

# ENVIRONMENTAL Science & Technology

*Emphasizing*

*Water,*

*Air, &*

*Waste*

*Chemistry*

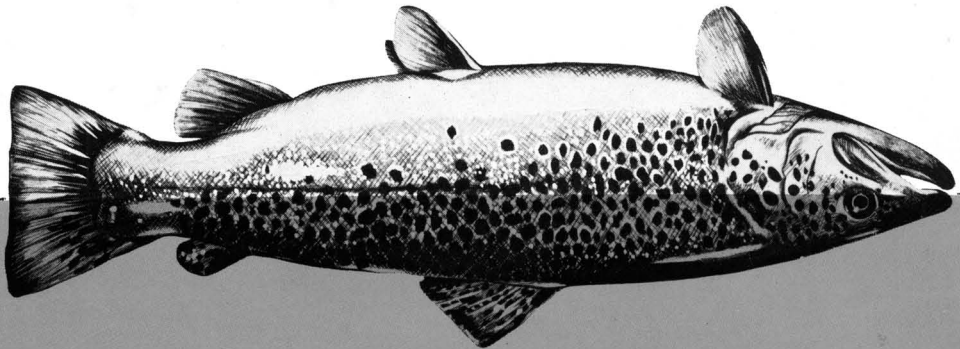
---

DECEMBER 1969



Acid mine drainage 1237

## Today the Fish. Tomorrow...



That tomorrow need never come with the Technicon® AutoAnalyzer® system, specially designed to analyze water quality in rivers, lakes, drinking water, and waste-treatment plants. A mobile system set up on site will analyze, simultaneously, six pollution parameters selected by the user. Because the system is fully automated, it will operate with virtually no human attention for periods up to one week. Continuous analyses may be performed for a period of hours, several days, or a week. A CSM® 6 Laboratory Model will analyze individual samples in the lab.

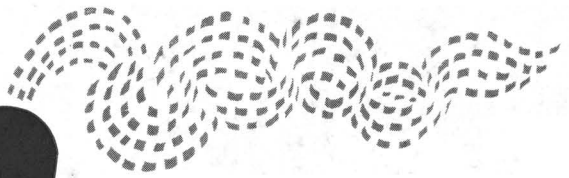
The automated analysis techniques employed in the CSM 6, based on "Standard Methods for Water and Wastewater," are of known specificity and selectivity. The system is capable of detecting pollutants over a wide sensitivity range. Analyses can be made in terms as small as parts per billion.

Before you get in too deep, contact Technicon for a solution to your pollution problems.



Department 65,  
Technicon Corporation,  
Environmental Science Division,  
Tarrytown, New York 10591.

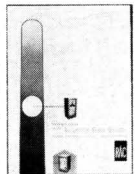




## Monitor...and record... stack particulates automatically 24 hours a day

Now you can automatically monitor particulate emissions from your stacks—and have a permanent record of day-by-day operations—with this new stack monitor developed in cooperation with the American Iron & Steel Institute. Readout and recording are remote, with accuracy to  $\pm 0.002$  grains/cu ft.

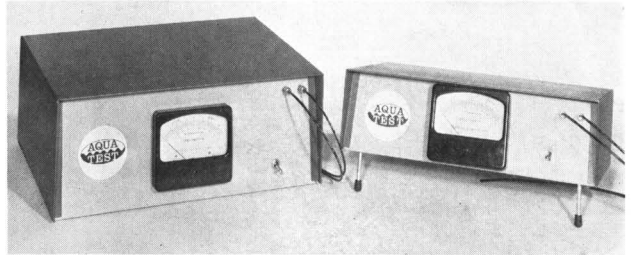
**Free bulletin** describes how AISI stack monitor can serve as process control device or air pollution monitor at your plant.



**RAC**

Research Appliance Company  
Route 8 and Craighead Road  
Allison Park, Pa. 15101

# Introducing **NEW** Water Quality Monitor!



## APPLICATIONS

Research Laboratories

Municipal Water Test and Treatment

River and Stream Water

Water Distillation Systems

Ultra-Pure Water Distillation

Waste Water Monitoring

Sewage Test or Treatment

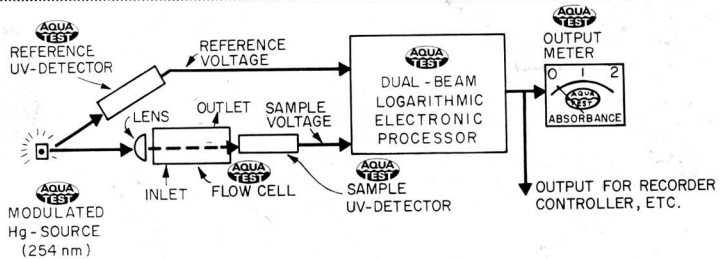
Pollution Control Programs

Pollution Surveys

Automated Water Treatment Systems

## AQUA TEST OPERATION

PATENT PENDING



### ADVANTAGES

- Simple reliable operation with no maintenance
- Most direct method of monitoring organics in water
- No chemical manipulations, reagents, cuvettes, etc.
- No waiting days to obtain readings
- Sample water flow read instantly, continuously
- Output directly linear with absorbance (0 to  $2 \pm 0.01$  units)
- Output available for recorder (0 to  $\pm 3$  volts = 0 to 2 abs. units)
- Inexpensive—1/10th the price of alternate equipment and no skilled personnel required
- Portable—may be operated from auto-battery inverter
- Reliable, long-life, all solid-state design

### FEATURES

- AQUA TEST Dual-Beam Logarithmic Processor converts signals to output linear with absorbance
- Dual-Beam feature keeps calibration constant with voltage changes or lamp aging
- Flow-cell optics design tolerates higher turbidity levels
- Fixed wavelength requires no selection (0.00001-in. Hg-line)
- Path-length adjustable to accommodate wide absorbance range, continuous settings from 20 to 140 mm

For further information, contact:



**AQUA TEST CORP.**  
791 Massachusetts Ave.  
Arlington, Mass. 02174  
Tel. (617) 272-3298

*Water Quality Instruments*

Circle No. 8 on Readers' Service Card

# ENVIRONMENTAL Science & Technology

Volume 3, Number 12  
December 1969

**Editor:** James J. Morgan  
**Managing Editor:**  
D. H. Michael Bowen  
**Assistant Editors:**  
Stanton S. Miller, Peter J. Piecuch  
**Editorial Assistant:**  
Carol A. Goode  
**Manager, Manuscript Reviewing:**  
Katherine I. Biggs  
**Manager, Manuscript Editing:**  
Ruth Reynard  
**Director of Design:**  
Joseph Jacobs  
**Production Manager:**  
Bacil Guiley  
**Layout and Production:**  
Norman W. Favin, Leroy L. Corcoran,  
Clarence L. Rakow, Geraldine D. Lucas  
**Associate Production Manager:**  
Charlotte C. Sayre  
**Editorial Assistant:**  
Arlene Ebner  
**Advisory Board:** R. D. Cadle, D. J. O'Connor,  
S. K. Friedlander, E. D. Goldberg, H. P. Gregor,  
Ulrich Merten, C. E. Moser, E. D. Palmes,  
J. N. Pitts, Jr., W. J. Weber, Jr.

**American Chemical Society Publications**  
1155 Sixteenth St., N.W.  
Washington, D.C. 20036  
**Director of Publications:**  
Richard L. Kenyon  
**Director of Business Operations:**  
Joseph H. Kunej  
**Publication Manager, Journals:**  
David E. Gushee  
**Executive Assistant to the Director of  
Publications:** Rodney N. Hader  
**Circulation Director:**  
Herbert C. Spencer  
**Assistant to the Director of Publications:**  
William Q. Hull  
**Advertising Management:**  
Reinhold Publishing Corporation  
For offices and advertisers see page 1312

© Copyright 1969 by the American Chemical Society  
ES&T ON MICROFILM: This publication is available on microfilm. For information, write to: Microfilm, Special Issues Sales, ACS, 1155 Sixteenth St., N.W., Washington, D.C. 20036

**SUBSCRIPTION SERVICE:** All communications related to handling of subscriptions including notification of CHANGE OF ADDRESS, should be sent to Subscription Service Department, American Chemical Society, 1155 Sixteenth St., N.W., Washington, D. C. 20036. Change of address notification should include both old and new addresses, with ZIP numbers, and be accompanied by mailing label from a recent issue. Allow four weeks for change to become effective.

**SUBSCRIPTION RATES 1969:** Members, domestic and foreign, 1 year \$5.00; nonmembers, domestic and foreign, \$7.00. Postage: Canada and Pan American Union, \$1.00; all other countries, \$1.50. Single copies: current issues, \$1.50. Postage: Canada and Pan American Union, \$0.15; foreign, \$0.20. Rate for back issues or volumes are available from Special Issues Sales Dept., 1155 Sixteenth St., N.W., Washington, D. C. 20036. Claims for missing numbers will not be allowed if received more than 60 days from date of mailing plus time normally required for postal delivery of journal and claim. No claims allowed because of failure to notify the Subscription Service Department of a change of address, or because copy is "missing from files."

Published monthly by the American Chemical Society, from 20th and Northampton Sts., Easton, Pa. 18042. Executive Offices, Editorial Headquarters, and Subscription Service Department, 1155 Sixteenth St., N.W., Washington, D. C. 20036. Advertising Office: 600 Summer St., Stamford, Conn. 06904. Second class postage paid at Easton, Pa. 18042.

The American Chemical Society assumes no responsibility for the statements and opinions advanced by contributors to its publications.

Please send manuscripts to:  
Manager, Manuscript Reviewing  
1155 Sixteenth St., N.W.  
Washington, D. C. 20036

ESTHAG

<b>Letters</b>	1223
<b>Editorial</b>	1225
<b>Currents</b>	
Environmental matters high on White House agenda	1229
GAO says \$5.4 billion water cleanup ineffective	1229
New bill to guarantee market for low emission vehicles	1229
Citizen activities get Congressional attention	1229
Philadelphia updates 15 year old air code	1231
Squeeze on landfills spurs ocean disposal	1231
Bay area to be site of resource data use test	1231
Physical-chemical treatment slated for pilot study	1233
Utility funds study of thermal discharges	1233
Scrap glass tested as paving material	1233
Potential fuel source distilled from garbage	1233
Ohio firm expands in steel pickle liquor recovery	1235
AWWA asks study of virus disease transmission	1235
N.Y. study links excess death rate to high SO <sub>2</sub> levels	1235
Steel industry can handle all junked autos	1235

## contents

<b>Outlook</b>	
States, coal industry making headway on mine drainage problem	1237
Industrial executives have guarded reactions to Interior's water pollution conference	1241
International group asks maximum effort on lower Great Lakes	1243
Canadian firms pool efforts on pollution control	1247
New Environmental Quality Council gears up for action	1249
<b>Features</b>	
Management of delta areas should consist of using natural forces to create desired effects, say LSU's J. D. Martinez and C. O. Durham, Jr.	1252
Air conservation differs from emission control, and 3M's J. T. Ling and M. J. Bolduc point out its role in product and process development	1258
<b>Bookshelf</b>	1301
<b>New products digest</b>	1302
<b>New literature digest</b>	1306
<b>Meeting guide</b>	1309
<b>Professional consulting services directory</b>	1310
<b>Annual index, Vol. 3, 1969</b>	
Names	1313
Subjects	1317
<b>Current research contents</b>	1222

## Current research

### Pesticides in drinking water: Waters from the Mississippi and Missouri Rivers 1261

M. L. Schafer, J. T. Peeler, and J. E. Campbell

Organochlorine pesticides in the Mississippi and Missouri Rivers are finding their way into municipal drinking water supplies that use these rivers as a source of water. Of 500 drinking water samples taken during March 1964-June 1967 from 10 suppliers, 200 contained detectable amounts of dieldrin; 150 contained endrin, DDT, and DDE. Chlordane, aldrin, HCE, and heptachlor were found occasionally, but no toxaphene or methoxychlor was found.

### Performance of porous cellulose acetate membranes for the reverse osmosis treatment of hard and waste waters 1269

A. R. Hauck and S. Sourirajan

Reverse osmosis—a promising method for purification of hard waters, polluted waters, and sewage effluents—can be used to remove such common pollutants as nitrates, phosphates, and the like. With primary sewage effluent, clean water was produced at a rate of 32.7 gallons per day per square foot of membrane at 100 p.s.i.g. and 18.3 gallons per day per square foot at 500 p.s.i.g. Average BOD removals were 85.8% at the higher operating pressure, and 80.8% at the lower one.

### Volumetric calibration of permeation tubes 1275

B. E. Saltzman, C. R. Feldman, and A. E. O'Keefe

Permeation tubes containing air pollutants such as sulfur dioxide, hydrogen fluoride, nitrogen dioxide, hydrocarbons, and the like serve as standards for the calibration of air monitoring equipment. A new volumetric technique is described for the calibration of these tubes which are especially suited for hydrocarbons. The microgasometric technique can be used in lieu of a gravimetric technique which is normally used.

### Size-separating precipitation of aerosols in a spinning spiral duct 1280

W. Stober and H. Flachsbart

Aerosol size distributions are important in understanding smog reactions in polluted atmospheres. Described as a true aerosol size spectrometer, the new instrument facilitates excellent size resolution over a size range of almost two orders of magnitude and accommodates a sampling rate of one liter per minute. The aerosol sampler uses a spiral duct of rectangular cross section cut into a special centrifuge motor and has been used to generate latex spheres under different operating conditions.

## Communication

### Microelectrode determination of oxygen profiles in microbial slime systems 1297

W. J. Whalen, H. R. Bungay, and W. M. Sanders

The respiration of aquatic organisms with respect to their environments now can be studied using a microelectrode of the polarographic type. The microelectrode determines oxygen concentrations and gradients in both liquids and microbial slime films.

# letters

## Automobile industry project support

Dear Sir:

The July issue of ENVIRONMENTAL SCIENCE & TECHNOLOGY contains an excellent selection of articles of interest to those concerned with solutions to the air pollution problem, including the report "NAPCA checks emissions of new autos" and the symposium material on "The technical significance of air quality standards."

With reference to the article "Odors from industries need controls," we note with interest the reference to several projects in odor identification which are in progress. In these instances, credit for the support of these research efforts is given to the National Air Pollution Control Administration (NAPCA), the American Petroleum Institute (API), and "the automobile industry." I would like to call to your attention that the automobile industry support for the funding of these types of projects is being provided through the Automobile Manufacturers Association, in the instances where NAPCA and API have joined to support the Coordinating Research Council's Air Pollution Advisory Committee efforts.

**William F. Sherman**

*Automobile Manufacturers Assoc.,  
Inc.*

*320 New Center Bldg.  
Detroit Mich. 48202*

## More on carbon monoxide

DEAR SIR:

I dislike adding more discussion to the confusion that many readers must be experiencing regarding the "Carbon monoxide hazards" letters (October 1969, page 876). However, both Silver and Weinstock could benefit from editorial assistance and more recent information.

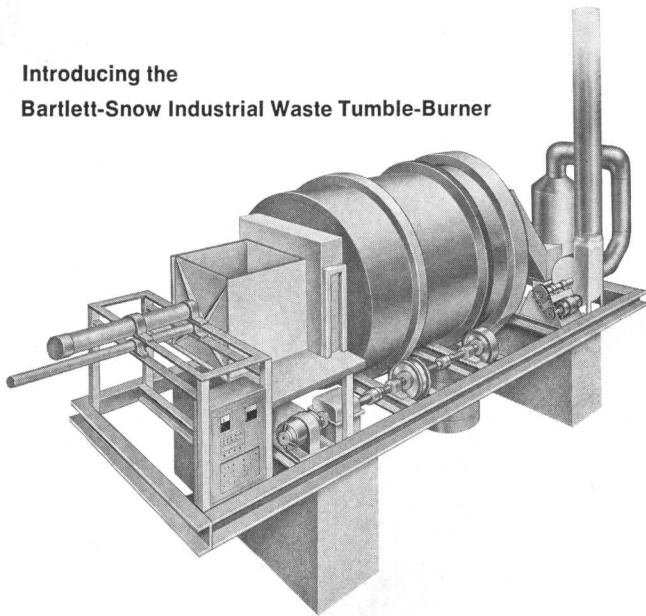
I do not feel constrained to edit, but would urge them (and other readers) to read the following publications on carbon monoxide:

R. Beard and G. Wertheim, *Amer. J. Public Hlth.*, 57, 2012 (1967).

DON'T JUST BURN IT-

# tumble-burn it!

Introducing the  
Bartlett-Snow Industrial Waste Tumble-Burner



The first economical-efficient answer for  
plant site incineration from 1/2-2 tons per hour!

The Tumble-Burner...designed especially to handle *all* solid industrial wastes without pre-crushing for smokeless, pollution-free operation.

The Complete Package...includes everything from the pneumatically operated loader (for batch or continuous feed)...the refractory lined incinerator...cylinder drive...heat source...wet scrubber...and complete installation including automatic controls...all from Bartlett-Snow...the "Total Capability" people in heating-drying-cooling for over 80 years!

**Right Now**...circle the inquiry number below...or **Write Now**...with your inquiry for computer sizing and costing.



# BARTLETT SNOW

A BANGOR PUNTA  
COMPANY

CLEVELAND, OHIO 44105: 6200 Harvard Avenue  
Buffalo • Chicago • Detroit • New York City  
Philadelphia • Pittsburgh • Lakeland, Florida  
LICENSEES THROUGHOUT THE WORLD

# ATLAS GAS ANALYZERS

THE NEW INDUSTRY STANDARD  
FOR AIR POLLUTION MONITORING

**SO<sub>2</sub>**  
Specific  
Colorimetric

**NO<sub>2</sub>**  
Specific  
Colorimetric

**NO**  
Specific  
Colorimetric

**NO<sub>x</sub>**  
Specific  
Colorimetric



**SO<sub>2</sub>**  
and Reducing  
Agents  
Iodometric

**O<sub>3</sub>**  
and Total  
Oxidants  
Iodometric

Aldehydes  
Specific  
Colorimetric

Now approved and recommended by many governmental agencies and private industry, Atlas analyzers are available for use with fixed, mobile and stack installations.

- Schulze patented chemical methods of analysis.
- Extremely accurate, best available sensitivity and response speeds.
- Continuous recording (or input to any recorder or telemetry system).
- Automatic re-calibration and standardization.
- Automatic water-make-up and reagent handling.
- Unique in design and easy to operate.
- Low installed cost.
- Highly reliable—unattended operation.
- Dual channel models available.



**ATLAS  
ELECTRIC  
DEVICES  
COMPANY**

4114 N. RAVENSWOOD AVE., CHICAGO, ILL., U.S.A. 60613

PHONE 312—327-4520 • CABLE, ATELECO

Circle No. 4 on Readers' Service Card

D. Bartlett Jr., *Arch. Environ. Hlth.*, **16**, 719 (1968).  
J. R. Goldsmith and S. A. Landaw, *Science*, **162**, 1352 (1968).

These papers should provide a more up-to-date familiarity with the subject of low level toxicity of carbon monoxide. I have no idea where Silver's "review" can be found and he is apparently not sure either.

**M. Y. Longley**

*Institute of Gas Technology  
IIT Center  
Chicago, Ill. 60616*

**Correction:** The standard for CO industrial exposure has been lowered from 100 p.p.m. to 50 p.p.m., and not 5 p.p.m. as printed in Silver's letter—Ed.

## Trichloroethylene and smog

DEAR SIR:

We would like to comment on the Stanford Research Institute (SRI) study on the smog forming capabilities of trichloroethylene—highlighted on page 869 of your October issue.

Considering the differences in experimental procedures used by SRI as compared to those of the Los Angeles County Air Pollution Control District—differences in light intensities, hydrocarbon:NO<sub>x</sub> ratios, residence times, and the use of dynamic conditions for some experiments—which make direct comparison of the data somewhat difficult, we feel that the SRI data confirm our findings regarding the relative activity of the hydrocarbons tested.

We do not agree with many of the conclusions that SRI has drawn from the data presented to us; for example, that "any contribution of trichloroethylene to photochemical smog manifestations would be negligible," or that comparison shows "that nearly identical effects resulted from the addition of *n*-paraffins and trichloroethylene." Our evaluation of the SRI data leads us to the conclusion that, photochemically, trichloroethylene more closely resembles olefins or xylenes than it does *n*-paraffins.

Our conclusion of the data in the report is that they essentially confirm the findings of the Los Angeles County Air Pollution Control District that trichloroethylene is a photochemically reactive solvent—a solvent that Rule 66 was designed to control.

**Robert L. Chass**

*Los Angeles County Air Pollution  
Control District  
Los Angeles, Calif. 90013*



## People pollution

Unchecked population growth threatens to destroy the quality of life just as surely as unchecked pollution

One of the most frightening things one can do these days is to read projections of population growth on this planet. According to the University of California's Walter E. Howard, writing in the September 1969 issue of *Bioscience*, world population is growing at a rate of 2% per year. This sounds innocuously slow, but, in reality, this is staggering growth that would, if unchecked, push total population from 3.3 billion to 25 billion in only 100 years. In the U.S. alone, if the birthrate of the 1950's were to be reestablished, it would take only 150 years for the population to reach the current world population, and, in another 500 years (that is, by the year 2620), there would be so many Americans that each one would be able to occupy only one square foot of this once empty country. One thousand years after the Declaration of Independence, there would be no place free of human bodies to plant the flag.

If these projections appear ludicrous to you, it is probably not because you argue with the inexorable logic of mathematics. It is because you will say, and rightly so, that before this horrendous crush of people could accumulate, some calamity would occur—as calamities have repeatedly occurred through history—to curtail population drastically. But at what level of human population will this happen? Man has been successful in conquering many of the diseases and hazards that for millennia kept his numbers in check. His success has resulted in the world's increasing birthrate and, more important, to the much greater number of children who survive long enough to reproduce. Unfortunately, the knowledge and skill that were brought to bear on man's traditional enemies were not accompanied by any foresight into a future in which birthrates continually outstrip death rates.

In developing countries, the result generally is starvation. In advanced countries, an increasing population and a marked trend toward urbaniza-

tion are causing grievous environmental problems. It does not take genius to see that continued population growth will exacerbate all the problems. The projected U.S. population of 338 million in the year 2000 will require more water supplies, more roads, more power stations, more oil refineries, and more of all the trappings of civilization. Yet, there is already, in 1969, so much opposition to new dam, road, and power station construction, that many projects have been indefinitely shelved. Concern for the quality of life eventually may supersede the traditional American goal of expansion, but, surely, it will be a hard fight. Part of the trouble is that business is—or feels itself to be—dependent for its success on an ever greater population. Some seriously doubt that this country's industry and government would know how to manage an economy geared to a populace whose birthrate and death rate were in balance. Yet, that balance has to come, if we are not to be subject to what experts euphemistically refer to as "involuntary self-limitation" (warfare seems the most probable way).

We recognize that the editors of *ES&T* are hardly likely to be regarded as experts on population control or as the right people to pass judgment on current social, political, and religious mores, most of which pose solid barriers to the attainment of stable world population. But I do believe that some effective way to check the birthrate is a necessity. Otherwise, we are merely playing a game when we try to keep 90% of our sulfur oxides out of the air and all of our raw sewage out of the rivers. If this country—which, after all, is dedicated to the idea of the pursuit of happiness as an inalienable right of all its people—cannot take the lead in halting the suicidal indulgence to human reproductive capacities, then who can?

*D. H. Michael Bowen*

**Monsanto Biodize Offers You:**

# **Total problem- solving for any water pollution.**

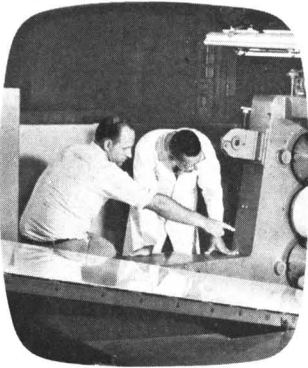
Monsanto Biodize is in business to solve all kinds of water pollution problems. And we're realists. We know that we must solve your problem at minimum capital and operating cost. To give you the most effective control, we cannot be

biased in favor of any single method of control. So we will recommend biological, deep well, activated carbon, ion exchange, whatever method will do the best job, economically and technologically.

When you face a water

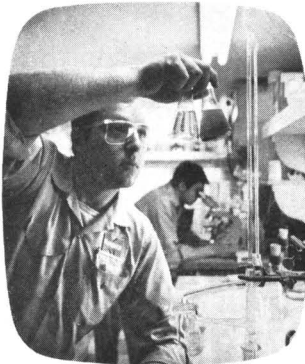
pollution problem, why not take the right step? Get a preliminary study and estimate from the people who can solve the whole problem. Write: Monsanto Biodize Systems, Inc., 112-20 14th Avenue, College Point, New York 11356.

**Visit us in Booth #4336 at the Chem Show  
(Coliseum, New York, Dec. 1-5)**



## Problem-Solving Step 1

**In-plant study:** Our specialists go to the source of your pollution problem. We talk to key people and frequently study your manufacturing process. Our experience often enables us to suggest in-plant modifications. The objective: Reduce pollution at its source and save you money.



## Problem-Solving Step 2

**Waste Analysis:** We go right to the problem itself — your waste water source. We take the necessary samples, and make a series of tests in laboratory. These tests enable us to determine possible solutions to your water problem.



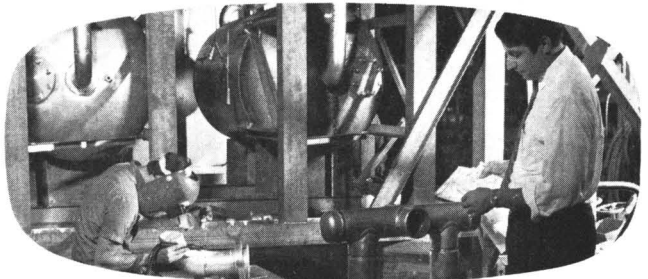
## Problem-Solving Step 3

**Determine Optimum Treatment Method:** We analyze all facts. Then recommend the most effective and economical solution to your problem, biological, deep well, ion exchange or whatever is required. Because Monsanto Biodize is unbiased about which control methods to use, we will provide the right solution to your problem.



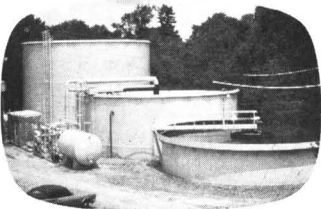
## Problem-Solving Step 4

**Design and Engineer System:** With basic decisions made, our design engineers and draftsmen prepare detailed specifications and drawings. When you work with Monsanto Biodize, you look to only one place for all answers, all responsibility.



## Problem-Solving Step 5

**Fabrication of System:** When required, we fabricate equipment in our own shops. And we secure all non-fabricated items on a competitive basis. High quality, maximum economics are the results.



## Problem-Solving Step 6

**Construction of System:** Our construction engineers supervise all phases of construction. They have expert knowledge of construction practices, techniques, and craft labor performance. Construction is handled smoothly, correctly.



## Problem-Solving Last Step

**Delivering Operational Plant to Your Trained People:** Monsanto Biodize handles everything—beginning to end. Even trains your people to run the control facility.



**Monsanto**  
BIODIZE SYSTEMS, INC.

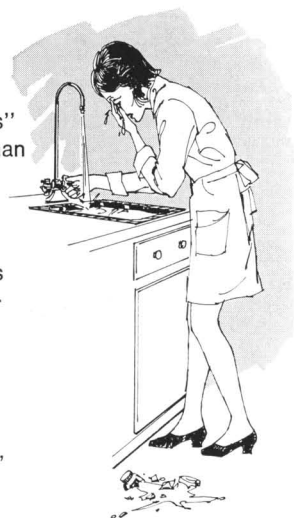


# Valuable safety information at your fingertips

This unique wall chart... "Emergency Procedures for Dangerous Materials" will help you protect lives and property. It includes information on more than 130 chemicals and enables you to quickly determine why a particular compound is dangerous, its relative degree of danger and how it should be handled.

Each chemical is rated as to its health, flammability and reactivity hazards as well as the degree of danger from eye contact, breathing, skin penetration and irritation, and swallowing. General first aid procedures are given for handling emergencies. Storage and disposal precautions for all chemicals listed are also covered.

This chart is invaluable wherever chemicals are stored, handled or used. **It costs only \$10.00. Orders yours today** from... Curtin Scientific Company, P. O. Box 1546, Houston, Texas 77001.



## CURTIN SCIENTIFIC COMPANY

SCIENTIFIC APPARATUS • CHEMICALS • LABORATORY FURNITURE

HOUSTON • TULSA • LOS ANGELES • NEW ORLEANS • ATLANTA • SAN FRANCISCO  
DALLAS • PITTSBURGH • BOSTON • MIDLAND, MICH. • JACKSONVILLE • WASHINGTON  
WAYNE, N. J. • ST. LOUIS • SEATTLE • MINNEAPOLIS • MEXICO CITY • MONTERREY

## **WASHINGTON** White House pays attention to environmental matters

A White House report, "The Universities and Environmental Quality—Commitment to Problem Focused Education," suggests a shortage of broadly trained professionals to deal with environmental problems, and indicates the possible expansion of educational programs from 10-100 times present efforts. Also, the White house announced immediate cancellation, after a 30 day waiting period, of all garden and household use of DDT in the U.S. and publication of intent to cancel all other DDT uses in the U.S. with a request for comment within 90 days. This action was taken based on the findings of the HEW pesticides commission (ES&T, July 1969, page 613), headed by Emil M. Mrak, whose report noted that the 30 p.p.m. of DDT in certain fish was nearly one fourth the amount that causes liver and lung tumors in mice.

## **Government auditors find water pollution control ineffective**

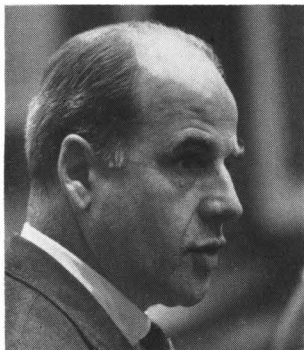
Regardless of the fact that \$5.4 billion has been expended since 1957 for waste treatment facilities, little or no cleanup has been achieved for the nation's waterways, according to a recent report of the General Accounting Office (GAO). Although the federal government contributed \$1.2 billion, cleanup efforts simply are overwhelmed by increasing industrial waste discharges and poor planning in the choice of Federal Water Pollution Control Administration's (FWPCA) 9400 projects, GAO reports. Last month, the Senate voted the full \$1 billion authorization for fiscal year 1970 for the construction of waste treatment facilities. The final appropriation for fiscal 1970 is up to Senate-House conferees who probably will agree on a figure of approximately \$750 million.

## **Congressmen propose low emission motor vehicle bill**

The federal low emission vehicle procurement act hopefully would stimulate the development, production, and distribution of such vehicles; S. 3072 and companion bill H.R. 14534 would create a legislatively guaranteed market for innovative developers of these vehicles. In practice, the developer would make application to a five member certification board, and any vehicle certified by the board would be eligible for purchase if its procurement and maintenance costs are no more than 125% of such costs of the vehicle it can replace.

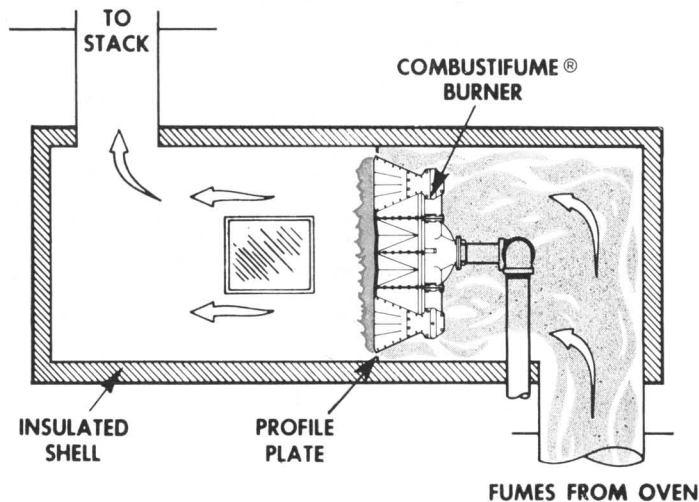
## **Volunteer citizens' group gains congressional attention**

The Fund for New Priorities in America, along with congressional participants, recently sponsored a two day conference on the environment (Washington, D.C.). A nationwide teach-in on all U.S. campuses has been proposed for next spring by Sen. Gaylord Nelson (D.-Wis.). The senator feels that the young people of the country are more concerned and more interested in such problems than the people of the so-called establishment. The recently established Center for the Study of Responsive Laws (CSRL) last summer evaluated several federal environmental programs, including those involving air pollution, water pollution, occupational health, and food poisoning. Gary Sellers, CSRL's legal counsel, notes that the organization will study the effectiveness of some of the federal organizations charged with pollution responsibilities; CSRL's report is due by the end of Dec.



Senator Nelson

# breathe easier



## solve your air pollution problems with **COMBUSTIFUME®-equipped incinerators**

You'll breathe easier—and so will everybody else—when you've installed COMBUSTIFUME®-equipped incinerators in your stacks. These efficient Maxon Line Burners are designed to burn out combustible portions of objectionable effluents *before* they can contaminate the outside air. This is accomplished by wide distribution of direct gas flame and uniform temperatures

extending across the entire combustion chamber . . . giving greater exposure to *all* the effluent . . . faster ignition of combustibles . . . more efficient utilization of fuel. You may need COMBUSTIFUME®-equipped incinerators in *your* stacks. Ask your Maxon representative, or write for our free booklet: "A Pollution Solution by Direct Gas-Fired Industrial Fume Incineration."

# MAXON

**MAXON PREMIX BURNER CO., INC.**

MUNCIE, INDIANA 47302

Circle No. 26 on Readers' Service Card

Ad No. 104

## **STATES Iowa water standards to be set by federal government**

Interior Secretary Walter J. Hickel has ordered Iowa to provide secondary treatment for its sewage which enters the Mississippi and Missouri Rivers and 25 smaller interstate streams by Dec. 31, 1973. Regarded as the first action of this kind taken under the Water Quality Act of 1965, Hickel's order also noted that the proposed federal standard—to be published in the *Federal Register*—contains language stating that dilution shall not be considered a substitute for proper waste treatment at any time. Industrial wastes amenable to biological treatment must be given secondary treatment by that date, while other types of waste are to receive the best practical treatment. "Before taking the step of publishing standards for Iowa, we exhausted all our other remedies under the law," says assistant secretary Carl L. Klein.

