological, Mathematical and Physical Data." *Health Physics 3,* 1 (1960).

3. D. E. Michels. "Log-Normal Analysis of Data for Plutonium in the Outdoors." Page 105 in *Proceedings of Environmental Plutonium Symposium.* USAEC Report LA-4756, Los Alamos Scientific Laboratory, Los Alamos, NM (1971).

4. R. P. Specht and A. Brodsky. "Log-Normal Distributions of Occupational Exposure to Medical Personnel." *Health Physics 31,* 160 (1976).

TABLE 1

Krypton-85 Concentrations Measured at Sampling Stations

Location	*No. of Weekly Samples*	^{85}Kr *Concentration, pCi/m*^{3}[a,b] *Minimum Value*	*Maximum Value*	*Arithmetic Mean*	*Geometric Mean*
Bush Field, Ga.	73	14.12	858.84	69.37	39.63
Bamberg, S. C.	68	13.3	266.0	47.5	30.44
Millen, Ga.	75	14.18	108.6	25.62	21.7
Wagener, S. C.	68	14.37	369.1	72.5	44.0
Greenwood, S. C.	62	14.32	122.8	23.99	19.67
St. Matthews, S. C.	71	14.42	220.	36.45	27.85
St. George, S. C.	61	14.45	124.	28.86	23.67
Columbia, S. C.	56	14.39	121.	33.62	26.86
Thomson, Ga.	71	14.4	279.	20.06	22.51
Swainsboro, Ga.	71	14.12	159.1	26.61	21.39
Statesboro, Ga.	75	14.34	76.9	19.73	18.26
Ridgeland, S. C.	64	13.7	111.2	21.8	18.64
Camden, S. C.	61	12.52	100.	24.57	21.19

a. Includes a natural background of ∿14 pCi/m^3, or ∿0.024 mrem/yr.

b. The ICRP value[2] for an exposure of 100 mrem for a 168-hr week is 3×10^6 pCi/m^3.

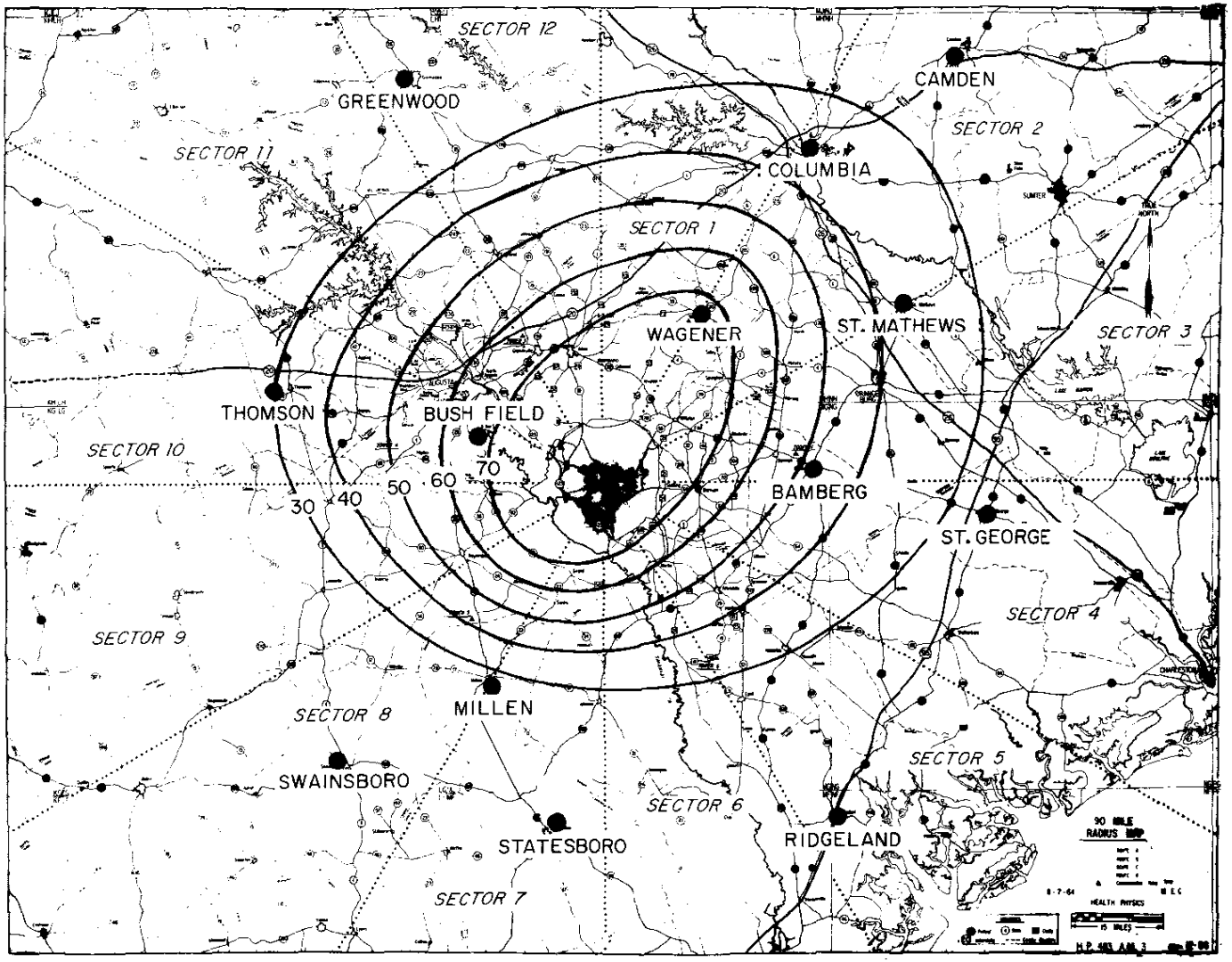

FIGURE 1. ^{85}Kr Concentrations in Vicinity of SRP, 1975 Through May 1976. Isopleths are arithmetic means in pCi/m^3; the ICRP value for a 100 mrem/week exposure is 3×10^6 pCi/m^3.

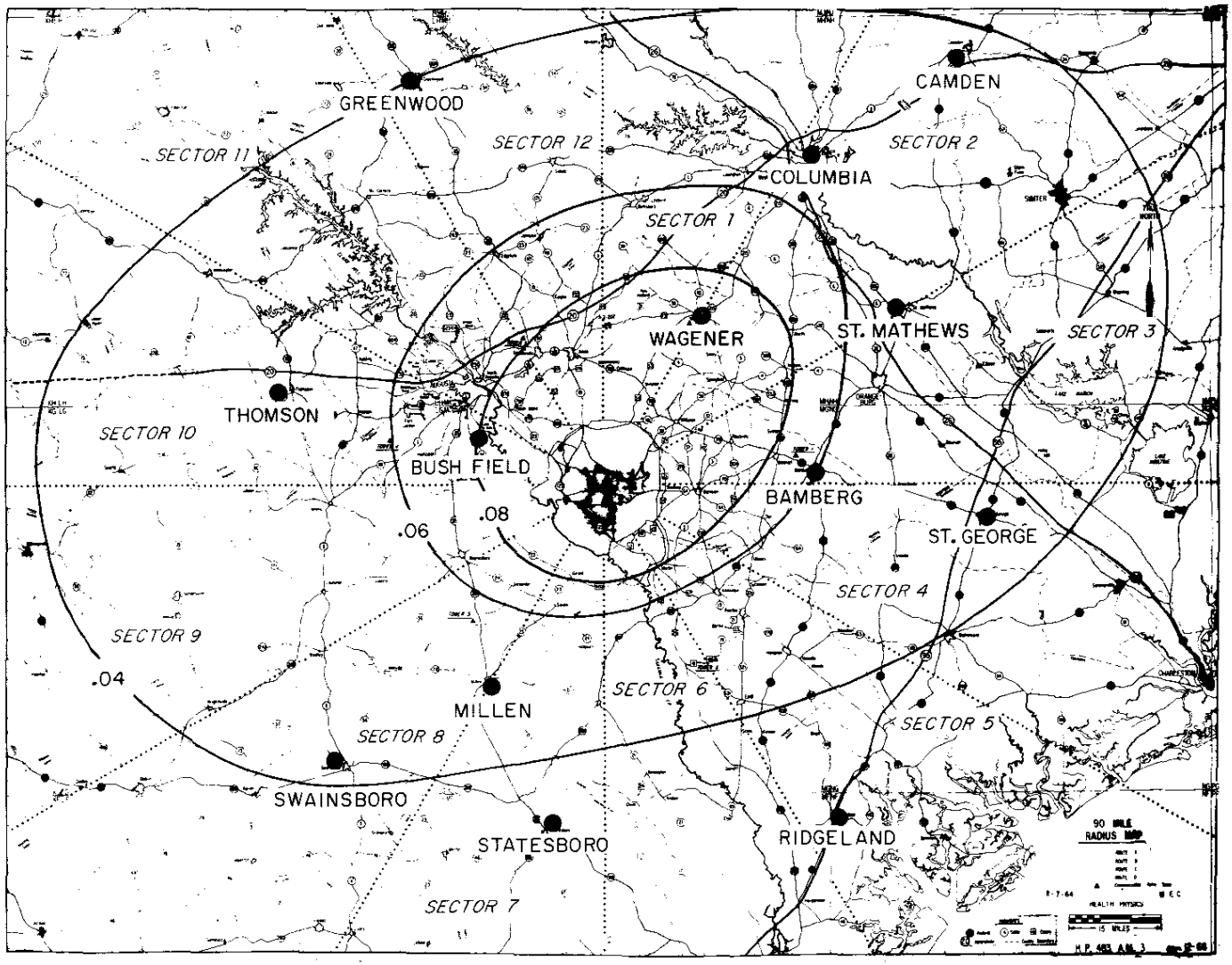

FIGURE 2. Exposure Rates (mrem/yr) from ^{85}Kr in Vicinity of SRP, 1975 Through May 1976. Isopleths are geometric means and include background radioactivity.

44. TRITIATED METHANE RELEASED FROM TRITIUM PRODUCTION FACILITIES†

INTRODUCTION AND SUMMARY

A sampler has been in use at the Savannah River Plant (SRP) for the past four years to determine the chemical forms and quantity of tritium released to the atmosphere.[1] In the tritium processing facility at SRP, some tritium is released that is neither elemental or oxide. This tritium was identified in an organic gas, probably methane. Although only released in small quantities, steps have been taken to reduce its release. In future work, the ratio of tritium to hydrogen in the methane will be determined.

SOURCES OF RELEASED TRITIUM

During the operation of the tritium processing facilities, large quantities of tritium are extracted from irradiated lithium-aluminum targets. A significant fraction of the released tritium is in the elemental form (29%). The tritium processing area releases an average of 1300 curies per week of the elemental form and 3200 curies per week of the oxide form. A summary of weekly tritium releases from SRP is shown in Table 1.

Releases of organic forms are shown in Table 2 for 6-hour periods. Measurements of these releases showed that low levels of organic tritium were released continuously. However, significant releases occur during one operation involving the regeneration of the liquid-nitrogen-cooled molecular sieve bed used in the purification of byproduct helium. During this operation, 81% of the total tritium released to the stack is in the organic form. Carbon is essential for the formation of organic tritium. The prime suspect source of carbon to form methane is carbon inclusions introduced into castings of lithium-aluminum alloy. The alloy is cast in graphite crucibles prior to fabricating the target shapes.

† Work done by R. C. Mulham.

TRITIUM COLLECTION AND IDENTIFICATION

Determinations of the form of released tritium were made with equipment consisting of (a) a sample collection system, (b) a processing system, and (c) two counting systems. This equipment is described in detail in Reference 1.

The sample collection system may be connected to a stack for measurements of releases or mounted in the field for environmental measurements. Briefly, the air sample is passed through a series of columns containing Linde Type 4A molecular sieve* material. The oxide form is removed by the first column. The elemental form is oxidized and removed on a second column of sieve material impregnated with palladium. The organic form is oxidized at 500°C and removed on a third column.

A processing system for dehydrating the sieve materials removes the collected oxide sample for analysis. The exposed sieve material is heated in a vacuum furnace to 480°C. Water leaves the sieves and is collected in a trap at -40°C. Stack effluent samples are diluted 1:1000 prior to scintillation counting. Environmental samples are counted directly.