## **Philadelphia strengthens its air pollution code**

Mayor James H. J. Tate recently signed a new air management code for Philadelphia, superseding its 15 year old air pollution code. The new code specifies the following fines: • \$25-300 for a first offense and/or 90 days imprisonment. • \$100-300 for a second offense and/or 90 days. • \$300 for each subsequent offense. The rules also require the use of low sulfur oil in commercial industrial fuel and retain the permits provision for construction of new installations. In addition, the new code: • Requires operating licenses which must be renewed annually and which can be revoked. • Allows drivers of vehicles which emit smoky exhaust to be halted and given an immediate summons by either the police or Health Department inspectors.

## **Oceanic disposal of solid wastes and industrial sludge in 1968**

	(millions of tons)
Pacific Coast	8.3
Atlantic Coast	23.8
Gulf Coast	15.9
Total	48.0

Source: Dillingham Corp.

## **Coastal states must face up to waste disposal**

Oceanic disposal of solid wastes has become the operating rule of the day in high density metropolitan areas where there is no land left for landfill operations. The civilian sector of U.S. coastal cities disposed of 48 million tons of this material by barging in 1968 at a cost of \$29 million, according to David D. Smith, director of the applied oceanography division of Dillingham Corp. (La Jolla, Calif.). In its recent report, "An Appraisal of Oceanic Disposal of Solid Wastes and Industrial Sludge from U.S. Coastal Cities," Dillingham notes that, excluding dredgings, the tonnage of material disposed to the oceans in 1968 was 9.8 million tons at a cost of \$13.5 million.

## **San Francisco Bay area is first for urban study**

Beginning next month, a regional scale demonstration project will be underway in the San Francisco area to test the usefulness of environmental resource data in improving comprehensive urban planning and decision-making. Sponsored jointly by the Departments of the Interior and Housing and Urban Development (HUD), the \$311 million study will coordinate the efforts of geologists, geophysicists, seismologists, cartographers, hydrologists, and engineers with the urban planner to achieve the comprehensive picture. The final products of the three year study are expected to be maps, reports, a guide manual, and other material presenting, interpreting, and evaluating the various elements of physical resource data for the region. The first of seven pilot studies, the Bay area region study is headed by George O. Gates, Geological Survey Field Center (Menlo Park, Calif.), and Arthur Zeisel, HUD headquarters (Washington, D.C.).



# how you create air pollution is your business cleaning it up is ours

No matter what business you are in—chemical processing, steel production, municipal incineration, foundry operation, cement, lime or gypsum manufacturing, power generation—until now, air pollution has been a natural by-product. Our business is supplying the most recent technology and advanced equipment designs to clean it up—99.9% of it, if necessary. Baghouses. Electrostatic precipitators. Wet scrubbers. Automatic, continuous pulse-type collectors. Mechanical cyclone collectors. We make them all. And, we install them, service them and stand behind promised efficiencies. From single collector installations to turn-key responsibility for your entire air pollution control problem, Wheelabrator has the right equipment, the know-how and the manpower to give you exactly what you need. Think about it. Then get in touch with the Air Pollution Control Division, The Wheelabrator Corp., 448 S. Byrkit Street, Mishawaka, Indiana 46544.

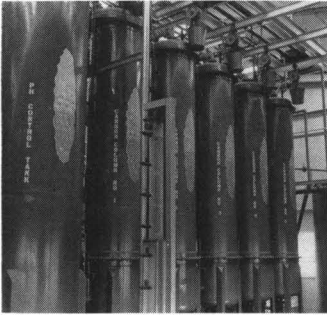
VITAL VALUES  
**W**<sup>®</sup>  
FOR INDUSTRY

**WHEELABRATOR**<sup>®</sup>  
**AIR POLLUTION CONTROL**

WORLD-WIDE OPERATIONS:  
Argentina, Australia, Brazil, Chile, Colombia, England, France, Germany, India, Japan, Mexico, Peru, Philippines, Puerto Rico, Singapore, South Africa, Spain, Sweden, Switzerland, Taiwan, Thailand, Venezuela.  
In Canada, WHEELABRATOR CORP. OF CANADA, LTD.



## **TECHNOLOGY** Blue Plains to pilot nonbiological treatment



Carbon columns

FWPCA has awarded a \$743,761 contract to the District of Columbia for demonstration of nonbiological waste water treatment at D.C.'s Blue Plains (Md.) plant. The process to be piloted, euphemistically described as physical-chemical treatment, involves several steps that are not new in themselves, but have been under investigation for tertiary treatment for some time at Blue Plains (ES&T, October 1968, page 750): Lime addition for solids and phosphate removal, ammonia stripping, mixed media sand and coal filtration, and activated carbon adsorption. But the pilot project will be the first time these steps have been used together for treatment of raw sewage. Plans call for treatment at the 100,000 gallon per day level, with results to be compared with the biological process around which the Blue Plains plant was originally conceived.

## **Power company funds study of thermal enrichment**

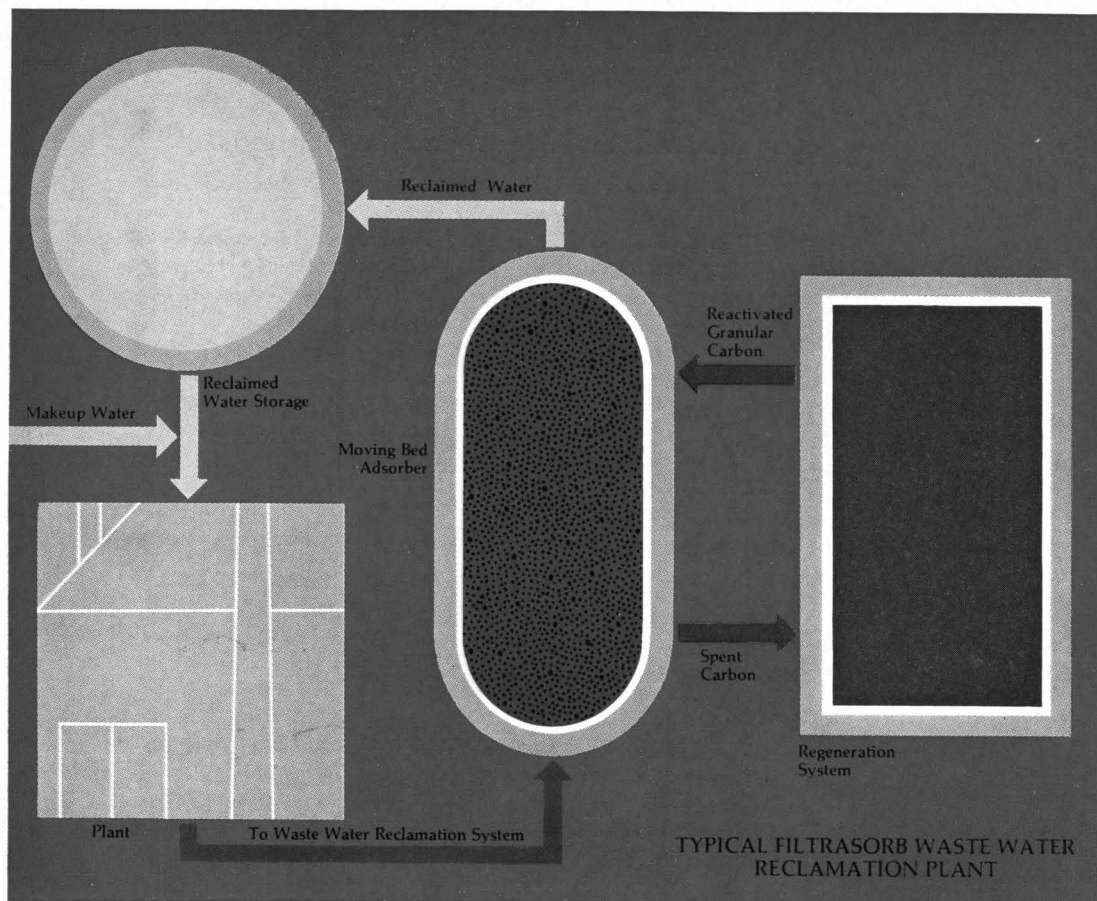
Maine Yankee Atomic Power Company will fund a \$200,000, five year study of the use of warm water discharges from power plants for cultivation of commercial shellfish. The study team will be headed by R. L. Dow, research director of Maine's State Fisheries Department, and will include work on such species as native and European oysters, hard clams, marine worms, and blue mussels. Of these, only oysters are an important cash crop in Maine, and the areas available for their culture are limited by pollution. Maine Yankee has previously funded studies at the University of Maine on the broad ecological effects of power plant discharges. In announcing the new grant, president W. H. Dunham expressed his confidence that Maine Yankee's atomic facilities will have no adverse affects on the environment.

## **Glass in the streets?**

Discarded glass containers may be a source of cheap paving material. In the first large-scale test of such a concept, Owens-Illinois has paved a stretch of road at its research center (Toledo, Ohio) with a mixture of glass and asphalt; initial test results indicate it performs as well as other paving materials. The glass, crushed to prevent tire cuts, substitutes for sand, gravel, or stone in conventional asphalt mixtures, and success of the project hinges on whether cost of processing waste glass is less than having to pay for disposal and then buying sand or stone for paving. The idea originated in a ceramic engineering class at the University of Missouri, which researched the project under a Bureau of Solid Waste Management grant.

## **Garbage yields possible hydrocarbon source**

Research chemists at the Bureau of Mines' Coal Research Center (Pittsburgh, Pa.) have demonstrated experimentally the conversion of garbage and waste paper into a derivative which might yield commercially valuable materials. Tests so far have been limited to laboratory scale runs in which the wet, ground, materials are treated with carbon monoxide and steam at 700° F. for 20 minutes in an airtight chamber. About 90% of the organic material is converted into a petroleum-like substance; minor amounts of gas and ash also are produced. If full-scale conversion plants prove practical, each ton of feed material would yield more than a barrel of crude distillate, from which fuels and other valuable hydrocarbons could be refined.



## phenol... dye... insecticide wastes... Filtrasorb® solves tough waste problems



**Problem:** Waste from a chemical manufacturing plant containing up to 2,500 ppm phenol and other pollutants was being pumped into lagoons. Capacity was about to be exceeded. Overflow would have been disastrous.

**Solution:** A simple filter bed of Filtrasorb granular activated carbon, supplied by Calgon Corporation, averted an expensive problem. Lagoon wastes are filtered through the Filtrasorb which adsorbs (removes) phenol and other organic wastes including a deep red color. Chemical regeneration is being used to restore the adsorptive capacity of Filtrasorb for re-use, and at the same time it provides a bonus in recovered phenol.

**Problem:** An insecticide plant was ordered to shut down on a specified date by regulatory agencies because of heavy organic wastes in plant effluent.

**Solution:** Adsorption with Filtrasorb proved to be the best answer. Filtrasorb engineers designed a plant that could be constructed quickly to prevent shutdown. The plant will treat an effluent containing mixtures of organic acids, phenol, mixed alcohols and many other chemicals. Filtrasorb will handle this complex job

economically because it will be regenerated thermally for repeated re-use.

**Problem:** A new carpet mill expects to use 1,000,000 gallons of water a day eventually in its dyeing and rinsing operations. Projected costs for using municipal sources for this amount of water were well over \$100,000 a year.

**Solution:** Calgon Corporation water specialists showed how Filtrasorb granular activated carbon could reclaim waste water economically. As a result, Calgon was awarded a contract for the design and construction of a complete Filtrasorb water reclamation plant which will provide a very substantial overall reduction in costs for the carpet manufacturer.

For the *tough* waste water treatment problems, call on the total capabilities of Calgon Corporation. Calgon can supply all, or any part of, the products and design technology for any Filtrasorb waste water treatment facility. For details, write or phone Filtrasorb Department, Calgon Corporation, Calgon Center, Pittsburgh, Pa. 15230. Phone (412) 923-2345.

## **INDUSTRY Steel pickling line maker moves into pollution control**

Wean Industries, Inc. (Warren, Ohio), one of the world's largest designers and builders of continuous steel strip pickling lines, has added pollution control capability to its manufacturing know-how by a recent agreement with KSF Chemical Processes, Ltd. (Toronto, Ont.). Under the agreement, KSF will serve as the engineering and manufacturing arm of a new Wean division. KSF has specialized in pollution control systems based on recovery and reuse of chemicals, and the Wean-KSF agreement allows Wean to offer KSF sulfuric acid pickle line pollution control technology to its customers in the steel industry. Previous agreements between Wean, Du Pont, Interlake Steel Corp., and Ionics, Inc., have resulted in pollution control technology for pickling lines using hydrochloric acid. The new Wean-KSF technology features recovery of sulfuric acid and ferrous sulfate.

## **ASSOCIATIONS Virus disease transmission needs study, says AWWA**

There is considerable room for research into the ways in which virus diseases can be transmitted by water supplies, according to the findings of a special study committee appointed by the American Water Works Association (AWWA). The committee recommends that a study be made to ascertain whether a problem of virus disease transmission does in fact exist—this has always been assumed in good water treatment practice whose object is the complete destruction of all pathogenic organisms. Other recommendations of the AWWA committee:

- Determination if the coliform index is an adequate index of water quality.
- Improvement of techniques for measuring viruses in water.
- Development of methods for detecting small numbers of viruses in large volumes of water and for detecting infectious hepatitis viruses.

## **New York study shows deaths attributable to SO<sub>2</sub>**

The number of excess deaths in New York City can be confidently stated to be in the range of 10-20 when the mean sulfur dioxide concentration in the air is between 0.2-0.4 p.p.m., revealed Leonard Greenburg and Marvin Glasser of New York's Albert Einstein College of Medicine at a meeting of the American Public Health Assoc. (Philadelphia). This is believed to be the first time that American data have been considered statistically sound enough for such a claim to be made.

## **Junked autos could all be reclaimed, say scrap processors**

There is no doubt whatsoever that the scrap industry has the equipment and the technology to turn every junked auto in the U.S. into high grade scrap that steel makers can use in the manufacture of high quality steel, says the Institute of Scrap Iron and Steel, Inc. (ISIS), in an official policy statement. The scrap processors concede, however, that new steel making technology and rising labor, freight, and processing costs have put scrap at a considerable disadvantage compared to foreign iron ore. ISIS specifically recommends:

- Financial aid for local governments to help defray the cost of moving scrap to the processor.
- Government cooperation in changing auto titling laws to speed processing of abandoned cars.
- Government and industry cooperation in providing expanded markets for processed scrap.



# There's now a method to the pollution madness.



George Clayton is a pollution control specialist.

Few men have equal experience in environmental health.

His reputation has been growing for 30 years. In the community. And in industry.

He heads George D. Clayton and Associates—the only firm in existence today offering a complete consulting service in all fields—air, water, sound and radiation pollution, industrial hygiene and solid waste disposal.

George D. Clayton and Associates have designed, equipped, and staffed a new laboratory to process pollution samples and help you solve your pollution problems.

Whatever it is. Wherever it is. Whoever you are.

There's a method to solve your maddening pollution problems.

George Clayton has it right now. Or he'll find it.

Write him today: George D. Clayton, George D. Clayton and Associates, Inc., 25711 Southfield Rd., Southfield, Michigan 48075. Or phone 313/352-3120. A subsidiary of Sitkin Smelting and Refining Co., Inc.

for better environment  
**Clayton**

# George Clayton has it.

## States make headway on mine drainage

Of the nation's major industrial water pollution problems, perhaps none is as complex as acid mine drainage. Certainly, it will be one of the most costly to remedy. The Federal Water Pollution Control Administration (FWPCA)—which, two years ago, placed a \$3 billion price tag on nationwide control programs—bases this figure on 80% reduction of acid pollution from active and inactive mines. Now, however, FWPCA feels that to meet most of the water quality objectives being proposed, 95% treatment will be necessary, and total costs of control programs may run as high as \$7 billion.

Few water pollution problems have effects as insidious as mine drainage. The chemical pollution and sedimentation it produces pose a severe threat to municipal and industrial water supplies in affected areas; streams that receive untreated mine drainage waters generally are rendered useless for recreational activities. In 1967, more than a million fish were killed by mine drainage, ranking this type of pollution as one of the primary causes of fish kills in the U.S.

About 75% of the mine drainage problem occurs in the Appalachia area alone, where it degrades over 10,000 miles of surface streams. This means that the major burden of the control costs—which ultimately must be met at local levels—will fall on a handful of states. Several of these states are gearing up control programs for enforcement of pollution abatement from active and operating mines, but these constitute less than half the problem. Fully 60% of acid drainage in the U.S. is from abandoned surface and deep shaft mines. Clearly, new legislative machinery will be necessary to cope with this problem; many states have taken the approach that control of drainage from abandoned mines by public funds is the only feasible alternative. Pennsylvania, for example, has estimated that its long-range plan for coping with abandoned mines may run as high as \$1 billion.

All types of mineral mining present some version of a drainage problem,



**Solomon's Creek.** Bleached rocks in Pennsylvania stream bed are direct result of untreated mine drainage. Effects on water quality are even more severe

but the most serious, because of its severity and magnitude, is from coal mining. Unneutralized acidity in mine drainage from both active and inactive coal mines amounts to about four million tons per year in the U.S. Actually, over twice this amount of acidity occurs, but more than half is neutralized by the natural alkalinity of receiving streams.

### Acid and sediment

The primary pollutants found in coal mine drainage are chemical contaminants—acids and iron and other metals—and sediment. Acid formation and some sedimentation occur when natural drainage patterns bring water into contact with sulfur bearing minerals in mines or refuse piles. Exposure

of pyritic materials (iron sulfides which usually occur in conjunction with coal deposits) to air or oxygen dissolved in the water results in oxidation of these materials. Leaching by the drainage water then results in high concentrations of sulfuric acid and acid salts. Most of the sedimentation occurs when the water erodes soil and minerals and carries them along into streams and ponds.

But only the gross mechanism of acid drainage formation is known; the basic reactions involved are, at best, incompletely understood. There is some question about the precise course of the various reactions and their products. For example, there is a great difference in reactivity among the various pyritic materials, which



**Source.** *Abandoned mines are more than half the problem in most states*

might be explained by the surface texture or size of crystals comprising the agglomerates. Finding the slowest, or rate-determining step in the kinetic mechanism might be an important clue to control methods, such as by inhibiting the controlling step in such acid formation with such materials as carbonates or phosphates. Treatment of drainage by phosphate rich sewage plant effluents is an attractive possibility.

Oddly enough, bacteria have been implicated in the formation of acid mine drainage. It has been found that the rate of pyrite oxidation increases greatly in the presence of certain bacteria, such as ferrobacillus ferroxidans, and bacteria have been claimed responsible for production of significant proportions of highly acid mine drainage. Some current research is based on the premise that the relative importance of bacterial process is determined, and might be controlled, by the ferric/ferrous ion ratio. Another hope is the development of counterorganisms to inhibit the acid producing bacteria.

### **Control programs**

Despite the tentative knowledge of the precise mechanisms involved, enough is known to make a start on coming to grips with the problem. Indeed, several programs already are underway, and are making some progress. An important part of these programs is prevention of the problem at its source. Sound water and soil management practices in mining areas can be effective in reducing the mine drainage problem. In surface mines, covering the mining cuts as soon as possible

after mining operations are completed effectively reduces the availability of oxygen, a key link in acid formation process. In depleted shaft mines, oxygen availability is reduced by flooding the mine shaft, after sealing mine portals, bore holes, and other cracks or openings to the mine. Another effective measure is wholesale diversion of natural watercourses away from active or inactive mine sites.

But, despite such preventive measures, a certain amount of drainage is inevitable from active mines, and some form of treatment of the drainage waters is necessary. A number of advanced waste treatment concepts, among them reverse osmosis, electro-dialysis, ion exchange, distillation, and crystallization, are under study for application to mine drainage. The only method as yet widely used is straightforward neutralization of the acidity, followed by flocculation and settling to separate the sludge and sediment.

### **Sludge problems**

Neutralization of acid mine drainage usually is accomplished by the addition of lime or limestone, although sodium hydroxide has been used. After neutralization, the sludge mass is aerated mechanically, either by diffused air or step aerators, and flocculated by slow mixing.

Sludge handling and disposal is the most troublesome aspect of treatment by neutralization. One alternative is to leave the sludge in place in the settling ponds, where the sludge dewatered by evaporation and percolation. Another possibility is disposal of the sludge, after dewatering, in abandoned strip mines. In either case, consideration of groundwater flows is a necessity for determining safe disposal areas, and, in some cases, this may be a limiting factor in the treatment step.

Another practice becoming more common is discharge of the sludge to abandoned deep mines or inactive portions of producing mines. The sludge can be easily trucked or piped to boreholes for discharge, and, if properly controlled, this method is very effective. The alkaline sludge appears to essentially remain in the solid form with little resuspension of dissolved solids.

Implementation of control programs at the state levels generally will follow from implementation of proposed water quality standards. Most of the standards that have been submitted contain limits on acidity and mineral

content of effluent discharges, and, in most cases, would be effective even though no specific mention is made of mine drainages. But a major stumbling block in the state programs is the problem of abandoned mines, where control techniques have not as yet been fully developed and where responsibility for control costs have not been fixed by existing legislation.

West Virginia, for example, has a plan that requires a permit for operation of active mines, which cannot be issued until the state is assured that discharge water will not pollute receiving streams. However, the state has taken the stand that an effective program for abandoned mines cannot be implemented until completion of sufficient research on control and construction costs. Indiana's implementation plan deals with mine drainage on a basin-by-basin basis; in general, the program requires that all industries, including mining, provide treatment equivalent to that required by municipalities in the same basin. In certain instances, additional treatment will be required by mining firms by the end of 1972. As in West Virginia, Indiana's abandoned mine problem has not yet been dealt with.

Pennsylvania generally is regarded as having the most comprehensive state program for the control of mine drainage pollution. This should not be surprising, in view of the fact that the state is the leading producer of anthracite coal and one of the leaders in bituminous coal mining. One state official has singled out coal mining as the largest source of pollution in Pennsylvania and the Ohio River basin.

Pennsylvania's mine drainage control program is built around a 1965 amendment to its Clean Streams Act. The basic law, originally enacted in 1937, was the state's first attempt at industrial water pollution control, but the original version specifically excluded mine drainage from its provisions. A 1945 amendment did include mine drainage, but as implemented, was aimed at preserving the quality of nonpolluted streams. Discharges to waters already polluted was allowed, and, where treatment was required, the only criterion spelled out was acidity.

The currently operative amendment of 1965 has a strongly worded non-degradation clause, which says the law's objective is "not only to prevent future pollution of the waters of the Commonwealth, but also to reclaim and restore to a clean, unpolluted con-



**Monitoring.** *Priorities for control programs must be based on assessment of problems. FWPCA is conducting nationwide inventory of sources, and industries and universities are studying mechanisms of acid formation and control methods*

dition every stream in Pennsylvania that is presently polluted." Basically, the amendment requires that all present and proposed mining operations be subject to permits obtained from the state's Sanitary Water Board. Applications for permits must be supported by technical data on pollution abatement programs both during operation of the mining and upon completion of mining activities; for strip mines, the act calls for complete backfilling and replanting of the mine sites. In implementing the act, the board has established discharge limitations on mine effluents; for active mines, the requirement is that all discharges be alkaline and the iron content must be less than 7.0 mg./l.

Pennsylvania officials are enthusiastic about the success of the 1965 regulations. Walter Heine, head of the division of mine drainage control of the Department of Health, points out that "in the three years since the amendment, the board has issued over 600 permits for deep mines, of which 200 required some form of treatment of discharges. Of these, well over half are already in operation." Heine is quick to acknowledge cooperation from the coal industry: "They have done commendable work in design and construction of treatment facilities and in treatment research." In fact, Heine estimates that, since the law was enacted, the industry has progressed farther in control technology than all federal, state, and industry efforts undertaken prior to its enactment. W. A. Lyon, director of Pennsylvania's Bureau of Sanitary Engineering, calls this

effort the "fastest industrial response to any water pollution legislation."

The Pennsylvania Clean Streams Act does not contain specific provisions for control from abandoned mines, but the state is moving in on this problem by other means. Most of these problem areas have been inventoried through a \$750,000 effort, in cooperation with FWPCA, and abatement plans are being formulated. Funding for this problem also is available through a 1967 state bond issue that earmarked \$150 million for abandoned mine drainage control over a 10 year period. Under this program, expenditures for 1968 and 1969 were \$13 million and \$17 million.

#### **Future programs**

Much of the optimism about the control of mine drainage pollution stems from the broad range of programs underway at all levels of concern. Backing up the legislative efforts in the coal mining areas are extensive research programs at local state universities. The University of West Virginia, Ohio State, Penn State, and the University of Kentucky all have major projects devoted to the problem. Most coal mining firms also are active in control technology. Bethlehem Steel, for instance, which conducts extensive mining operations in western Pennsylvania, recently announced pilot plant testing of a new process for mine drainage treatment. The company has not released many details, but does say the new process can quickly neutralize the acid waters and that the precipitated solids are

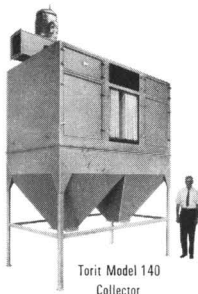
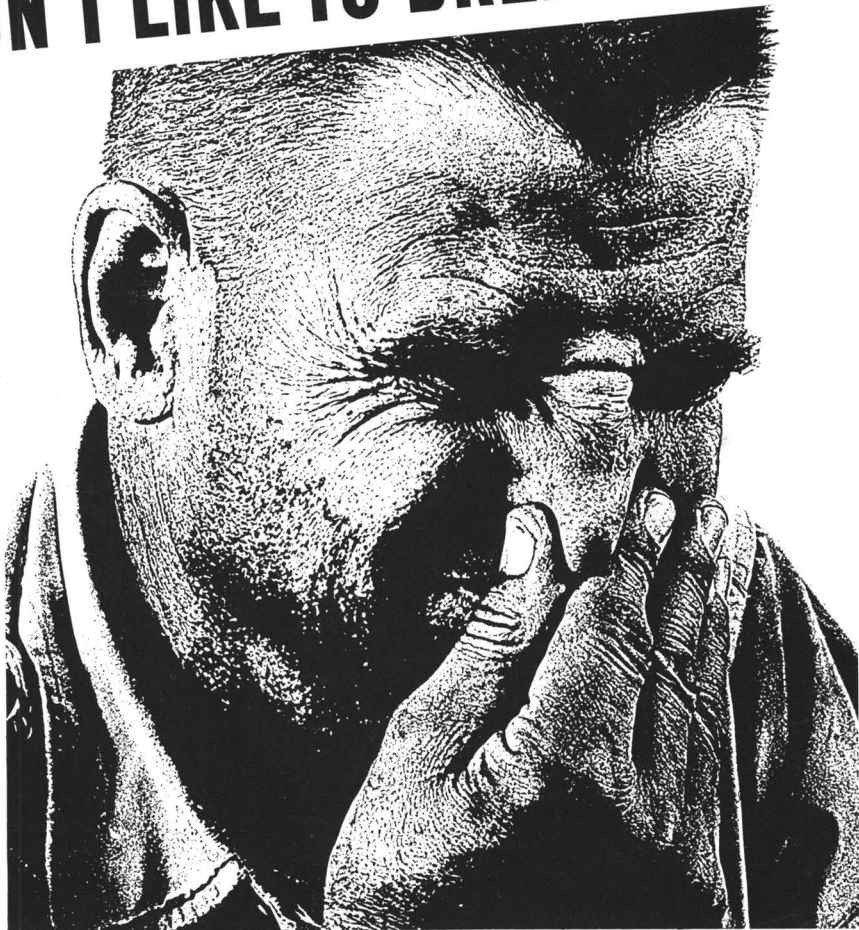
formed in such a way that, without prolonged settling, a clear effluent and a concentrated sludge result.

On the regional level, the Ohio River Valley Water Sanitation Commission (ORSANCO) is becoming increasingly active in the mine drainage problem. Last fall, ORSANCO's engineering committee heard testimony from member states, most of which have heavy concentrations of coal mining operations, on their control programs, with a view towards setting up a basin-wide control criteria. ORSANCO is also a principal sponsor of a series of symposia on mine drainage control, the third of which will be held at the Mellon Institute (May 19-20, 1970).

Also, on the regional level, the Appalachian Regional Council has asked the National Research Council to assist in the development of recommendations for a public program for dealing with the problem. The commission is preparing a report to Congress on research, development and engineering aspects of mine drainage control in Appalachia.

At the federal level, FWPCA shows every sign of continuing efforts on the problem, both through inventories of pollution sources and funding of research and demonstration control projects. More than \$6 million has been allocated for such projects through just three sponsors—the coal industry, FWPCA, and the State of Pennsylvania—and more funds appear to be on the way. S. 7, the administration water quality bill now close to ratification by Congress, would provide \$15 million in new funds for such programs.

# "I LIKE MY WORK, BUT I DON'T LIKE TO BREATHE IT!"



Torit Model 140  
Collector

If you've heard that in your plant, take a tip. Get rid of the dust and you'll breathe easier too, in a lot of ways—  
Fewer workers quitting for cleaner jobs.

Fewer workers off sick.

Fewer short-of-help problems.

Fewer new employees to hire and train.

Fewer headaches all the way around. And fewer headaches with the profit-and-loss statement, too. Annual absenteeism cost in the U.S. is now more than \$10 billion. So getting rid of dust in the plant is not just a case of doing right by the employees; it's doing right by the company.

It pays.

That's where we come in. For over 30 years we've been

making dust collection systems that pay. And we take pride in doing the job right, doing even more than you would expect—like trapping particles even smaller than you can see. Much smaller. Naturally, if we can trap the "invisible" particles, we get the bigger ones too. More of them. Cleaner air.

Cleaner air that pays. No wonder more Torit unitized systems are installed in more plants, to our knowledge, than any other. Everywhere. Since we make models for every size plant, every need, we make no compromises with performance. Try us and see.

Just look us up in the Yellow Pages under Dust Collection Systems. Or write to Frank Chase direct at the address below.

**THE TORIT CORPORATION** LEADERS IN CONTROL OF IN-PLANT AIR POLLUTION

1133 Rankin St., St. Paul, Minn. 55116, Dept. 6687

Circle No. 59 on Readers' Service Card



# Executives join clean water fight

*Industrial representatives meet federal officials,  
setting precedent for U.S. water pollution abatement efforts*

The National Executives' Conference on Water Pollution Abatement, a recent meeting (Washington, D.C.) of U.S. business leaders and federal officials, featured an illustrious group of international corporate executives, many of whom are listed in the "World Who's Who in Commerce and Industry." Executives from the chemical, paper, electric utility, steel, and oil industries in the U.S., Europe, and Canada discussed the practical economic aspects of water pollution abatement in their respective countries. International speakers included: Wilfrid Baumgartner, Rhone Poulenc; Harrison F. Dunning, Scott Paper; Rein Henriksen, A/S Borregaard; Neil Iliff, Chemical Industries Assoc. (London); Charles F. Luce, Consolidated Edison of New York; Brooks McCormick, International Harvester Co.; Charles B. McCoy, E. I. du Pont de Nemours; Robert M. Schmon, Ontario Paper; Edgar B. Speer, U.S. Steel; John E. Swearingen, Standard Oil of Indiana; Giorgio Valerio, Montecatini; and Casmir Prinz Wittgenstein, Metallgesellschaft A.G.

Federal representatives included: Walter J. Hickel, Secretary of the Interior; Russell E. Train, Undersecretary of the Interior; Carl L. Klein, Interior's assistant secretary for water quality and research; David D. Dominick, Federal Water Pollution Control Administration; and Lee A. DuBridge, presidential science adviser.

All conference participants recognize the importance of the fight for clean water, and look forward to a



International Harvester's McCormick  
**"Within the limits of technical  
and economic feasibility, our  
company intends to prevent pollution  
of water and air by its facilities."**



U.S. Steel's Speer  
**"The problem reduces itself to  
one of cost effectiveness—  
selecting those tasks which will  
do the most good."**

better business environment in which they and other business leaders can continue abatement efforts. One fact made clear early in the meeting was that the Nixon administration feels a commitment to satisfy the will of the electorate in this area. "The public wants a clean environment, and they are going to have it," says Interior's Klein. He notes that clean air, clean water, and unspoiled countryside are more easily attained through preventive rather than restorative methods.

## Corporate viewpoints

Without exception, business leaders at the conference acknowledge the fact that water conservation is the cost of doing business, and progress or lack of it usually boils down to the question of economics.

Referring to International Harvester's industrial category as automotive metalworking, Brooks McCormick concedes that his company's policy on industrial pollution can be summed up in 21 words: Within the limits of technical and economic feasibility, our company intends to prevent pollution of water and air by its facilities. "This is fully as much a description of past practices as a declaration of intentions," McCormick asserts. Yes, the company recognizes its social responsibility for environmental quality protection, yet, in the present decade, International Harvester's net income has averaged about 3.6% of sales dollars.

Within industries, recycle and reuse is practiced. Over a period of 25 years, International Harvester's Wis-

consin Steel has reduced by 50% its demand for input water. The cost was \$11.5 million at this one location, and company plans call for expenditures of an additional several million dollars. "We anticipate that our mill will be one of the first in the Chicago area to return no water whatever to the Calumet River," McCormick says.

#### **Steel's view**

Looking at the steel industry in the U.S., Edgar B. Speer states that the critical factor is water quality, not quantity, since the steel mill returns at least 90% of its water to the source. "Water treatment in the steel industry is basically a holding action in which adequate space and time must be provided to hold process water while gravity, chemical coagulation, filtration, and centrifugal force remove the pollutants picked up in the manufacture of steel."

If the money is available, cleanup will proceed, according to steel's spokesman. "Anyone is entitled to any degree of pollution abatement that he wants, but can he or the public afford it?" Speer questions. There is no problem with new plants; it's the old ones that give the industry a headache. "We just aren't earning enough money to install all the controls that, ideally, might be desirable, everywhere, all at once, just as it is manifestly impossible for the government to finance the simultaneous solution for all the major problems it faces," Speer continues. "The problem reduces itself to one of cost effectiveness—selecting those tasks which will do the most good."