Two counting systems are used. Most samples are counted by liquid scintillation (sensitivity: 1 pCi/m^3). Other samples are counted by gas proportional counting (sensitivity: 0.01 pCi/m^3).

REFERENCES

1. R. C. Milham and A. L. Boni. "Detection and Measurement of Tritium Forms Released from A Nuclear Production Complex." Presented at the *24th Conference on Remote Systems Technology, 1976 Winter Meeting, American Nuclear Society, Washington, DC, November 14-19, 1976.*

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* Linde Div., Union Carbide Corp., New York, NY.

TABLE 1

Weekly Averages of SRP Tritium Releases from August 1974 to August 1975

	Releases, Ci/wk			*% of Total SRP Tritium Released*		
	HTO	*T_2[a]*	*% T_2*	*HTO*	*T_2[a]*	*Total T*
Reactors	4100	32	1	47	0.4	47
^{235}U, $^{238,239}Pu$ Separations Areas	16	42	72	0.2	0.5	1
Tritium Processing Area	3200	1300	29	37	15	52
Total	7300	1400	16	84	16	100

a. Elemental tritium form (HT, T_2, DT).

TABLE 2

Distribution of Tritium Forms Released from Tritium Processing Area

Measured Release, Ci/(6 hr)			*% of Tritium Measured*		
HTO	*T_2*	*Organic*	*HTO*	*T_2*	*Organic*
14	2.8	0.09	83	17	0.54
2.7	2.9	0.03	48	51	0.49
0.53	3.2	0.05	14	85	1.4
42	27	290	12	7.6	81[a]
11	19	0.14	37	62	0.46
110	25	0.10	81	19	0.08
3.9	34	0.07	10	90	0.18

a. During regeneration of molecular sieve material.

45. DESCRIPTION OF THE ARAC MULTI-LABORATORY TESTS OF DECEMBER 1975 †

INTRODUCTION

In December 1975, multi-laboratory aircraft-supported tests extended the tests performed in June 1974 (see Reference 1 for details of the 1974 tests). The earlier tests were to demonstrate concepts of the Atmospheric Release Advisory Capability (ARAC) developed by the Lawrence Livermore Laboratory (LLL). These December 1975 tests were to demonstrate further the feasibility of the LLL-ARAC concepts to predict location, time, and concentration of releases to the atmosphere. Since the aircraft had been funded for a specific period of time, a number of other missions were also performed, some in collaboration with other ERDA-supported laboratories.

AIRBORNE RELEASE EXPERIMENTS AT SRP

ARAC Tests

Three tests were performed to repeat and expand the June 1974 tests[1] of the ability of Savannah River Laboratory (SRL) and LLL personnel and their mathematical models to predict the trajectory and concentration within plumes emitted from the Savannah River Plant (SRP) within a time scale that would be useful for emergency response. Argon-41, routinely released from the three SRP production reactors, was the primary tracer. Argon concentrations were predicted both by SRL and LLL and tracked by instrumentation aboard the aircraft. Sulfur hexafluoride was also released from one of the reactor 61-m-high exhaust stacks. The sulfur hexafluoride (SF_6) was measured and read out directly on the aircraft using a gas chromatograph. Sulfur hexafluoride can be tracked in real-time for greater distances than can argon-41. The gas chromatograph was provided and operated by Brookhaven National Laboratory (BNL) personnel.

The ARAC tests were performed December 10, 18, and 19, 1975. The ARAC test performed on December 10 was part of the multi-laboratory test and is described in greater detail below and in

† Compiled by C. D. Kern.

Reference 2. During the test of December 18, the Livermore ARAC Center was alerted. Then LLL and SRL computer model outputs were calculated from local and National Weather Service meteorological data. On that day, the aircraft flew a single mission tracking argon-41 from the three reactors. The weather for that day was such that a straight-line plume model would give good results. On the last test day with the aircraft, December 19th, the last ARAC test was performed in a similar manner.

Two missions were flown whick tracked argon-41 and sulfur hexafluoride released through a reactor exhaust stack. The meteorology for this day was such that the flow was straight and quite consistent early in the day during the time of release of sulfur hexafluoride. By the afternoon, the winds became very light and variable and actually changed direction about 180°. The sulfur hexafluoride was successfully tracked by the aircraft to distances greater than 40 km. Argon-41 data were obtained relatively close to the plant boundary. The data from these two missions have yet to be fully evaluated. The meteorology conditions during the afternoon were such that normal plume models were not satisfactory and provided a good test of the LLL-ARAC models.

Sulfur Hexafluorides/Heavy Methane Release

LASL proposed that heavy methanes ($^{12}C^{2}H_4$ and $^{13}C^{2}H_4$), which they manufacture, could be used as long-range atmospheric tracers. These tracers should also be tested against the more widely used shorter-range tracers (sulfur hexafluoride and krypton-85 released from routine production from the fuel separations plant at SRP). A test was performed in conjunction with the National Oceanic and Atmospheric Administrations (NOAA) Air Resources Laboratory (ARL) and the Los Alamos Scientific Laboratory (LASL). This test was done on December 10th in conjunction with one of the ARAC tests mentioned above.

Sulfur hexafluoride and heavy methanes were released along with the routine releases of ^{85}Kr during this test. The aircraft was able to track the sulfur hexafluoride to ascertain the plume location in real time. The heavy methanes were collected, along with ^{85}Kr, in the 13 cryogenic samplers located around the plant. Thirty-three portable air bag samplers collected small amounts of ambient air at locations between the cryogenic ^{85}Kr stations. These gas samples were analyzed by BNL to determine sulfur hexafluoride concentrations. ARL arranged to have the ^{85}Kr concentrations determined along with the concentrations of the heavy methane. ARL and SRL trajectory/diffusion models were tested against all measured data. For some preliminary results see Reference 2.

TRITIUM MEASUREMENTS

An instrumented flight was made to measure tritiated hydrogen (HT), tritiated water vapor (HTO), and their ratios (HT/HTO) in, about, and over the plantsite. A three-dimensional picture of HT, HTO, and their ratios was sought in order to obtain a better understanding of the residence time of HTO in the forest canopy of the plant and to determine if aircraft measurements can help in determining the conversion rate of HT or HTO in HT plumes. This test was conducted on December 13th. The winds were relatively steady in direction and speed. Two missions were flown this day. On the early morning mission, data were obtained at several levels with aircraft flying through the expected position of the plume approximately 10 to 15 km downwind. The tritium sampler[3] was operated onboard the aircraft for 30 minutes at each level. The aircraft flew back and forth through the principal portion of the plume for 30 minutes at altitudes of 300, 1000, 2000, and 3000 ft on the first mission. Comparable measurements were sought 40 to 50 km downwind. However, with the slight change in wind direction by the time the second mission was flown, the plume at this distance passed through an airspace control area for Bush Field and a restricted area for Fort Gordon. This second mission was then flown much further downwind and meaningful data were not obtained.

CONTROLLED FOREST BURN

A controlled forest burn was conducted by the U.S. Forest Service of a section of the SRP.[4] This burn was photographed in the visible and infrared on December 5, 1975. During the conduct of the burn, photos were taken of the smoke plume as it developed. The smoke plume was penetrated by the aircraft, and particulate sizes of the smoke particles were determined by a sampler device provided by the U.S. Forest Service.

MULTI-SPECTRAL PHOTOS OF SRP

The plant site was photographed from several altitudes with the multi-spectral photographic cameras on the aircraft. Photos in the visible and infrared wavelengths were taken of the heated streams, Par Pond, Savannah River Swamp, and the forested areas of SRP. These images provided the biologists and forest service personnel with productivity estimates, type of forest cover, and other surface biological features.[5]

The entire plant was photographed on December 11 and 12th by these special cameras mounted on the aircraft. These special cameras consisted of four cameras mounted such that all four cameras worked simultaneously. Each camera was fitted with different films and filters sensitive to different wavelengths in the visible and near-infrared. At the same time, an infrared scanning radiometer (sensing in the wavelength of 10 to 13 micrometers) provided images where surface temperature was represented by gray shades on the photographic film. All the film was processed, and samples were made available to the biological researchers at SRL, the Savannah River Ecology Laboratory (University of Georgia), the U.S. Forest Service, and other users. These data are being used for biological interpretation of living flora on SRP. The infrared images of Par Pond disclosed certain surface temperature characteristics of the hot arm of that pond that were previously suspected, but absolutely verified by the scanning infrared radiometer.

RADIOLOGICAL SURVEY OF THE SAVANNAH MARINE REGION

The banks of the Savannah River below SRP and the low-land estuaries (at low tide) were overflown by the aircraft. With the sodium-iodide gamma detectors mounted on this aircraft, surface concentrations of natural and man-made radioactive material in the exposed areas were measured to ascertain if any radioactive material that might have been released during the past twenty years by SRP could be detected. No man-made radioactive levels of consequence were measured.[5]

DATA COLLECTION

Aircraft Data

Measurements onboard the aircraft were made at 1-sec intervals and stored on magnetic tape. The aircraft had an average speed of 90 m/sec. The data recorded on magnetic tape at 1-sec intervals are as follows:

1. Time in Greenwich Mean Time.

2. Analogue output of an epsilon meter which provided a measure of atmospheric turbulence.

3. Distance from two base stations measured by a microwave ranging system. These two stations were located in Georgia, just across the river from SRP, such that the intersecting distance curves from these two locations intersected at nearly right angles at the center of the plant. Over the plant site,

locations were obtained within 3 m accuracy. When the aircraft was flying well south of SRP (as in the case of the December 10th mission), contact with the microwave ranging system was lost. In this instance, locations were stored on magnetic tape from an inertial navigation system. This system was less accurate with an accuracy of about 30 m. Computer programs were used to change both the inertial navigational system data and the microwave ranging system data to latitude and longitude.

4. Wind speed and direction.

5. Radar altitude (altitude above ground).

6. Pressure altitude.

7. Outside air temperature.

8. Dew point temperature.

9. Air speed.

10. Absolute air pressure.

11. Argon-41 data from the gamma radiation detector onboard the aircraft. These data were taken over 3-sec periods and were logged each 3 sec.

12. Analog output. For the forest burn mission, the analog output recorded data from the nephelometer. During the two missions in which sulfur hexafluoride was released (December 10 and 19th), output from the BNL gas chromatograph were stored on these channels.

All data from the aircraft missions test are available at SRL on 17 magnetic tapes.

Meteorological Data

Mesoscale meteorological information is available for the period of these tests from a network consisting of an instrumented 335-meter TV tower and seven instrumented 62-meter towers on the plantsite. The TV tower is located approximately 20 km to the northwest of the plant site. The instruments are scanned by a computer-controlled data acquisition system and stored on magnetic tape. Data are stored for each 5-sec of observation from all the channels of the TV tower and from the wind sensors on the plantsite. The TV tower is instrumented to measure wind speed, horizontal wind direction, vertical wind direction, and temperature

at seven levels from 2 to 335 meters. Hourly data are available from the National Weather Service stations located at key airports throughout the country. These data are available on magnetic tapes from the Air Resources Laboratory. During the December 10th test, members of LASL took frequent pilot balloon soundings prior to and during the conduct of these particular tests. These data are available from SRL-EDT personnel.

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2. C. D. Kern. "Preliminary Results from Sulfur Hexafluoride and Deuterated Methane Releases of December 10, 1975." Article No. 46 of this report.

3. D. W. Hayes and R. C. Milham. "A Technique for Field Measurements of Atmospheric Tritiated Hydrogen and Tritiated Water Vapor." *SRL Environmental Transport and Effects Annual Report - 1974.* USERDA Report DP-1374, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, SC (1975).

4. C. E. Murphy, *et al.* "Smoke Dispersal from a Controlled Fire in Logging Debris over a Cleared Pine Forest Area." Article No. 47 of this report.

5. D. W. Hayes. "An Aerial Radiological Survey of the Savannah River Marine Region." Article No. 10 of this report.

46. PRELIMINARY RESULTS FROM SULFUR HEXAFLUORIDE AND DEUTERATED METHANE RELEASES OF DECEMBER 10, 1975†

INTRODUCTION AND SUMMARY

Multi-laboratory experiments were performed at the Savannah River Plant (SRP) during December 1975.[1] Of all the experiments, the one involving the sulfur hexafluoride and deuterated methane on December 10 was the most extensive. This experiment tested the LLL ARAC system[1] and the relative effectiveness of several different tracers for atmospheric transport and diffusion studies.

The goals of this test were: (1) to determine whether sulfur hexafluoride, krypton-85, and deuterated methane tracers [methane-20 ($^{12}C^{2}H_4$) and methane-21 ($^{13}C^{2}H_4$)] give comparable results when they are released and sampled simultaneously; (2) to study the transport and dispersion of the plume out to 100 km from the point source; (3) to gain experience in release, sample processing, and analyzing these tracers; and (4) to exercise the LLL ARAC system.

The comparisons of the relative effectiveness of the deuterated methane and sulfur hexafluoride as tracers indicated that the methane concentrations were a factor of 4 below the sulfur hexafluoride concentrations when normalized to consistent units. The ^{85}Kr results differed from the other two tracers as a result of a different time sequence of release.

EXPERIMENTAL DESCRIPTION

Deuterated methanes were released on December 10, 1975, from two areas: (1) methane-21 and sulfur hexafluoride were released through the H-Area, 62-m-high exhaust stack at the same time that ^{85}Kr was being released through the F- and H-Areas 62-m exhaust stacks as a result of normal SRP operations; (2) methane-20 was released through a plastic tube from the top of the 62-m-high meteorological tower in A-Area; and (3) ^{41}Ar was released from the reactor exhaust stacks (Figure 1).

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† Work done by C. D. Kern with contributions by G. Ferber (ARL), Paul Guthals (LASL), S. Barr (LASL), and R. Deitz (BNL).

Two aircraft missions were flown on that day. The aircraft initially located the ^{41}Ar plumes from the reactor areas with gamma spectra equipment in order to estimate the location of the sulfur hexafluoride plume. Multi-altitude traverses were made at 16 km and at 45 km. Aircraft data were collected along Interstate 95 at about 100 km downwind of the release point (Figure 2).

Thirty-three small airbag samplers were placed along Interstate 95: every 3.2 km near the location where the center of the plume was forecast to cross the highway, and every 4.8 km elsewhere (Figure 2). The plume did cross the sampling station line, and sulfur hexafluoride, ^{85}Kr, and deuterated methane were collected by bag samplers. Thirteen ^{85}Kr cryogenic sampling stations[2] are located around SRP at distances between 25 and 140 km. Three of these stations were located more or less downwind from the release location during the December 10 experiment at St. George, Bamberg, and Ridgeland, South Carolina. There were also bag samplers co-located with the cryogenic samplers at St. George and Ridgeland. Data from these sampling stations were collected during this experiment.

PRELIMINARY RESULTS

Since sulfur hexafluoride and methane-21 were released simultaneously through the same stack, their normalized concentration profile should coincide if there were no flaws in the release, sampling, processing, or analysis procedures, and if the two tracers behaved the same in the atmosphere. The methane-20 would be expected to have a somewhat different profile with a slightly lower peak concentration, because it was released about 10 km upwind of the sulfur hexafluoride and methane-21 release.

For the ground samplers, all four tracers showed a peak at Mile Post 46 on I-95, with sulfur hexafluoride and ^{85}Kr in good agreement, and the methanes a factor of 3 to 4 lower (Figure 3). The concentration of ^{85}Kr was high relative to that of sulfur hexafluoride on the south side of this peak, and low to the north side. Since wind data indicate that the plume shifted with time from south to north along the sampling line, this observation is in qualitative agreement with the measured decrease in ^{85}Kr release rate during the tracer release. The mass balances for the two methanes appear to be in good agreement with each other. The ratio of methane-20/methane-21 concentrations summed over the sampling line is 3:6, in good agreement with the ratio of the molecules released, 3:4.

CONCLUSIONS

This experiment provided another operational test of the ARAC system; provided good data to study the transport and dispersion of a plume from a point source out to 100 km; and provided considerable experience in releasing, sampling, processing, and analysis of tracers. The discrepancy between the sulfur hexafluoride and methane tracer systems has yet to be resolved.

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2. M. M. Pendergast. *Evaluation of the Wind Rose Meteorological Model Using Krypton-85 Receptor Data.* Article No. 38 of this report.