The 7% investment tax credit for pollution control facilities again is in jeopardy and under serious Congressional consideration. "Whatever relief provisions are adopted, they should recognize that such expenditures are not a productive investment," says U.S. Steel's president. "I am confident that the incorporation of these provisions in the federal tax code will be needed to permit the steel industry to continue its present rate of pollution control progress," Speer concludes.

#### **Chemical industry**

Revealing an European viewpoint on the chemical industry, Neil Iliff notes that the industry has a right to its own views as to what pollution controls are adequate and what are unreasonable. "The chemical industry in Britain is expanding at twice the na-

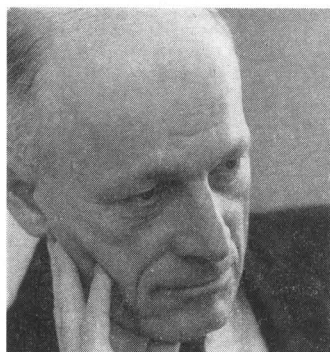
tional average growth rate, and the industry recognizes that conservation problems are a normal part of the expansion. Hence, the increasing importance of a serious study of pollution in a wide context," Iliff says.

Iliff also notes that a study on the use and reuse of water by the chemical and allied industries is being conducted by the Society of the Chemical Industry in Britain. The findings will be available next April or May.



England's Iliff

**"....The industry recognizes that conservation problems are a normal part of expansion."**



Du Pont's McCoy

**"We must pay more attention to the cost-benefit equation.... Most (efforts) have failed because of the economics involved."**

But water pollution is just one form of environmental pollution. Du Pont's Charles B. McCoy notes that, if an effective national policy is to be created, it must be based on the pollution problem as a whole, and not just its separate parts. "We must pay more attention to the cost-benefit equation," he asserts. "To be sure, the chemical industry has been trying to find ways to retrieve useful materials from liquid outfalls and stack gases. A few of these efforts have succeeded. But most have failed because of the economics involved."

"In France, industry uses 7.4 billion gallons of water per day, of a total supply of 124 billion gallons, says Rhone Poulenc's Baumgartner. But the chemical industry's share is quite small, considering electric utility, mining, and steel industry use of water." He also notes that nine French ministries are involved in water pollution control, and the problem has been subjected to legislation.

"The total cost of water pollution eradication should represent about 14% of the annual French budget—including about 4.5% for treatment," Baumgartner says. "It is quite obvious that such expenditures will have to be spread over a period of time, currently estimated at 20 years." But he notes that the chemical industry is far from being behind, since, already, it has attained 35% of the investments necessary in the initial stage for cleanup, whereas public communities have not yet attained 15%.

#### **Other approaches**

A U.S. oil executive expresses the message of cost effectiveness in similar terms. "The central question is not whether we should have cleaner water, but how clean, at what cost, and how long to take to do the job," says Standard Oil's Swearingen. "Our challenge is to identify the complex sources of pollution and keep them within socially and economically tolerable limits."

From the viewpoint of the pulp and paper industry in Europe, "The choice is between a bigger or smaller improvement in the water situation, connected with a bigger or smaller increase in prices for pulp and paper," comments Borregaard's Henriksen.

Attended by almost 1000 industrial and business leaders, this conference is just a beginning; a second is planned for next year. Worldwide water pollution abatement is the goal.

# Rx for ailing lakes—a low phosphate diet

*Boundary Commission study sees detergent reformulation and tertiary treatment as only hope for lower Great Lakes*

At first glance, the technical report issued last month to the U.S.-Canadian International Joint Commission on the pollution of Lakes Erie and Ontario and the St. Lawrence River contains few surprises: Yes, these waters are already in an advanced state of eutrophication, and deteriorating rapidly; yes, phosphates are a key link in the deterioration process; and yes, municipal waste effluents are the major culprit, although industrial effluents are also a threat. But the significance of the report is that it goes well beyond confirming what is already known about the lakes. Specifically, the report:

- Contains perhaps the most comprehensive inventory yet of pollution sources to these waters, and includes estimates of costs of control.

- Sets up water quality objectives appropriate to the area and recom-

mends accelerated programs to meet these goals.

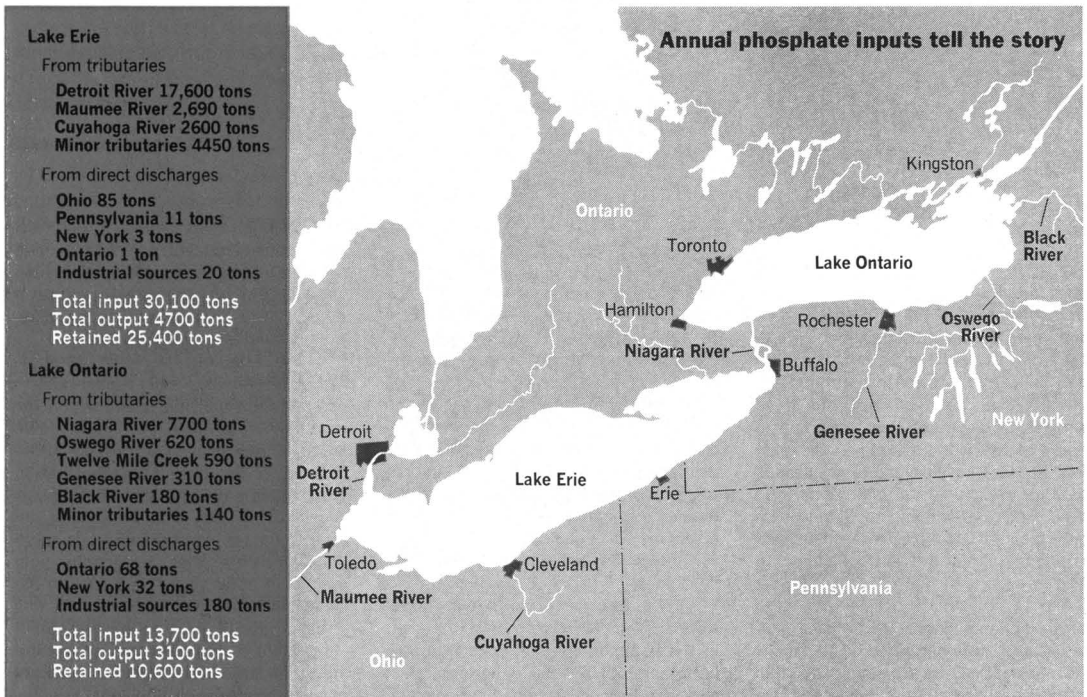
- Makes a vigorous argument that control of phosphate inputs would significantly curb eutrophication of the lakes, even in the absence of similar controls on nitrates.

- Firmly endorses elimination of phosphates from household detergents. The report maintains that partial replacement now is possible, and that complete replacement might be possible in a few years.

The report asks for continued and expanded cooperation between the U.S. and Canada on the whole range of lake pollution problems, through an appropriate board appointed to coordinate the effort. The commission plans to conduct public hearings on the report early in 1970, after which it will determine what recommendations to make to the U.S. and

Canadian governments. The report's programs, if duly implemented, would result in the most thorough international pollution control compact ever enacted.

Such close cooperation could provide a formal mechanism for supplementing the Federal Water Pollution Control Administration's efforts on restoring the Great Lakes through pollution abatement enforcement conferences. A minor point of contention often broached at these conferences is the efficacy of unilateral control measures on such problems as oil spills, exploratory drilling for oil and gas, and disposal of harbor dredging spoils, that are taken without implementation on both sides of the lakes. At last year's Lake Erie conference (Cleveland, Ohio), Representative Thomas L. Ashley (D.-Ohio) contended that, for many years, both



the U.S. and Canada have been in violation of the 1909 boundary treaty; one article of that treaty specifically provides that "boundary waters shall not be polluted on either side to the injury of health or property on the other."

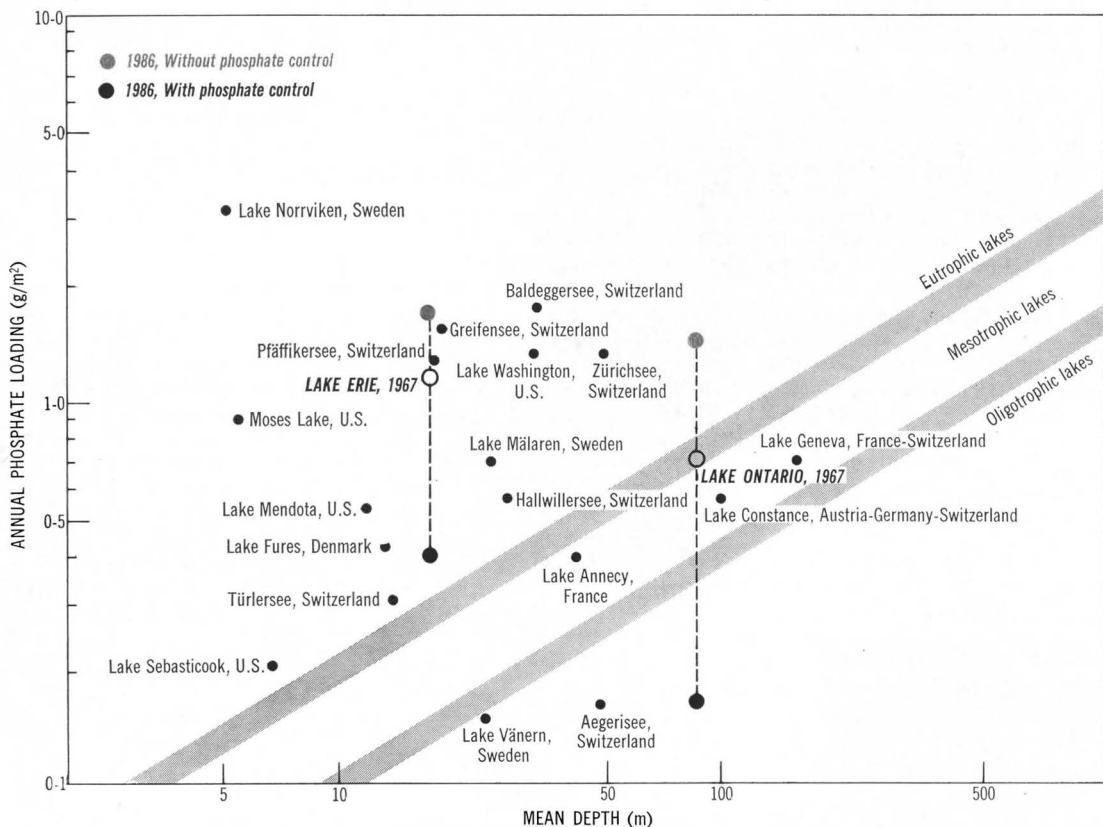
### Earlier studies

The international implications of pollution of Lakes Erie and Ontario certainly was not news to the com-

mission, whose earliest look at the problem dates back to 1918 with issuance of a report on investigations conducted from 1913-16; another report in 1950 covered studies undertaken from 1946-48. The 1918 report was concerned with bacterial pollution from domestic sewage; it concluded that open sections of the lake were free of it, but localized contamination in nearshore areas was

a direct threat to municipal water supplies.

The 1950 report indicated that many of the municipalities in the lake basins had constructed sewage treatment works and water filtration plants, but extensions of sewer services had not kept pace with population growth. Industrial pollution, not significant in 1918, was recognized as a growing problem in 1950, as was the fact that



### Lower Great Lakes not beyond repair, report says

Is man-made eutrophication irreversible? The current report to the International Joint Commission proceeds from the premise that it is not: "The similarity of the eutrophication resulting from man's activities . . . to natural eutrophication is often overemphasized . . . . The extent of enrichment and eutrophication which has occurred in many of the world's lakes in the past few decades would require thousands of years under natural conditions. Indeed, such enrichment might never be possible naturally. It is unfortunate, and misleading, that the eutrophication in lakes affected by man is so often referred to as a mere acceleration of a natural phenomenon. This analogy often gives the impression that [such] eutrophication is irreversible. That this is not true has been demonstrated in a

number of cases . . . ." As to the present status of and future outlook for Lakes Erie and Ontario, the report draws on the work of R. A. Vollenweider of the Canada Centre for Inland Waters, and a contributor to the report. Vollenweider has obtained, from data on 20 lakes throughout the world, a general correlation between annual phosphate loading and mean lake depth on the one hand, and degree of enrichment—defined as oligotrophy, mesotrophy, and eutrophy, in increasing order of severity—on the other. The report then concludes:

• **Lake Ontario presently is mesotrophic.** Vollenweider's analysis puts it in the upper range nearer to eutrophy, but other criteria, such as bottom fauna, phyto- and zooplankton populations, and

physicochemical characteristics, indicate that it is more oligotrophic than this. Effective phosphate controls would return Lake Ontario to an oligotrophic condition, as indicated.

• **Lake Erie, on the other hand, is highly eutrophic,** and Vollenweider's parameters would put it still within the eutrophic range, even with implementation of phosphate controls, by 1986. But, as in the case of Lake Ontario, other criteria suggest that Lake Erie is considerably less eutrophic than indicated on the chart. If so, it is more than probable that phosphate control would bring Lake Erie back into the mesotrophic range. But Lake Erie was a mesotrophic lake before the rapid enrichment of recent years, and control measures probably would not alter its condition below mesotrophy.

much of the industrial, municipal, and agricultural development was occurring without regard to the effects of multiple releases of wastes to the lakes.

The current study was initiated in 1964 when the International Joint Commission, in response to requests from the U.S. and Canada, set up advisory groups on the status of pollution in the two lakes and the international segments of the St. Lawrence River. The report of these groups disposes of the problem of cross-boundary pollution by frankly admitting that it probably exists: "While difficult to state that a given concentration of pollutant on one side of the lakes is tied to a particular source on the other, it is clear that inputs from both sides have transboundary effects."

Instead, the report devotes much of its effort to recommending technical and legislative machinery for control measures. Phosphate enrichment is singled out for special emphasis, and is the subject of the report's most sweeping recommendations. Phosphate content of detergents should be reduced immediately to minimum practical levels, with complete replacement of phosphorus in detergents with less innocuous substances as soon as possible, but not later than 1972. Furthermore, 80% removal of phosphates from all effluents should be provided, by 1972 in the Lake Erie basin and by 1975 in Lake Ontario. Treatment of waste effluents for phosphate removal must be in addition to, and not a substitute for, detergent reformulation.

#### Controlling nutrients

The rationale for the necessity of both measures is somewhat intricate. Phosphorus and nitrogen are, of course, widely recognized as the most important nutrients responsible for eutrophication, but some debate still occurs about whether phosphorus or nitrogen is controlling. The report states that there is every reason to believe that phosphate is the controlling factor in the enrichment of the lower Great Lakes. As evidence, the report cites the work of J. R. Valentyne of the Fisheries Research Board of Canada's Freshwater Institute (Manitoba). In his studies, Valentyne showed that algae blooms could be produced in lake water samples by the addition of 2% raw sewage, or even 2% effluent from secondary treatment plants. Addition of effluent treated to remove phosphor-

us, but not nitrogen, showed no algae bloom, but subsequent addition of phosphate alone to these samples did.

One other reason for the control of phosphorus in the absence of nitrate controls is that the phosphate loadings can be controlled more effectively. The report notes that 57-70% of the phosphorus loadings is from municipal and industrial waste effluents, as opposed to 30-40% for nitrogen. Furthermore, efficient and relatively inexpensive methods are available for 80-95% removal of phosphorus during sewage treatment, whereas comparable elimination of nitrogen compounds is not yet feasible.

#### Removal costs

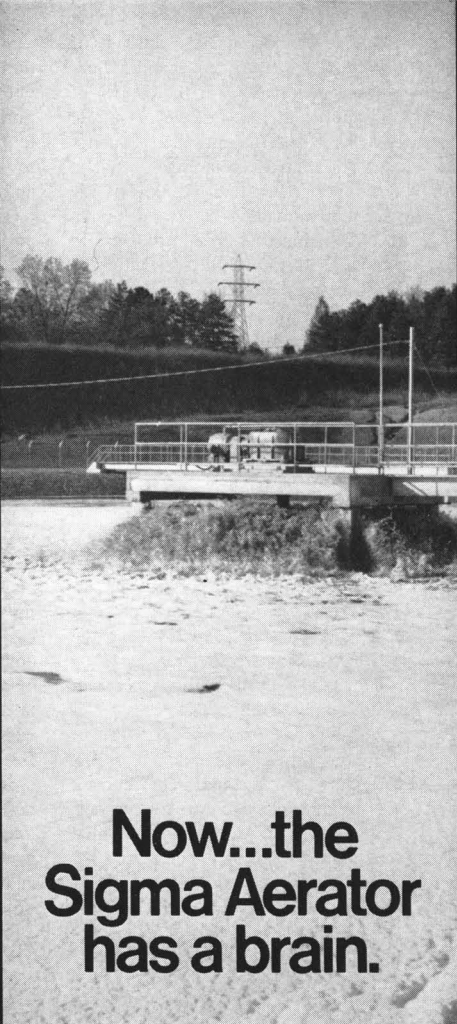
Given this evidence of the desirability of phosphorus control, the argument for both detergent reformulation and removal at the treatment plants is largely one of economics. The report estimates that treatment costs for phosphate removal at the treatment plant would be reduced by a half to two thirds with replacement of phosphate detergent builders. Detergent sources account for 70% of the phosphorus in municipal waste, and 50% in Canada. The current average phosphate content of sewage is about 10 mg./l.; if the detergent contribution were eliminated, an 80% removal process would reduce the typ-

ical concentration to 0.6 mg./l. To achieve the same effluent concentration without replacement of detergent phosphates would require 95% removal at the treatment plant, at two to three times the cost, largely due to the additional chemicals needed and the solid waste produced.

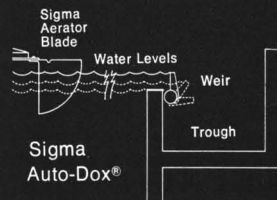
The total cost of meeting the report's water quality objectives is put at about \$1.4 billion in the U.S. and \$212 million (Canadian dollars), in Canada. These figures include capital costs for phosphate removal of \$265 million in the U.S. and \$40 million in Canada. Although detergent reformulation probably would have little effect on capital costs for phosphate removal, the report states that the operating costs for the treatment plants would be greatly reduced. For example, in the Lake Erie-Detroit-St. Clair River system, the cost of 95% phosphate removal from a 10 mg./l. effluent would involve a total annual cost for chemicals of \$17.6 million dollars. The same results could be obtained at a cost of \$5.3 million by 80% treatment of a 3 mg./l. effluent which would result from phosphate-free detergents. Scaling up these figures to the entire Lake Erie-Lake Ontario-St. Lawrence River basin, the total annual savings for each country would be \$478 million in the U.S. and \$26 million in Canada.

### Water quality objectives for lower Great Lakes

Parameter	Limits	Remarks
COLIFORMS	Less than 1000 total and 200 fecal coliforms per 100 ml.	International waters will be protected if local conditions meet these standards
DISSOLVED OXYGEN	Not less than 6.0 mg./l. in epilimnion	Established to support fish and associated biota
DISSOLVED SOLIDS	No more than 200 mg./l.	Water supplies affected at 500 mg./l.
TEMPERATURE	No change which affects beneficial use	Lack of data on effect of changes precludes absolute limits
TASTE AND ODOR	Virtually none	Phenols not to exceed a monthly average of 1.0 µg./l.
pH	No change from present	Present pH within desirable level limits
IRON	Not to exceed 0.3 mg./l.	Conforms to USPHS and Canadian drinking water standards
PHOSPHORUS	Limited to extent necessary to prevent nuisance growth of algae	Algae blooms can be expected phosphorus and nitrogen exceed 10 and 300 µg./l.
RADIOACTIVITY	Gross beta less than 1000 pCi/l., radium-226 3 pCi/l., and strontium-90 10 pCi/l.	Meets USPHS drinking water standards.



**Now...the  
Sigma Aerator  
has a brain.**



Yeomans, leader in the field of surface aeration, announces a major step forward in the economy, management and automation of wastewater treatment systems. It's the Sigma Auto-Dox®—and it's like an aerator with a brain. Designed to conserve horsepower during low loading periods, Auto-Dox automatically varies the water level in the aeration tank, automatically changes the depth of the aerator blades—automatically saves money!

Auto-Dox has been thoroughly researched and has been under constant field testing for the past three years.

Before you make any decision on waste treatment equipment, find out about Yeomans Sigma Aerators with exclusive Auto-Dox. It's the only surface aerator with a brain.



**YEOMANS** 1999 N. Ruby Street/Melrose Park, Illinois 60160

**Solutions to tough waste treatment problems.**

Circle No. 9 on Readers' Service Card

# Firms pool anti-pollution efforts

*Pioneer venture shows how companies benefit from concerted action on environment*

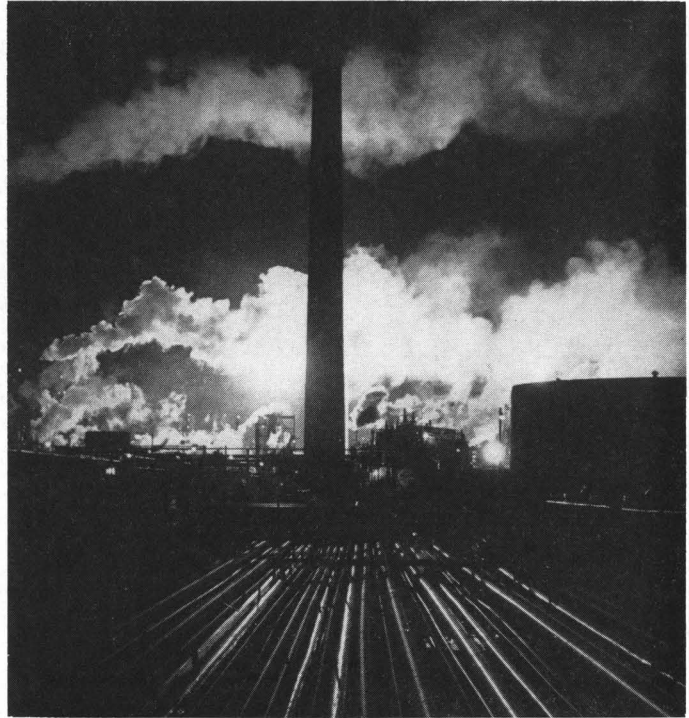
According to the local chamber of commerce, it is "fascinating by day, a fairyland of lights by night . . . an awe inspiring sight." And, while it is perhaps no great rival to Disneyland, there is no doubt that the concentration of refineries and chemical plants stretching for 20 miles along the east bank of the St. Clair River in southwestern Ontario is an impressive sight indeed. Refinery flare stacks give off a fiery glow that can be seen at night for miles around.

There's no great secret about the attractiveness of the area to the chemical industry. First, there is the St. Clair River—a fast running stream that, for much of its length, is a full half mile wide—which is both a source of water and a vital part of the St. Lawrence Seaway linking the upper Great Lakes with the Atlantic Ocean. Second, and probably even more important, the first oil in North America was discovered just 20 miles from Sarnia, the chemical valley's biggest city. Imperial Oil Co. (now 70% owned by Standard Oil of New Jersey) built a refinery here in 1897, and, from small beginnings, the area has grown into Canada's biggest concentration of chemical industry. As elsewhere, chemical plants were built to utilize the petroleum based feedstocks a big refinery can provide. There are three refineries near Sarnia now.

## Active cooperation

The overall appearance of the area is, of course, very much like that of other areas where chemical and petroleum companies have moved in a big way. This might be a strip along the Ohio River in West Virginia or the Delaware River in Pennsylvania and Delaware. What is different about the chemical industry along the St. Clair River in Lambton County, Ontario, is its ability to speak with one voice to citizens and government, even though more than a dozen different firms are located there. This situation was made possible by the establishment of an industrywide cooperative group known as the Lambton Industrial Society (LIS).

LIS originated in embryo in 1952 when the Ontario Research Council (a now defunct group set up by the



**Pipelines.** Refinery products are feedstocks for neighboring chemical plants

provincial government) suggested to the area's three largest chemical concerns—Imperial Oil, Dow, and Polymer Corp.—that they undertake studies of air, water, and soil pollution in the St. Clair River region. The three companies set up the St. Clair River Research Committee and, in that same year, initiated an air monitoring survey of the area that has continued in constantly expanding form. As time passed, other firms joined the committee until, today, there are 12 members. The 12 include all of the major chemical firms located along the river for 20 miles south of Sarnia. In 1967, the name of the committee was changed to the Lambton Industrial Society, and LIS was incorporated as a nonprofit association.

## Organization

Broad policy decisions for LIS are made by the society's board of directors, which is composed of 12 men, one from each member company. A director usually is the senior man at

his company's plant (works manager, for instance), but some directors are corporate vice presidents of companies that have corporate headquarters as well as plants in the region. Five of the directors comprise the executive committee of president, vice president, secretary, treasurer, and member at large. The executive committee runs LIS within the framework of its board's policy guidelines. Assisting the executive committee is one of LIS' two paid, full-time employees—the society's manager (the other is the manager's secretary). In many ways, establishment of the position of manager in 1967 was a very smart move for LIS to make. Two years of experience have shown that manager H. Mason Jones has been able to make substantial contributions to the smooth running of the society and, equally important, to act as an informal communications channel between the various member firms.

Two committees serve the detailed information and planning needs of



## Members of the Lambton Industrial Society

Allied Chemical Canada  
 Cabot Carbon of Canada  
 Canadian Industries  
 Chinook Chemicals Corporation  
 Dow Chemical of Canada  
 Du Pont of Canada  
 Ethyl Corporation of Canada  
 Fiberglas Canada  
 Imperial Oil Enterprises  
 Polymer Corp.  
 Shell Canada  
 Sun Oil Co.

support. Results of the ORF surveys, together with air quality information gathered by the individual companies themselves, is shared with the Ontario government and made public from time to time.

At present, LIS has no water quality monitoring program of the magnitude of its air quality efforts, although setting up such a program is under discussion. However, every few years, LIS has commissioned a biological specialist to conduct a complete biological survey of the bottom of the St. Clair River from Lake Huron to Lake St. Clair. These surveys have the purpose of taking an inventory of pollution sensitive organisms from natural bottom life.

### Advantages for members

What advantages do LIS members enjoy as a result of membership?

- **First**, there is an opportunity to share in a responsible program to inform the public of what it and other companies are doing to combat pollution. The public tends to see industry as a single entity, and membership by all the firms in the area permits companies to respond to criticism in a unified way.

- **Second**, joint support of air quality data gathering and pooling of in-house data, especially when these data are made public (whether or not favorable to industry), lends considerable credibility to the sincerity of member companies' intentions.

- **Third**, and somewhat more intangible, there is the benefit to be derived from close contact with the people responsible for pollution control in other companies. Although technical information and even technical aid is given on occasion, a major benefit is that the society's manager can and does exert pressure on any member firm that is guilty of poor practice which might bring approbation on all area industry from an aroused public.

### Outlook

The success of the Lambton Industrial Society should make the cooperative idea worthy of emulation elsewhere. Mason Jones is aware only of one other similar cooperative effort in North America—that of the Laval Industrial Association in Quebec. But, if the arrangement works in Ontario, there seems no reason why it would not work in any of the other heavily industrialized regions on this or any other continent.

LIS' board of directors—one is a technical committee and the other covers public relations. The 12 members of the technical committee—again, one from each company—generally are their companies' plant pollution control administrators. This year's chairman, Herbert S. Wilson, is environmental control coordinator at Imperial Oil's refinery. The public relations committee is composed of just five or six public relations men; not all member firms have P.R. men in the Sarnia region. A big task for the P.R. committee is the arranging of the once a year briefing LIS gives for the benefit of local government, civic, and news media officials.

### Programs

The general objective of LIS was spelled out in 1967 as: "To promote joint and individual effort by member industries in fields of education and research to achieve control of industrial pollution of air, soil, and water consistent with government regulations and good corporate citizenship." LIS programs in education are centered around the need to let the public know what the companies are doing about their pollution problems. To this end, LIS has held three annual briefings for press and radio, with generally good reception being afforded the industry representatives. Manager Mason Jones feels that press relations now are excellent, after an early unfortunate incident in which newspapers used LIS' own air quality data to browbeat its members.

Each member company performs its own in-house research on pollution

control techniques; such research is not performed under the auspices of LIS. LIS research programs are based on the need for information on air and water quality in the region. The laws in Ontario are strict by U.S. standards and the province's air pollution legislation specifies air quality criteria in terms of several parameters (oxides of nitrogen, hydrocarbons, and hydrogen sulfide, among others) that are only now being talked about in the U.S. New construction or plant modification will not be granted a permit by Ontario's Department of Energy and Resources Management unless certain design standards, based on these criteria, are complied with. The same department requires compliance with water pollution standards, although these are by no means so well specified as the ones for air quality. Nevertheless, there are, in effect, effluent criteria with respect to pH, oxygen demand, oil, phenolic materials, etc., imposed on plant waste waters.

The air monitoring program which the St. Clair River Research Committee started in 1952 has expanded to encompass five main monitoring stations around the county. The stations continuously measure atmospheric conditions such as temperature and wind speed, and concentrations of sulfur oxides, nitrogen oxides, aerosols, particulates (dustfall and suspended), and hydrocarbons. LIS itself does not take the measurements; instead, it retains the Ontario Research Foundation (ORF) on a contract basis. ORF employs three men full time in Sarnia to run the monitoring network, which costs LIS about \$100,000 a year to



# Nixon administration: Its first environmental step

*Created by Executive Order on May 29,  
the Environmental Quality Council is  
gearing up for an assault on environmental problems*

Like an iceberg whose visible portion is a mere fraction of its total mass, the activities of the Nixon administration's Environmental Quality Council (EQC) that have surfaced seem small in comparison with EQC's inner working and planning activities that still lie deep beneath the waters of federal bureaucracy. Nevertheless, considerable activity is being coordinated at various interdepartmental and interagency meetings, in committee assignments, and on federal agencies' environmental quality programs.

"One main objective of EQC is to get the federal government to march as much in the same direction on policies that affect the environment as seems reasonable to do," says John L. Buckley, technical assistant at the office of Science and Technology (OST). Buckley, key coordinator for EQC activities, offers some insight to the Nixon administration's council.

## Activities

Organizationally, EQC members are President Richard M. Nixon, Vice President Spiro T. Agnew, and secretaries of six federal departments—Agriculture; Commerce; Health, Education, and Welfare (HEW); Housing and Urban Development (HUD); Interior; and Transportation. The President's science adviser, Lee A. DuBridg, serves as EQC's executive secretary. But, within each department, there is a rotating group of federal personnel who attend EQC meetings and with whom OST's technical assistant maintains close contact. Buckley also is concerned with the direction that the federal government will take on environmental matters.

To date, three EQC meetings have been held; all secretaries attended

the second meeting. A number of other federal departmental officials have attended and participated in EQC meetings as well as a number of other less formal interagency and interdepartmental meetings. In addition, observers from the Bureau of the Budget (BOB), the Council of Economic Advisers (CEA), and other federal departments and agencies—such as the Department of State, Department of Defense, and the Atomic Energy Commission (AEC)—participate in both types of meetings, Buckley explains.

Within EQC, seven committees have been established with chairmanships and memberships spread over the six departments. Each cabinet member chairs one or more of the committees. Agriculture Secretary Clifford M. Hardin chairs the newly-formed pesticides committee. Transportation Secretary John A. Volpe and Interior Secretary Walter J. Hickel each head two committees. The automotive air pollution committee and the handling and transportation of toxic and hazardous materials committee are headed by Volpe, while Hickel chairs the outdoor recreation committee and a water pollution committee. HEW Secretary Robert H. Finch chairs an air pollution committee; George Romney, Secretary of HUD, chairs one for solid wastes; Secretary of Commerce Maurice H. Stans' noise committee rounds out the existing seven. There is now a specific committee assigned to pesticide problems (previously, the activities on pesticides that occurred in Agriculture, HEW, and Interior apparently were to be pulled together by DuBridg's staff). "If necessary, further studies would be sponsored by OST," Buckley explains.

"Many EQC activities are not as formal as its three earlier meetings,"



**John L. Buckley**

*"... Environmental Quality Council is using the talents of the federal government to focus on environmental problems. . . . Very often, the inputs on any one environmental problem are broad due to the background of the various council members. This leads to a further understanding of a particular problem and, often, departs from any parochial view of any one department or agency."*



### Environmental Quality Council

Membership and committees

Committees	Agriculture Clifford M. Hardin	Commerce Maurice H. Stans	HEW Robert H. Finch	HUD George Romney	Interior Walter J. Hickel	Transportation John A. Volpe	Other federal participants
Automotive air pollution							
Solid waste							
Handling and trans- portation of toxic and hazardous materials							Defense AEC State
Outdoor recreation							
Noise							Labor
Water pollution							BOB CEA
Air pollution							

Denotes membership      Denotes chairmanship

Buckley notes. "Many things are going on even though some of the committees have not yet met formally. In fact, much of the committee activity is being performed by staff personnel within the departments . . . . EQC is more than a mere discussion forum," Buckley continues. "Very often, the inputs on any one environmental problem are broad due to the background of the various council members. This leads to a further understanding of a particular problem and, often, departs from any parochial view of any one department or agency. Ulti-

mately, a decision at the highest level for best national interest will be reached."

For example, based on his earlier experience as director of a major U.S. manufacturer of automobiles, HUD's Romney can make considerable impact on the automotive air pollution committee. "In this way, EQC is using the talents of the federal government to focus on environmental problems," the OST spokesman says. "There is a whole range of environmental matters in which the federal government can play a major role." EQC con-

sideration will be given to how the council can help make the day-to-day activities and procedures of the federal government more responsive to the needs of the environment.

"The federal government exercises fairly strong leverage simply by being a major purchaser of materials," Buckley explains. Federal muscle could be used in purchase specifications which would then provide incentive to the public and private sectors to improve environmental quality. For example, the purchase of low pollution automobiles by the federal

government would tend to set a precedent for the rest of the nation to follow. The requirement of degradable packaging materials in specifications would be another way that the federal government could bring environmental quality considerations to bear on the activities of the public and private sectors. But the direction that this country ultimately will take rests on the President's decision on the environment, Buckley believes.