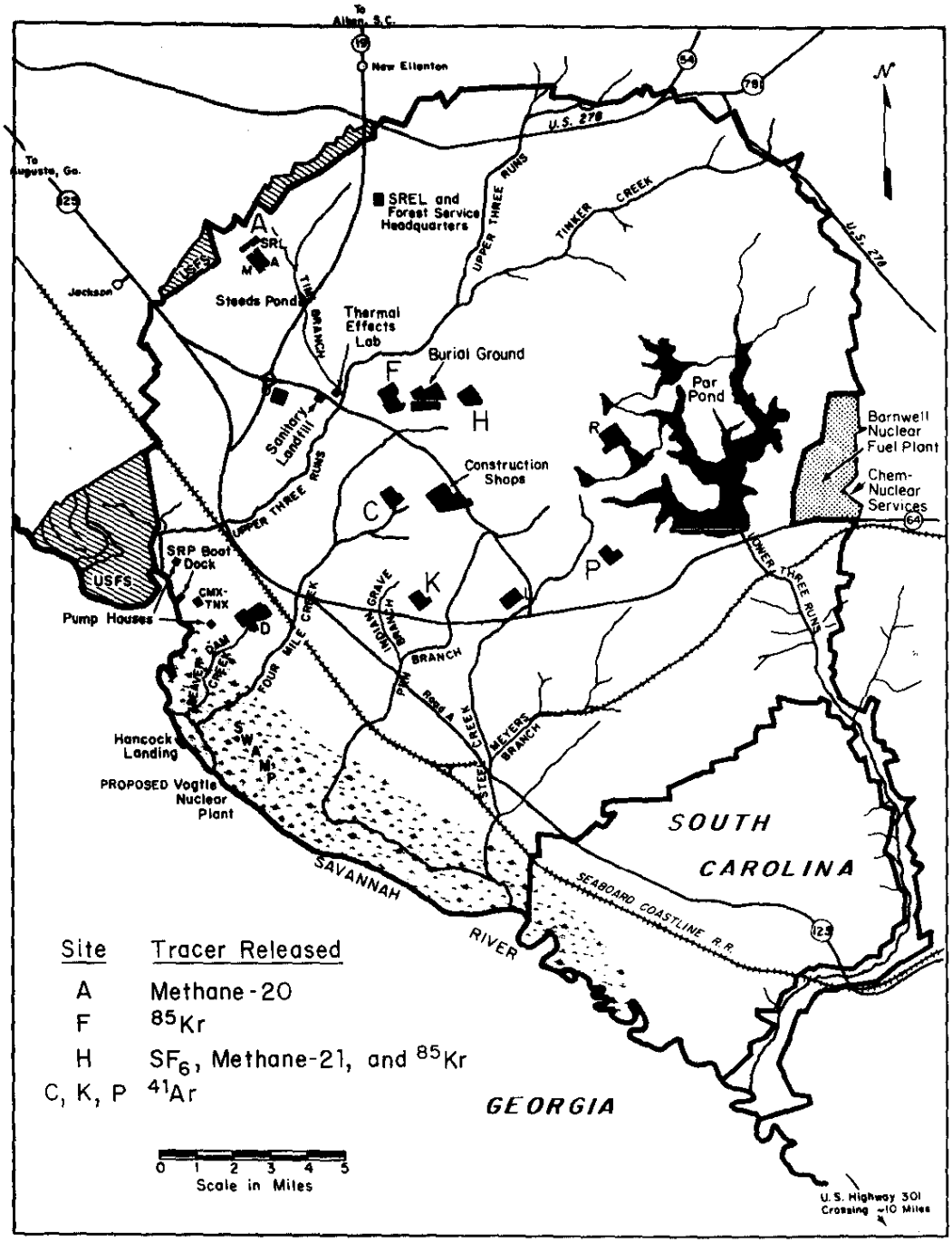

FIGURE 1. Savannah River Plant Site

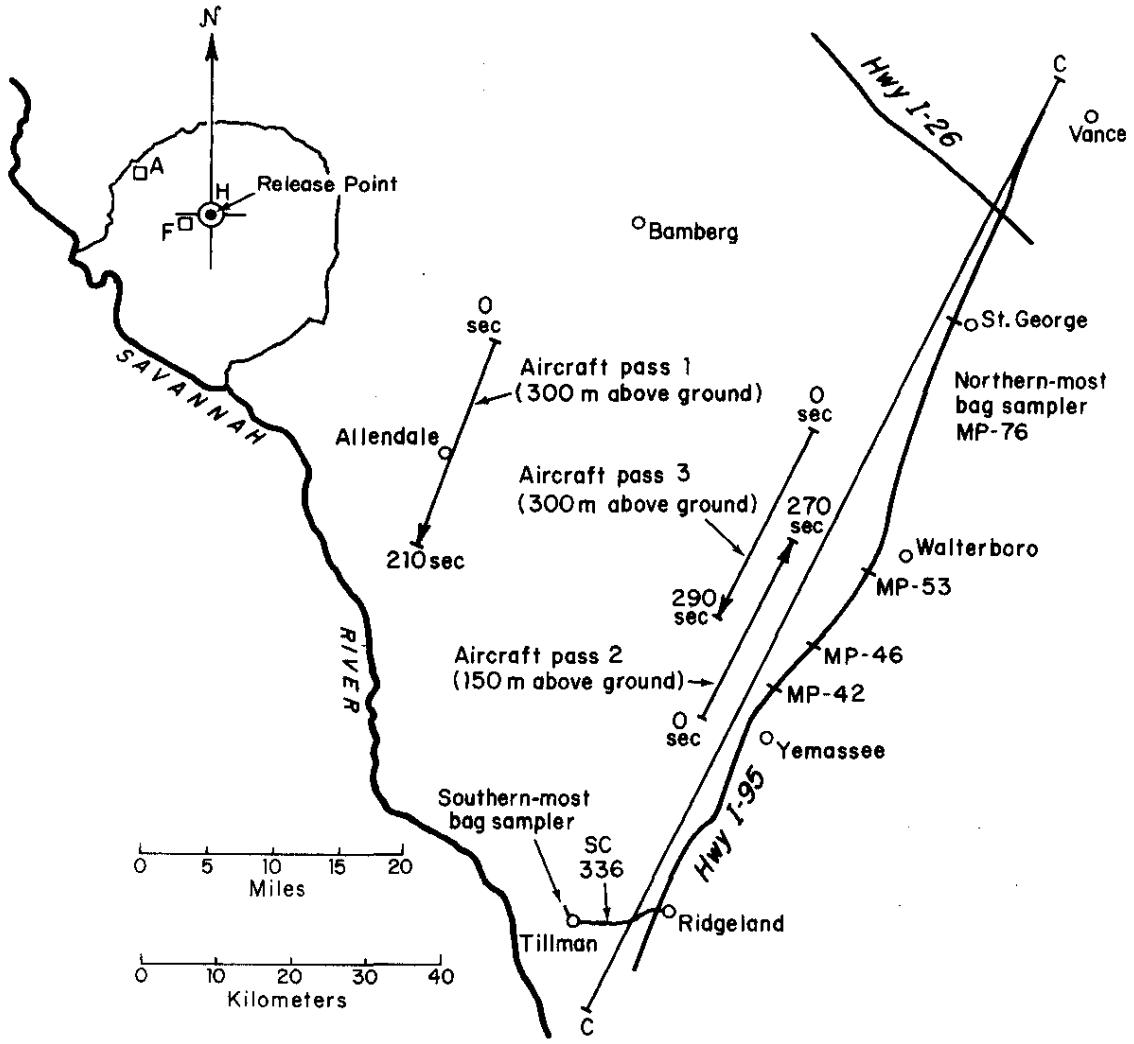

FIGURE 2. Sampling Sites Along Interstate 95

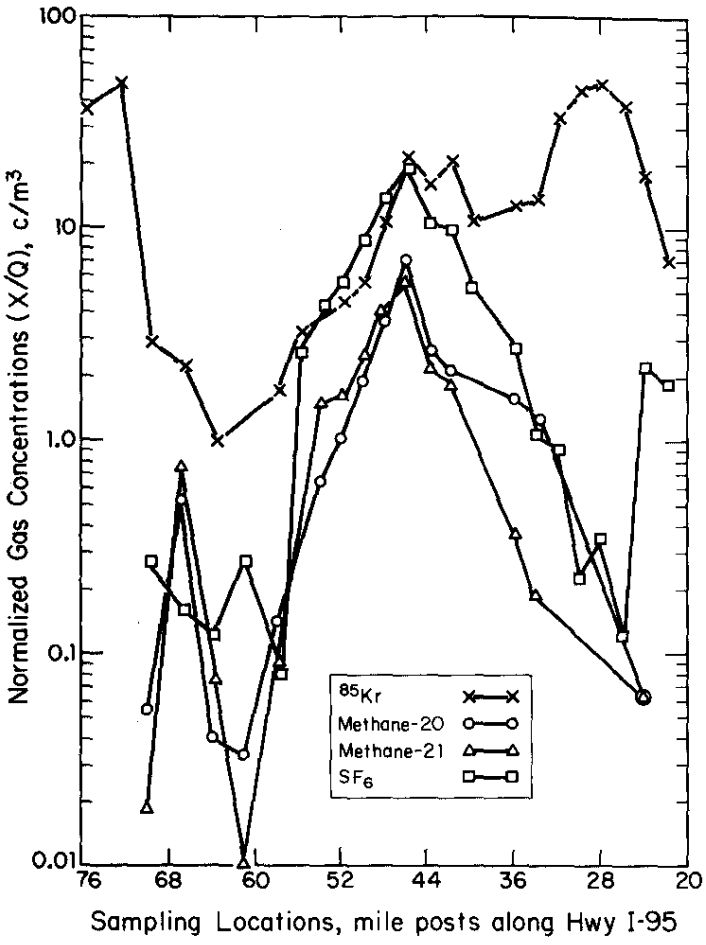

FIGURE 3. Tracer Concentrations Along Sampling Route

47. SMOKE DISPERSAL FROM A CONTROLLED FIRE IN LOGGING DEBRIS OVER A CLEARED PINE FOREST AREA†

INTRODUCTION AND SUMMARY

The dispersion of smoke in the atmosphere was studied during a controlled fire of forest debris on the Savannah River Plant. The objectives of the research were to (1) provide a data base for testing models of smoke dispersion, and (2) improve understanding and prediction capabilities for dispersion of atmospheric pollutants in general.

An instrumented aircraft measured smoke density and other parameters in multiple traverses through the smoke plume. The data permitted contour maps of constant smoke density to be drawn in three dimensions. Centerline smoke density reached a maximum of 0.43 $\mu g/m^3$. Supporting meteorological data were taken at an array of towers (7 towers, each 62 meters high) near the fire, and at different elevations on a TV tower (400 meters high) located 35 km from the site of the fire.[1]

Preliminary analysis of the data indicates that the simple Gaussian plume model with an effective stack height does not predict the smoke pattern. This may be caused by "leakage" from the plume or by multiple sources associated with parts of the burned area being at different stages of fire activity.

SITE DESCRIPTION

The topography of the control burn area is moderately hilly with an elevation change of about 15 m from the highest to lowest point. The area had been covered with an even-age pine stand, which was harvested by clear-cutting a few months before the fire. The soil is sandy through most of the area, and drainage of moisture proceeds rapidly after rainfall. This promotes rapid drying of forest fuels. There was no measurable rainfall in the three-day period preceding the fire; however, the relative humidity was high. On the day of the fire, the minimum humidity was 42%. The high temperature for the day was 22°C. The mass of fuel on the

† Work done by C. E. Murphy, Jr; J. T. Sigmon, Duke University, Durham, North Carolina; and D. T. Williams, P. W. Ryan, and W. H. McNab of the U.S. Forest Service, Macon, Georgia.

ground before burning was estimated to be 32.5 metric tons per hectare. The fuel consisted of 23.3 metric tons per hectare of logging slash and 9.2 metric tons per hectare of forest floor litter. Post-burn measurements indicate that 5.6 tons per hectare of logging slash and 6.1 metric tons per hectare of forest floor litter were consumed during the fire.[2] The area burned by the fire was 15 hectares.

AIRCRAFT DATA ACQUISITION

Measurements of smoke dispersal were made by flying transects through the smoke plume with an instrumented aircraft. The aircraft instruments recorded the following information:

- Greenwich time
- analog output of an epsilon meter, which provided a measure of atmospheric turbulence
- distance from two base points A and B measured by a microwave range system
- wind speed
- wind direction
- radar altitude
- pressure altitude
- air temperature
- dew point temperature
- air speed
- absolute air pressure
- analog output of nephelometer, which provided a measure of smoke density

Measurements were made at one-second intervals and stored on magnetic tape. The aircraft had an average speed of 90 m/sec. The flight pattern of the aircraft was designed to define the plume in three dimensions. Flight passes at 90° to the wind direction were made at altitudes above ground of 160, 400, 500, 725, and 850 meters 1.6 km downwind from the fire. The time

of the flights were 14:00, 14:05, 14:09, 14:13, and 14:17, respectively, on December 5, 1975. Passes were also made 8 km downwind at the visible base and top of the plume, and along the length of the plume: one pass above the visible centerline, and one pass along each edge of the plume.

FLIGHT DATA

Figure 1 shows the outputs of the epsilon meter and the nephelometer. The air temperature and the pressure altitude are also reported. The effect of the presence of the plume is seen in the increase in turbulence registered by the epsilon meter, the increase in air temperature, and the increase in the density of smoke as measured by the nephelometer. The displacements in the peaks of the turbulence, temperature, and density of smoke are most likely to have been caused by the different response times of the instruments.

Figure 2 illustrates the density of smoke in the plume at five altitudes at a distance 1.6 km from the fire. The general shape of the cross section of the smoke plume is outlined by the contours of constant smoke density. At a distance of 1.6 km, the plume is denser and wider at the highest flight path. U.S. Weather Bureau soundings from Charleston, South Carolina, and Athens, Georgia, indicated the height of the mixing layer was about 1000 m at 1900 EST on the day of the fire. Thus, under the low wind speed condition which prevailed during the fire, the majority of the buoyant plume quickly rose to the top of the mixing layer and diffused in an approximately Gaussian manner in the horizontal plane. However, the vertical smoke density profile does not seem to be a simple Gaussian model with diffusion from an apparent elevated source. The high centerline concentrations at the lower altitudes can be interpreted as "leakage" from the buoyant smoke column produced by the fire, or as multiple sources from the actively burning and the burned-over, smoldering portions of the fire. In either case, the character of smoke dispersion from a forest fire will vary with the stage of the fire's development, i.e., from a fairly hot fire that has just been set, through the stage of maximum combustion, to the stage of smoldering remnants.

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2. W. H. McNab, E. E. Ach, and J. W. Shimmer. *Broadcast Burning in Slash Pine Clearcuts: The 1975 Savannah River Plant Study.* USDA Forest Service, Macon, GA (1976).

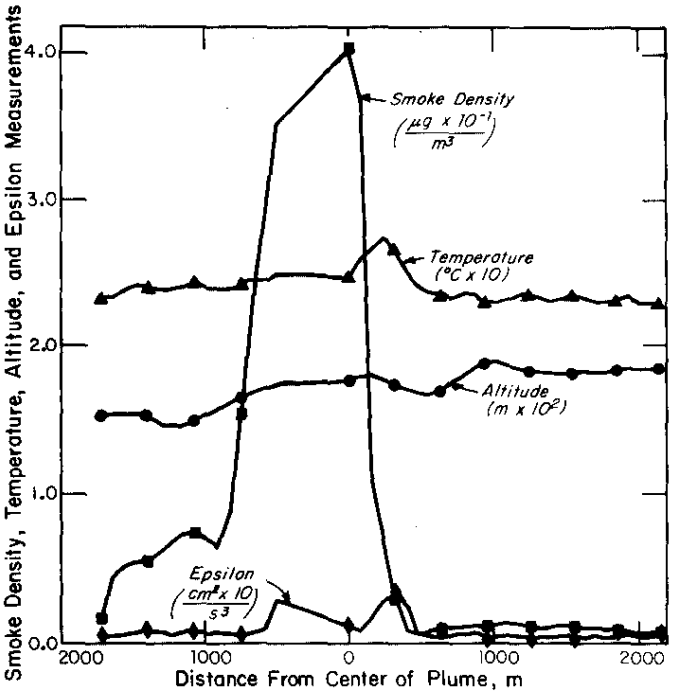


FIGURE 1. Smoke Plume Data Perpendicular to the Wind Direction

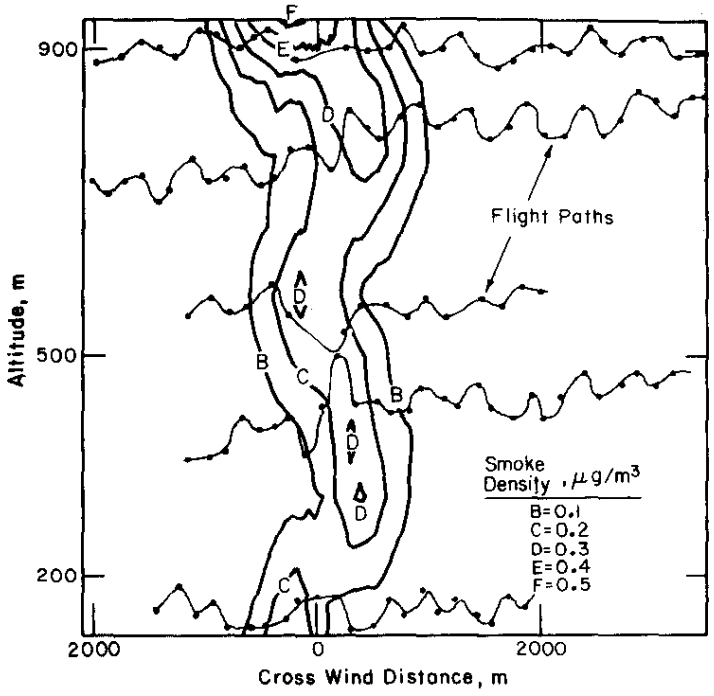
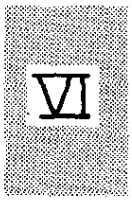


FIGURE 2. Smoke Plume Density Above the Fire

VI. EMERGENCY RESPONSE STUDIES

The objectives of emergency response studies are to develop and test systems which enable the rapid assessment of accidental releases to the environment. Efforts have focused on developing programs approaching real-time either on a locally installed minicomputer system or on the main computer processor at the Savannah River Laboratory. Displays have been designed for Health Physics personnel to make consequence-limiting decisions to cope with these atmospheric and aqueous releases.



48. AIDS FOR THE RAPID ASSESSMENT OF ENVIRONMENTAL RELEASES TO SUPPORT EMERGENCY RESPONSE†

Operations at the Savannah River Plant (SRP) involve the handling of large quantities of both radioactive and toxic chemical materials, which have the potential for hazardous releases to the environs. When material is accidentally released to the environs, the hazard must be quickly evaluated so a proper emergency response can be provided. In the past, the emergency response capability depended on the use of nomograms for an assessment of conditions, and a computerized program to provide more detailed and up-to-date information as the situation developed. Since meteorological dispersion is governed by many parameters, an adequate description of this process by nomograms is not practical. It is also presumed that there may be a significant time lapse following an accidental release before the Emergency Operating Center (EOC) at SRP would become operational. As a consequence of these inadequacies, graphical data were compiled and incorporated into an emergency procedures manual to provide a rapid and reasonably accurate assessment of hazardous conditions.

An example of these graphical data is presented in Figure 1. There are three curves as a function of downwind distance representing slight, moderate, or severe exposure potential based on the amount of material released. Similar data were generated for various kinds of potential releases (radioactive and chemically toxic), appropriate release heights, and dispersion categories based on the Pasquill-Gifford classifications. Meteorological data requirements are minimal. The proper dispersion category is chosen based on the band width of a wind direction recorder. The graph shown in this example (Figure 1) is for a wind speed of 1 m/s. This graph may be adjusted for the measured wind speed by dividing the source term by the measured wind speed. The adjusted source term is then used as the abscissa value for estimating hazard level. When radioactive decay is significant with respect to travel time for the distances indicated, the graphs are generated as a function of wind speed.

These graphical data are organized within the emergency procedures manual in a manner intended to provide efficient indexing (including the use of index tabs) for rapid access to the appropriate graph.

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† Work done by R. E. Cooper.

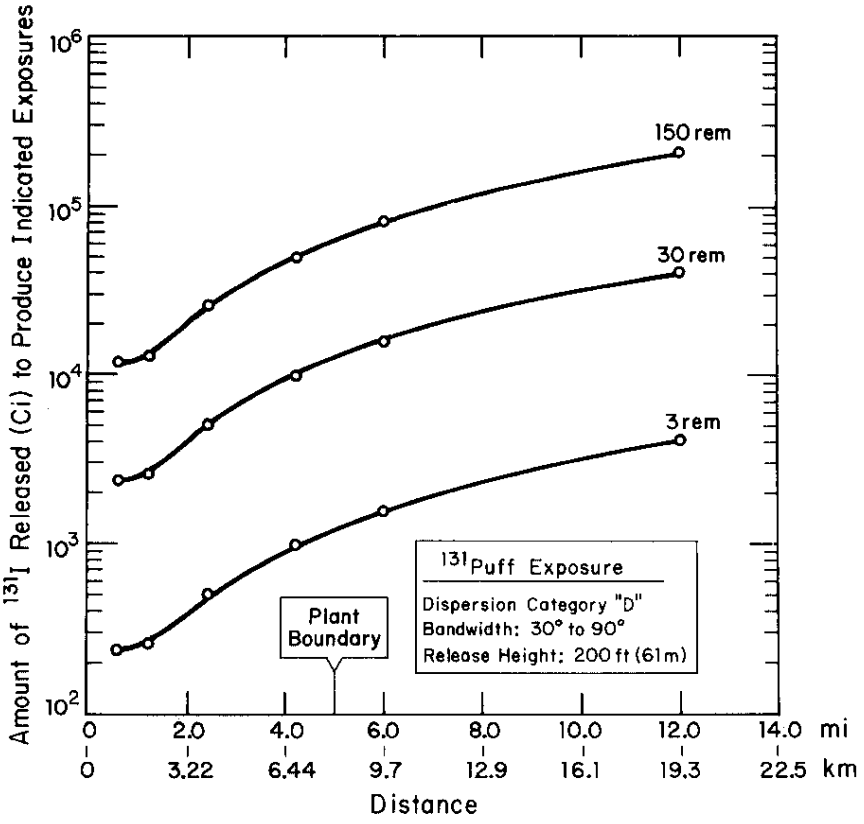

FIGURE 1. Ground-Level Exposures to Moving Puff of Airborne Radioactive Material

49. STATUS OF WEATHER INFORMATION AND DISPLAY *(WIND)* SYSTEM†

INTRODUCTION

The Environmental Transport Division (ETD) conducts an extensive program of research on atmospheric transport and dispersion. At the same time, ETD personnel provide improvements to the emergency meteorological response to accidental releases into the atmosphere.* Support of this program requires acquisition and archiving of current meteorological data on a regional basis both near the Savannah River Plant (SRP) and throughout the southeastern United States.

The Weather Information and Display (WIND) minicomputer system enables scientists to have at their disposal these archived data which provide input to a number of research activities. The WIND system contains programs which calculate transport and dispersion rapidly and displays the results in tabular and graphic form. These programs improve the basis for management decisions during an accidental release of pollutants to the atmosphere.

CURRENT STATUS

Data from an instrumented 335-m-high TV tower and seven plant towers are routinely being read by the WIND system. The WIND system provides graphical displays of these data hourly for purposes of quality control, emergency response, and meteorological understanding of the time/space variability of winds at exhaust stack heights over SRP.

Archiving of data from the TV tower has been completed, and archiving of data from the seven plant towers is nearing completion.

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† Work done by R. A. Mueller and C. D. Kern.

* For additional background see "A Weather Information and Display System for Research and Emergency Response" in *SRL Environmental Transport and Effects Research, Annual Report — FY 1975*, USERDA DP-1412, pp. 1-1 to 1-3, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, SC (1976).

The meteorological predictions and emergency response capabilities have been enhanced with improved computer programs and with software and hardware additions to the WIND system.

The WIND system will be linked to the JOSHUA system* as an interactive graphic terminal with access to current meteorological data. This link will connect the main JOSHUA terminal with the WIND system for emergency and routine impact assessment and will supply the Emergency Operating Center (EOC) terminal. This configuration will enable the transmission of current meteorological data to the IBM 360/195, where more sophisticated meteorological models than currently in the WIND system can predict atmospheric behavior based on current conditions.

A microprocessor is being designed and built at the Savannah River Laboratory to minimize problems in handling signals from National Weather Service Teletype Services "A" and "C" before acquisition of these data by the WIND system.

As of January 1977, the WIND system contains a 128 K memory, three RK05 disk platter drives (1.2 megabytes in each disk), a DIVA (44 megabyte) disk drive, a TV10 magnetic tape drive, a Centronics 101 printer, two Tectronix display terminals with hard copy, an LA36 Decwriter, two VT55 display terminals, and the associated hardware and software that enable the system and peripherals to function properly.

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* The JOSHUA system is a Savannah River Laboratory (SRL) system developed to provide a data-base operating system not available with the IBM operating system for the 360 series computers. The JOSHUA Operating System provides the capability to develop modular data-based computational systems for large-scale multistep iterative calculations oriented for use with remote terminals. See the *JOSHUA System*, USERDA Report DP-1380, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, SC (1975).

50. EXTENDING EMERGENCY RESPONSE CAPABILITIES TO ESTIMATE DOSES FROM GAMMA RAYS†

INTRODUCTION

A confinement system in each of the production reactors at the Savannah River Plant (SRP) would limit the release of radioactive material from the reactor building in the event of an accidental release from the reactor. High efficiency particulate air (HEPA) filters would retain almost all particulate material, and charcoal beds would sorb most of the iodine. The release of radioactive material from the building through the stack would thus consist primarily of noble gases (xenon and krypton).

Two programs (ERGAM and PUFGAM) have been made available through the WIND system to extend the emergency response capabilities to include calculations of whole-body gamma doses. These computer programs are used to estimate integrated whole-body gamma dose and dose rate as a function of downwind distance in the unlikely event of a reactor accident involving the melting of fuel and a subsequent release of radioactive gases to the atmosphere.

ERGAM is a program that provides an estimate of whole body gamma dose from an instantaneous release of noble gases from a reactor and has been described previously.[1] PURGAM is a program that provides an estimate of exposure rate as a function of time for specified distances downwind if the material is released as puffs of varying source strength. The strength of each puff and the time interval between puffs are user-specified so that complicated release modes may be reasonably simulated. The mathematical modeling of PUFGAM is very similar to ERGAM; however, PUFGAM takes more computer time because spatial integrals of gamma exposure must be computed as a function of time. PURGAM will be useful in providing an estimate of radiation field intensity for survey teams investigating the effects of an accident during the passage of the radioactive material, and may be useful in guarding against entrapment in hazardous radiation fields.

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† Work done by R. E. Cooper and C. E. Bailey.

DETERMINATION OF A GAS RELEASE OF NOBLE GAS

In the event of an accidental release of radioactive material from one of the SRP production reactors, the quantity of noble gases (krypton and xenon) released to the atmosphere would be determined by integration of the response of an ionization chamber located in the exhaust stack of the reactor building. The ionization chamber responds to the gamma rays produced by decay of the radioactive isotopes.

There are four krypton isotopes and six xenon isotopes that would contribute significantly to the total gamma activity. The relative quantities of these isotopes that would be present in a release depends both on the irradiation time of the fuel and on the time of the release after reactor shutdown. Because only the total gamma activity would be measured, a study was made to identify the effects of irradiation time and the time of release after reactor shutdown on the change in the total gamma ray energy with time after a release.

The normalized gamma ray energy of the krypton and xenon isotopes in a reactor core following shutdown after sufficiently long irradiation for these isotopes to reach equilibrium (~25 days) is shown in Figure 1. The decrease in gamma energy following a postulated release from a core with the noble gases saturated is shown in Figure 2 for several assumed release times after shutdown. A puff release, occurring over a short time interval, was assumed. As shown in Figure 2, a delay in the release time following shutdown reduces the rate at which the gamma activity of the cloud decreases following the release. If the noble gases contained in a given fraction of the core were released, the total dose from the puff would be lower the longer the release were delayed following reactor shutdown, because of the decay that would occur between shutdown and release (see Figure 1). However, for releases measured to be the same by the ionization chamber in the exhaust stack, the total dose from the puff would be higher the longer the release occurred after shutdown, as illustrated in Figure 2.

The effect of irradiation time on the gamma activity of the noble gases following a postulated puff release is shown in Figure 3. The ratio of the gamma activity of the cloud to that for the same measured release from a core saturated with noble gases is shown. The activity ratio changed significantly with the time of release following shutdown for a core irradiated for only four hours. However, after 2- and 10-day irradiations, the ratio changes only slightly with the release time, and the single curve given for each of these irradiation times holds for all release times following shutdown. The gamma activity of a puff release from a core irradiated for 10 days does not show a large decrease relative to

a release from a core saturated with noble gas; while releases from cores irradiated for 4 hr and 2 days do show a significant decrease. Thus, a significant reduction in gamma dose for the measured release from an irradiated core (compared to a core saturated with noble gases) would only occur if the core had been irradiated no longer than a few days.

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1. T. V. Crawford. *Savannah River Laboratory Environmental Transport and Effects Research, Annual Report, FY-1975.* USERDA Report DP-1412, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, SC (1976).