### Committee insights

Automotive air pollution occupied a large part of the business at EQC's second meeting (San Clemente, Calif.). Here, Transportation Secretary Volpe urged that EQC undertake some kind of a program to speed progress in this area, but the program details are not yet public. A prime goal is rapid improvement of the environmental situation with respect to the automobile.

Held prior to the hearings on extension of the Solid Waste Disposal Act of 1965, Secretary Romney's recent committee meeting focused attention on the posture of the federal government with regard to solid waste. Committee consensus was amply emphasized by administration officials as they testified before Senator Muskie's air and water pollution subcommittee (ES&T, November 1969, page 1160).

"Interior's Bureau of Outdoor Recreation has statutory authority for coordination of outdoor recreation across the U.S. as a whole," Buckley explains. There are many state and local agencies having public lands that are managed by the federal government. So, this committee's first concern will be the question of consistency of policies with regard to public use. For example, the U.S. Army Corps of Engineers has a large number of visitors each year to its reservoirs, and the public's use of these waters for recreational purposes needs to be considered, along with use of other public areas such as National Parks and Forests.

### Agency comments

James D. Braman, Transportation's assistant secretary for urban systems and the environment, points out that the various EQC committee chairmen ultimately will be reporting their findings and suggesting policies to the council. (In fact, several chairmen presented reports at its third meeting held last month.) These reports

will indicate some steps that the chairmen hope to follow to bring environmental problems under control.

Braman, formerly mayor of Seattle, was a wise choice for the newly established post of urban systems and environment. He brings considerable experience and knowledge of urban systems to his new assignment. As mayor, he participated extensively in the activities of the National League of Cities and the U.S. Conference of Mayors, and served as head of each group's transportation committee.

The assistant secretary noted that Transportation's involvement is confined at this time to the impact of transportation on the total environment. The Department of Transportation has nothing to do with the broad field of poisons in the air, soil, water, etc. "These are important concerns of other federal agencies," Braman says. "But the department is concerned with the kinds of programs that will be more productive of progress in the field of automotive air pollution in the near future."

Progress on automotive air pollution, the largest item on the San Clemente meeting schedule, might have bogged down over jurisdictional disputes were it not for EQC. The cleanup program for the present gasoline engine might well be the responsibility of HEW, according to Braman. HEW has developed an organization that is familiar with the problem, knows what progress has been made and the goals for the next few years. "So, Transportation concerns itself with future transportation systems with accompanying low level of pollutants," Braman notes. "This is our goal."

Within Agriculture, Secretary Hardin's memorandum #1664, dated Oct. 3, established an environmental quality executive committee. The primary purpose of this standing committee will be to coordinate the department's interests and responsibilities in the nation's effort to assure a quality environment for all people. Theodore C. Byerly, chairman of the committee, points out that pollution is only one aspect of Agriculture's involvement with environmental quality programs and EQC. "Pollution programs are not synonymous with environmental quality programs . . . . Actually, they are only a minor part."

Discussing pollution, Byerly noted that sediment is the main pollutant, tonnage wise; animal wastes come next based on volume considerations;

and forestry and crop residues are the next main pollution concerns. Moving to Agriculture's environmental quality interests—which Byerly admits are a bit harder to pin down—he notes that the number one priority perhaps is a national pattern of land use. Here, main concern must be devoted to the use of land for its highest productive capacity. Byerly observes that statistics reveal that 50 million acres less croplands are cultivated now than 50 years ago. In addition, there are 80 million acres less for livestock grazing than 50 years ago.

So, multiple use land concepts also must be applied in the agricultural field. Agriculture's Forest Service, for example, might assess the economic tradeoffs for the development of land used for food and fiber, water, wildlife, and recreation.

### Commerce's role

James R. Hibbs, adviser on environmental quality in Commerce, says that the department's interest in noise is not limited to aircraft noise, but includes industrial, traffic, and residential noises. Hibbs noted that Secretary Maurice H. Stans chairs a committee on noise. A draft policy is being formulated, and will be considered by the council at a later time.

Another area in which Commerce is involved is solid waste, Hibbs continues. The department has prepared reports on:

- Steel industry scrap problems.
- Auto abandonment.
- Auto wrecking industry.

Similar to the inner organizational activity within Agriculture, Commerce's staff participates in committee staff work and develops background information to meet continuing department policy responsibilities in the environmental area.

What federal direction will grow out of EQC activities only time can tell. Probably, only after the committees report back to the council, and after President Nixon announces his order of priorities will the public become aware of the continuing federal attention to environmental matters.

In any event, the comments on environment in Nixon's first State of the Union message next month and the attention for environmental funds in the budget request of the U.S. Government for fiscal year 1971 certainly will be followed by the growing number of environment watchers.

# Man and nature at odds in the delta

Joseph D. Martinez and Clarence O. Durham, Jr.

Louisiana State University, Baton Rouge, La. 70803

**O**ne who knows the Mississippi will promptly aver—not aloud but to himself—that ten thousand River Commissions, with the minds of the world at their back, cannot tame that lawless stream, cannot curb it or confine it, cannot say to it, ‘Go here,’ or ‘Go there,’ and make it obey; cannot save a shore which it has sentenced; cannot bar its path with an obstruction which it will not tear down, dance over and laugh at . . . . But a discreet man will not put these things into spoken words; for the West Point engineers have not their superiors anywhere; they know all that can be known of their abstruse science; and so, since they conceive that they can fetter and handcuff that river and boss him, it is but wisdom for the unscientific man to keep still, lie low, and wait till they do it.”

Mark Twain

“Life on the Mississippi”

And do it, they have. The accomplishments of the Corps of Engineers have been remarkable and far reaching. The question arises, however: Have the consequences ranged beyond their expectations?

In any region, man’s environment is a complex and interrelated system. Modifications to any element of the system, whether beneficial or harmful, can cause changes to other elements which may have similar or dissimilar effects. Today, the emphasis is on harmful environmental changes. However, man has been engineering and introducing changes to improve his environment for many centuries. Modern technology has, of course, accelerated this process. Man has never, except in the course of warfare, deliberately set out to degrade his environment; however, it is a fact that the harmful changes caused by man generally have resulted from his introduction of major improvements.

The use of the automobile—which has been greatly accelerated by de-

velopment of today’s highway system—has resulted in a major source of air pollution. Intensive use of groundwater has, in many instances, resulted in degradation of the aquifers by salt-water encroachment. Insecticides and fertilizers have polluted surface waters; and so on. Weather modification, which promises much help to arid regions as well as those often beset by hurricanes, also carries the threat of undesired side effects—even disasters.

It has become increasingly apparent that the physical and biological framework of our environment is an intricately interwoven system. The input from man—either intentional or otherwise—has an effect which ultimately is controlled by the system itself.

These complexities vary considerably in detail from region to region. Mark Twain’s alluvial valley and delta provide an excellent example of the strong effect of regional complexities. The Mississippi’s assets include its navigable channel and the rich natural levee deposits that bound it, while its tendency to flood and to migrate by meandering are deficits. The U.S. Army Corps of Engineers has endeavored to enhance navigability and to protect the natural levees by controlling floods and stabilizing banks. In so doing, however, they have eliminated the river’s ability to construct new natural levees through deposition at the time of overflow. Meanwhile, inability to completely stabilize banks has resulted in the loss of previously existing natural levees. Other complex aspects of the lower Mississippi alluvial valley and its delta include population distribution, agricultural pattern, and natural resource and industrial development.

The alluvial valley of the Mississippi River and its delta constitute approximately half of southeast Louisiana. A distinctive pattern of land use exists, with the natural levees of the present and ancient channels originally providing the only land suitable for rural and urban habitation and develop-

ment. Generally, this still is true today. The remainder of this area consists of swamps, marshes, and myriad interconnected streams. With the exception of the Mississippi and Atchafalaya Rivers, the streams are very sluggish and drainage is poor. The Mississippi River, in particular, dominantly influences the region. It drains nearly half of the continental U.S. and, together with its major distributary, the Atchafalaya River, now carries approximately 1,700,000 tons of sediment daily to the Gulf of Mexico.

The Mississippi also provides fresh water and navigable facilities to scores of industries and cities which line its banks. An expensive system of levees and floodways has been constructed to protect the land use of its alluvial valley. The lower alluvial valley is confined by terraced uplands which progressively decrease in elevation southward. In an area 25 miles southeast of Baton Rouge on the east side, and in the vicinity of New Iberia on the west side, this older surface slopes beneath the present fan shaped deltaic plain.

The climate of the region is distinctive. Large masses of moisture-laden air, blown inland from the Gulf of Mexico, have blessed the area with abundant rainfall. A high runoff from the streams and at least partial recharge of groundwater aquifers is thus assured. Furthermore, because of the wind pattern, the development of atmospheric inversions conducive to extreme air pollution conditions is uncommon. While these are plus factors, the same set of climatic conditions is responsible for occasional hurricanes. The devastation caused from these frightful storms is accentuated by the low relief of the coastal areas.

## Industrial development

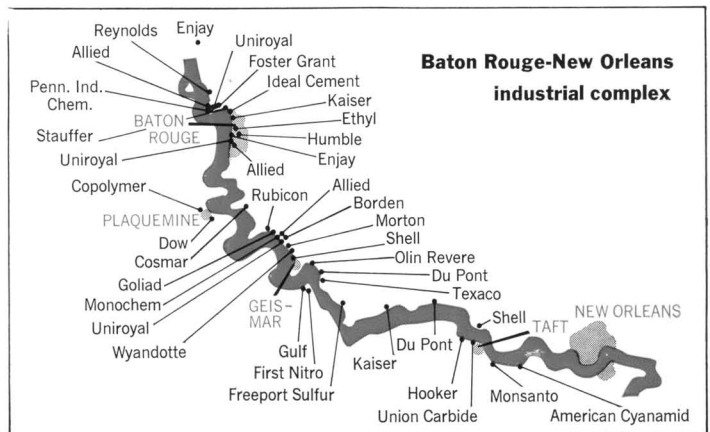
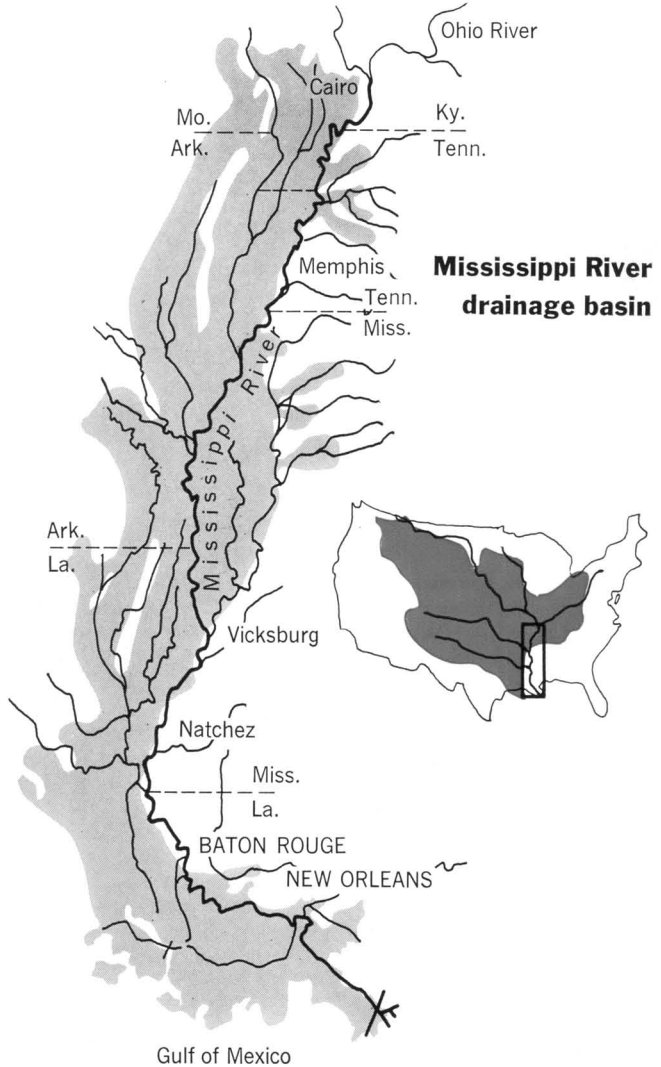
Vast underground mineral resources constitute a major regional factor in the pattern of environmental development. In 1967, petroleum produc-

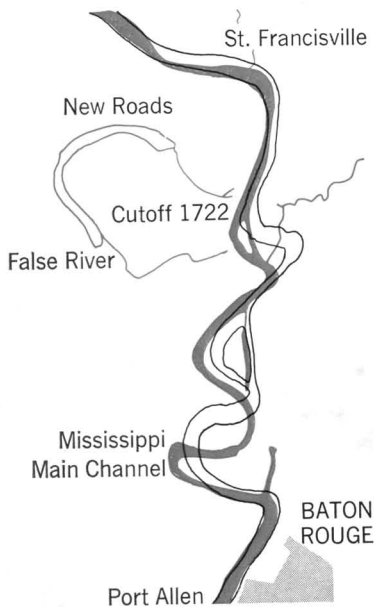
tion in Louisiana amounted to more than \$3.5 billion; sulfur, more than \$140 million; and salt, nearly \$50 million. A major part of this mineral wealth was produced from the southeast part of the state. In Twain's day, the agricultural potential was well developed (and is tremendously more so today), but the enormous possibilities of the mineral resources were undreamed of; the gold that Cortez and the conquistadors sought was, figuratively, buried in the Gulf Coast. The presence of these natural resources has been a major factor in attracting a great chemical complex to the area.

A major part of this industrial growth has occurred along the banks of the Mississippi. The river serves as both a superb waterway and a source of the large quantities of water required by the modern chemical industry. The stretch of the river from Baton Rouge to New Orleans has been compared to the Ruhr valley in Germany. Certainly, the character of the region has been rapidly and markedly changed; however, the blessings of this development have not been obtained without a price. The usual air, water, and thermal pollution and noise associated with large chemical plants now threaten the tranquility and health of the populace.

Somewhat less appreciated is the disappearance of the unique culture that once graced the banks of the Mississippi and was described so eloquently by Mark Twain.

The Mississippi River, its alluvial valley, its delta, and the associated natural and artificial processes, must be understood for proper environmental planning in southeast Louisiana. This is especially true with regard to major changes in the surficial environment. However, these physical characteristics also are a very important set of basic parameters to consider in planning concerned with air, water, thermal, and noise pollution.





**Meander.** False River (above) was formed by natural short circuit in main channel of the Mississippi River

#### Alluvial and deltaic processes

The especially unique environmental aspects of the Mississippi's alluvial valley and delta—more than 30,000 square miles of it—are its relative youth, the changeable nature of its surficial features, and its susceptibility to large-scale alteration by man. Generally, other types of physiographic regions can be modified only to a more limited degree. Major control of geologic processes elsewhere usually consists of changes to the groundwater regime.

Since the close of the last continental glaciation more than 15,000 years ago—which was followed by a rise in sea level of several hundred feet—the Mississippi has meandered back and forth across the valley, filling it with deposits of sand, silt, and clay. During this period of time, a series of deltas has been built and abandoned on the continental shelf, culminating in the modern bird's foot delta.

A complicating factor is the regional subsidence of the deltaic plain, particularly along the coastal margin. In the area where sedimentation is concentrated locally, the effect of subsidence is counteracted and the delta is extended gulfward, thus lengthening the channel and eventually resulting in abandonment of the channel for a new and shorter course. The abandoned sub-delta eventually sinks beneath gulf level and is destroyed by coastal waves and currents.

H. N. Fisk traced the development of these ancient channels and deltas. The two remarkable things about this changing pattern of the river are its relatively rapid tempo of movement and the apparent delicate balance of its temporary positions of equilibrium. Of the early channels of the lower Mississippi, Old River now is a large oxbow lake created by the Raccourci cutoff of 1848, and False River was formed in 1722 by abandonment of a former meander loop. The farthest downstream point where rapid changes occurred is in the Solitude Point-Thomas Point area just northwest of Baton Rouge. A little farther north, the town of Port Hudson (a Civil War battle site) has been abandoned because the river meandered away from it. Channel changes between Baton Rouge and the Gulf during historic time have been relatively minor because this part of the channel is cut into silt and clay rather than sand.

#### Artificial changes

The works of man have had some effect on these channel and deltaic changes. This effect has become increasingly important with time. Considered broadly, these man-made changes have been effected in two ways:

• **As a result of deliberate attempts to control the river.** For example, the Bonnet Carre Spillway was built just west of New Orleans to divert flood waters at critical times

from the channel to Lake Pontchartrain. This spillway, used only three times (1937, 1945, and 1950) has not resulted in any permanent major changes other than some filling of the spillway itself. There is a contrasting pattern of land use on either side of the spillway—the old, typical agricultural development of the natural levee, and, opposite, a modern petrochemical plant. The West Atchafalaya, Morganza, and Atchafalaya Basin Floodways have had profound environmental effects. The streams, lakes, swamps, and wildlife within and without this system have been drastically altered in order to provide a second major outlet of floodwaters to the sea. Related to this vast project has been the design of control structures to regulate the flow of the Atchafalaya River—the most important and northernmost distributary of the Mississippi River. An increase in the flow of the Atchafalaya River, observed as early as 1880, continued at a rapid rate during the 1930's and 1940's. The possibility of modern abandonment of the Mississippi's channel from the head of the Atchafalaya River to the Gulf in favor of the shorter route by way of the Atchafalaya alarmed the Corps of Engineers, prompting the corps to commission a study by Fisk, Kolb, and Wilbert to investigate the likelihood of this occurrence. As a result of this study, it was decided to build a control-gate structure at the origin of the Atchafalaya to limit its flow and prevent diversion of the Mississippi. This represented a major environmental control by man.

This great river, one of the largest in the world, has—for the moment—been tamed. Its channel has been shortened, part of its flow is diverted by floodways, and it is contained by levees for much of its length and throughout the region under discussion. It remains to be seen whether such control can be maintained effectively.

• **Large-scale developments in the alluvial valley and the delta that have resulted in unplanned changes.** In this category, the exploitation of petroleum resources can be considered a major influence. In order to reach critical areas in the swamps of the valley and marshes of the coast and delta, many miles of canals were constructed to tie in with the complex interconnected system of bayous and rivers. These canals have altered

water distribution and wildlife patterns. And the very fact that they have made an extremely remote area readily accessible also has affected wildlife distribution.

The most striking changes have occurred in the delta. Comparisons of aerial photographs taken in 1950 and 1968 show that a large section of marshland in the delta has become open water. The effect of this major physiographic and environmental change on wildlife is, as yet, unknown.

A few examples have been given of large-scale man-made changes in the regional environment that have had unexpected and unintended results. An assessment of their ultimate worth is difficult to make and any conclusions will have to be based on highly subjective considerations.

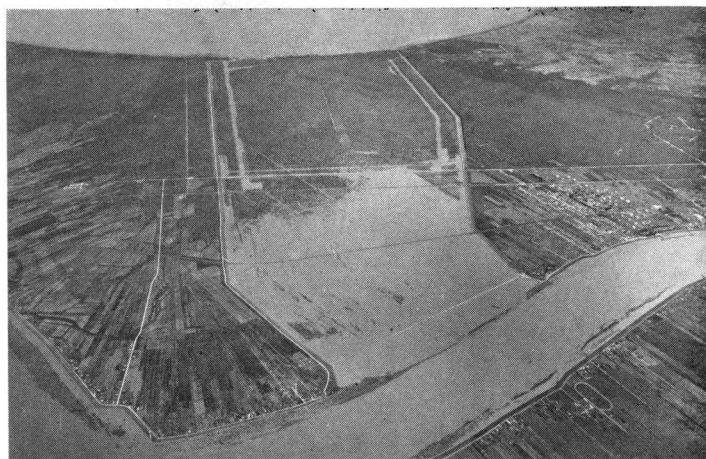
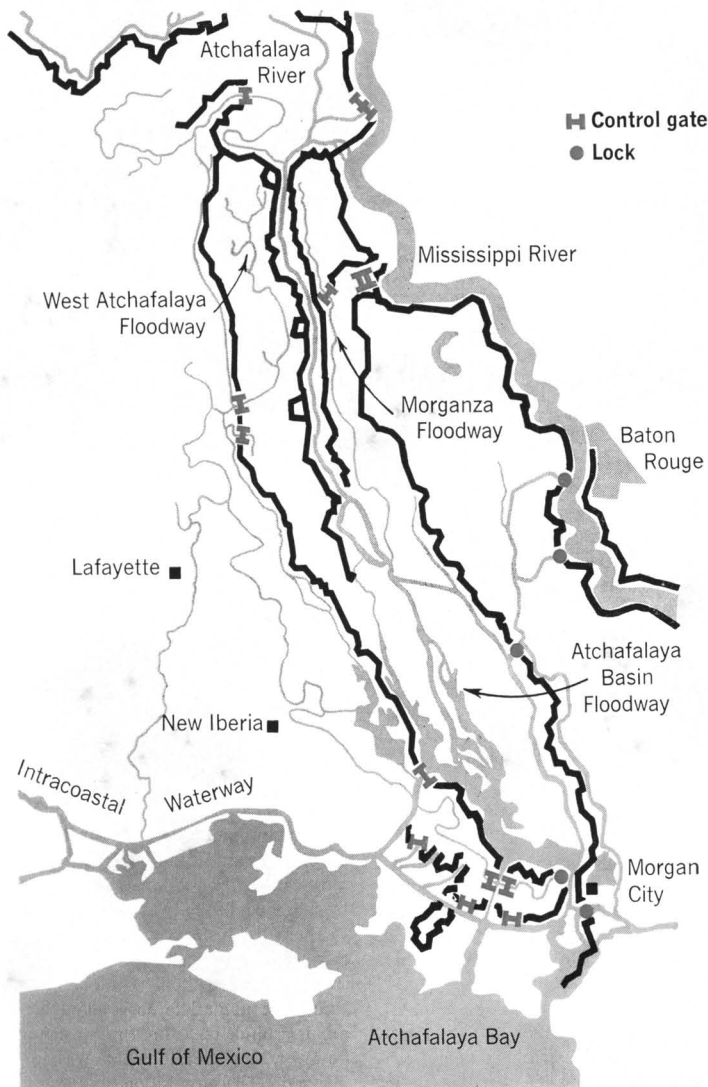
#### Future possibilities

Many opportunities for further environmental changes still exist. The ease of major physical changes in the environment, with attendant biological alterations, results from the relatively high rate of the geological processes in operation here. The natural processes operable in this alluvial and coastal environment proceed at a much higher rate than do most other geologic processes.

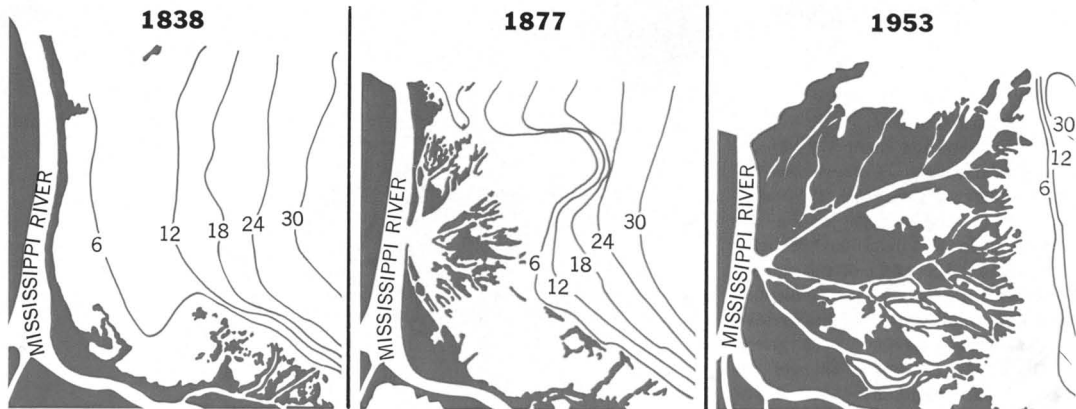
Three examples of such engineered changes include one dealing with the modern channel of the Mississippi, another with the delta, and the third with Lake Pontchartrain.

One of the prime large recreational bodies of water nearest Baton Rouge is False River, an abandoned channel of the Mississippi. However, it is about 20 miles from the city, which is undergoing rapid growth as an urban and industrial center. Fortunately, the natural pattern of the Mississippi River and the plans for its control by the Corps of Engineers present the opportunity for creating a lake similar to False River within five miles of Baton Rouge.

A large constricted meander loop occurs in the Mississippi River between Baton Rouge and Plaquemine, just northeast of Plaquemine. The point of land enclosed by this loop is known as Manchac or Australia Point. The Corps of Engineers has built a levee across this point so that a cutoff could be made across the point in times of exceptional flooding. This option has never been implemented, but it remains an active possibility. It is suggested that a new



**Diversion.** Bonnet Carre Spillway, built for flood control, has caused no permanent changes in drainage basin other than filling of the spillway itself



**Marsh growth.** Ditch cut across dike in 1862 inadvertently caused slow formation of sub-delta (water depth in feet)

channel (for the river) be constructed across the neck of the point. The construction of two dams across the present channel then could create a large lake similar to False River. One of these dams would be located across the north arm of the meander downstream from the beginning of the new cutoff, the other at the bendway just north of Manchac Landing, where a proposed waterway would connect the Mississippi to Lake Pontchartrain and points east.

The portion of the old channel thus closed off would serve as a large, deep recreational lake of great beauty. The dam at Manchac Landing would ensure that the southern arm of the bend would remain open to serve as a deep water port to industries that may build along its banks.

A more ambitious proposal envisions the transformation of Lake Pontchartrain from a brackish to a fresh water lake. This change would be effected by constructing a dam and lock system in the Rigolets, which connects Lake Borgne and, through it, with the Gulf of Mexico. After the brackish water is flushed out, the new, fresh water character of Lake Pontchartrain would be maintained principally by the Tangipahoa, Tchefuncte, and Amite Rivers which flow into Lake Maurepas which outlets into Lake Pontchartrain through Pass Manchac. If the flow of these three rivers proves insufficient to reduce and maintain the salinity of the lake at an acceptably low level, it might prove feasible to divert the flow of Pearl River into the lake. (This proposal probably will meet with serious objections from the fishermen who operate in the lake.) Careful con-

sideration will have to be given to the advantages and disadvantages which would follow from this development.

A third proposal—the formation of a new sub-delta for the Mississippi River—would involve significant physical and ecological changes for the region. It has already been pointed out that major changes have occurred in the present delta with attendant loss of marshland because of man's activities. The forced development of a new sub-delta would replace all or part of the marshland that has been invaded by marine waters. However, adverse effects would occur, with almost certain destruction of oyster beds by subsequent salinity changes.

There is historical precedent for this action by man. In 1862, construction of a ditch (Cubitts Gap) across the natural levee resulted in a minor sub-delta. In this instance, however, the development was unplanned. The proposition offered here is novel, since the idea advanced is to deliberately form a man-made delta. Similar suggestions probably have been made in the past but have not been formally presented in the literature.

All of the three proposals described represent major alterations in the geomorphology of the region, with consequent effects on the biological community—including man. This is particularly true for the last two ideas. Serious consideration of all consequences would have to be given before any implementation of these ideas could be undertaken. In fact, we want to stress the interactions which follow single purpose acts designed to change conditions in this kind of region and to emphasize the need for early study and thought of unfavorable feedback.

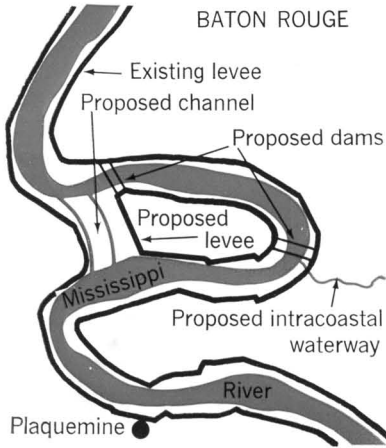
### Conclusions

A general principle to consider in modifying, regulating, or controlling large-scale geologic features or processes is to use the natural forces, so far as possible, to create a desired effect. For example: It is a natural tendency for a river like the Mississippi to meander. Attempts to rigidly maintain the position of its channel by the use of such controls as levees and revetments pit the engineer against the natural forces of the river. Cutoffs, spillways, newly constructed distributaries, and other similar works are compatible with natural morphological changes, however, and use the natural forces to advantage. It is not intended to imply that levees and revetments should not be used as control structures, but it is suggested that their basic artificial nature should be recognized in planning their use.

The complexities of the interaction between the total environmental system (land, water, and air) are well known. We call attention to the unique nature of these relationships for a specific kind of regional environment represented by a low lying coastal area. Southeast Louisiana does have special sets of conditions. However, many parallels can be drawn with other coastal environments.

The significant point is the need for special consideration of regional factors in environmental planning and management. These regional factors go far beyond the set of physical parameters which have been discussed here. They also include such things as sociological and political characteristics and influences. These conclusions suggest the advisability of nationwide training of environmental planners,





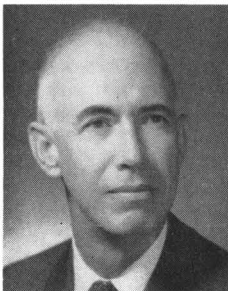
**Recreation.** Proposed Manchac cutoff would create a large artificial lake

engineers, and scientists. Certainly, such programs should not be provincial. However, there will be a real need for environmentalists with a special knowledge of the regions in which they will work.

**ADDITIONAL READING**

Fisk, H. N., "Geological Investigation of the Alluvial Valley of the Lower Mississippi River," Mississippi River Commission, Vicksburg (1944).  
 Fisk, H. N., et al., "Geological Investigation of the Atchafalaya Basin and the Problem of the Mississippi River Diversion," Waterways Experiment Station, Vicksburg (1952).  
 Kolb, C. R., and Van Lopik, J. R., "Depositional Environments of the Mississippi River Deltaic Plain—South-eastern Louisiana Deltas in their Geologic Framework," Houston Geological Society (1966).  
 Twain, Mark, "Life on the Mississippi," Harper (June 1896).  
 Welder, F. A., "Processes of Deltaic Sedimentation in the Lower Mississippi River," Tech. Report No. 12, Coastal Studies Institute, Louisiana State University, Baton Rouge (1959).

**Joseph D. Martinez** is professor of environmental engineering, assistant director of the Environmental Sciences Institute, and director, Institute of



**Delta.** Aerial photographs taken in 1950 (top) and 1968 (bottom) show that large areas of marshland have become open water. Long-term effects are unknown

Saline Studies, Louisiana State University. Previously, he taught at the University of Wisconsin, Northern Illinois University, and Rice University. He received his B.S. (1937), M.S. (1952), and Ph.D. (1959) from Louisiana State. A contributor to many journals and scientific publications, Martinez holds several patents. He is a member of the American Geophysical Union, American Association of Petroleum Geologists, Geological Society of America, and Sigma Xi.

**Clarence O. Durham, Jr.**, is director, School of Geology, and professor of geology, Louisiana State University. Previously, he was chairman of the geology department, and director of research for the Louisiana Geology Survey. He received his B.S. from the University of Texas (1942) and his Ph.D. from Columbia University

(1957). Durham has served as consultant to oil and mineral companies, and directed a study of the geological aspects of the Baton Rouge groundwater survey. He is a member of the American Association of Petroleum Geologists, American Geophysical Union, AAAS, Sigma Gamma Epsilon, and Sigma Xi.



# Designing for air conservation

Applying sound criteria to potential emission sources should be first step in design and development

**Joseph T. Ling and  
Michael J. Bolduc**

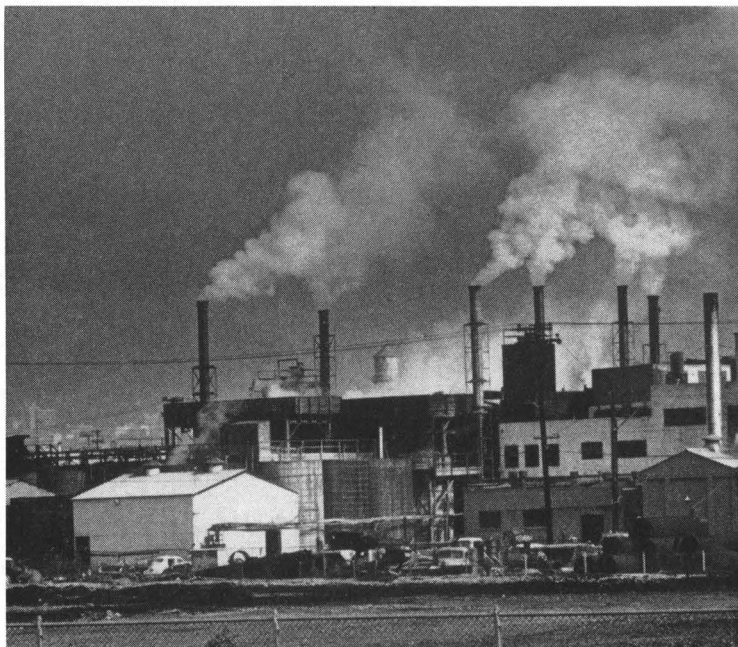
*3M Co., St. Paul, Minn. 55101*

Conservation of air is a matter of major and growing concern. As the Air Conservation Commission of the American Association for the Advancement of Science recently stated, "The commission has been impressed by the need not only to control pollution, but also to develop programs to conserve the air." The application of a basic concept of industrial air conservation programs to process design and product development, we feel, requires additional emphasis in the overall air pollution control problem.

The concept of air conservation can be related directly to the dictionary definition of conservation: "deliberate, planned or thoughtful preserving; . . . preservation." In other words, air conservation is the preservation of air as a natural resource. As applied to industrial activity, it means the prevention of emission of undesirable materials to the air by thoughtful planning at the process design and product development stages, and should be the first step in any air pollution control program.

## **Foresight**

Air conservation should be distinguished from other basic methods for correcting air pollution problems, such as removing the pollutant material from an effluent just prior to the final exhaust stage. This normally is accomplished by the addition of control equipment at the point of exhaust; the equipment often is added after a production facility has been designed and put in operation. In most cases, air pollution control is actually an afterthought, without proper consideration given to this problem prior to plant construction.



Another control technique—atmospheric assimilation—has been utilized to dilute pollutants after they are emitted. However, the environment—especially on a local or regional basis—has a limited assimilation capacity, and these limits must be understood at the early stages in the design and development of source operations.