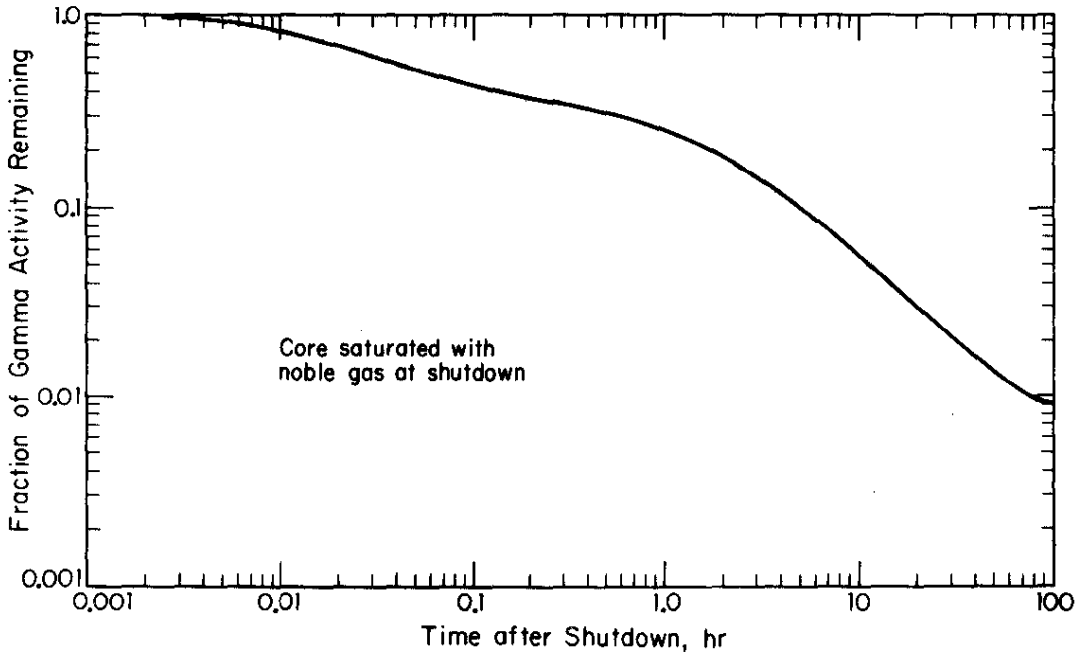

FIGURE 1. Decay of Noble Gas Gamma Activity in Core Following Shutdown

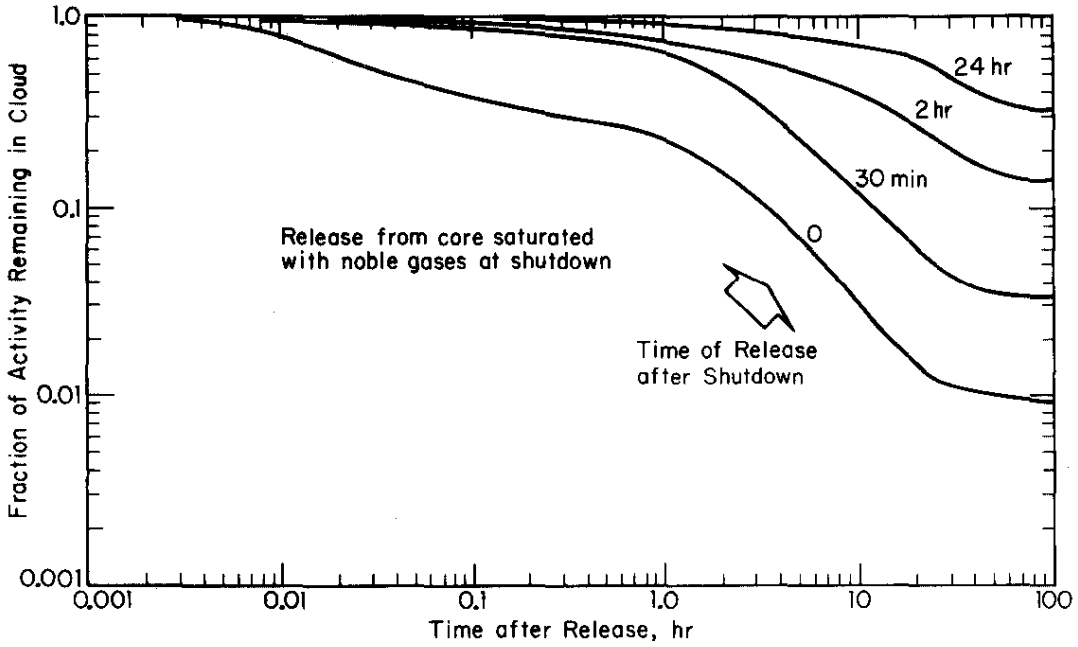

FIGURE 2. Decay of Gamma Activity Following a Puff Release of Noble Gases

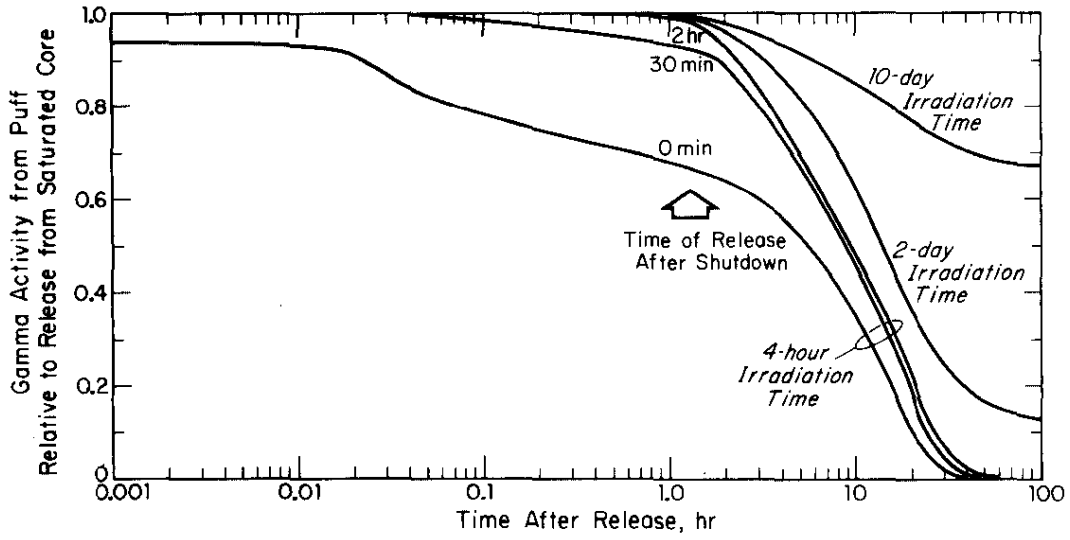

FIGURE 3. Effect of Irradiation Time on Activity of Noble Gas in Puff Releases

51. A COMPUTER CODE TO GENERATE POPULATION GRIDS FOR VARIOUS GEOGRAPHIES†

INTRODUCTION

The Environmental Transport Division at the Savannah River Laboratory (SRL) is engaged in studies which require gridded population data to estimate environmental effects of various pollutants released to the environs. Although the major concern at SRL is the ultimate fate and environmental effects of materials released from the Savannah River Plant, some studies pertain to other regions of the contiguous United States. The studies may also involve various grid shapes which require the ability to generate population data for a wide variety of situations. A computer code, PODGE, was written to provide this capability.

The basic requirement of PODGE is a large population data base from which to operate. This requirement is fulfilled by the acquisition of a data base from the Oak Ridge National Laboratory (ORNL) RUSTIC program.[1] These data, covering the United States, are organized into geographic areas (defined by increments of longitude and latitude) for various grid sizes. The PODGE code reorganizes these data to conform to various grids as described below. All grids are defined by an $n \times m$ array of coordinate pairs (longitude and latitude), which are automatically generated by the PODGE code with one exception, which involves totally arbitrary coordinates. PODGE is operational under the SRL JOSHUA system.[2] As population grids are generated as a result of specific requirements, they are stored as named records within the JOSHUA system and kept available for future use.

GRID SYSTEMS

Four grid options are available with the PODGE system: the standard grid, the latitude-longitude grid, the arbitrary coordinate grid, and the polar coordinate grid. The main features of each of these four grid options are described below.

Standard Grid

The standard grid is a modified and miniaturized version of a northern hemispheric grid obtained from the National Meteorological Center (NMC). This grid allows the generation of incremental longitude and latitude grids by specifying starting coordinates

† Work done by R. E. Cooper.

in terms of grid indices for the standard grid. Incremental grids may be generated for any part of the standard grid and may vary in mesh size by the use of a control parameter. The grids thus generated define areas that are very nearly equal over the entire grid.

Longitude-Latitude Grid

The utilization of this option allows the generation of longitude and latitude coordinates by specifying starting coordinates, coordinate incrementing parameters, and the size of the array. This, of course, results in a rectangular grid specification. However, arbitrarily shaped population regions may be defined by the specification of boundary indices for each longitude within the rectangular region.

Arbitrary Coordinate Grid

In this option, a rectangular array of coordinates is read directly into the computer. Although the array must be rectangular, the actual grid area may be arbitrary in shape.

Polar Coordinate Grid

A polar grid system is generated by specifying a coordinate pair for the origin, the number of radial increments, and the radial increment size. The grid is assumed to be of such a size that the curvature of the earth is not significant in this application.

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2. H. C. Honeck. *The JOSHUA System.* USERDA Report DP-1380, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, SC (1975).

52. EMERGENCY RESPONSE CAPABILITIES FOR AQUEOUS RELEASES†

SUMMARY

Computer models of stream and river systems were developed to predict the possible consequences of releases of short duration to major creeks on the Savannah River Plant (SRP) and to the Savannah River. The models predict concentration-time profiles at selected downstream locations. Model and computer parameters are retained in the computer to enable emergency response to releases at selected locations.

MODEL DEVELOPMENT

Dye studies were completed on all major creeks of SRP to provide the data to derive the model parameters. Transport coefficients were determined from the data by the analysis code called TETRAD.[1] Coefficients developed from the dye studies are for conservative transport (i.e., no tracer or pollutant interaction with the stream or the environment). The predictive transport is accomplished by the JOSHUA module called LODIPS.[1,2] The model for the Savannah River was developed from data from a dye study by the USGS.

Release locations are specified for the major plant areas (P, K, C, H, F, and D) and some road-creek intersections. Downstream profiles are given at sampling locations at road-creek intersections, creek mouths, road-river intersections, and the entrance to the Savannah River estuary.

Computer parameters were optimized for a 10- to 240-minute interval of release and a computation time of one minute or less.

IMPLEMENTATION

Any SRL-SRP user of the IBM 360-115 computer has access to LODIPS. Execution requires familiarity with the JOSHUA system.[3] To initiate execution, the user selects the stream case name and then specifies a concentration-time profile for the release

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

(Table 1). Output is given in a tabular form (Table 2). If desired, the predictions may also be displayed graphically.

REFERENCES

1. T. V. Crawford, et al. "Computer Modeling of Stream and River Systems. Article 12 in the *Savannah River Laboratory Environmental Transport and Effects Research Annual Report - 1974*. USAEC Report DP-1374, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, SC (1974).

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3. H. C. Honeck. *The JOSHUA System*. USERDA Report DP-1380, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, SC (1975).

TABLE 1

Profile of a Hypothetical Release to Beaver Dam Creek from the 400-D Area

Case Name: BVRDMPOD

Release Location: D-Area Outfall

Time, min	*Concentration, arbitrary units*
0.0	1000
15.0	1000
15.1[a]	0

a. Release passes observation point.

TABLE 2

Predicted Profile at the Mouth of Beaver Dam Creek at the Savannah River for the Hypothetical Release of Table 1

Time Since Release, min	*Concentration, arbitrary units*
408	0.046
433	0.407
463	1.33
493	3.01
523	5.49
553	8.42
583	11.15
613	13.00
643	13.50
673	12.65
703	10.80
733	8.48
763	6.17
793	4.17
823	2.64
853	1.55
883	0.839
913	0.399
943	0.141
953	0.079
963	0

VII. COMPUTER METHODS DEVELOPMENT FOR ENVIRONMENTAL TRANSPORT STUDIES

The objectives of this effort are to provide the computational and data management tools required by the environmental science programs of ETD. JOSHUA-compatible data management and display techniques are being developed in two directions: geographical and cartographic methods to support the environmental data editing requirements; and relational information retrieval systems to support a variety of non-computational data bases now under development, such as the SRP water-level file, the well-location file, and the deer-data file.* Atmospheric transport computer codes are being packaged for execution under the present JOSHUA system. Improvements in computational capability now under development can then be readily integrated with the entire spectrum of atmospheric effects calculations, i.e., from meteorological observations to measuring dose effects.

* The deer-data file is a joint effort of the U. S. Forest Service, the Savannah River Ecology Laboratory (University of Georgia), and the Savannah River Laboratory and Plant.

53. DEVELOPMENT OF A GENERALIZED ENVIRONMENTAL DATA BASE EXTRACTION AND GRAPHICAL DISPLAY SYSTEM†

INTRODUCTION

The JOSHUA data management system[1] is being extended to accommodate the characteristics typical of environmental data bases.[2] At the present time, the capabilities permit the retrieval of a subset of records from the data base and their graphical display on a cathode ray tube. In the future, context-dependent modules will be written to include the conventions of the several environmental science disciplines.

STATUS OF PROGRAM

At this time, it is possible to retrieve records from the data base for a given record type, based on record names. Thus, for example, one could request all occurrences of sea-surface temperature records for the South Atlantic Bight, for a designated month. These selection parameters are all controlled by the JOSHUA record names. The ability to retrieve by date within the record itself is now under development. This permits, for example, selection of data by year, month, day, and hour.

Having retrieved the data, JOSHUA graphics modules can create interactive displays on the cathode ray tube in a wide variety of formats. These displays permit the user to evaluate the data and enhance his knowledge of the distribution of the information.

The JOSHUA graphics modules were developed for output from computational models and achieve a certain degree of smoothness in the data and compactness of representation. Work is now under way to enhance data smoothing of typical environmental data to reduce effects of observational noise and loose, sparse representation.

One may also at this time reformat the data for ERDA-inter-laboratory exchange. A machine-independent format for this exchange is being implemented at most ERDA national laboratories. Work is nearing completion to permit the user to go directly from JOSHUA to the inter-lab format using JOSHUA data descriptions. Further extensions required are non-JOSHUA data descriptions and a means of loading data from the inter-lab format into a JOSHUA data base.

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† Work done by J. E. Suich.

REFERENCES

1. H. C. Honeck. *The JOSHUA System.* USERDA Report DP-1380, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1975).

2. T. V. Crawford and C. E. Bailey. "Environmental Science and Computations: A Modular Data-Based Systems Approach." Page 199 in *Proceedings of the Conference on Computer Support of Environmental Science and Analysis.* USERDA Report CONF-75-706, National Technical Information Service (NTIS), Springfield, VA (1975).

54. INITIAL DEVELOPMENT OF THE *JEREMIAH* SYSTEM FOR SIMULATION OF POLLUTANT TRANSPORT IN THE ENVIRONMENT†

A modular environmental transport and dose computational system is being developed to provide emergency and routine response capabilities for environmental assessment of pollutant releases at the Savannah River Plant (SRP). The system is called JEREMIAH (JOSHUA Emergency and Routine Environmental Impact Assessment Handler) and operates under the JOSHUA system.[1] The JOSHUA system provides extensive data management facilities and convenient programming interfaces for modular structuring. The initial JEREMIAH system handles atmospheric pollutant releases from SRP as well as from other nuclear facilities in the southeastern United States.

Current meteorological conditions are provided by the Weather Information and Display (WIND) minicomputer system (Figure 1). These data include the wind and temperature data from the instrumented (TWRS) plant towers and the WJBF television tower, as well as weather information from the National Weather Service (NWS) stations located in the southeastern United States. These data are currently archived on tape (ARCHIVE in Figure 1) for routine use. Current conditions are provided from the METOBS data set for use in developing wind fields. This currently requires hand transfer of the meteorological data from the minicomputer system to the JOSHUA IBM-360 computer system.

Wind fields are developed from these data for three grid networks which are centered on the SRP site. Grid spacings of 2.5 km, 10 km, and 40 km are available. An objective analysis scheme[2] is applied by the GRIDW module to provide wind fields from the meteorological data. These data are output in a standard form to an intermediate data set (EIDS). Diffusion modules (DIFF in Figure 1) then use these wind fields to calculate the transport and dispersion of atmospheric pollutant releases as specified by the SOURCE data (Figure 1). Both two-dimensional puff/plume and three-dimensional finite-difference calculational modules are being developed for the JEREMIAH system. The pollutant

† Work done by M. R. Buckner.

concentrations, C(t), are then used by the dose modules (DOSE in Figure 1) along with population data (POPXY in Figure 1) to calculate individual and population dose rates on the specified grid network. A gamma dose module is also being developed for estimating the whole body gamma dose resulting from a reactor release.

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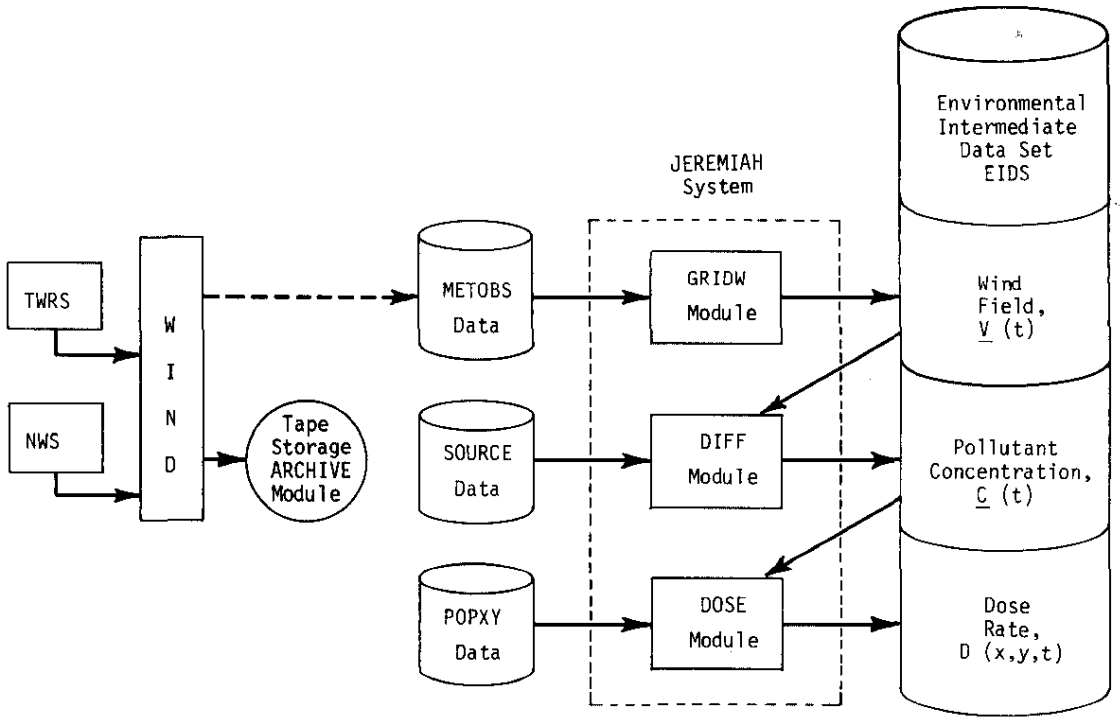

FIGURE 1. Environmental Computational System for Atmospheric Pollutant Releases

55. MODELING THE DISPERSION OF ATMOSPHERIC POLLUTION USING CUBIC SPLINES AND CHAPEAU FUNCTIONS†

The application of cubic splines and chapeau functions (Galerkin methods) to the solution of partial differential equations is becoming increasingly widespread. Both methods are simple to use, computationally fast, and reasonably accurate.

Knowledge of the inaccuracies inherent in each method are necessary prior to their use in modeling the dispersion of atmospheric pollutants. The accuracy and amount of artificial diffusion and dispersion of each method can be easily visualized by conducting a simple test: A cosine hill distribution of concentration with a peak value of 100 is advected in a clockwise direction (Figure 1). The peak value and distribution should remain constant throughout the rotation. Hence, a measure of the accuracy of a method lies in its ability to transport the distribution without change. This test was used by Long and Pepper[1] in analyzing six numerical schemes for advecting pollutant concentrations. A part of their analysis is shown here.

Figure 2 shows concentration contours obtained from the implicit solutions of the advection terms using cubic splines and chapeau functions after 0.75 revolution. Implicit techniques permit large time steps to be utilized in the computations. The cubic spline technique slightly alters the distribution and reduces the maximum value by 9%. The chapeau function technique alters the concentration insignificantly, the maximum value decreasing by only 2%. After 4-3/4 revolutions, contours of concentration obtained from cubic splines appear more circular than those obtained using chapeau functions, but the maximum value is less (Figure 3). While chapeau functions are more accurate in maintaining peak concentration values, concentration contours may become slightly distorted over long periods of time.

Based on these results, a computer code was developed which calculates time-dependent, three-dimensional dispersion of atmospheric pollutants using chapeau functions. Both advection and diffusion terms are solved by implicit methods and time-splitting techniques employed by Yanenko[2] and Long and Hicks.[3] Although

† Work done by D. W. Pepper, P. E. Long, and C. D. Kern.

advection and diffusion must be solved implicitly in each of the three directions, computational running times appear to be relatively fast. A grid network of 33 × 33 node points is combined with 10 levels of vertical planes ranging from 2 m to 1000 m above the ground. Use of such a mesh permits the dispersion of ^{85}Kr from nuclear fuel separation sites at the Savannah River Plant (SRP) to be calculated out to 100 km. Initial concentration distributions are assumed to be Gaussian. Advection is calculated from real-time wind data, and vertical diffusivity is determined with an O'brien cubic profile.

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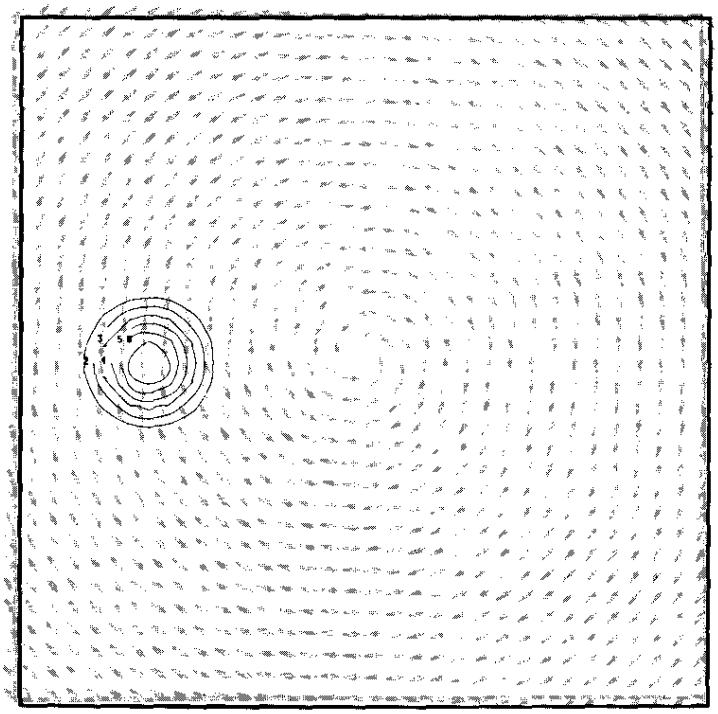
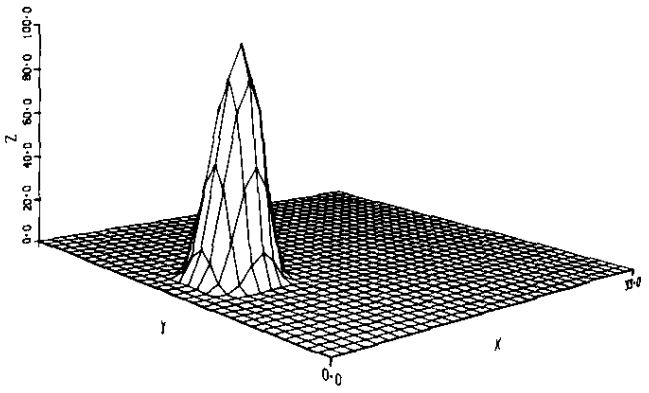