A successful industrial air conservation program begins with increased communications between research and development personnel, pilot plant operators, and engineers within a company. By creating an awareness of the problem, new criteria can be applied to process design and product development. Awareness of the potential air pollution problem is initiated by asking some basic questions: Will the process or product have an effluent? Will it create an effluent in its operation, use, or disposal? Does the effluent have potential air pollution capability?

## **Process design**

Air conservation can be applied to process design in each of four different phases of a manufacturing operation—

raw materials, process reactions, process equipment, and operating procedures.

• **Raw material substitution.** It is possible that a nonessential ingredient in the raw material may cause an air pollution potential. In this case, removal of the nonessential ingredient before the raw material is introduced into the process should be explored. If the raw material itself presents the air pollution potential, use of an alternate material should be studied.

An example of the removal of an unwanted raw material ingredient to prevent air contamination is the substitution of low sulfur fuel oil and coal in boiler operations to reduce sulfur dioxide emissions. Regulations requiring use of low sulfur fuels are in effect in most of the areas on the East Coast, and fuel desulfurization methods are being developed by the coal and petroleum industries. The selection of raw materials—in this case, the boiler fuel—represents an application of air conservation to new boilers as well as boilers in existing plants.

Another example of substitution of an alternate raw material to prevent air

pollution is the use of nonreactive solvents in process operations in areas where photochemical smog is a problem and solvents are evaporated to the atmosphere. Regulations requiring this substitution are in effect in several regions of the West Coast. In this case, the solvent itself may be reformulated. Promulgation of hydrocarbon solvent regulations to control photochemical smog has created a new demand for aqueous solvent systems for many process operations.

• **Process modification.** Modification of a process to correct a potential air pollution problem requires examination of the reactions and unit operations involved. Some unit operations may be added to conform with the objectives of air conservation. These ideas can be applied to a wide range of process sizes and types.

The use of thermonuclear energy to replace fossil fuel in electrical power generation is process modification on a large scale. The unit operation, in this case, is changed from fuel combustion to nuclear fission, and one criterion for making this change is a reduction in air pollution potential.

Another process modification for correcting an air pollution potential is utilization of electric battery or fuel cell power to replace the internal combustion engine for motor vehicles, or the use of the cleaner burning turbine engine to replace the piston engine. Here again, one of the incentives for making this change in unit operation is the air pollution problem created by the internal combustion engine now used in automobiles.

The addition of a unit operation to a process can present an opportunity for byproduct recovery. For example, in the petroleum industry, waste hydrogen sulfide gases that used to be burned in flares now are reacted by the Claus process to yield elemental sulfur. This process modification produces one and a quarter million tons of sulfur per year in the refinery industry in addition to preventing an air pollution problem.

Byproducts need not always be recovered; they can be used in other ways. For instance, in hydrocarbon solvent drying operations, the solvent in the exhaust gases can be either col-

lected for reuse, or used as a source of heat for the drying process. The addition of a catalytic or direct flame combustion unit and a heat exchanger to the process can make this heat available. The use of such closed loop processes that recycle either waste solvents or heat from the solvents is gaining increased attention as a process technique.

• **Equipment alteration.** Another approach to air conservation takes the form of either alteration of the basic equipment or replacement of one type of equipment with another. This obvious approach to correcting the air pollution potential of a process often may be overlooked because of time honored methods of equipment purchase and use.

Equipment alteration ranges from the use of floating roof storage tanks in place of vapor vented tanks in refineries and solvent plants to the use of reverberatory furnaces in place of cupolas in iron foundries. More well-known examples are alterations to the internal combustion engine to reduce automotive emissions. The positive crankcase breather valve system now used to return crankcase vapors to the carburetor is one result of applying air conservation criteria; others include such engine changes as carburetor leaning, spark retardation, and so on.

In industrial applications, whether to make equipment alterations often can be decided by evaluating the arrangement and the ventilation requirements for process operations. This may reveal that some operations are over ventilated and create increased evaporation or entrainment of material. The replacement of open vat cooking kettles or open air operations under a hood with a closed reactor may significantly reduce air pollution. In some cases, the hood over an open vat cooking operation can be redesigned to reduce the overall exhaust volume and reduce the size and cost of any control equipment required.

• **Procedural changes.** Changing operating procedures, although not as well documented as other approaches to air conservation, is, nevertheless, a basic method that often can be applied where atmospheric assimilation is relied upon to disperse contaminants.

This can be illustrated by the Tennessee Valley Authority power plant at which sulfur dioxide emissions are reduced during adverse meteorological conditions by changing to a low sulfur fuel. It is also common practice in boiler operations to employ special procedures for starting, cleaning, and stoking fires.

An example of procedural changes for air conservation that occurred at 3M Co. recently involved addition of reactants to ventilated batch operations. Some reactants with strong odors were being evaporated in large amounts when the operators made manual additions to the batch process. These peak concentrations in the exhaust caused odors downwind from the plant. Instead of adding a wet scrubber or other air pollution control equipment to control the exhaust, the operating procedures were changed to feed reactants at a controlled rate to the process; evaporation of material was reduced to a minimum. This not only corrected the odor problem, but allowed a reduction in the total amount of reactant required for the process.

Procedural changes are most useful where manual operations can be replaced by automatic control. The continuous development of operating procedures and good housekeeping practices that are consistent with air conservation principles is an important part of maintaining an effective industrial air pollution control program.

Many other examples of application of these four approaches to air conservation in process operations can be cited. In some cases, a combination of approaches can be used; however, this is most useful at an early stage of process design.

#### **Product development**

For purposes of applying air conservation to product development, it is possible to consider a product at three stages: Manufacture, use, and disposal. The manufacturing process has already been discussed; here we shall consider criteria involving a product's use and its ultimate disposal.

• **Product use.** Safety and hygiene have long been considerations for product use; now it is becoming necessary to add one more consideration, air

conservation, to both consumer products and intermediate products for industrial use.

The photochemical solvent regulations represent one example of applying product use considerations. Some of the regulations impose on the seller restrictions or responsibilities for product composition. For example, the sale or use of hydrocarbon solvent containing material of photochemically reactive composition in one quart containers or larger is prohibited. In addition, the use of a photochemically reactive solvent for architectural coatings is restricted to emissions of one gallon per day. These restrictions point up the necessity of considering air conservation criteria where product use will be a factor in air pollution.

An example of an intermediate product that is subjected to similar requirements is fuel oil. As previously mentioned, the sulfur content of fuel oils is subject to restrictions in some areas on the East Coast, and the refinery producing this product must apply air conservation criteria to the product as well as to the refinery process.

On a larger scale, the automobile is a product that is now subject to air conservation needs in its future development. This sequence of events, where the requirements which were once regional and are now nationwide, has set the pattern for other products now faced with regional restrictions. The two factors accelerating this trend are the interstate nature of most markets and the economy of producing a uniform product throughout all areas of the country.

• **Product disposal.** In general, not all ingredients of a product are completely consumed in its use. The residual material must be disposed of. Due to the tightening of air, water, and land pollution regulations at various government levels, air conservation considerations should be applied to the product residue itself, including those times contaminated by the product, such as containers. This is becoming increasingly important to a society which stresses disposable consumer products and no deposit-no return containers. Landfill has been a common practice for final disposal, but is not satisfactory when the residual

products are nondegradable or may contaminate the soil or groundwater.

Disposal of product residues by incineration is likely to be the future trend, and will require evaluation of both the degree of combustion that can be achieved and the products of combustion. This is particularly important in combustion of halogenated byproducts and hydrocarbon materials which produce combustion products such as phosgene and oils.

Applying these conservation considerations during process design and product development not only can aid in correcting an air pollution potential but also can determine true profitability and marketability. It is important that this be done at the research and development and pilot plant levels—before any new process or product reaches its final stage.

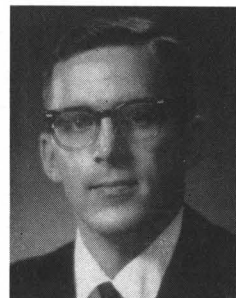
The air conservation program in any business organization should start with strong management support and be implemented through intracompany coordination and information exchange. In large industries, this can be done through a central staff with defined responsibilities for pollution control and awareness. One of the most useful methods for creating the required awareness is the use of seminars for key personnel in design and development. Efficient distribution of pertinent literature and updating of regulatory requirements also are helpful.

This is especially important in a multiproduct company. The 3M Co., for instance, markets more than 40 major product lines and has 100 manufacturing plants in the U.S. and abroad. The importance of applying air conservation at the design and development levels is borne out by the fact that 25% of the products presently marketed by 3M were developed in the last five years.

The concept of air conservation represents prevention of pollution before the fact by close scrutiny at the process design and product development stages. In the long run, this could result in a considerable saving in the total cost of an industrial air pollution control program. Air conservation or air pollution prevention will receive increasing emphasis in industrial pollution control programs.



**Joseph T. Ling** is manager, environmental and civil engineering department, 3M Co., a position he has held since 1960. Previously (1953–60), he was with General Mills Co. He received his B.S. from Hangchow Christian College, Shanghai, China (1944), and his M.S. (1950) and Ph.D. (1952) from the University of Minnesota. A registered professional engineer, Ling is the author of a number of technical papers. He is a member of the American Society of Civil Engineers, Air Pollution Control Association, Water Pollution Control Federation, and American Water Works Association.



**Michael J. Bolduc** is senior air pollution control engineer, environmental and civil engineering department, 3M Co., a position he has held since 1966. Previously (1962–66) he was chemical engineer, Universal Oil Products. Bolduc received his B.S. from the University of New Mexico (1962), and is completing graduate work at the University of Minnesota. The author of numerous papers, he is a member of the Air Pollution Control Association, Minnesota Association of Commerce and Industry, Metropolitan Clean Air Committee, and ACS.

## Pesticides in Drinking Water

### Waters from the Mississippi and Missouri Rivers

M. L. Schafer, J. T. Peeler, W. S. Gardner,<sup>1</sup> and J. E. Campbell

Consumer Protection and Environmental Health Service, Public Health Service, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio 45202

Over 500 grab samples of finished drinking water and related raw water were assayed for 10 organochlorine pesticides, their metabolites, and related compounds. The samples were collected between March 1964 and June 1967 from 10 selected municipal finished water supplies whose source was either the Mississippi or the Missouri River. Both 100-ml. and 1-gallon sample sizes were assayed. Included is a statistical evaluation of the one-step extraction method using 1-gallon samples to which known amounts of the 14 compounds were added at levels ranging from 0.06 to 5.0 p.p.b. Over 40% of the finished water samples contained detectable dieldrin and more than 30% contained detectable endrin, *p,p'*-DDT, and *p,p'*-DDE. Twenty per cent of the 63 samples assayed for chlordan contained detectable concentrations; five of these were in excess of 0.25 p.p.b. Aldrin, HCE, and heptachlor were found only occasionally. No toxaphene nor methoxychlor was detected.

In the early 1940's, a synthetic organic compound was used for the first time for pesticidal control. The effectiveness of this organic compound, commonly called DDT [1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane], stimulated the synthesis of many organic compounds with varying degrees of pesticidal, herbicidal, and fungicidal activity. Today a large number of these synthetic compounds are being used routinely as pesticides in agricultural programs. One type, the organochlorine compounds, including dieldrin (1,2,3,4,10,10-hexachloro - 6,7 - epoxy - 1,4,4a,5,6,7,8,8a - octahydro - 1,4-*endo,exo*-5,8-dimethanonaphthalene), endrin (1,2,3,4,10,10-hexachloro - 6,7 - epoxy - 1,4,4a,5,6,7,8,8a - octahydro - 1,4-*endo,exo*-5,8-dimethanonaphthalene), and aldrin (1,2,3,4,10,10 - hexachloro - 1,4,4a,5,8,8a - hexahydro - 1,4 - *endo,exo*-5,8-dimethanonaphthalene), is not readily degraded under normal conditions. Although extremely small concentrations of these compounds are required for pesticidal control, the effect on public health of their gradual increase in our environment is under close scrutiny.

Realizing that river water was becoming contaminated with

these organochlorine compounds from runoff after permissible spraying procedures and possibly from careless handling of these compounds during manufacture or application, the Public Health Service has monitored major river basins in the United States for organochlorine pesticidal compounds since 1957. Breidenbach, Gunnerson, *et al.* (1967) report that the presence of DDT and related compounds has been fairly common during the entire period and that dieldrin has dominated the pesticide occurrences in all river basins since 1958.

The observation that the massive fish kills in the Mississippi River in 1963 were produced by one of these, endrin, caused concern about the efficiency of water treatment plants in removing these compounds from finished drinking water where river water is the source. Many of these pesticides, such as DDT, may occur in the water with no observable effect on odor or taste.

To monitor the river water, the pesticides from several thousand gallons of water were concentrated by adsorption on carbon. Assays were then made of the chloroform extracts of the carbon. The results from this method indicate general trends of contamination. To detect the high concentration that might occur in a spill of pesticides into water, grab samples must be assayed. When this surveillance study was started, no suitable methods were available to detect pesticides in the part per billion (p.p.b.) concentration range in small samples of water. Now, with the gas chromatographs equipped with electron-capture detectors, a 1-gallon sample can be quantitatively assayed for organochlorine compounds in this concentration range. Also, there were no suggested limits for these pesticidal compounds in finished waters. Concentrations in the part per trillion (p.p.t.) range were being reported for river water.

In 1964, a concentration level of 0.1 p.p.b. was used as the lower limit for the quantitative assays for endrin, dieldrin, *p,p'*-DDT, and related compounds in the grab samples of finished water. Concentrations less than this were reported as "detectable." In 1965, maximum permissible levels were assigned to each of the organochlorine compounds based on the "maximal acceptable concentrations" suggested on July 9, 1965, by the Subcommittee on Toxicology to the Public Health Service Advisory Committee on Drinking Water Standards. These concentrations ranged from 0.001 p.p.m. for endrin to 0.078 p.p.m. for heptachlor. In 1967, the "maximum reasonable stream allowances" suggested by Ettinger and Mount (1967) were accepted as guidelines. These ranged from 0.1 p.p.b. for endrin to 20 p.p.b. for methoxychlor.

<sup>1</sup> Present address, Department of Water Chemistry, U. of Wisconsin, Madison, Wis. 53806

With the use of gas chromatographs equipped with electron-capture detectors, a precision of  $\pm 0.01$  ng. per 5  $\mu$ l. is easily attainable for solutions of the commonly used organochlorine pesticides in concentration ranges from 0.1 to 1 ng. per 5  $\mu$ l. (20 to 200 ng. per ml. or p.p.b.). Residues of these compounds are extracted from the environment into organic solvents. For increased sensitivity the solvents may be concentrated before portions are chromatographed. The vapor pressure of these compounds is such that the error due to loss during the concentration step is minimal if the final volume is at least 1 ml. With smaller final volumes, considerable skill is required for quantitative analysis. If the pesticide analyst has an unlimited supply of the environmental media available for assay, purification steps can be included, so that it is possible to observe these residues when they are present in a part per trillion range.

Two methods were used in this surveillance study. One required a 100-ml. sample and the other a 1-gallon sample. During 1964, 100-ml. samples were collected for assay. Studies to evaluate the precision and accuracy of this method, employing the recovery of endrin added to the water at a level of 0.1 p.p.b. were run parallel with the surveillance samples. In 1965, the method using 1-gallon samples was developed, and both 100-ml. and 1-gallon samples were collected for assay. In 1966-67, only the statistically evaluated method, using 1-gallon samples, was used.

The number of pesticides looked for in the water samples was gradually increased from the initial three compounds, endrin, dieldrin, and DDT, to a total of 14 compounds including 10 pesticides, their metabolites, and related compounds.

#### *Experimental Procedures and Materials*

**Sampling Sites.** Grab samples were collected from municipal finished-water treatment plants in Carville, La.; Algiers Treatment Plant, New Orleans, La.; Carrolton Treatment Plant, New Orleans, La.; Vicksburg, Miss.; Cape Girardeau, Mo.; Burlington, Iowa; St. Louis, Mo.; Jefferson City, Mo.; Kansas City, Mo.; and Omaha, Neb.

**Sample Preparation.** MATERIALS. Gallon jugs with flat bottoms and narrow mouths, capped with Teflon-covered cork-lined plastic caps, were calibrated at the 3.5-liter volume level. Glass-stoppered, 125-ml. reagent bottles were calibrated at the 100-ml. volume level.

**COLLECTION OF SAMPLES.** After the jugs and bottles were cleaned and calibrated, they were shipped in insulated containers to the sampling stations. Water samples were collected directly in the jugs or bottles. A 10-ml. volume of pesticide quality hexane was added immediately to each sample, and the jug or bottle was closed tightly, and shipped in the insulated container to the laboratory in Cincinnati, Ohio, by air parcel post.

**EXTRACTION.** In both the 1-gallon and the 100-ml. methods, the pesticides were extracted from the water phase into the hexane phase without a transfer step. For this, the 100-ml. water samples, each containing 10 ml. of hexane, were shaken for 4 minutes. For the 3.5-liter samples, each containing 10 ml. of hexane, the gallon jug was placed on a stir jack somewhat off-center from the stirring motor. When the stirring apparatus was started, the hexane was drawn down through the vortex formed in the water by the rotating stirring bar and circulated in the form of small droplets into the water. These droplets rose through the water to the top of the jug and recirculated through the vortex. Placing the jug off-center on the stir jack caused the bottom of the vortex to be slightly

off-center from the center of the rotating stirring bar. In this position, the stirring bar tended to "cut off" the lower portion of the hexane vortex and resulted in greater displacement of hexane and in more uniform droplets of hexane. The stirrer kept the water in motion, so that the circulating hexane was relatively evenly distributed throughout the water sample during the extraction.

After extraction, sufficient water of known quality was added to both sized samples so that the hexane layer was localized in the neck of the bottle. A portion of the hexane layer was transferred to a conical 15-ml. centrifuge tube with the use of a suitable device such as a pipet and pipet bulb or dropper. Quantitative removal of hexane was not required, since calculations were based on the original volume of hexane added. The extracts were then transferred to dry, conical, 15-ml. glass-stoppered centrifuge tubes and held until assayed. The intermediate transfer step was useful in obtaining a hexane sample free of the water phase. Occasionally there was an emulsion at the interface of the two phases; if so, it was broken during the intermediate step. Five-microliter portions of the hexane extracts from the gallon sample, representing extractives from 1.75 ml. of water, were chromatographed. The hexane extracts were concentrated by placing each centrifuge tube in a beaker of water on a steam bath for the statistical evaluation of the method for chlordan, toxaphene, and endrin, and for the routine assays of the drinking water samples.

For the 100-ml. samples, the hexane extract was chromatographed after a fourfold concentration (from 8 to 2 ml., where 5  $\mu$ l. of extract represented extractives from 0.2 ml. of H<sub>2</sub>O) and again after an additional 20-fold concentration, where 5  $\mu$ l. represented extractives from 4 ml. of H<sub>2</sub>O. This 20-fold concentration step was sensitive to small deviations in handling and was the source of the low precision observed with this method as compared with the method employing a 3.5-liter sample.

**Assays.** All assays were run on gas chromatographs equipped with electron-capture detectors. The following instruments were used: Beckman Model 2 modified by the addition of electron-capture detector, Jarrell-Ash Models 26700 and 28-730, and MicroTek Model 220.

The Beckman and Jarrell-Ash units were equipped with parallel plate electron-capture detectors with a tritium source. These detectors were held at 210° C. for 24 hours a day, 7 days a week. The MicroTek unit was equipped with an electron-capture detector of the pin cup design with a Ni<sub>63</sub> source. This detector was held at 275° C. for 24 hours a day, 7 days a week. For all detectors, the potential across the electrodes was optimized when necessary to produce about 80% of the maximum current. Tritium foils were replaced when the maximum current dropped below  $2 \times 10^{-9}$  ampere. In routine work, this replacement was required about every 12 months. In the 2 years that the Ni<sub>63</sub> detector was in use on this project, the maximum current did not drop below  $4.0 \times 10^{-9}$  ampere.

Either prepurified or extra-dry nitrogen was used as the moving phase. A precolumn consisting of a 4-foot, 1/4-inch o.d. copper column packed with Molecular Sieve 5A, 60- to 80-mesh, was used on all of the instruments. The precolumns were activated just before use by heating to 500° C. for 2 hours. They were replaced when necessary; the lifetime was usually measured in months. Suitable flow control was maintained on the Beckman and Jarrell-Ash units with the second stage of the two-stage cylinder regulator. Flow rates, as measured by the soap bubble technique at the detector exit, of 30 to 100 ml. per minute were used. They varied with the column

Table I. Column Characteristics

Column	Length, Feet	Diameter, I.D., In.	Composition	Stationary Phase	Inert Phase	Mesh	Oper. Temp., °C.	N <sub>2</sub> Flow, Ml./Min.	Av. Life of Column, Months	Special Characteristics
1	6	1/8	Glass	5% DC-200	Gas-Chrom Q	80/100	200	30	<3	No on-column decomp.
2	4 1/2	1/4	Aluminum	3% OV-17	Gas-Chrom Q	60/80	190	70	over 12	No on-column decomp.
3	6	1/4	Aluminum	4% QF-1 2% Epon 1001	Anakrom ABS	50/60	200	60	6-12	Epon added to increase endrin sensitivity
4	5	1/4	Aluminum	3% XE-60	Gas-Chrom Q	100/120	175-200	100	6-12	
5	6	1/4	Aluminum	1% Apiezon L 2% Epon 1001	Anakrom ABS	50/60	202	130	12-18	Shift in rel. ret. of DDE and dieldrin
6	6	1/4	Aluminum	4% Reoplex 400 2% Epon 1001	Anakrom ABS	50/60	192	100	12-14	

diameter and length, the stationary phase, and the mesh size of the inert support.

The stationary phases used in these studies included:  
 Silicone gum. GE-XE-60, cyanoethyl methyl and dimethyl type  
 Silicone fluids. DC QF-1, trifluoro propyl methyl type  
 DC 200, methyl type  
 OV-17, methyl phenyl type (50-50)  
 Polyester. Reoplex 400  
 Hydrocarbon. Apiezon L  
 Polymer. Epon 1001 (epoxy resin)

The inert supports, either Gas-Chrom Q or Anakrom ABS, were used. The column characteristics are described in Table I. For the statistical evaluation of the preferred method, column 1 was used for series A and column 2 for series B and C. Columns 2, 3, and 4 were used for assaying finished-water samples, and columns 5 and 6 for verifying the identity of peaks observed on the other columns. The relative retention

times for 12 organochlorine compounds on the six columns are listed in Table II. Electron-capture detectors with a tritium source were used with columns 3, 4, 5, and 6. For these four units, 1 to 2 ml. of hexane were injected at the end of each working day. This routine that retards the gradual decrease in efficiency and sensitivity of the system was not required for column 2, which was attached to a detector with a Ni<sub>63</sub> source. Two sets of data were obtained on column 2 for evaluation of the precision and accuracy of the one-step extraction method. The first set was collected on the column just after it was built; the second set, 7 months later. During this 6-month interval, over 300 finished-water samples were assayed on this unit. The higher detector temperature is believed to be a major contributing factor in the stability of this unit over such a long period of time. During 1964, assays were run on columns containing Dow 11 and Epon 1001 coated on Fluoropak 80. These columns lacked the efficiency of those described above and were discontinued as more efficient stationary phases became available. Column 2, used on the

Table II. Relative Retention Times of Pesticide in Columns<sup>a</sup>

Pesticides	Liquid phase	DC 200	OV-17	QF 1 + Epon	XE 60	Apiezon L + Epon	Reoplex 400 + Epon
	Column No.	1	2	3	4	5	6
α-BHC		0.23	0.18	0.21	0.33	0.10	0.15
Heptachlor		0.41	0.32	0.34	0.40	0.27	0.24
Lindane		0.19	0.25	0.39	0.42	0.23	0.37
Aldrin		0.52	0.40	0.41	0.38	0.27	0.34
δ-BHC		0.27	0.36	0.67	0.20	0.29	0.26
β-BHC		0.23	0.31	0.62	0.23	0.36	0.93
HCE		0.65	0.62	0.81	0.77	0.53	0.62
p,p'-DDE		1.0	1.0	1.0	1.0	1.0	1.0
Dieldrin		1.0	0.98	1.4	1.2	0.90	1.1
Endrin		1.1	1.2	1.7	1.4	1.1	1.5
p,p'-DDT		1.7	1.9	2.0	2.1	1.7	2.8
Methoxychlor		2.6	4.0	2.3	2.4	3.4	2.7

<sup>a</sup> Ratio of retention time for each compound, measured in cm., to retention time for p,p'-DDE.

Table III. Pesticides Used As Standards

Pesticide	Source	Purity as Described by Supplier, %
Aldrin	Shell Chemical Co.	99 ±
Chlordan	Panta Industries, Inc.	60
γ-Chlordan	Velsicol Corp.	99.8
Dieldrin	Shell Chemical Co.	99.1 ± 0.3
<i>p,p'</i> -DDT	Recrystallized in lab.	MP 106–107
DDE	Geigy Agricultural Chemicals	<sup>a</sup>
Endrin	Shell Chemical Co.	99 + W
Heptachlor	Panta Industries, Inc.	99 +
HCE	Velsicol Chemical Corp.	99
Lindane	DHEW, Food and Drug Adm.	—
α-BHC	DHEW, Food and Drug Adm.	—
β-BHC	DHEW, Food and Drug Adm.	—
δ-BHC	DHEW, Food and Drug Adm.	—
Methoxychlor	E. I. du Pont de Nemours and Co., Inc.	99 +
Toxaphene	Panta Industries, Inc.	100

<sup>a</sup> No data available.

MicroTek 220 gas chromatograph equipped with the Ni<sub>63</sub> electron-capture detector, was the most efficient unit for assaying organochlorine compounds. It had a theoretical plate number of 1500 and a HETP of 0.09 cm. for dieldrin. The retention time for dieldrin was 19 minutes.

**Identification of Compounds.** In gas chromatography, compounds are identified by comparison of the retention time or retention volume with that for known compounds. The source and purity of the compounds used for identification in this surveillance project are listed in Table III. In 1964, only three of these standards, *p,p'*-DDT (and *p,p'*-DDE), dieldrin, and endrin, were used in examining the chromatograms from the surveillance project. By December 1966, standard solutions of all of the 15 compounds listed in Table III were used for identification of compounds in the water samples. Either pesticide quality hexane or spectroquality ethyl acetate was used to prepare concentrated standard solutions of 1.00 mg. per ml. for each of the 15 compounds. With the use of pesticide quality hexane, suitable dilutions of each standard were prepared to attain three or more concentration levels on the linear portion of the calibration curves. A concentration range of 0.1 to 0.6 ng. produced linear calibration curves for most of the compounds used in these studies.

**Quantitative Analysis.** Since symmetrical peaks were produced, peak heights were used as a measure of concentration. To measure the peak height, the base line was extended under the peak to form the peak base. Then a perpendicular was dropped from the peak maximum to the peak base. The peak height was this perpendicular measured in centimeters. Calibration curves were prepared by plotting peak height in centimeters against the concentration in nanograms.

**Recovery Studies.** For statistical evaluation of the efficiency of the preferred method, the 10 pesticides were added to finished water, each at a concentration level equal to or less than the maximum reasonable stream allowance suggested by Ettinger and Mount (1967). The one isomer of chlordan that was available and the three isomers of lindane, α-, β-, and δ-BHC, that occur with lindane in pesticide mixtures were also included in the evaluation of the precision and accuracy of the method.

The concentrations of each pesticide actually used were chosen so that a 5-μl. injection of the hexane extract (before any concentration step) produced a peak height of 2 to 10 cm. and appeared on the linear portion of the calibration curve for each compound. These concentrations were less than the maximum reasonable stream allowances that Ettinger and Mount (1967) suggested for all of the pesticides, except endrin, chlordan, and toxaphene. For these three compounds, a second series of data was then collected after a fourfold concentration of the hexane extract.

Mixtures of the standard solutions were prepared for the recovery studies by diluting known volumes of the concentrated solutions so that a 50-μl. portion could be added to each 4-liter sample of water for the recovery studies—for example, an 8 to 1000 dilution of the concentrated standard solution produced a solution containing 400 ng. of contaminant per 50 μl. This 50-μl. portion, when added to 4 liters of water, produced a sample containing 0.1 p.p.b. Each mixture of standard solutions contained from one to six of the pesticidal compounds. Combinations were chosen to give well-resolved peaks on the gas chromatograph. Each compound except toxaphene, chlordan, and the chlordan isomer was assayed in at least two different combinations under each of the three instrumental conditions. To prepare the theoretical amounts in the known solution, 50-μl. portions of the mixture of standard solutions were diluted to 10 ml. with "distilled-in-glass" hexane. A 5-μl. portion of the solutions containing theoretical concentrations was injected into the gas chromatograph before and after each injection.

Three sets of data, series A, B, and C, were compiled for estimating the precision and accuracy of the one-step extraction method. Since there was a variation in the sensitivity of the instruments at the time each series was run, the concentration of each compound was not held constant for the three sets of data. The actual concentrations used are shown in Table IV.

For the recovery studies, 1-gallon portions of water of known quality (Cincinnati tap water put through an activated carbon filter) were placed in each of several gallon jugs for replicate assays. A stirring bar was added to each. A 100-μl. Hamilton syringe was used to add a 50-μl. portion of the mixture of standard solutions to each jug; a precaution observed was having the needle of the syringe below the surface of the water when each sample was discharged. After the cap to the jug was screwed on tightly, the sample was allowed to mix for 1 hour with the magnetic stirrer on low speed. Then it was left undisturbed until extracted. This period between contamination and extraction varied from 12 to 64 hours. The 10-ml. volume of hexane was added immediately before extraction.

Under the conditions described above, the samples were extracted and assayed. A theoretical solution was prepared with each set of replicate samples by diluting a 50-μl. portion of the mixture of standard solutions to 10 ml. with hexane. This technique in preparing the theoretical solutions was used to cancel volumetric calibration errors. Five-microliter portions of the theoretical solutions were chromatographed before and after each of the replicate samples.



Table IV. Estimates of Mean Recoveries and 99% Confidence Intervals for 14 Pesticides

	Concentration Range, P.P.B.	Series	Std. Deviation, <i>S</i>	Degrees of Freedom, <i>v</i>	$\bar{X} \pm \frac{St(v, 1-\alpha/2)}{\sqrt{n}}$
Endrin	0.2 to 0.3	A, BC	6.4	28	104.4 <sup>b</sup> ± 3.1
	0.06 <sup>a</sup>	C	10.9	11	88.4 ± 9.8
α-BHC	0.06 to 0.1	A, BC	5.6	32	89.2 ± 2.5
Dieldrin	0.1 to 0.3	A	6.1	33	94.1 ± 5.3
		BC			102.6 ± 3.2
Aldrin	0.06 to 0.1	A			90.6 ± 4.7
		BC			97.4 ± 3.0
Methoxychlor	2.5 to 4.6	A	6.0	9	85.0 ± 6.2
		BC	5.1	20	101.3 ± 3.0
Chlordan isomer	0.12	A	NR		NR
Lindane	0.06 to 0.1	C	6.6	14	95.6 ± 4.9
		A	2.2	9	85.3 ± 2.3
Heptachlor	0.1	BC	4.8	20	89.7 ± 2.8
		A	2.5	9	63.3 ± 2.6
HCE	0.1 to 0.3	B			71.6 ± 2.7
		C	3.8	19	85.6 ± 4.4
p,p'-DDT	0.5 to 1.1	A	2.8	9	101.7 ± 2.9
		B	4.5	25	105.0 ± 2.7
δ-BHC	0.06 to 0.5	C <sub>1</sub>			94.3 ± 4.4
		C <sub>2</sub>			
β-BHC	0.2 to 1.3	A	11.7	9	71.1 ± 13.1
		B	5.6	20	88.0 ± 4.0
Chlordan, 60%	1.3	C			102.4 ± 6.0
		A	5.1	9	54.8 ± 5.2
Toxaphene	2.5	B	5.8	4	52.2 ± 7.2
		C <sub>1</sub>	1.0	7	54.0 ± 0.8
Toxaphene	2.5 <sup>a,c</sup>	C <sub>2</sub>	6.0	7	58.1 ± 4.7
		A	2.0	9	46.1 ± 2.1
Toxaphene	2.5 <sup>a,c</sup>	B			48.5 ± 3.6
		C <sub>1</sub>			42.0 ± 2.8
Toxaphene	2.5 <sup>a,c</sup>	C <sub>2</sub>	2.8	18	45.6 ± 2.8
		A	6.0	9	85.0 ± 6.2
Toxaphene	2.5 <sup>a,c</sup>	C <sup>d</sup>	...	...	...
		A	11.2	9	94.7 ± 11.5
Toxaphene	2.5 <sup>a,c</sup>	C <sup>d</sup>	...	...	...

<sup>a</sup> Fourfold concentration of hexane extract before it was chromatographed.

<sup>b</sup> True mean ( $\mu$ ) is expected to lie between  $\bar{X} - \frac{St(v, 1-\alpha/2)}{\sqrt{n}}$  and  $\bar{X} + \frac{St(v, 1-\alpha/2)}{\sqrt{n}}$  99% of time when  $\alpha = 0.01$ .

<sup>c</sup> When adjusted for 60% purity, concentrations become 0.75 and 0.15 p.p.b.

<sup>d</sup> Only qualitative studies.

## Results and Discussion

**Statistical Evaluation.** To obtain estimated proportion recoveries, the sample peak height for each compound in each replicate sample was divided by the standard peak height preceding it on the chromatograph. Because toxaphene and chlordan are mixtures of compounds, they produced multiple peaks with all the columns. Areas under the multiple peaks for these two pesticides were plotted against the concentration for the data in the series A recovery study. For the C series, run on column 2, quantitative results were not possible for these compounds. Quantitative recovery data, however, were collected for one isomer of the chlordan mixture on column 2.

The standard deviation (*S*), the mean per cent recovery ( $\bar{X}$ ), and the 99% confidence intervals were used to evaluate the recovery efficiencies (Table IV).

For these statistical evaluations, endrin, at a concentration

level <0.1 p.p.b., toxaphene, and chlordan were treated separately and data from series B and C were combined. This combination series, BC, consisted of 38 sets of data, each set consisting of five to eight replicate recovery assays for each compound. Series A consisted of 11 sets of data with each set made up of 10 replicate assays for each compound.

All statistical tests were performed with a prechosen significance level of  $\alpha = 0.01$ . The assumption that the per cent recoveries were independent observations obtained from a normal population was tested with the use of two techniques: a test for nonnormality (Pearson and Hartley, 1962) and a graphical test (Dixon and Massey, 1957).

The mean recoveries and standard deviations were computed for the 14 compounds. Estimates were calculated for each of the runs within each of the three series for each compound. Homogeneity of variance tests as shown by Dixon and Massey (1957) was computed, and variances were pooled

Table V. Pesticides in 1-Gallon Samples of Water<sup>a</sup>

Location	Date	Lindane	BHC's	Aldrin	<i>p,p'</i> -DDE	<i>p,p'</i> -DDT	Dieldrin	Endrin	Heptachlor	HCE	Chlordan
FINISHED DRINKING WATER											
Algiers	03/31/65 08/25/65			0/7	1/12	1/12	10/12	4/12			
Carrolton	03/31/65 08/25/65			0/6	0/12	0/12	6/12	3/12			
Carville	03/29/65 12/14/67	1/1	1/1	1/19	1/19	1/19	9/19	1/19	1/10	1/10	
Vicksburg	03/29/65 05/25/67	4/6	5/6	3/45	23/45	23/45	21/45	7/45	1/24	6/37	0/6
Cape Girardeau	04/19/65 06/07/67	6/6	6/6	9/39	7/39	6/39	18/39	3/39	0/13	0/13	0/6
Omaha	05/04/65 05/23/67	3/5	4/5	2/19	1/19	1/19	4/19	1/19	0/19	0/19	0/6
St. Louis	12/11/66 05/25/67	6/7	6/7	2/7	1/7	0/7	5/7	1/7	0/7	0/7	1/6 <sup>b</sup>
Burlington	03/24/65 06/06/67	5/6	5/6	2/11	4/11	3/11	3/11	0/11	0/6	1/6	0/5
Jefferson City	05/30/66 05/26/67	4/7	5/7	2/15	5/15	4/15	5/15	0/15	0/15	0/15	1/6
Kansas City	03/19/65 05/23/67	5/9	5/9	16/52	10/54	10/54	24/54	4/54	1/33	13/54	12/28 <sup>c</sup>
Total		34/47	37/47	37/220	53/233	49/233	105/233	24/233	3/127	21/161	14/63
RAW WATER											
Carville	12/14/66 01/05/67	2/2	2/2 <sup>b</sup>	0/2	1/2	1/2	0/2	0/2	0/2	0/2	0/1
Vicksburg	02/27/67 05/25/67	4/4	4/4	1/4	2/4	2/4	2/4	1/4	1/4	0/4	1/4
Cape Girardeau	03/29/65 06/07/67	4/8	5/8	4/8	3/8	2/8	5/8	2/8	0/8	0/8	0/6
Jefferson City	05/30/66 05/26/67	4/7	6/7	5/15	3/15	4/15	8/15	0/15	0/15	1/15	1/7
Kansas City	05/04/66 05/23/67	7/7	7/7	12/22	3/22	3/22 <sup>b</sup>	10/22	1/22	1/22	4/22	9/22 <sup>d</sup>
Omaha	04/20/66 05/23/67	4/6	5/6	4/16	3/16	3/16	4/16	1/16	0/16	0/16	0/6
Total		25/34	29/34	26/67	15/67	15/67	29/67	5/67	2/67	5/67	11/46

<sup>a</sup> Ratio of number of samples with detectable concentrations to total number of samples.

<sup>b</sup> One sample assayed at 0.5 p.p.b.

<sup>c</sup> Four samples assayed from 8 to 0.25 p.p.b.

<sup>d</sup> Two samples assayed from 0.5 to 0.3 p.p.b.

where insufficient evidence existed to reject the null hypothesis that they were equal. Standard analysis of variance tests were performed to examine a similar hypothesis that the mean recoveries for a given pesticide were equal. The significant results were separated into groups of means by Duncan's test (1955). For example, the variances from all runs were pooled for dieldrin and aldrin, but, for each compound, the mean recovery for series A was lower than the mean recovery for BC (see Table IV). Only two compounds were found, endrin, at 0.2 to 0.3 p.p.b., and  $\alpha$ -BHC, where a single estimate could be reported for both mean recovery and variance.  $\delta$ -BHC was the compound showing the widest differences in precision, and none of the runs could be pooled.

There is no explanation to date for the mean recovery values greater than 100% that were observed for endrin, at 0.2 to 0.3 p.p.b., dieldrin, methoxychlor, HCE, and DDT. The water used in these studies did not contain detectable

concentrations of these pesticides. The proportional amount of the hexane in the vapor phase was held at a minimum during the extraction step.

For some of these pesticides the actual concentrations used in these recovery studies is significantly lower than the maximum stream allowances suggested by Mount and Ettinger (see Table VII). The safety factors range from 50 times for lindane and 10 times for heptachlor to 2 to 5 times for aldrin, HCE, and methoxychlor. Dieldrin and DDT were studied at the same concentration as the suggested allowance. None of the columns used in these studies had sufficient sensitivity for endrin and chlordan for them to be detected at the suggested levels without concentrating the hexane extract. To look for synergistic effects, endrin was included in mixtures with the other 10 compounds at a level that could be measured quantitatively. An additional recovery study was then done for endrin at a lower concentration. For this the water was

**Table VI. Pesticides in 100-Ml. Samples of Water<sup>a</sup>**

Location	Date	Aldrin	<i>p,p'</i> -DDE	<i>p,p'</i> -DDT	Dieldrin	Endrin
FINISHED DRINKING WATER						
Algiers	03/03/64 12/17/64	0/2	5/19 <sup>b</sup>	5/19 <sup>b</sup>	2/19	14/19 <sup>b</sup>
Carrollton	03/03/64 12/17/64		3/20	3/20	7/20	14/20 <sup>c</sup>
Carville	04/16/64 06/08/66	4/26 <sup>b</sup>	13/39 <sup>c</sup>	12/39 <sup>b</sup>	14/39	24/39 <sup>d</sup>
Vicksburg	03/31/64 06/30/66	4/41	29/41 <sup>e</sup>	28/41 <sup>e</sup>	23/41 <sup>d</sup>	34/41 <sup>f</sup>
Cape Girardeau	06/02/64 03/14/66	2/25	13/25 <sup>b</sup>	14/25 <sup>b</sup>	13/25 <sup>c</sup>	11/25 <sup>d</sup>
Burlington	06/30/64 03/22/66	0/10	2/10	2/10	2/10	4/10 <sup>b</sup>
St. Louis	06/11/64 06/16/66	3/32	14/32 <sup>b</sup>	14/32 <sup>b</sup>	17/32 <sup>b</sup>	10/32 <sup>b</sup>
Jefferson City	06/04/64 07/16/64	1/7	3/7	3/7	7/7	6/7
Kansas City	06/11/64 05/23/66	3/10	1/10	1/10	0/10	5/12 <sup>d</sup>
Omaha	06/01/64 03/07/66	4/20	7/20	6/20	6/20	10/20 <sup>d</sup>
Total		21/173	90/223	88/223	91/223	132/225
RAW WATER						
Carville	06/17/64 03/10/66	0/3	5/10	5/10	6/10	3/10 <sup>b</sup>
Cape Girardeau	06/02/64 03/14/66	1/12	2/12	2/12	4/12	4/12 <sup>d</sup>
Kansas City	04/27/66 05/23/66	0/2	0/2	0/2	0/2	0/2
Total		1/17	7/24	7/24	10/24	7/24

<sup>a</sup> Ratio of number of samples with detectable concentrations to total number of samples.

<sup>b</sup> One sample assayed >0.1 p.p.b.

<sup>c</sup> Two samples assayed >0.1 p.p.b.

<sup>d</sup> Three samples assayed >0.1 p.p.b.

<sup>e</sup> Four samples assayed >0.1 p.p.b.

<sup>f</sup> Six samples assayed >0.1 p.p.b.

contaminated with endrin at a 0.06-p.p.b. concentration level and extracted according to the usual procedure. Then the hexane extract was concentrated fourfold before being chromatographed. The resultant mean recovery was 88.4%, with a standard deviation of 10.9. Because of the difference in sensitivity of columns 1 and 2 for toxaphene, recovery data were obtained at the suggested level of 2.5 p.p.b. for the unconcentrated hexane extract on column 1 and for an extract concentrated fourfold on column 2. Chlordan was assayed on column 1 at a level 5 times higher than the suggested allowance of 0.25 p.p.b. and at the 0.25-p.p.b. level on column 2 after a fourfold concentration of the hexane extract. In series A, column 1, recoveries of 85 and 95% were estimated for chlordan and toxaphene by comparing the area under the multiple peaks with those for the standards. For the series C, column 2, quantitative data were not collected for these pesticides. A mean recovery of 96%, however, was obtained for the chlordan isomer. The concentrated sample extract for toxaphene and concentrated standard produced chromatographs that could not be distinguished from each other.

Mean recovery values greater than 85% were attained in all sets of data for lindane,  $\alpha$ -BHC, and aldrin each at levels ranging from 0.06 to 0.1 p.p.b.; for HCE and dieldrin each

at levels ranging from 0.1 to 0.3 p.p.b.; for endrin at levels of 0.2 and 0.3 p.p.b.; and for methoxychlor at levels of 2.5 and 4.5 p.p.b. Mean recovery data for *p,p'*-DDT at concentration levels ranging from 0.5 to 1.1 p.p.b. ranged from 71% in series A through 88% for series C to 102% for series B. Recoveries for heptachlor at a concentration level of 0.1 p.p.b. ranged from 63% in series A through 86% in series B to 72% in series C. Low but consistent recoveries were observed for the  $\beta$  and  $\delta$  isomers for BHC in all of the sets of data.

**Surveillance Samples.** Data for 300 1-gallon samples of water (233 samples of finished water and 67 samples of raw water) collected between March 1965 and May 1967 are given in Table V. These data include the samples used to compare the two methods. Data for 249 small, 100-ml. samples of water (225 samples of finished water and 24 samples of raw water) that were collected between March 1964 and June 1966 are given in Table VI. In 1964 the chromatographs of the water samples were compared with chromatographs for standard solutions of *p,p'*-DDT, *p,p'*-DDE, dieldrin, and endrin. In samples assayed after December 1966, the chromatographs for standard solutions of 15 compounds were used for identification of peaks in the sample chromatographs. For this reason, all data in Tables V and VI are given as the ratio of

**Table VII. Guidelines for Maximum Permissible Levels of Pesticides in Finished Waters**

	(Parts per billion)		
	1964	1965-6 <sup>a</sup>	1967 <sup>b</sup>
Lindane		56.0	5.0
Aldrin		32.0	0.25
Heptachlor		78.0	1.0
HCE		18.0	1.0
Dieldrin	<0.1	18.0	0.25
Endrin	<0.1	1.0	0.1
<i>p,p'</i> -DDT plus related compds.	<0.1	42.0	0.5
Methoxychlor		35.0	20.0
Toxaphene		5.0	2.5
Chlordan		52.0	0.25

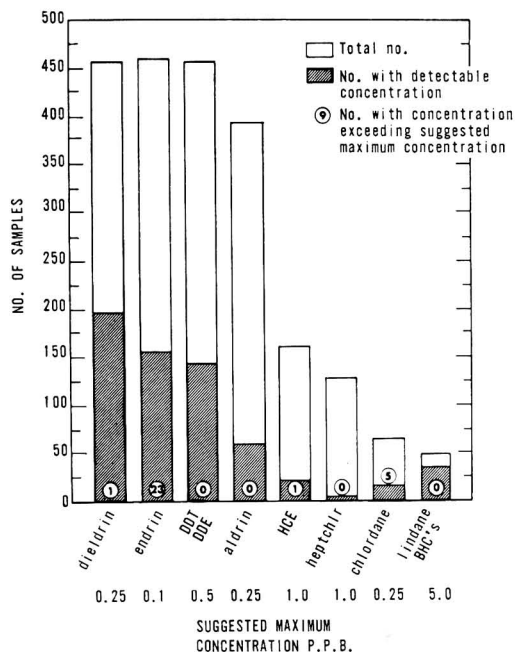
<sup>a</sup> Based on "maximal acceptable concentrations" of Subcommittee on Toxicology (1965).  
<sup>b</sup> Based on the "maximum reasonable stream allowances" of Ettinger and Mount (1967).

the number of samples containing observable concentrations of the pesticide over the number of samples assayed for the pesticide. Those observable concentrations that produced peak heights less than 2 cm. were assayed qualitatively. The standard curves of peak height vs. concentration were used to quantitate data from the 1-gallon samples for larger concentrations. Only those quantitative data in excess of 0.1 p.p.b. are reported in the footnotes of Table V. Because of the low precision with the method using 100-ml. samples, the number of samples with assays in excess of 0.1 p.p.b. are listed in the footnotes of Table VI. Occasionally the presence of a large concentration of either an unknown compound or one of the pesticides prevented assay for the other pesticides in this group; this is reflected in the varying values for the denominator.

Table VII lists the three sets of guidelines used in this surveillance study for maximum permissible levels of pesticides. The "maximum reasonable stream allowances" of Ettinger and Mount (1967) were used as a guideline for all of the data reported in Table V on 1-gallon samples.

Lindane ( $\gamma$  isomer of 1,2,3,4,5,6-hexachlorocyclohexane) and the BHC's were observed in more than 80% of all assayed samples from Vicksburg, Carville, Cape Girardeau, Burlington, and St. Louis. In contrast, only 55 to 60% of water samples from the other stations contained detectable concentrations of lindane. Although a few of the samples from Burlington, Omaha, and Jefferson City contained detectable concentrations of endrin, up to 40% of the samples from stations along the lower Mississippi contained detectable concentrations of this pesticide.

The number of samples containing concentrations in excess of 0.1 p.p.b. of endrin decreased from 23 in the period 1964-65 to none in the period 1965-67. Only one sample was observed during the entire period with a concentration of dieldrin in excess of the 0.25-p.p.b. limit suggested by Ettinger and Mount. However, six samples in 1964-65 contained dieldrin in excess of 0.1 p.p.b. The 63 samples assayed after December 1966 were examined for toxaphene (essentially a mixture of isomers of octachlorocamphene), but none of these results were positive. In contrast, 14 of these samples contained chlordan (2,3,4,5,6,7,8,8 - octachloro - 2,3,3a,4,7,7a - hexahydro - 4,7-methanoindene), and in five of these samples, the level was



**Figure 1. Pesticides in finished drinking water, 1964-67**

greater than 0.25 p.p.b. Twelve of the 14 samples containing chlordan came from one location.

Results of all of the samples of finished water assayed by both methods are summarized in Figure 1. Over 40% of all samples contained detectable dieldrin; about one third of the samples contained endrin, *p,p'*-DDT plus *p,p'*-DDE, or both. Although only 47 of the samples were assayed for lindane and the BHC's, over 70% of the samples contained detectable concentrations of these pesticides. None of these samples, however, contained concentrations in excess of the suggested allowance of 5.0 p.p.b.

In the statistical evaluation of the method it became obvious that the three different sets of instrumental conditions used in these studies affected recoveries and precision data for the organochlorine pesticides. For this reason, it was not possible to treat these recovery data in the conventional way of averaging data from all runs and reporting confidence limits. For an evaluation of this method using one set of instrumental conditions, the following procedure is suggested.

The formula in Equation 1 may be used to calculate the number of samples needed to estimate the per cent recovery within certain limits.

$$\begin{aligned} \text{Upper limit} &= \bar{X} \pm \frac{St_{(\nu, 1-\alpha/2)}}{\sqrt{n}} \\ \text{Lower limit} & \end{aligned} \quad (1)$$

$$\text{where } \bar{X} = \text{mean recovery} = \left( \sum_{i=1}^n x_i / n \right)$$

$$S = \text{standard deviation} = \sqrt{\frac{\sum_{i=1}^n X_i^2 - \left( \sum_{i=1}^n x_i \right)^2 / n}{n - 1}}$$

$n$  = number of observations

$t_{(\nu, 1-\alpha/2)}$  = critical  $t$  value at prechosen  $\alpha$  level and  $\nu$  degrees of freedom

**Table VIII. Confidence Limits Computed for an Example Where  $S = 6.0$  and  $\alpha = 0.01$**

No. of Observations, $n$	$\bar{X} \pm St_{(v, 1-\alpha/2)}/\sqrt{n}$
3	$\bar{X} \pm 34.4^a$
4	$\bar{X} \pm 17.5$
5	$\bar{X} \pm 12.4$
6	$\bar{X} \pm 9.9$
7	$\bar{X} \pm 8.4$
8	$\bar{X} \pm 7.4$
9	$\bar{X} \pm 6.7$
10	$\bar{X} \pm 6.2$
15	$\bar{X} \pm 4.6$
20	$\bar{X} \pm 3.8$
25	$\bar{X} \pm 3.6$

<sup>a</sup>  $v$  is degrees of freedom associated with  $S$ ,  $n - 1$  for this situation.

The problem is to calculate  $n$  when  $a = \frac{St_{(v, 1-\alpha/2)}}{\sqrt{n}}$  is fixed at some desired level and when  $\alpha$  is specified—e.g., to estimate the recovery of the method  $\bar{X} \pm 4.0$  ( $a = 4.0$ ) when  $\alpha = 0.01$ . This formula also requires some idea of the  $S$  (standard deviation) value. These studies indicate that  $S \cong 6.0$  for aldrin, dieldrin, endrin, and DDT. Table VIII shows the limits for various sample sizes ( $n$ ) between 3 and 25. To achieve an expected value of the limit of  $\bar{X} \pm 4.0$ , 20 observations would be needed. The expected value of the limits are interpreted to mean that the true mean recovery will lie within the interval  $\bar{X} - 4.0$  and  $\bar{X} + 4.0$  in 99% of

the experiments. These studies are performed in a narrow concentration range. The number of observations,  $n$ , can be selected to obtain the confidence desired in estimating the mean recovery.

A wider range of concentrations and the resulting regression problems may also be considered; estimates for the present study are in the concentration range  $\leq 1$  p.p.b.

#### Acknowledgment

The authors gratefully acknowledge the technical assistance of C. H. Hamilton. They are indebted to F. B. Taylor, J. H. Eagen, and their coworkers for alerting us to this problem and for organizing the surveillance network, and also to individuals who so kindly collected samples in each of the water treatment plants.

#### Literature Cited

- Breidenbach, A. W., Gunnerson, C. G., Kawahara, F. K., Lichtenberg, J. J., Green, R. S., *Pub. Health Rept.* **82**, 139–56 (1967).  
 Dixon, W. J., Massey, F. J., Jr., "Introduction to Statistical Analysis," 2nd ed., McGraw-Hill, New York, 1957.  
 Duncan, D. B., *Biometrics* **11**, 1–42 (1955).  
 Ettinger, M. B., Mount, D. I., *ENVIRON. SCI. TECHNOL.* **1**, 203–5 (1967).  
 Pearson, E. S., Hartley, H. O., "Biometrika Tables for Statisticians," Vol. I, 2nd ed., pp. 61–3, Cambridge University Press, 1962.  
 Stockinger, H. E., chairman, Actions taken by the Subcommittee on Toxicology of the Advisory Committee on Public Health Service Drinking Water Standards, July 9, 1965.

Received for review October 21, 1968. Accepted June 6, 1969. Mention of commercial products does not imply endorsement by the U. S. Department of Health, Education, and Welfare.

## Performance of Porous Cellulose Acetate Membranes for the Reverse Osmosis Treatment of Hard and Waste Waters

Andrew R. Hauck

City of Ottawa Pollution Control Center, Ottawa, Ontario, Canada

S. Sourirajan

Division of Applied Chemistry, National Research Council of Canada, Ottawa, Ontario, Canada

Reverse osmosis is a general separation process. Its application for saline water conversion and similar problems is being studied extensively using the Loeb-Sourirajan type porous cellulose acetate membranes (Sourirajan, 1967). This process is particularly suitable for the treatment of hard waters, polluted waters, and sewage waters (Ironsides and Sourirajan, 1967). This paper gives some performance data of the CA-NRC-18 type porous cellulose acetate membranes (Sourirajan and Govindan, 1965) for such applications. These data are significant from the points of view of industrial water treatment, water renovation and re-use, and water pollution control.

#### Experimental Details

Reagent grade chemicals and porous cellulose acetate membranes (designated as CA-NRC-18 type films) made in the laboratory were used. The films were cast at  $-10^\circ$  C. in accordance with the general procedure described earlier (Sourirajan and Govindan, 1965) using 68.0 weight % acetone, 17.0 weight % cellulose acetate (acetyl content 39.8%), 13.5 weight % water, and 1.5 weight % magnesium perchlorate for the film casting solution. Membranes shrunk at different temperatures were used to give different levels of membrane porosity and performance at preset operating conditions.

■ The performance of a few typical Loeb-Sourirajan type porous cellulose acetate membranes is reported for the treatment of hard, polluted, and sewage waters. The membranes used are specified in terms of pure water permeability constant and solute transport parameter for sodium chloride. Using feed waters containing 300- to 800-p.p.m. hardness (expressed as  $\text{CaCO}_3$ ), product waters containing 2 p.p.m. or less could be obtained with 90% product recovery and an

average initial flux of 38 gallons per day per sq. foot at 1000 p.s.i.g. The possibility of producing "ultrapure" waters by repeated reverse osmosis processing is indicated. The separation of common pollutants such as nitrates, borates, fluoride, alkyl benzene sulfonate (ABS), ammonia, and phosphates, and a few others usually present in plating wastes, and the applicability of the reverse osmosis process for the treatment of sewage waters and water renovation are illustrated.

The experiments were carried out at the laboratory temperature ( $23^\circ$  to  $25^\circ$  C.) in the pressure range 200 to 1000 p.s.i.g., using the apparatus described by Sourirajan (1969). The reverse osmosis cell was a stainless steel pressure chamber consisting of two detachable parts. The film was mounted on a stainless steel porous plate embedded in the lower part of the cell through which the membrane-permeated product water was withdrawn at the atmospheric pressure. The upper part of the cell contained the feed solution under pressure in contact with the membrane. Two parts of the cell were clamped and sealed tight, using rubber O-rings. Compressed nitrogen gas was used to pressurize the system. About 250 cc. of feed solution were used each time. The feed solution was kept well stirred during the experiment by means of a magnetic stirrer fitted in the cell about  $1/4$  inch above the membrane surface. Of the feed, 25 to 90% was recovered as product, and the product concentrations given in this paper are the over-all product concentrations. The compositions of the feed and product solutions were analyzed by a Bausch & Lomb precision refractometer, by conductance measurements, or by the other standard methods of analysis indicated below.

Each membrane was subjected to a temperature (shrinkage) and then a pressure treatment before use in reverse osmosis experiments. The temperature treatment consisted of heating the film gradually under water from the laboratory temperature to the required temperature, where it was kept for 10 to 15 minutes and subsequently cooled rapidly. The shrunk membrane was mounted in the cell and subjected to a pressure treatment which consisted of permeating water under pressure through the membrane at 1200 p.s.i.g. for at least an hour. The pressure was then released, and the membrane kept in contact with water at atmospheric pressure for several hours. The membrane was then ready for use in reverse osmosis experiments. The effective area of the film in the cell was 9.6 sq. cm. In each experiment, the pure water permeability [PWP], and average product rate [PR] in grams per hour per 9.6 sq. cm. area of film, the volume fraction product recovery, and the initial feed concentration and the average product concentration were determined. In all cases, the terms "product" and "product rate" refer to the membrane-permeated product solutions, and the separation and product rate data can be reproduced within  $\pm 1$  and  $\pm 5\%$ , respectively. The variation in product rate data is due to the viscosity change of product, which is about 2.5% per degree centigrade.

**Water Analysis.** Calcium and magnesium ions were analyzed by titration with EDTA, biochemical oxygen demand (B.O.D.) was determined using the azide modification of the iodometric method, ABS was determined colorimetrically, and total dissolved solids were determined by evaporation, following the procedures given for each by the American Public Health Association (1965). Phosphates and nitrates were analyzed by autoanalyzers, and very low concentrations of calcium and magnesium were determined by the atomic

absorption technique. Other inorganic salts were analyzed by the specific resistance measurements, using a conductivity bridge.

### Results and Discussion

**Basic Transport Equations.** The Kimura-Sourirajan analysis (Kimura and Sourirajan, 1967) gives rise to the following basic equations relating the pure water permeability constant,  $A$ , the flux of solvent water,  $N_B$ , the solute transport parameter,  $(D_{AM}/K\delta)$ , and the mass transfer coefficient,  $k$ , on the high pressure side of the membrane:

$$A = \frac{[\text{PWP}]}{M_B \times 9.6 \times 3600 \times P} \quad (1)$$

$$N_B = A[P - \pi(X_{A2}) + \pi(X_{A3})] \quad (2)$$

$$= \left(\frac{D_{AM}}{K\delta}\right) \left(\frac{1 - X_{A3}}{X_{A3}}\right) (c_2 X_{A2} - c_3 X_{A3}) \quad (3)$$

$$= k c_1 (1 - X_{A3}) \ln \left(\frac{X_{A2} - X_{A3}}{X_{A1} - X_{A3}}\right) \quad (4)$$

From the experimental [PWP], [PR], and feed and product concentration data, the values of  $A$ ,  $(D_{AM}/K\delta)$ , and  $k$  can be calculated for each experiment. Both  $A$  and  $(D_{AM}/K\delta)$  depend on the porous structure of the membrane surface, and hence they are different for different membranes; both are functions of operating pressure, and, in addition  $(D_{AM}/K\delta)$  depends on the chemical nature of the solute. For the type of membranes used in this work  $(D_{AM}/K\delta)$  is independent of feed concentration and  $k$  at a given operating pressure for solutes such as sodium chloride.

**Membrane Specifications and Applicable Mass Transfer Coefficient Correlation.** It has been shown (Sourirajan, 1969) that the membrane performance data given in terms of product rate and solute separation (or feed and product concentra-

Table I. Membrane Specifications\*

Film No.	$\frac{A \times 10^6}{\text{G. Mole H}_2\text{O}} / \text{Sq. Cm. Sec. Atm.}$	$(D_{AM}/K\delta) \times 10^6, \text{ Cm./Sec.}$
H-1	1.618	0.679
H-2	1.765	6.990
H-3	1.914	9.232
H-4	0.886	0.972
H-5	1.695	3.457

\* Film type CA-NRC-18 System [NaCl-H<sub>2</sub>O] Operating pressure 1000 p.s.i.g.

Table II. Separation of Calcium and Magnesium Ions in Aqueous Solution<sup>a</sup>

Film No.	System	Feed Water	Product Water	
		Hardness, P.P.M. CaCO <sub>3</sub>	Hardness, p.p.m. CaCO <sub>3</sub>	Product rate, gal./ (day) (sq. ft.)
H-1	CaCl <sub>2</sub> -H <sub>2</sub> O	302	2	38.6
	CaCl <sub>2</sub> -H <sub>2</sub> O	498	2	42.3
	CaCl <sub>2</sub> -H <sub>2</sub> O	782	2	41.4
	MgCl <sub>2</sub> -H <sub>2</sub> O	315	<1	41.1
	MgCl <sub>2</sub> -H <sub>2</sub> O	516	<1	37.4
	MgCl <sub>2</sub> -H <sub>2</sub> O	800	2	36.1
	(CaCl <sub>2</sub> + MgCl <sub>2</sub> )-H <sub>2</sub> O	300	<1	34.2
	(CaCl <sub>2</sub> + MgCl <sub>2</sub> )-H <sub>2</sub> O	495	<1	36.7
	(CaCl <sub>2</sub> + MgCl <sub>2</sub> )-H <sub>2</sub> O	807	<1	35.1
H-2	CaCl <sub>2</sub> -H <sub>2</sub> O	302	17	42.8
	CaCl <sub>2</sub> -H <sub>2</sub> O	504	21	42.8
	CaCl <sub>2</sub> -H <sub>2</sub> O	806	26	42.6
	MgCl <sub>2</sub> -H <sub>2</sub> O	315	24	49.2
	MgCl <sub>2</sub> -H <sub>2</sub> O	509	36	43.7
	MgCl <sub>2</sub> -H <sub>2</sub> O	829	45	41.5
	(CaCl <sub>2</sub> + MgCl <sub>2</sub> )-H <sub>2</sub> O	304	19	43.5
	(CaCl <sub>2</sub> + MgCl <sub>2</sub> )-H <sub>2</sub> O	504	28	43.8
	(CaCl <sub>2</sub> + MgCl <sub>2</sub> )-H <sub>2</sub> O	805	41	42.6
H-3	CaCl <sub>2</sub> -H <sub>2</sub> O	301	28	45.2
	CaCl <sub>2</sub> -H <sub>2</sub> O	508	42	50.4
	CaCl <sub>2</sub> -H <sub>2</sub> O	802	64	51.2
	MgCl <sub>2</sub> -H <sub>2</sub> O	302	29	51.6
	MgCl <sub>2</sub> -H <sub>2</sub> O	505	43	51.7
	MgCl <sub>2</sub> -H <sub>2</sub> O	806	60	47.3
	(CaCl <sub>2</sub> + MgCl <sub>2</sub> )-H <sub>2</sub> O	289	22	51.9
	(CaCl <sub>2</sub> + MgCl <sub>2</sub> )-H <sub>2</sub> O	498	36	50.0
	(CaCl <sub>2</sub> + MgCl <sub>2</sub> )-H <sub>2</sub> O	812	52	43.5

<sup>a</sup> Operating pressure 1000 psig. Product recovery 90%.

tions) have firm significance only if the membrane is specified in terms of  $A$  and  $(D_{AM}/K\delta)$  for a reference solute, and the appropriate mass transfer correlation applicable to the high pressure side of the membrane under the experimental conditions is given. Accordingly, the specifications of the particular membranes used in this work are given in Table I in terms of  $A$  and  $(D_{AM}/K\delta)$  for sodium chloride at 1000 p.s.i.g. The  $A$ -values given are the initial ones; they usually decrease as a function of time because of membrane compaction, but the  $(D_{AM}/K\delta)$  values do not change (Kimura and Sourirajan, 1968). Following the earlier work (Kimura and Sourirajan, 1967; Sourirajan and Kimura, 1967), the mass transfer coefficient correlation applicable for the experimental conditions used may be expressed as a generalized dimensionless parameter  $(N_{Bh}/N_{Bo}^{0.33})$  where

$$N_{Bh} = \frac{kd}{D} \quad (5)$$

and

$$N_{Bo} = \frac{v}{D} \quad (6)$$

The values of the above parameter were determined in a large number of experiments using several feed solution systems (NaCl-H<sub>2</sub>O, CaCl<sub>2</sub>-H<sub>2</sub>O, and MgCl<sub>2</sub>-H<sub>2</sub>O), and different concentrations of the system NaCl-H<sub>2</sub>O. The average of the

values obtained for the above parameter was 124, most of the values obtained being within 10% of the average value.

**Reverse Osmosis for Treatment of Hard Waters.** Hardness is of special concern in municipal and industrial water supply. Hard water requires much soap before a lather is formed, and hard water deposits sludges or incrustations on surfaces with which it comes into contact and in vessels and boilers in which it is heated. The responsible substances are calcium and magnesium ions, and to a lesser extent (because of their normally smaller concentrations), those of iron, manganese, strontium, and aluminum. In the operation of boilers, foaming, priming, scale formation, caustic embrittlement, and corrosion increase with operating pressures. Foaming and priming entrain moisture and solids in steam. The solids carried over may then be deposited in steam lines, turbines, and other equipment. The tolerances for hardness (expressed as p.p.m. CaCO<sub>3</sub>) of water are 80, 40, 10, and 2 for boilers operating in the pressure ranges below 150, 150 to 250, 250 to 400, and over 400 p.s.i.g., respectively (Fair and Geyer, 1961b).

Therefore, the treatment of hard waters to produce boiler feed waters of acceptable quality is an important industrial problem. The application of reverse osmosis for the treatment of hard waters was hence investigated and some results are presented in Tables I to IV and Figure 1. These experimental data do not represent the limits of separation and product rate obtainable with each film. With a higher mass transfer

**Table III. Separation of Iron, Manganese, Strontium, and Aluminum Ions in Aqueous Solution<sup>a</sup>**

System	Solute Concn. in Feed, P.P.M.	Product Water	
		Solute concn., P.P.M.	Product rate, gal./ (day) (sq. ft.)
FeCl <sub>3</sub> -H <sub>2</sub> O	795	40	19.0
MnSO <sub>4</sub> -H <sub>2</sub> O	500	<1	25.7
SrCl <sub>2</sub> -H <sub>2</sub> O	485	17	23.7
AlCl <sub>3</sub> -H <sub>2</sub> O	503	11	26.9

<sup>a</sup> Film H-4.  
Operating pressure 1000 p.s.i.g.  
Product recovery 90%.

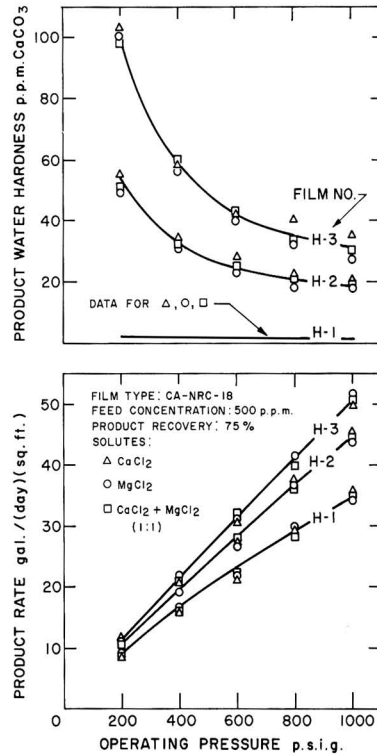
coefficient on the high pressure side of the membrane, a better solute separation and product rate can be obtained in most cases. Under the given experimental conditions, the data, however, illustrate the combination of separation and product rate obtainable for each film. Since the mass transfer correlation applicable for the high pressure side of the membrane is the same for all the experiments in this work, the above comments are applicable for all the data presented in this paper. Further, since the data presented are for high product recovery (90% in most cases), the experiments often took several hours to complete; consequently, the reported product rate data already include at least a part of the membrane compaction effect. On the basis of the known characteristics of the films used in this work (Kopeček and Sourirajan, 1969), it is reasonable to expect that product fluxes of about 70 to 80% of those reported here will be realized practically under conditions of continuous operation for long periods of time.