a. Plan View



b. Isometric View

FIGURE 1. Cosine Hill Distribution of Concentration

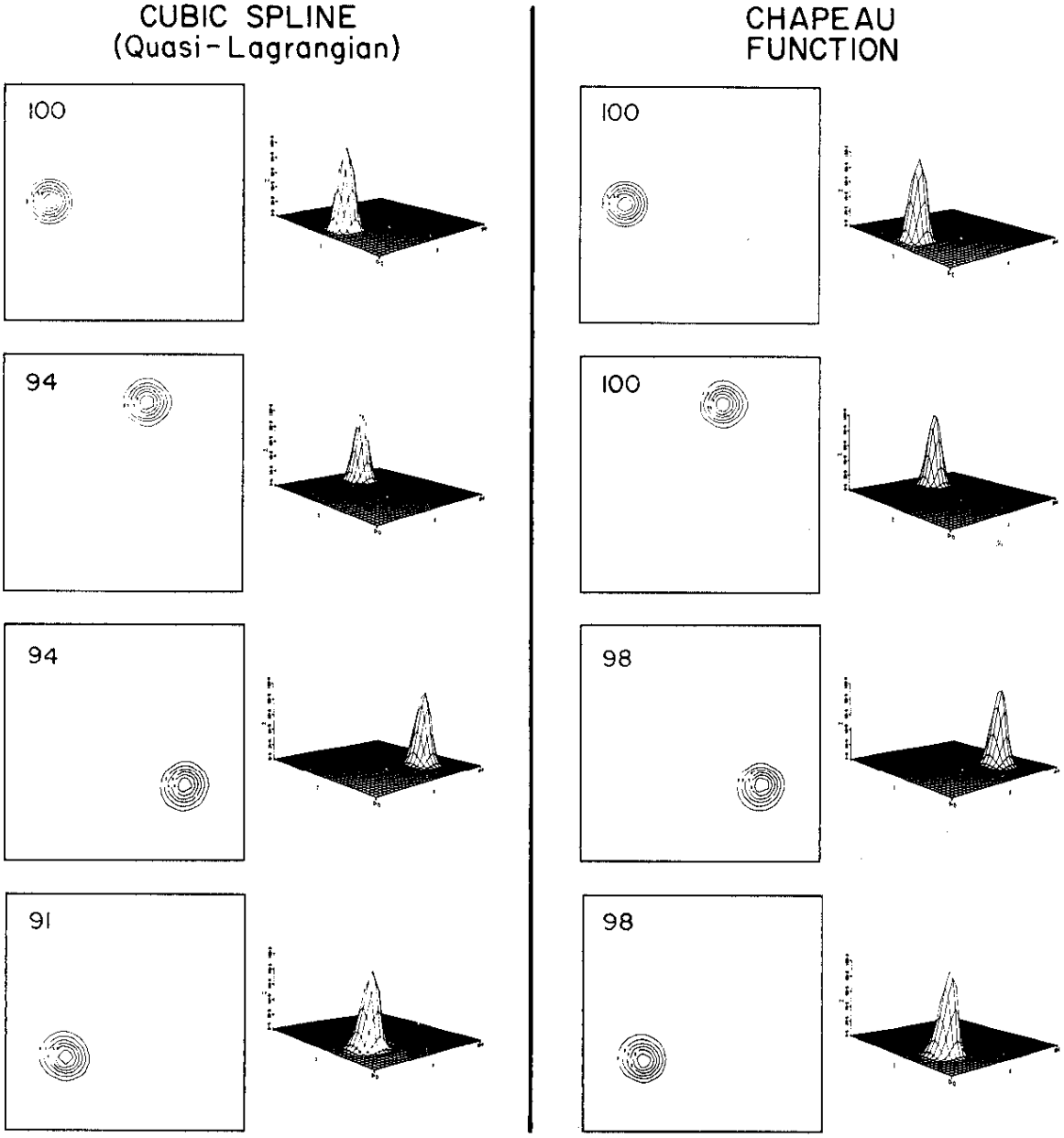
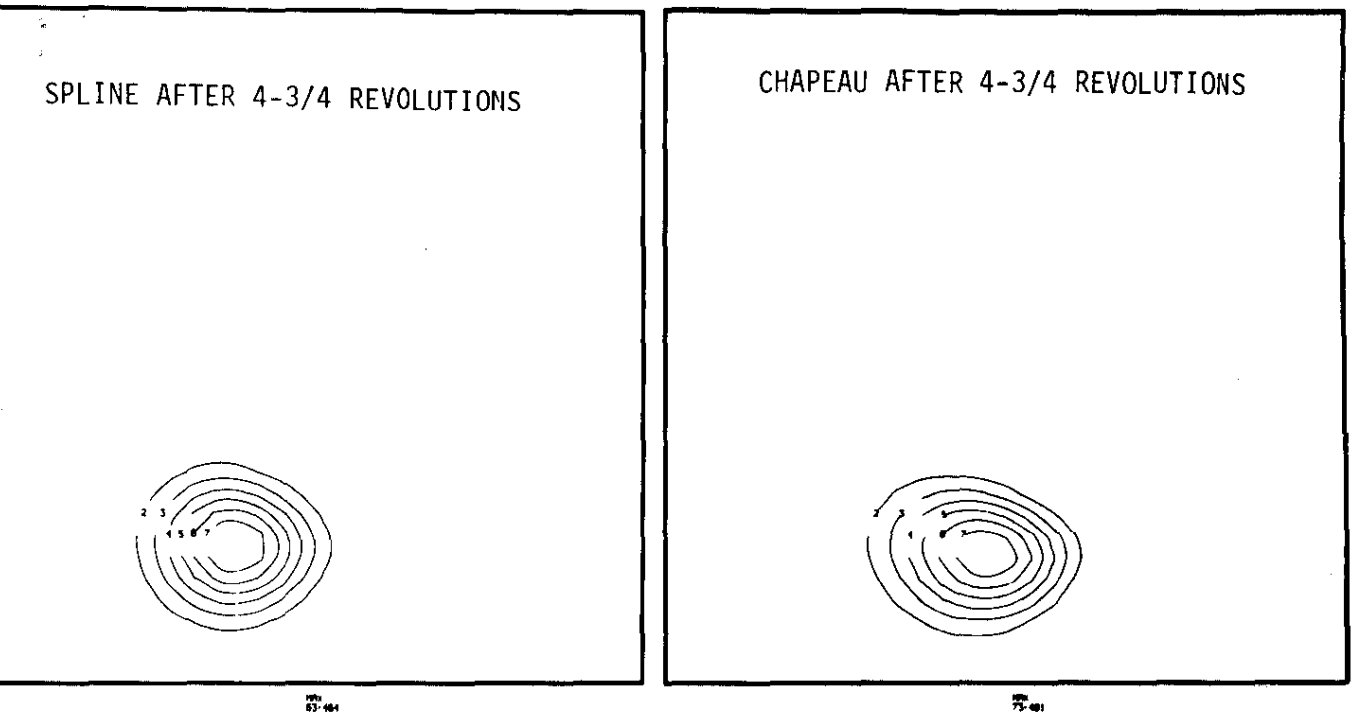


FIGURE 2. Concentration Contours After 3/4 Revolution Using (a) Cubic Splines and (b) Chapeau Functions



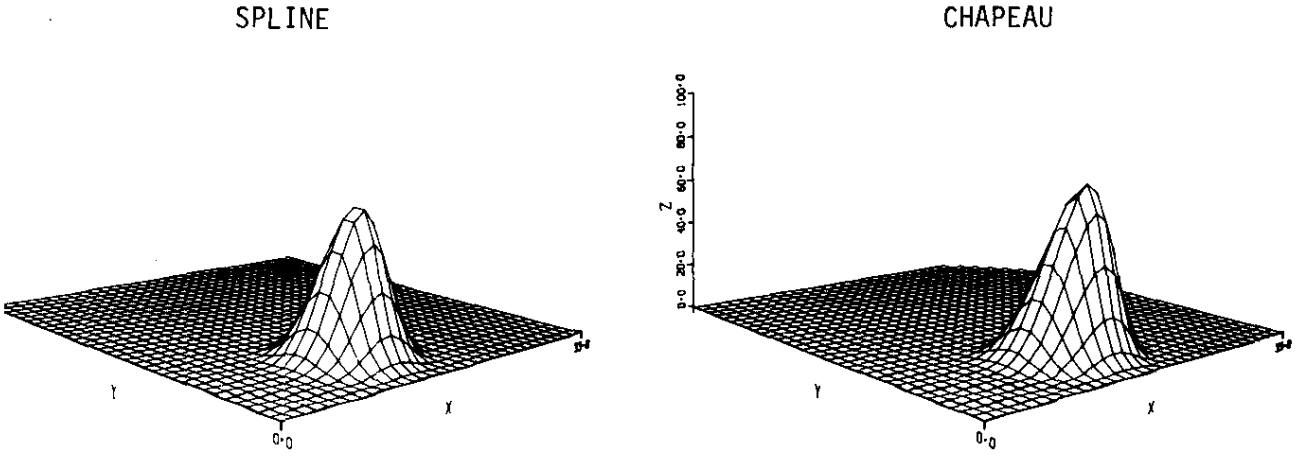


FIGURE 3. Concentration Contours After 4-3/4 Revolutions Using (a) Cubic Splines and (b) Chapeau Functions

56. THREE-DIMENSIONAL MODELING OF PRIMITIVE EQUATIONS BY STRONGLY IMPLICIT TECHNIQUES†

A numerical model has been developed which solves three-dimensional, laminar flow in enclosures. The technique can be used to solve natural convection as well as recirculating flow problems. The method is based on an extension of the two-dimensional, strongly implicit procedure (SIP) previously used by Pepper and Harris.[1] Preliminary results are in good agreement with prior experimental and theoretical results (although limited). Although the method requires a considerable amount of storage, computation times are relatively fast due to the efficient use of matrix inversions.

The SIP method requires the equations of motion to be separated into discrete finite differences by forward-in-time, centered-in-space approximations for the deviative terms. This creates a sparse matrix banded by seven diagonal elements. SIP alters this matrix into a series of tri-diagonal matrices, which can be solved efficiently by Gaussian elimination techniques.

Three-dimensional problems are generally much harder to solve than two-dimensional problems because the boundary conditions become quite complicated. The detail and error in the calculations increase by at least a factor of ten over two-dimensional calculations.[2] Numerical instability as well as time and memory requirements are likewise more severe. The SIP method appears to be a reliable computational scheme in overcoming some of these restrictions.

To assess the computational model, a simple case is analyzed: three-dimensional, laminar, natural convection in a fluid with constant properties. One vertical wall is heated, and the opposite vertical wall is cooled. The top and bottom walls are insulated. The temperature gradients created by these boundary conditions influence buoyancy; which, in turn, causes the fluid to rotate. For low Rayleigh numbers, the transient solutions converge to steady

† Work done by D. W. Pepper.

state. In this test case, the Rayleigh number is equal to 1000 and the Prandtl number is equal to 1. Steady-state results are shown (Figure 1) for isotherms and streamline contours in both the horizontal and vertical planes midway through the enclosure. The results are in agreement with theoretical results obtained by Ozoe, et al.[2] and Mallinson and deVahl Davis.[3]

Solutions obtained by solving the equations of motion and the Poisson equation for pressure were compared with solutions of the vortices and velocity vectors (stream functions) in three dimensions. Results were virtually identical. However, solutions of the momentum equations and the elliptic pressure equation require considerably more computation time. Even though the boundary conditions in the vorticity - velocity vector system are more complicated algebraically, they are easier to solve numerically. The velocity-pressure system of equations is hindered by the highly non-linear nature of the pressure equation, requiring solutions of a set of von Neumann boundary conditions in terms of velocity gradients.

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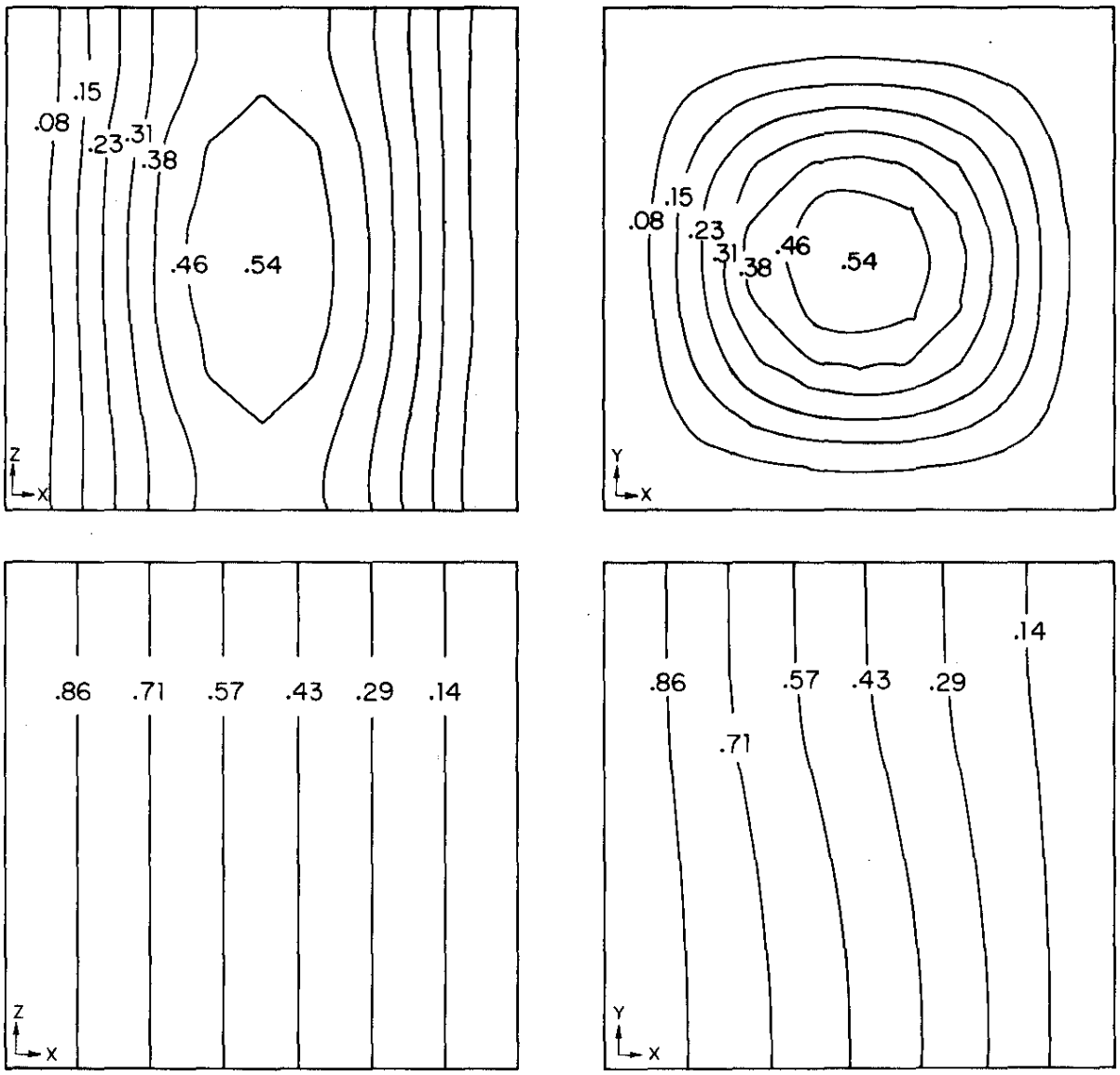

FIGURE 1. Streamline and Isotherm Contours for R_a = 1000