Table II gives the results obtained with three films. CaCl<sub>2</sub>, MgCl<sub>2</sub>, and 1-to-1 mixture of CaCl<sub>2</sub> and MgCl<sub>2</sub> were used as solutes. Three different initial feed concentrations (~300, 500, and 800 p.p.m. expressed as CaCO<sub>3</sub>) were tested. The hardness and rates of product water obtained at volume recoveries of 25, 50, 75, and 90% were determined. Only the

**Table IV. Softening of Natural Hard Waters<sup>a</sup>**

Film No.	Source of Feed Water	Feed Water	Product Water	
		Hardness, P.P.M. CaCO <sub>3</sub>	Hardness, p.p.m. CaCO <sub>3</sub>	Product rate, gal./ (day) (sq. ft.)
H-1	Coalinga, Calif.	843	<1	26.5
	Webster, S.D.	610	<1	28.6
	Roswell, N.M.	641	4	29.6
	San Diego, Calif.	340	2	30.4
	Indianapolis, Ind.	247	4	30.0
H-2	Coalinga, Calif.	843	12	40.1
	Webster, S.D.	610	5	43.2
	Roswell, N.M.	641	14	42.9
	San Diego, Calif.	340	7	45.1
	Indianapolis, Ind.	247	11	45.0

<sup>a</sup> Operating pressure 1000 p.s.i.g.  
Product recovery 90%.



**Figure 1. Effect of pressure on membrane performance for reverse osmosis water softening**

90% recovery data are presented in Table II. The results show that even with 90% recovery, product water hardness of ~2 p.p.m. was obtained with film H-1 with an initial average product rate of 38 gallons per day per sq. foot at 1000 p.s.i.g. Under the same conditions the hardness of product water obtained ranged from 17 to 45 p.p.m. for film H-2 and 22 to 64 p.p.m. for film H-3, with corresponding average product rates of 43.6 and 49.2 gallons per day per sq. foot, respectively. With lower recoveries, the hardness of product water was even less, and product rate more favorable in all cases.

Table III illustrates the performance of film H-4 for the separation of iron, manganese, strontium, and aluminum ions present in low concentrations. The data also show that the reverse osmosis technique can be successfully applied for such separations.

Figure 1 shows the effect of pressure on the quality and flux of product water with a feed whose hardness was 500 p.p.m. Since solute separation generally decreases with decrease in operating pressure, data of the type presented in Figure 1 determine the minimum operating pressure necessary for specific applications. The results show that film H-1 gives product water hardness of 2 p.p.m. or less in the entire pressure range 200 to 1000 p.s.i.g. tested.

Table IV illustrates the performance of films H-1 and H-2 for softening some natural hard waters obtained from different sources.

The high solute separations and product rates obtained with the films used in this work indicate that reverse osmosis can be successfully used for the economic treatment of industrial and natural hard waters to give product waters of



**Table V. Results of Repeated Reverse Osmosis Operation<sup>a</sup>**

System	Feed Water <sup>b</sup> Hardness, P.P.M. CaCO <sub>3</sub>	Product Water		
		Recovery, %	Hardness, p.p.m. CaCO <sub>3</sub>	Product rate, gal./ (day) (sq. ft.)
CaCl <sub>2</sub> -H <sub>2</sub> O	2.25	25	0.125	35.2
		50	0.125	35.8
		75	0.175	35.2
MgCl <sub>2</sub> -H <sub>2</sub> O	2.14	90	0.225	36.6
		25	0.120	35.2
		50	0.140	35.7
	2.18	75	0.140	35.9
		90	0.260	36.6

<sup>a</sup> Film H-1. Operating pressure 1000 p.s.i.g.  
<sup>b</sup> Product obtained from once-processed hard water.

acceptable quality for domestic use as well as for high pressure boilers.

**Production of Ultrapure Waters by Repeated Application of Reverse Osmosis.** The development of new industries in the electronic, semiconductor, and nuclear areas, and the expansion of many old industries such as the pharmaceutical, utility, and electrochemical fields have created a demand for large quantities of "ultrapure" water. A leading contributor to the field of production of ultrapure water is the electrical power industry. The use of boilers operating at or close to supercritical pressure is on the increase. Typical specifications for feed water quality for subcritical boilers (operating at 1800 to 2400 p.s.i.g.), and supercritical boilers (operating at pressures >3200 p.s.i.g.) are, respectively, 0.5 and 0.05 p.p.m. total dissolved solids (Calmon and Kingsbury, 1966). Such ultrapure waters can be produced by repeated application of the reverse osmosis process to the available feed water. This is illustrated in Table V, where the feed used was a composite sample of the product waters obtained from the once processed hard waters (hardness = 300 to 800 p.p.m. CaCO<sub>3</sub>). The product water obtained by the twice-operated reverse osmosis process (Table V) is already suitable as feed for subcritical boilers. An additional reverse osmosis processing of the above waters can give waters suitable as feed for supercritical boilers. In view of the facts that the data given in Tables I and V refer to 90% recovery, and the product rates

**Table VI. Separation of Some Water Pollutants<sup>a</sup>**

System	Solute Concn. in Feed, P.P.M.	Product	
		Solute concn., P.P.M.	Product rate, gal./ (day) (sq. ft.)
NaNO <sub>3</sub> -H <sub>2</sub> O	492	87	27.3
Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> -H <sub>2</sub> O <sup>b</sup>	524	16	26.1
NaF-H <sub>2</sub> O	505	26	26.4
NaCl-H <sub>2</sub> O	507	78	27.6
ABS-H <sub>2</sub> O	95	<1	20.9
ABS-H <sub>2</sub> O	300	<1	19.6
NH <sub>4</sub> NO <sub>3</sub> -H <sub>2</sub> O	487	97	23.2
Na <sub>3</sub> PO <sub>4</sub> -H <sub>2</sub> O	480	3	20.4

<sup>a</sup> Film H-4.  
 Operating pressure 1000 p.s.i.g.  
 Product recovery 90%  
<sup>b</sup> pH of feed = 9.0.

**Table VII. Separation of Some Salts Present in Plating Wastes<sup>a</sup>**

System	Solute Concn. in Feed, P.P.M.	Product	
		Solute concn., p.p.m.	Product rate, gal./ (day) (sq. ft.)
ZnSO <sub>4</sub> -H <sub>2</sub> O	535	48	20.7
Pb(CH <sub>3</sub> COO) <sub>2</sub> -H <sub>2</sub> O	504	32	20.4
CuSO <sub>4</sub> -H <sub>2</sub> O	500	8	19.2
NiCl <sub>2</sub> -H <sub>2</sub> O	500	14	19.2
CrO <sub>3</sub> -H <sub>2</sub> O	512	22	21.5
SnCl <sub>2</sub> -H <sub>2</sub> O	500	49	20.8
AgNO <sub>3</sub> -H <sub>2</sub> O	500	135	22.6
Fe(SO <sub>4</sub> ) <sub>2</sub> (NH <sub>4</sub> ) <sub>2</sub> -H <sub>2</sub> O	525	19	20.1
Ni(SO <sub>4</sub> ) <sub>2</sub> (NH <sub>4</sub> ) <sub>2</sub> -H <sub>2</sub> O	515	22	20.9
Cr(SO <sub>4</sub> ) <sub>3</sub> -H <sub>2</sub> O	500	9	22.1
HAuCl <sub>4</sub> -H <sub>2</sub> O	500	109	19.1

<sup>a</sup> Film H-4.  
 Operating pressure 1000 p.s.i.g.  
 Product recovery 90%.

obtained are sufficiently high (~36 gallons per day per sq. foot at 1000 p.s.i.g.), the technique of repeated operation of the reverse osmosis process might prove economical for the production of large quantities of ultrapure waters.

**Separation of Common Water Pollutants.** Excessive amounts of nitrates, borates, fluorides, chlorides, phosphates, ABS, and ammonium ions are usually regarded as pollutants in municipal and industrial water supply. Nitrates and phosphates serve as nutrients for the growth of algae and other aquatic plants which render the water unfit for recreational and other uses; further, fish and other aquatic life are deprived of oxygen by the decomposing algae and plant life. While small concentrations of fluorides appear beneficial in reducing the prevalence of dental caries, excessive amounts of fluorides are definitely associated with the prevalence of mottled teeth in many communities. Excessive amounts of nitrates are held responsible for some infant illnesses (Fair and Geyer, 1961a), and excessive amounts of chlorides render the water unfit for drinking. The presence of ABS even in concentrations of only 1 p.p.m. will produce substantial frothing and, being nonbiodegradable, it will accumulate in water, producing very undesirable foams. The pretreatment of water for the removal of the above pollutants may be necessary in many water supply systems. Table VI shows that the above pollutants can be effectively removed by the reverse osmosis process. As pointed out earlier, the solute separations given in Table VI do not represent the limits obtainable by the reverse osmosis process. By the appropriate choice of the porosity of the preshrunk membrane, practically any degree of solute separation can be obtained. The data presented in Table VI show that the separations and product rates obtainable with the type of films used in this work are sufficiently significant for consideration for practical industrial applications.

**Separation of Pollutants from Plating Wastes.** The waste effluents from metal finishing plants contain numerous toxic constituents (Promisel, 1960). The toxicity limits to fish life with respect to, for example, copper, lead, zinc, and chromium are 0.02, 0.1, 0.1, and 1.0 p.p.m., respectively (Hawksley, 1967). Hence the treatment of plating wastes, especially dilute wastes, is a serious problem in the metal-finishing industry. Since profuse rinsing is a prerequisite of a sound finish, very large quantities of water are involved; and some of the waste constituents have economic value (Lancey, 1955).

Consequently, the problem of treating plating wastes is important from the points of view of water pollution control, water re-use, and waste recovery. The data presented in Table VII illustrate the possible applicability of the reverse osmosis technique for the removal of substances present in plating wastes. The data given are for 90% recovery in a single-stage reverse osmosis process using ~500 p.p.m. of solutes. The actual concentration of solutes in plating wastes is usually much less. Since the same degree of separation can be expected at lower concentrations also, more than one reverse osmosis processing may not be necessary in many situations. In any case, by repeated operation of the process with 90 to 95% recovery in each operation, product water of any desired quality can be obtained along with concentrated solutions suitable for waste recovery.

Table VIII. Reverse Osmosis for Sewage Water Treatment<sup>a</sup>

Solute or Equivalent	Solute Conc. in Feed, P.P.M.	Operating Pressure, P.S.I.G.	Product	
			Solute concn., p.p.m.	Product rate, gal./ (day) (sq. ft.)
B.O.D.	24	1000	3	29.6
	46	1000	8	35.8
	37	1000	2	38.4
	25	1000	5	31.0
	36	1000	5	28.7
	44	500	15	14.6
	46	500	8	16.2
	24	500	5	19.6
	37	500	7	18.8
	21	500	4	18.4
	NO <sub>3</sub> <sup>-</sup>	0.24	1000	0.1
0.50		1000	0.25	34.0
0.07		1000	0.03	28.7
PO <sub>4</sub> <sup>-</sup>	2.5	1000	0.01	34.2
	1.8	1000	0.01	34.0
	3.5	1000	0.02	29.7
ABS	0.7	1000	0.05	29.6
	0.8	1000	0.05	35.8
	0.4	1000	0.02	38.4
	1.2	1000	0.08	31.0
	1.5	1000	0.10	28.7
	1.8	500	0.20	14.6
	0.8	500	0.08	16.2
	1.2	500	0.01	19.6
	1.1	500	0.01	18.8
	1.3	500	0.01	18.4
Total dissolved solids	284	1000	32	29.6
	454	1000	9	35.8
	76	1000	0.1	38.4
	324	1000	9	31.0
	278	1000	7	28.7
	434	500	49	14.6
	385	500	19	16.2
	350	500	30	19.6
	265	500	23	18.8
	294	500	62	18.4

<sup>a</sup> Film No. H-5.  
Feed raw sewage water.  
Product recovery 90%.

**Reverse Osmosis for Sewage Water Treatment.** The present primary and secondary sewage treatment facilities have as their main objectives the removal of B.O.D. and suspended solids. These treatments are not designed to remove nitrates, phosphates, or the nonbiodegradable surfactants. The removal of the latter would be the objective of tertiary sewage treatment facilities which are not in extensive use today. Reverse osmosis can effectively take the place of tertiary treatment, and sometimes both secondary and tertiary treatments, and offers an effective means of upgrading sewage water to a quality practically suitable for all water uses. Some pilot plant results of sewage water treatment by reverse osmosis have been reported (Bray *et al.*, 1965; Sudak and Nusbaum, 1968). Table VIII gives the results obtained with a typical film and a number of samples of raw sewage water obtained from the Ottawa City primary sewage treatment plant. Experiments were made at two operating pressures, 1000 and 500 p.s.i.g., with particular reference to the removal of B.O.D., nitrate, phosphate, ABS, and total dissolved solids. The performance of the membrane was found to be very good with respect to the removal of all the above contaminants. The average B.O.D. removals were 85.8 and 80.8% at 1000 and 500 p.s.i.g., respectively. Under the conditions of the experiments made, the average separations of nitrates, ABS, and phosphates were 50.3, 93, and >99%, respectively. The average product rates were 32.7 and 18.3 gallons per day per sq. foot at 1000 and 500 p.s.i.g., respectively. The above results indicate that the reverse osmosis process using the type of porous cellulose acetate membranes used in this work has the potentialities of becoming an economic means of renovation of waste waters.

#### Acknowledgment

One of the authors (A.R.H.) is grateful to Frank Ayers, William Key, and Lloyd Larson of the Ottawa City Hall for their support to this work, and I. E. Puddington for permission to carry out much of this work at the National Research Council Laboratories. The authors thank Paul St. Onge, Leo Laurin, Andre Charron, Art Baxter, and Lucien Pageau for their help in this work.

#### Nomenclature

- $A$  = pure water permeability constant, gram mole H<sub>2</sub>O/sq. cm. sec. atm.
- $c$  = molar density of solution, gram mole per cc.
- $d$  = effective diameter of membrane surface, cm.
- $D$  = diffusivity of solute, sq. cm. per sec.
- $(D_{AM}/K\delta)$  = solute transport parameter, cm. per sec.
- $k$  = mass transfer coefficient, cm. per sec.
- $M_B$  = molecular weight of water
- $N_B$  = water flux through membrane, gram moles per sq. cm. per sec.
- $N_{Sc}$  = Schmidt number
- $N_{Sh}$  = Sherwood number
- $P$  = operating pressure, atm.
- [PR] = product rate, grams per hour per 9.6 sq. cm. of film area
- [PWP] = pure water permeability, grams per hour per 9.6 sq. cm. of film area
- $X_A$  = mole fraction of solute
- $\pi(X_A)$  = osmotic pressure corresponding to  $X_A$ , atm.
- $\nu$  = kinematic viscosity of feed solution, sq. cm. per sec.

#### SUFFIXES

- 1 = bulk solution on high pressure side of membrane
- 2 = boundary solution on high pressure side of membrane
- 3 = product solution

#### Literature Cited

- American Public Health Association, New York, "Standard Methods for Examination of Water and Waste Water," 12th ed., 1965.
- Bray, D. T., Merten, U., Augustus, M., "Reverse Osmosis for Water Reclamation," Gulf General Atomic, Inc., San Diego, Calif., Rept. GA-6337 (1965).
- Calmon, C., Kingsbury, A. W., in "Principles of Desalination," K. S. Spiegler, Ed., p. 453, Academic Press, New York, 1966.
- Fair, G. M., Geyer, J. C., "Water Supply and Waste Water Disposal," p. 12, Wiley, New York, 1961a.
- Fair, G. M., Geyer, J. C., "Water Supply and Waste Water Disposal," p. 859, Wiley, New York, 1961b.
- Hawksley, R. W., *Analyzer* 8 (1), 13 (1967).
- Ironside, R., Sourirajan, S., *Water Res.* 1, 179 (1967).
- Kimura, S., Sourirajan, S., *A.I.Ch.E.J.* 13, 497 (1967).
- Kimura, S., Sourirajan, S., *Ind. Eng. Chem. Process Design Develop.* 7, 197 (1968).
- Kopeček, J., Sourirajan, S., *J. Appl. Polymer Sci.* (in press), 1969.
- Lancey, L. E., "Integrated Treatment of Metallurgical Wastes," Proceedings of Second Ontario Industrial Waste Conference, p. 41, Ontario Water Resources Commission, Toronto, 1955.
- Promisel, N. E., in "Metal Finishing Guidebook," 28th ed., p. 658, Metals and Plastics Publications, Westwood, N.J., 1960.
- Sourirajan, S., in "Water Resources of Canada," C. E. Dolman, Ed., p. 154, University of Toronto Press, Toronto, 1967.
- Sourirajan, S., "Reverse Osmosis," Logos Press, London (in press), 1969.
- Sourirajan, S., Govindan, T. S., Proceedings of First International Symposium on Water Desalination, October 1965, Washington, D.C., U.S. Dept. Interior, Office of Saline Water, Vol. I, pp. 251-74 (1965).
- Sourirajan, S., Kimura, S., *Ind. Eng. Chem. Process Design Develop.* 6, 504 (1967).
- Sudak, R. G., Nusbaum, I., "Pilot Plant Operation of Spiral Wound Reverse Osmosis Systems," Gulf General Atomic, Inc., San Diego, Calif., Rept. GA-8515 (1968).

Received for review October 24, 1968. Accepted June 25, 1969. Issued as N.R.C. No. 10920.

## Volumetric Calibration of Permeation Tubes

Bernard E. Saltzman

Department of Environmental Health, University of Cincinnati, Cincinnati, Ohio 45219

Charles R. Feldmann<sup>1</sup> and Andrew E. O'Keeffe

National Air Pollution Control Administration Cincinnati, Ohio 45226

■ Alternative means were needed for calibration of permeation tubes used to generate accurately known low concentrations of gases for use as standards. A microgasometer technique was developed employing a compensated Warburg syringe manometer with a sensitivity of 0.1  $\mu$ l. The average 95% confidence interval was  $\pm 1\%$  for rate measurements made over 1- to 2-hour periods on sulfur dioxide permeation tubes; agreement with gravimetric calibrations was good. The theoretical relationships are given for rate calculations with allowances for temperature, pressure, solubility, and compressibility corrections. The method is a simple, rapid, inexpensive, and broadly applicable fundamental technique.

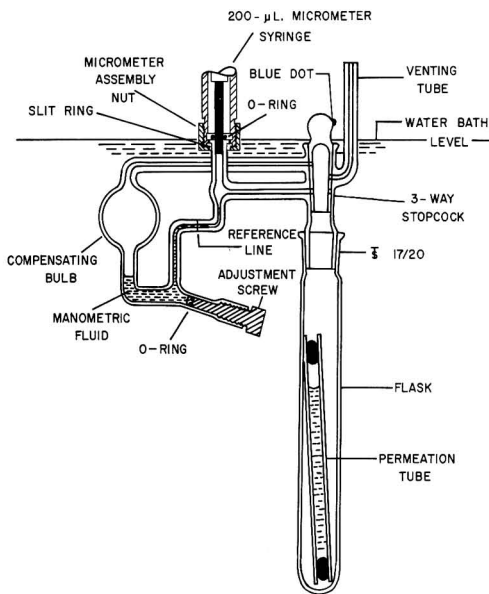
Permeation tubes have been developed as simple, convenient, and accurate means for generating accurately known low concentrations of gaseous pollutants to serve as standards for testing and calibration. O'Keeffe and Ortman (1966) showed that liquefiable gases such as sulfur dioxide,

nitrogen dioxide, various hydrocarbons, halogenated compounds, ammonia, and hydrogen sulfide, when enclosed in tubes of inert plastic such as FEP Teflon, escape by permeating the tubing walls at constant, reproducible, temperature-dependent rates. Such tubes also have been prepared for anhydrous hydrogen fluoride (Jacobson, 1967), and for phosgene and organic mercury compounds (Linch, Stalzer, *et al.*, 1968). Scaringelli, Frey, *et al.* (1967) demonstrated exact equivalence between weight losses of sulfur dioxide permeation tubes and measurements made both colorimetrically and microcoulometrically. Thomas and Amtower (1966) also reported successful tests. Sulfur dioxide permeation tubes were collaboratively tested in the Analytical Methods Evaluation Service Study No. 1 (Saltzman, 1968; Tye, O'Keeffe, *et al.*, 1968), with favorable results.

Devices such as thermal conductivity and flame ionization detectors can serve as secondary standards; however, they ordinarily determine only relative values, and must be calibrated with known quantities of the test substances. Primary standards, on the other hand, are prepared by techniques involving calibrations by weight, volume, pressure, coulometry, etc., in an accurate and preferably convenient manner.

Because permeation tubes are used as primary standards, convenient and accurate techniques are needed for their calibration. Most of such work has been done by gravimetric measurements; however, this method requires maintaining the tubes at precisely controlled temperatures for

<sup>1</sup> Present address, Federal Water Pollution Control Administration, Cincinnati, Ohio 45226



**Figure 1.** Schematic diagram of microgasometer assembly submerged in water bath

Apparatus, except for flask, commercially available as Gilmont Warburg compensated syringe manometer. Capacity of micrometer syringe, 200  $\mu\text{L}$ , in 20 turns with 0.2- $\mu\text{L}$  divisions. Stopcock, shown in venting position, is turned 180° for operation

several weeks to get sufficient weight losses for accurate determinations. Colorimetric and coulometric techniques require special reagents or equipment. This report deals with the volumetric calibration of permeation tubes. A microgasometer technique is recommended as a simple, rapid, accurate, and broadly applicable alternative means of measuring the gas permeation rates. It is especially convenient for substances such as hydrocarbons, which otherwise could not be conveniently determined in a primary standard manner with microgram sensitivities. The work reported was conducted with sulfur dioxide permeation tubes of the type used in the collaborative study.

#### Apparatus

The apparatus was a Gilmont compensated Warburg syringe manometer (Figure 1). The microgasometer was completely submerged in a water bath to maintain a known constant temperature. Volumetric measurements were made with a Gilmont micrometer syringe having a capacity of 200  $\mu\text{L}$  in 0.2- $\mu\text{L}$  divisions (10  $\mu\text{L}$  per turn), and fabricated of polypropylene. The permeation tube was placed in the test tube flask shown at the lower right of the figure, connected to the syringe manometer at the  $\text{F} \frac{17}{20}$  joint. During operation the vent outlet of the apparatus was closed. The measurements therefore were independent of changes in barometric pressure during a run. The closed compensating bulb connected to the manometer on the side opposite the flask prevented minute changes in bath temperature from inducing any pressure differentials.

The permeation tubes tested were constructed of FEP Teflon tubing, 5 inches long, of  $\frac{1}{4}$ -inch outside diameter and 0.03-inch wall thickness and were filled with liquid sulfur dioxide (at approximately 3-atm. pressure). Each end was sealed

with a 1-cm. length of FEP Teflon rod and clamped with a crimped aluminum band.

In initial work a constant-temperature bath was employed. Because its intermittent heating and cooling produced excessive fluctuations of the measured volumes, later runs were made with an insulated 20-gallon plastic container filled with water. The top was covered with a piece of Plexiglas whenever adjustments were not being made. This heat sink was adequate for the purpose; for more constant temperature, one can insert a metal coil through which thermostatically controlled water is circulating.

#### Procedure

The apparatus was carefully cleaned, so that the manometric fluid presented a good meniscus at the reference line. The three-way stopcock was greased with fluorosilicone grease and left in the vented position (blue dot facing venting outlet). The flask joint also was greased.

The manometric fluid for this work was *n*-nonane containing a few hundredths of 1% of a nonionic surfactant (SAG-47; Union Carbide Corp.). The solubility of sulfur dioxide in this liquid was so slight that no corrections were necessary. (In later work dodecane without a surfactant was used successfully.)

The adjustment screw was removed, and 1.3 ml. of nonane were introduced from a pipet into the apparatus. The volume of fluid was adjusted so that upon replacement of the adjustment screw the meniscus in the horizontal capillary was near the reference line. The screw and capillary were examined carefully, and any bubbles were discharged at the compensating bulb. Care was taken never to allow the nonane to wet the stopcock joint, since this necessitated cleaning and regreasing the joint.

The flask containing the permeation tube was connected to the apparatus with the stopcock in the venting position, and the system was submerged in the heat sink, as shown in Figure 1. The micrometer screw was set initially to extend the plunger fully. The adjustment screw was turned so that the meniscus of the manometric fluid was close to the reference line. One hour sufficed to reach thermal equilibrium if the tube and the water bath were initially at a controlled constant temperature close to the ambient value. The stopcock was then turned 180° to the closed operating position. The micrometer screw was turned to bring the meniscus of the manometric fluid a few millimeters to the right of the reference line and the volume reading was noted. A stopwatch was started at the exact moment when the permeating sulfur dioxide pushed the meniscus past the reference line. After 10 or more minutes, the meniscus was returned to a position just to the right of the reference line by readjusting the micrometer screw, and the volume reading again was noted. At the moment when the meniscus crossed the reference line for the second time, the stopwatch reading was noted. This procedure was repeated without stopping the watch for a number of additional intervals up to a total time of about 2 hours.

#### Results

Early runs were made with water as a manometer fluid, but constant permeation rates could not be obtained because of the solubility of the sulfur dioxide in this liquid. Good results were then obtained with nonane.

Figure 2 is a plot of volume *vs.* time for seven runs conducted on four permeation tubes. Very close adherence to a linear relationship was observed for volumes up to 200  $\mu\text{L}$ . The slopes of the lines, which represent the permeation rates in microliters per minute, were determined by fitting straight

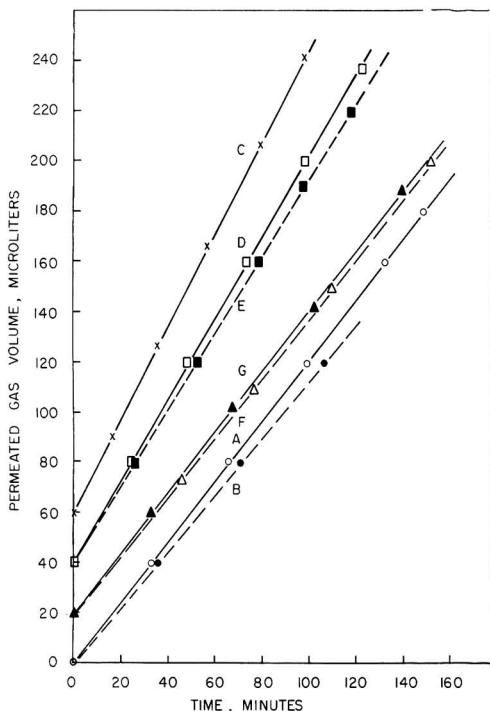


Figure 2. Volumetric calibrations of four sulfur dioxide permeation tubes

Letters refer to run designations, at different temperatures listed in Table I. Lines displaced vertically for easier visibility

- , ● Tube 1
- × Tube 2
- , ■ Tube 3
- △, ▲ Tube 4

lines to the points by the method of least squares. In this calculation the volume reading at zero time was taken as one point of equal statistical weight with the other measurements. The fitted lines thus did not necessarily pass through these initial readings; the intercepts differed from the latter by amounts ranging from  $-0.8$  to  $+0.5 \mu\text{l}$ . The average difference was  $+0.07 \mu\text{l}$ . The slopes obtained from these calculations are given in the eighth column of Table I. The 95% confidence interval of each slope, expressed in per cent, is indicated in the ninth column. This averaged about 1%, which is very satisfactory considering the microvolumes that were measured in the short times. Accurate results can be obtained with measurements over intervals of even less than an hour.

The validity of these measurements was determined by comparing them with earlier gravimetric calibrations of the same tubes (Table II). After the weighings were completed, the volumetric measurements were conducted at various times over a period of a month and a half. Thus there were intervals of several weeks between the two sets of measurements.

#### Calculations

Because of the high temperature coefficient of the permeation rate, it was necessary to correct all measurements to a standard temperature, taken as  $25^\circ\text{C}$ ., for comparisons.

The calculations for converting the slope,  $S$ , of the volumetric measurements to the gravimetric rate at  $25^\circ\text{C}$ . were made by means of Equation 1. A correction of about 4 Torr

was required for the vapor pressure of the nonane. Assumedly, as the volume expanded, additional nonane evaporated to maintain this vapor pressure. (This correction was negligible for dodecane used in later work; at  $25^\circ\text{C}$ . its vapor pressure is only 0.13 Torr.)

$$G_o = S \frac{298.16}{(t + 273.16)} \frac{(P - p)}{760} \frac{W}{24.47} B \quad (1)$$

where  $G_o$  = gravimetric rate,  $\mu\text{g}$ . per minute, corrected to  $25^\circ\text{C}$ .

$S$  = experimental volumetric rate,  $\mu\text{l}$ . per minute

$t$  = temperature,  $^\circ\text{C}$ .

$P$  = barometric pressure, Torr, at the moment the microgasometer vent was closed

$p$  = vapor pressure of manometer fluid, Torr, at  $t^\circ\text{C}$ .

$W$  = molecular weight of test gas (= 64.066 for  $\text{SO}_2$ )

$B$  = gravimetric temperature correction factor,

$$\frac{G_o}{G}$$

24.47 = gram molecular volume, liters, at  $25^\circ\text{C}$ ., 760 Torr

Several investigators (O'Keeffe and Ortman, 1966; Scaringelli, Frey, *et al.*, 1967) have shown that the variation of the gravimetric permeation rate with temperature follows the quantitative relationship in Equation 2, which is similar to that for a chemical reaction. The activation energy was 14,540 cal. per gram mole. Only about a third of this was accounted for by the heat of vaporization of liquid sulfur dioxide. The remainder was required for the activated diffusion process. The molecules of sulfur dioxide rupture the weak intermolecular bonds of the Teflon as they move through the walls of the tube in a series of discontinuous jumps. The energy of bond recombination behind them is dissipated and lost.

Since the gravimetric corrections were applied over a relatively small temperature range, a few degrees centigrade, the calculations were simplified. The approximation in Equation 3 leads to the final relationship shown in Equation 4. This latter equation gave results within 2 parts per thousand of the exact Equation 2 for this work.

$$\ln \left( \frac{G}{G_o} \right) = - \frac{E}{R} \left[ \frac{1}{T} - \frac{1}{T_o} \right] \quad (2)$$

$$\frac{1}{T} - \frac{1}{T_o} = \frac{1}{T_m^2} (T_o - T) \quad (3)$$

$$\log_{10} \left( \frac{G_o}{G} \right) = \log_{10} B = K (25 - t) \quad (4)$$

where  $G$  = gravimetric rate,  $\mu\text{g}$ . per minute

$E$  = activation energy, cal. per gram mole

$R$  = gas constant, 1.986 cal. per gram mole

$T$  = absolute temperature,  $^\circ\text{K}$ . ( $= t + 273.16$ )

$T_o$  = standard temperature, 298.16 $^\circ\text{K}$ . ( $= 25^\circ\text{C}$ .)

$T_m$  = mean temperature,  $(T_o + T)/2$

$K$  = empirical constant determined for each type of permeation tube ( $= 0.03637$  for these tubes in range  $20^\circ$  to  $25^\circ\text{C}$ .)

Final results of these temperature correction calculations for the volumetric calibration data are shown in the last column of Table I, and for the gravimetric calibrations in the fourth column of Table II. The ratios of the corrected rates determined by the two techniques are indicated in the sixth column of Table II. The rates from the volumetric measurements averaged about 3% higher than those from the gravimetric measurements. In view of the long time interval be-

**Table I. Volumetric Calibration Data**

Tube No.	Run	Mean Temp., °C.	Temp. Range, °C.	Initial Press., Torr	No. of Run, Min.	No. of Points	Calcd. Slope, $\mu\text{L./Min.}^a$	95% Confidence Interval of Slope, %	Calcd. Grav. Rate at 25°C., $\mu\text{g./Min.}$
1	A	22.19	0.06 <sup>b</sup>	744.9	149	6	1.209	0.48	3.943
	B	21.61	0.04	750.2	106	4	1.128	0.76	3.900
2	C	24.18	0.22	753.9	98	6	1.839	0.34	5.101
3	D	23.56	0.11	752.5	122	6	1.618	1.08	4.731
	E	23.01	0.15	751.1	118	6	1.528	0.80	4.679
4	F	22.44	0.10	745.0	152	5	1.187	2.10	3.787
	G	22.16	0.43	744.5	140	5	1.205	1.72	4.297

<sup>a</sup> Straight line fitted to experimental points by method of least squares.  
<sup>b</sup> Constant temperature bath utilized; all other runs with heat sink water bath.

tween the two sets of measurements and the different techniques involved, this agreement is good.

*Corrections for Gas Solubility*

To outline the theoretical limitations for general applications of this method, calculations were made to determine the corrections for the solubility of the test gas in the manometer fluid. The total volume of permeated gas is equal to the sum of the gas present in the air space and that dissolved in the manometer fluid. The volume of dissolved gas is proportional to the volume of liquid and to the mole fraction of test gas in the air space; it is corrected from 0°C. (the usual standard gas temperature for published values of solubility coefficient,  $\alpha$ ) to t°C. The correction for solubility is given by the last term on the right of Equation 5:

$$V = (V_2 - V_1) + \alpha v \frac{(V_2 - V_1)(t + 273.16)}{V_2 \cdot 273.16}$$

or

$$V = (V_2 - V_1) \left[ 1 + \frac{\alpha v (t + 273.16)}{V_2 \cdot 273.16} \right] \quad (5)$$

where  $V$  = total volume of permeated gas, ml. [t°C., (P - p) Torr]

$V_2$  = final gas volume, ml

$V_1$  = initial gas volume, ml.

$v$  = volume of manometer fluid, ml.

$\alpha$  = solubility coefficient of test gas in manometer fluid at temperature t, ml. of gas (0°C., 760 Torr) per ml. of liquid

For the present work with sulfur dioxide and nonane, the value of  $\alpha$  was estimated to be 0.03, about the same as for O<sub>2</sub> in water at 25°C. ( $\alpha$  for CO<sub>2</sub> is 0.76). Since  $v$  is 1.3 ml. and

$V_2$  about 50 ml. for the flask and apparatus, the fraction  $\alpha v/V_2 = 0.03 \times 1.3/50 = 0.0008$ . The temperature correction factor at 25°C. is 1.0915. The product of these numbers is negligible compared with the value of unity in the preceding term.

In an extreme case, for a very low permeation rate and a soluble test gas, a little test gas could leak into the compensating bulb. With proper choice of manometer fluid, these corrections can be made negligible.

*Corrections for Gas Compressibility*

The foregoing calculations were made on the basis of ideal gas volumes. For some gases, however, deviations from the perfect gas law occur within ambient pressures and temperatures. Estimates of these errors for common applications were therefore developed.

These deviations are usually expressed as the compressibility factor,  $z$ , defined as the ratio of the actual to ideal gas volume. If compressibility data for a specific gas are not available, a generalized plot may be employed. This expresses the relationships among compressibility, reduced pressure (ratio of actual to critical pressure for the substance), and reduced temperature (ratio of actual absolute temperature to critical absolute temperature). Such calculations were made assuming 25°C. temperature and 1-atm. partial pressure for acetylene, ammonia, butane, hexane, hydrogen sulfide, pentane, propane, and sulfur dioxide. Reduced temperatures ranged from 0.63 to 0.97, and reduced pressures from 0.01 to 0.03. A generalized plot extending to these low reduced pressures (Saltzman, 1958) indicated compressibility factors ranging from 0.99 to 0.95. However, if the gas partial pressures were taken as 0.1 atm., in all cases the compressibility factors were between 0.99 and 1.00. A single run can be made with less than 500  $\mu\text{L.}$  of permeated gas, including

**Table II. Comparison with Gravimetric Calibration Data**

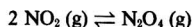
Tube No.	Weight Loss, G. <sup>a</sup>	Grav. Rate, $\mu\text{g./Min.}^a$	Calcd. Grav. Rate at 25°C., $\mu\text{g./Min.}$		Ratio Vol. to Grav. Rate	Deviation from Mean Ratio, %
			From gravimetric data	From volumetric data		
1	0.0644	2.984	3.759	3.922 <sup>b</sup>	1.043	+1.2
2	0.0839	3.888	4.898	5.101	1.042	+1.0
3	0.0812	3.763	4.740	4.705 <sup>b</sup>	0.993	-3.9
4	0.0661	3.063	3.858	4.042 <sup>b</sup>	1.048	+1.6
Mean					1.031	

<sup>a</sup> Weight loss during 21,580-minute interval (approx. 15 days), at mean temperature of 22.24°C., temperature range 0.05°C.

<sup>b</sup> Mean of two runs.

equilibration time in the vented position. Assuming a total flask and apparatus volume of 50 ml., the test gas partial pressure easily could be kept below 0.01 atm., and the compressibility correction can thus be kept negligible.

In the case of nitrogen dioxide, however, corrections are appreciable because of the equilibrium between the monomer and the dimer:



Some calculations showed that the effective compressibility factors (on a monomer basis) decreased in an approximately linear manner from 1.00 to 0.94 as the partial pressure of  $\text{NO}_2 + \text{N}_2\text{O}_4$  increased from 0 to 0.01 atm.

The correction is calculated as follows:

$$V' = \frac{(V_2 - V_0)}{z_2} - \frac{(V_1 - V_0)}{z_1} \quad (6)$$

where  $V'$  = corrected ideal volume of permeated gas, ml.

$$[t^\circ\text{C.}, (P - p) \text{ Torr}]$$

$(V_2 - V_0)$  = total permeated gas volume in apparatus at end of run

$(V_1 - V_0)$  = total permeated gas volume in apparatus at beginning of run

$z_2$  = compressibility factor at end of run

$z_1$  = compressibility factor at beginning of run

Application of this exact equation is difficult, because only  $(V_2 - V_1)$  is experimentally measured during the run. A close approximation is more convenient:

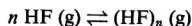
$$V' = \frac{(V_2 - V_1)}{z_m^2}$$

where  $z_m$  = mean of compressibility factors at beginning and end of the volume measurement.

The mean compressibility factor is that for the mean partial pressure of gas. This may be calculated from the time interval beginning at the moment when the permeation tube is placed in the flask and connected to the apparatus, until the middle of the measuring run. It may be assumed that the vented gas is essentially only air.

Available nitrogen dioxide permeation tubes have a relatively short life. Calibration by the rapid volumetric method thus would be more advantageous than by the slower gravimetric method.

In the case of hydrogen fluoride, the following reactions occur:



At ordinary temperatures, the vapor is a mixture of the monomer and polymers up to  $n = 8$ ; of the polymers, the trimer and tetramer are most abundant. The fraction of polymers increases with partial pressures of the gas and of

water vapor as well as with decreasing temperature. At low pressures the gas is essentially the monomer. Thus volumes may require a polymerization correction, but such data are not now available. The compressibility corrections on the basis of the critical pressure and temperature were found to be negligible by means of the generalized plot. This calibration, of course, could not be carried out in a glass apparatus because of chemical reaction.

#### Discussion

Mathematical correction equations have been presented for effects of gas solubility and compressibility. One other effect that should be considered is the reduction of permeation rate because of gas partial pressure in the apparatus. The driving force for the permeation process is the difference in gas pressure inside and outside the tube. An appreciable percentage change in this difference as the gas accumulates outside the tube will occur only for substances having vapor pressures of about 1 atm. or less at ordinary temperatures, such as hexane, pentane, hydrogen fluoride, and nitrogen dioxide. With proper choice of manometer fluid and with short runs, all these corrections can be kept at a negligible level.

The volumetric calibration technique should be broadly applicable to all types of permeation tubes. For gases such as hydrocarbons, the use of manometer fluids such as water and stopcock lubricants based on glycerol would be more appropriate. The technique has been demonstrated to be simple, rapid, and accurate, and requires relatively inexpensive apparatus. It is recommended as a useful means of calibrating permeation tubes.

#### Literature Cited

- Jacobson, J. S., "Permeation Tubes as Gaseous Hydrogen Fluoride Sources," Division of Water, Air, and Waste Chemistry, 153rd Meeting, ACS, Miami, Fla., April 10-14, 1967.
- Linch, A. L., Stalzer, R. F., Lefferts, D. T., *Am. Ind. Hyg. Assoc. J.* **29**, 79-86 (1968).
- O'Keefe, A. E., Ortman, G. C., *Anal. Chem.* **38**, 760-3 (1966).
- Saltzman, B. E., *ENVIRON. SCI. TECHNOL.* **2**, 22-32 (1968).
- Saltzman, B. E., *Ind. Eng. Chem.* **50**, 1593-8 (1958).
- Scaringelli, F. P., Frey, S. A., Saltzman, B. E., *Am. Ind. Hyg. Assoc. J.* **28**, 260-6 (1967).
- Thomas, M. D., Amtower, R. E., *J. Air Pollution Control Assoc.* **16**, 618-23 (1966).
- Tye, Russell, O'Keefe, A. E., Feldmann, E. R., "Report on Analytical Methods Evaluation Service Study No. 1," Ninth Conference on Air Pollution and Industrial Hygiene Studies, Pasadena, Calif., February 1968.

Received for review October 30, 1968. Accepted July 2, 1969. Mention of commercial products does not constitute endorsement by the Public Health Service. Investigation supported, in part, by the Center for Study of the Human Environment under USPHS Grant ES00159.

# Size-Separating Precipitation of Aerosols in a Spinning Spiral Duct

Werner Stöber and Hermann Flachsbarth

Department of Radiation Biology and Biophysics, University of Rochester, School of Medicine and Dentistry, Rochester, N.Y. 14620

■ A new instrument is described, facilitating particle size spectrometry and size distribution analysis of aerosols in terms of aerodynamic diameters. The aerosol particles are precipitated according to their aerodynamic size along a strip foil about 180 cm. in length. This foil forms the outer wall of a spiral duct, which is cut into a plane disk mounted on the rotor of a special centrifuge. Aerosol flow rates of up to 3 liters per minute can be fed into the centrifuge rotor at the center of rotation, where the aerosol is entrained into a laminar flow of clean air passing by the aerosol inlet and traveling through the spiral duct to the perimeter of the rotor. Total flow rate, aerosol intake, and rotor speed can be varied independently. This provides various operating conditions to be set for optimum performance with regard to deposition range, sampling rate, and size resolution. During a single test run, the instrument precipitates aerosol particles that differ in size by about two orders of magnitude. Best results are obtained at a rotor speed of 3000 r.p.m., where the centrifuge precipitates aerosol particles of sizes between  $5 \times 10^{-4}$  cm. and at least  $8 \times 10^{-6}$  cm. in diameter with a reasonably high degree of size resolution in different locations along the strip foil. For sizes above  $3 \times 10^{-5}$  cm., an excellent size resolution is obtained which facilitates the determination of aerodynamic diameters of aggregates of uniform spheres which differ only by their geometrical configuration. Calibration curves as obtained with latex spheres under different operating conditions are given to demonstrate the performance of the instrument. The influence of secondary flow patterns in the spiral duct is investigated, and an estimate of the entrance losses of the aerosol is given.

In 1950, five years after May (1945) had introduced the principle of cascade impaction for the size separation of airborne particles, Sawyer and Walton (1950) built the first centrifugal device capable of separating aerosols into a continuous spectrum of sizes. The instrument, called a conifuge, deposited the particles according to their aerodynamic size along the outside wall of a conical annular duct. In spite of the promising aspects of this design, the cascade impactor remained for a long time the only precipitator for size-selective sampling of airborne particles. In later years, another principle of centrifugal precipitation of airborne particles was introduced (Goetz, Stevenson, *et al.*, 1960; Kast, 1961) which partially abandoned the desired size separation in favor of a higher sampling rate. These instruments had curved quadrangular ducts and achieved merely a quasi-cumulative size distribution of the precipitate. Due to the complexity of the deposition patterns,

however, great difficulties were encountered in attempts to devise a mathematical method for an accurate size distribution analysis (Stöber and Zessack, 1964). This and other drawbacks put serious restrictions on the general applicability of such cumulative centrifugal devices. It is surprising that during that period of quest for a real aerosol-size spectrometer, the size-separating conifuge principle of Sawyer and Walton has not been utilized again, except for one aerosol size distribution study on cigarette smoke (Keith and Derrick, 1960).

In recent years, however, with the growing interest in small, respirable airborne particles in the micron and submicron size range, attempts were revived to improve size-separating precipitation by centrifugal devices. A number of publications appeared in the literature describing instruments which all made use of the conifuge principle (Berner, 1968; Hauck and Schedling, 1968; Stöber, 1967; Tillery, 1967). In all of these designs, the aerosol is fed into a spinning annular duct with a coaxial flow of clean air, which is traversed by the aerosol particles according to their aerodynamic diameter. Stöber and Flachsbarth (1969) critically reviewed these efforts. Although the sampling rate can be improved considerably in comparison to the original design of Sawyer and Walton, it became apparent that within the dimensions of a feasible design of this kind, an acceptable resolution of sizes is confined to a size range of, at best, one order of magnitude. For a desirable extension of this range, it seems to be necessary to abandon the conifuge principle and develop an instrument which provides an extended path length along which the particles can be separated.

This paper describes a new design which uses a spiral duct of rectangular cross section cut into a special centrifuge rotor. The instrument is a true aerosol-size spectrometer and facilitates excellent size resolution over a size range of almost two orders of magnitude, while the aerosol sampling rate is of the order of 1 liter per minute.

## *Design of the Spiral Centrifuge*

The essential part of the new device is a spiral duct cut into the disk-shaped rotor of a centrifuge. Figure 1 shows a photograph of the top of the rotor disk. The arrow indicates the direction of rotation. The disk has a diameter of 26.2 cm. The spiral duct consists of six semicircles of different radii. It has a straight, almost radial, extension beyond the center of the rotor. The height of the duct parallel to the axis of the rotor is 3.30 cm. The width is 1.73 cm. at the center of the rotor and narrows down to 1.00 cm. at the outer end of the first semicircle. From there on, the rest of the spiral duct is of constant width. Along the outer wall of the spiral section of the duct a small groove is cut into the bottom. It holds in place a chromium-plated brass foil of 0.015-cm. thickness and 179.5-cm. length. The foil is 3.35 cm. wide and forms a strip which covers the entire curved section of the outer wall.

While the rotor is spinning, clean air enters the duct through



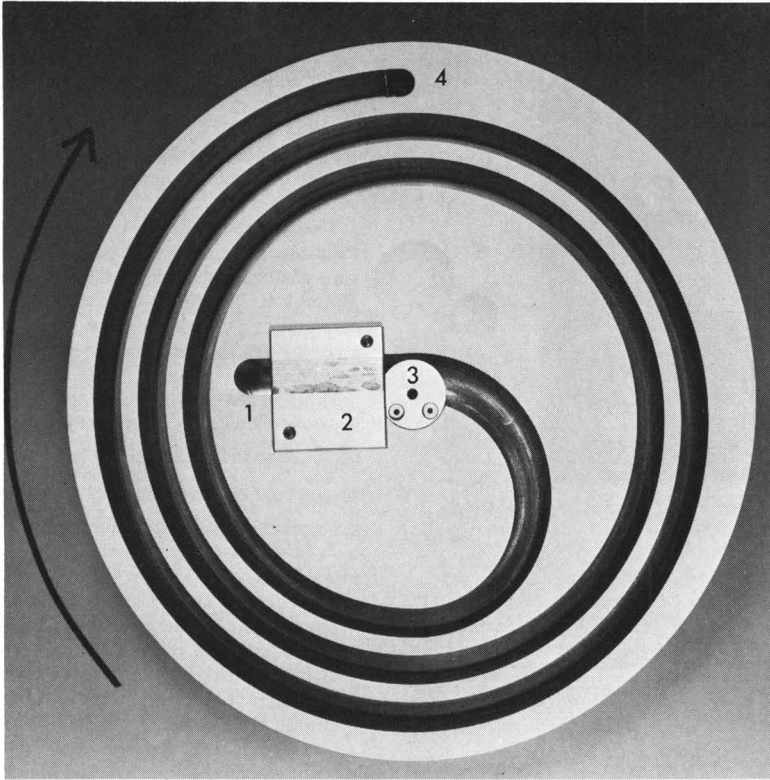


Figure 1. View of centrifuge rotor and spiral duct

the off-center air inlet, 1 (Figure 1), and flows to the inserted laminator, 2. In Figure 2 the laminator is removed from the rotor to show the five thin brass foils mounted parallel to the vertical walls of the rectangular duct. In this section, the clean air is quickly stabilized and emerges as a laminar flow from the downstream end. It then approaches an exchangeable aerosol inlet section, 3, at the center of the rotor. The aerosol enters the inlet section through the center bore and is released into the duct as an air sheath parallel to the inner wall of the duct, where it will be entrained into the laminar flow. Figure 3 shows an aerosol inlet section which was used in experiments with high aerosol flow rates. This particular design releases the aerosol through a set of short capillaries. For high-resolution tests, however, where reduced aerosol flow rates are required, another design was employed which had a narrow slit adjacent to the inner wall.

When leaving the center of rotation, the aerosol particles are subjected to the centrifugal forces of the spinning rotor and start moving in a radial direction across the laminar air stream. Their trajectories are determined by the operating conditions of the centrifuge and the aerodynamic size of the particles. Thus, while the air is flowing down the duct to the outlet, 4, the particles are settling, according to their size, in different locations on the strip foil along the outer wall. For analysis of the deposit, the strip can easily be removed from the rotor.

Figure 4 is a schematic vertical section of the rotor assembly.

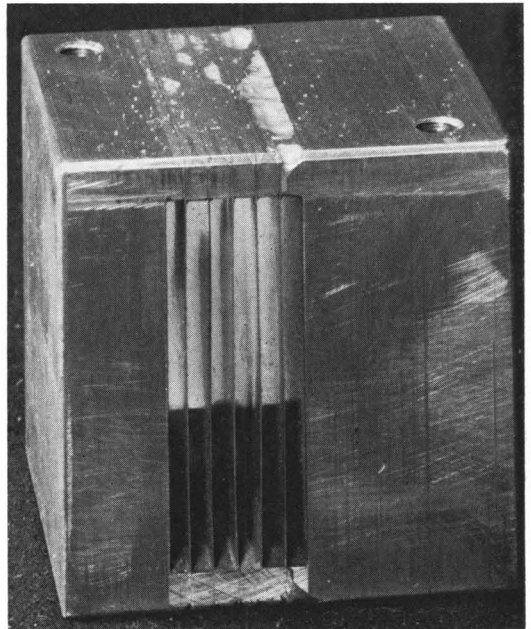


Figure 2. Laminator section of clean air duct

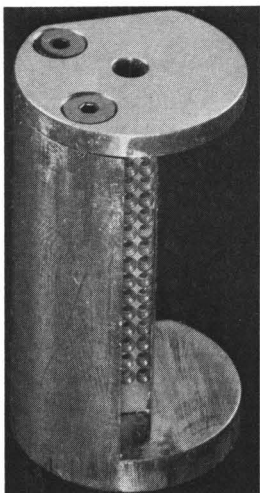


Figure 3. Aerosol inlet section (for relatively high aerosol flow rates)

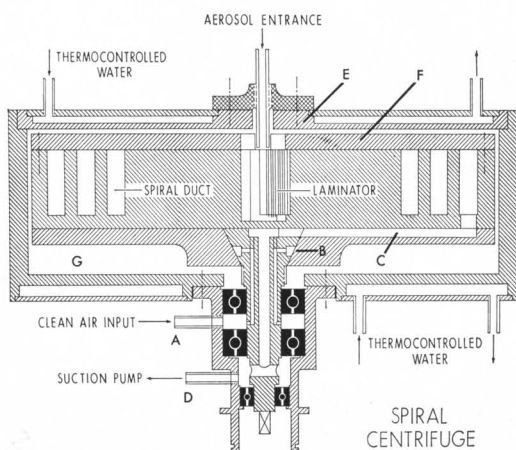


Figure 4. Vertical section of rotor assembly

It shows the housing and the technical arrangements for the air flow. Clean air under constant pressure is supplied to the air inlet, A (Figure 4), where it enters a chamber formed by the bushing of the rotor housing and two sealed ball bearings. Then, the air passes through six capillaries (only two of which are visible in Figure 4) parallel to the axis of the shaft and enters an annulus, B, from where a duct (invisible in Figure 4) leads to the air inlet of the spiral channel. When properly adjusted, the air pressure will be down to atmospheric level just before the flow reaches the center of the rotor. From there on, a subpressure supplied by a suction pump will maintain the flow through the rest of the conduit. After passing the spiral, the air enters a radial duct, C, at the perimeter of the rotor. This duct connects to a coaxial bore in the shaft, which opens into the exit chamber between the lower pair of sealed bearings. From here the air is finally removed by the suction line, D, which is operated at constant subpressure.

By varying and adjusting the pressure of the clean air supply and the subpressure of the suction line, a wide variety of flow

rates can be established, independent of any selected rotor speed. A controlled excess suction at the outlet, D, generates a slight subpressure at the aerosol inlet section and, thus, controls the aerosol flow through the nonrotating aerosol duct of the housing lid, E, into the rotor.

The housing lid, E, is inserted into the cylindrical housing wall. By removing it and unscrewing the rotor lid, F, the spiral duct and the foil strip are accessible for inspection and analysis.

The housing of the rotor is made of copper to provide good thermal conductivity for the coolant ducts, which are integral parts of all outside walls (not all ducts are shown in Figure 4). The coolant is supplied by a thermostat and facilitates the temperature control of the instrument. The temperature is measured by means of thermoelements extending into the free space, G.

The rotor assembly is fitted to the drive unit of a commercial high-speed laboratory centrifuge (Sorvall, SS-3) and permits speeds up to 12,000 r.p.m.

### Theoretical Considerations

None of the aerosol centrifuges with spinning curved ducts built in the past used the principle of entraining the aerosol into a flow of clean air, nor were they designed to give a real particle size spectrum. The new instrument, however, works as an actual size spectrometer. It is, in principle, the centrifugal version of a type of gravitational dust separator with a horizontal duct which has been used successfully for the size spectrometry of airborne particles of diameters above  $10^{-4}$  cm. (Timbrell, 1954; Boose, 1962).

Since the new centrifuge provides complete size separation, it permits a simple empirical calibration with test aerosols and does not necessitate a mathematical method of size distribution analysis that depends upon theoretical models of the pattern of deposit concentrations. In view of this, the technical details of the instrument were chosen with little regard to the requirements of a feasible theoretical approach for a calculation of particle trajectories, location of deposition, or deposit concentrations under specific operating conditions of the centrifuge. Instead, priority was given to practical aspects, as long as a laminar flow in the duct was maintained and turbulent mixing of the aerosol with the clean air was avoided.

The spiral duct is composed of semicircles which are alternately eccentric and concentric with respect to the center of the rotor. In spite of the fact that this causes a rather odd relationship between the radius vector and the length of the outer wall, the semicircular arrangement was chosen because, for a given rotor diameter, it permits a greater length for the curved duct than in the case of an Archimedean spiral with continuously increasing radius vector.

The cylindrical coordinates of the spiral pattern of the outer wall of the duct and the length of the wall depending upon the radius vector are given by

$$0 \leq \phi \leq \pi \text{ (first semicircle)}$$

$$r = \sqrt{r_0^2 - a^2 \sin^2 \phi} - a \cos \phi \quad (1a)$$

$$l = r_0 \arccos \frac{r_0^2 + a^2 - r^2}{2ar_0} + l_a \quad (2a)$$

$$\pi \leq \phi \leq 2\pi \text{ (second semicircle)}$$

$$r = r_0 + a \quad (1b)$$

$$l = (r_0 + a)(\phi - \pi) + \pi r_0 + l_a \quad (2b)$$

$$2\pi \leq \phi \leq 3\pi \text{ (third semicircle)}$$

$$r = \sqrt{(r_0 + a + k)^2 - k^2 \sin^2 \phi} - k \cos \phi \quad (1c)$$

$$l = (r_0 + a + k) \arccos \times \frac{(r_0 + a + k)^2 + k^2 - r^2}{2k(r_0 + a + k)} + \pi(2r_0 + a) + l_a \quad (2c)$$

$$3\pi \leq \phi \leq 4\pi \quad (\text{fourth semicircle})$$

$$r = r_0 + a + 2k \quad (1d)$$

$$l = (r_0 + a + 2k)(\phi - 3\pi) + \pi(3r_0 + 2a + k) + l_a \quad (2d)$$

$$4\pi \leq \phi \leq 5\pi \quad (\text{fifth semicircle})$$

$$r = \sqrt{(r_0 + a + 3k)^2 - k^2 \sin^2 \phi} - k \cos \phi \quad (1e)$$

$$l = (r_0 + a + 3k) \arccos \frac{(r_0 + a + 3k)^2 + k^2 - r^2}{2k(r_0 + a + 3k)} + \pi(4r_0 + 3a + 3k) + l_a \quad (2e)$$

$$5\pi \leq \phi \leq 6\pi \quad (\text{sixth semicircle})$$

$$r = r_0 + a + 4k \quad (1f)$$

$$l = (r_0 + a + 4k)(\phi - 5\pi) + \pi(5r_0 + 4a + 6k) + l_a \quad (2f)$$

A graphical plot of the foil length,  $l$ , vs. the radius vector,  $r$ , is shown in Figure 5.

For the desired total flow rates of up to 20 liters per minute, laminar flow conditions were provided by selecting suitable dimensions for the cross section of the spiral duct. A conservative interpretation of existing experimental data (Cornish, 1928) shows that the critical Reynolds number for stable laminar flow in rectangular ducts is certainly not less than 1300 if we define

$$\text{Re} = \frac{\bar{v} Q}{\nu U} = \frac{2F}{(B_0 + H_0)\nu} \leq \text{Re}_{\text{crit}} \quad (3)$$

From the design data of the instrument, we obtain

$$\text{Re} = 3.25F \leq \text{Re}_{\text{crit}} \quad (4)$$

as a maximum value of the Reynolds number in the spiral duct. Accordingly, we may expect a stable laminar flow of up to 24 liters per minute.

If, in a first approximation, we disregard the curvature of the duct, we may make use of a general analytical solution for the stationary laminar flow in a straight rectangular duct (Cornish, 1928). The corresponding velocity profile is close to a superposition of two parabolic functions along the wall coordinates (Stöber and Zessack, 1964). For the spinning spiral duct, however, there will be a certain stationary deformation

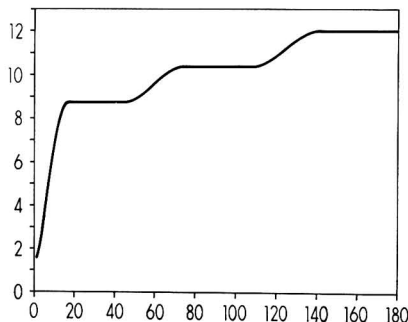


Figure 5. Relationship between radius vector  $r$  and distance  $l$  along the sampling foil

(abscissa:  $l$  in cm., ordinate:  $r$  in cm.)

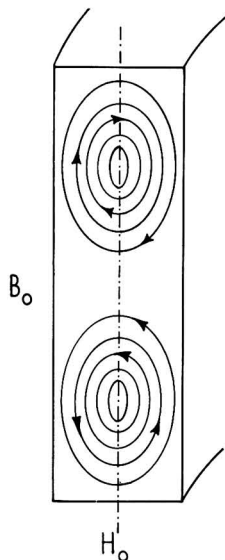


Figure 6. Schematic diagram of secondary flow in the cross-sectional plane of the air duct

of such laminar flow. This effect is, in part, due to a special field of centrifugal forces which is caused by the curvature of the flow. It tends to move the air toward the outer wall of the duct. In addition, with the direction of rotation as shown in Figure 1, the eccentric semicircles generate Coriolis forces which result from the radial flow components and act toward the outer wall. Since the viscous flow of air along the streamlines is moving faster in the center of the duct than close to the walls, the correlated transversal forces are finally effecting a double vortex of secondary flow in the cross-sectional plane of the duct, as schematically shown in Figure 6.

The double vortex causes the laminar streamlines to form a pair of counter-rotating helices along the path of the duct. These helices will limit the effectiveness of the instrument. As long as the outward velocity components in the center of the duct are small compared to the radial particle velocities created by the centrifugal field of the spinning rotor, the vortex may be disregarded. This will be the case for sufficiently large aerosol particles. If, however, the outward velocity components of the vortex are comparable or even greater than the particle velocities, as in the case of sufficiently small aerosol particles, the properties of the vortex become increasingly predominant; the actual size resolution of the instrument will decrease, and finally disappear.

For an optimum performance of the instrument, operating conditions must be found so that the helices will not turn more than a fraction of one revolution along the total length of the spiral duct. Although this has to be done experimentally by trial and error, a computation of the forces normal to the outer wall of the duct as depending upon total flow and rotor speed is very useful for this purpose, because these forces are responsible for the vortical motion, and they may serve as an indicator of the degree of the flow deformations.

Neglecting the actual width of the duct, the centrifugal forces caused by the curved flow and acting upon a volume element of air are approximately described by

$$dK_{fl} = \rho_{air} b_{fl} dh db dl \quad (5)$$

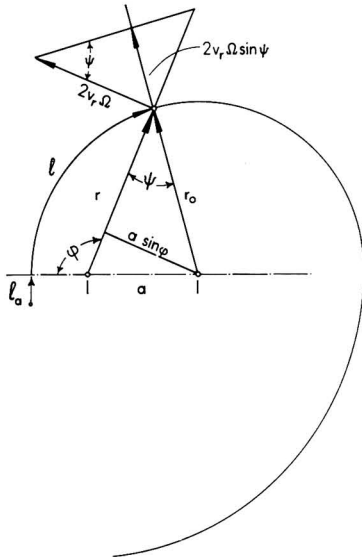


Figure 7. Diagram of Coriolis forces in the air duct

with the acceleration

$$b_{fl} = \frac{v^2}{R} \quad (6)$$

where  $R$  is the local radius of the curvature of the duct and  $v$  depends upon the cross-sectional coordinates  $b, h$ .

In addition to the centrifugal effect of the curved flow, there are Coriolis forces occurring in the eccentric semicircles of the duct. They cause a tangential acceleration

$$b_{cor} = 2v_r\Omega \quad (7)$$

which contributes to the acceleration normal to the wall of the duct. The components of these forces can be derived from geometrical relations, as shown for the first semicircle, where  $R_0 \simeq r_0$ , in Figure 7. We obtain from the graph

$$(b_{cor})_{norm} = 2v_r\Omega \sin\psi \quad (8)$$

where

$$\sin\psi = \frac{a \sin\phi}{r_0} \quad (9)$$

With the simple relation

$$v_r = \frac{dr}{dl} v \quad (10)$$

and, from Equation 2a,

$$\frac{dr}{dl} = \frac{a \sin\phi}{r_0} \quad (11)$$

the total acceleration normal to the outside wall is obtained by combining Equations 6 to 11. We find for

$$0 \leq \phi \leq \pi \quad (\text{first semicircle})$$

$$b_{norm} = 2a^2\Omega \sin^2\phi \cdot \frac{v}{r_0^2} + \frac{v^2}{r_0} \quad (12a)$$

In a similar way, we obtain for

$$\pi \leq \phi \leq 2\pi \quad (\text{second semicircle})$$

$$b_{norm} = \frac{v^2}{r_0 + a} \quad (13a)$$

$$2\pi \leq \phi \leq 3\pi \quad (\text{third semicircle})$$

$$b_{norm} = 2k^2 \frac{v\Omega \sin^2\phi}{(r_0 + a + k)^2} + \frac{v^2}{r_0 + a + k} \quad (12b)$$

$$3\pi \leq \phi \leq 4\pi \quad (\text{fourth semicircle})$$

$$b_{norm} = \frac{v^2}{r_0 + a + 2k} \quad (13b)$$

$$4\pi \leq \phi \leq 5\pi \quad (\text{fifth semicircle})$$

$$b_{norm} = 2k^2 \frac{v\Omega \sin^2\phi}{(r_0 + a + 3k)^2} + \frac{v^2}{r_0 + a + 3k} \quad (12c)$$

$$5\pi \leq \phi \leq 6\pi \quad (\text{sixth semicircle})$$

$$b_{norm} = \frac{v^2}{r_0 + a + 4k} \quad (13c)$$

With the numerical values of the design data, these equations indicate that the largest transversal forces occur in the first semicircle. The strong initial acceleration is due to the Coriolis forces which, in this section, exceed by far the forces caused by the curvature of the flow.

For the regular direction of rotation (Figure 1), the transversal forces generate a displacement,  $\Delta H$ , which causes the effective width

$$H_{eff} \simeq H_0 - \Delta H \quad (14)$$

in the center of the duct to be smaller than the geometrical width,  $H_0$ . This will extend the lower size limit of precipitation in the center of the duct to smaller particles, but, at the same time, it reduces the quality of the size separation. This adverse effect becomes predominant when the displacement,  $\Delta H$ , approaches values comparable with the width,  $H_0$ . Under this condition, the vortical motion parallel to the height,  $B_0$ , is no longer negligible, because it carries successively a significant amount of air from the sides into the center of the duct and, thus, increases the foil area accessible for a given aerodynamic size. As a result, overlapping of deposits of distinct particle size occurs more readily—i.e., the actual size resolution is reduced.

Spinning the rotor in the opposite direction will cause the double vortex to reverse its rotation in the first semicircle, because the reversed Coriolis forces dominate this section. Since the displacement,  $\Delta H$ , in the center of the duct changes directions accordingly, the effective width,  $H_{eff}$ , in the center of the duct will actually be larger than the geometrical dimension,  $H_0$ . This effect reduces the range of particle sizes collectable on the foil, so that the lower limit of complete precipitation occurs at coarser sizes. At the same time, an increase of size resolution for moderate values  $|\Delta H| < H_0$  may occur. This improvement, however, will be impaired by the vortical motion which, as before, becomes of significant influence when  $|\Delta H|$  approaches or exceeds  $H_0$ .

#### Calibration of Size-Separation Patterns

No attempts were made to derive a theoretical expression for the particle trajectories in the duct, because the design of the instrument facilitates a simple calibration with quasi-monodisperse aerosols of known size.

A few representative operating conditions were selected for

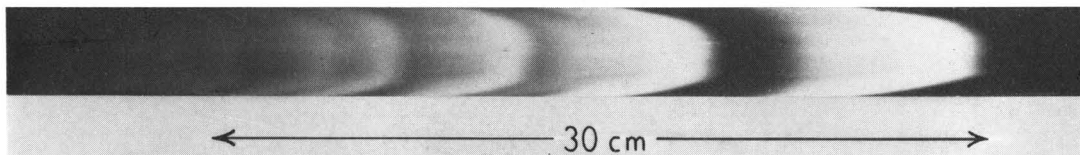


Figure 8. Deposit of latex aerosol ( $5 \times 10^{-5}$  cm. spheres) collected at an aerosol flow rate of 1.6 liters per minute  
Operating conditions: 3000 r.p.m.; total flow rate, 19 liters per minute; slit width, ca. 0.3 mm.

a number of test series with commercially available latex-spheres (Dow Chemical Co., Midland, Mich.) of uniform sizes between  $8.8 \times 10^{-6}$  and  $3.5 \times 10^{-4}$  cm. in diameter.

The uniform latex spheres in the form of aqueous suspensions were fed into an air blast nebulizer. The latex concentrations of the suspensions were increased with increasing particle size up to 10 mg. per ml. The nebulization rate was about 0.15 ml. per minute. The aerosol output of 8 liters per minute was fed into an open-ended vertical duct. Dry air at a flow rate of 2 liters per minute was added to the duct to facilitate easy evaporation of the original water droplets of the nebulizer. With properly adjusted concentrations in the aqueous suspension, this arrangement produced aerosols of latex spheres which consisted of a mixture of single airborne spheres and aggregates of two and more spheres. The aerosols were sampled under isobaric conditions from the lower end of the duct. To obtain heavy visible deposits on the foil, the samples were taken over extended periods of time, varying between 10 minutes for coarse latex particles and several hours for latex spheres smaller than  $10^{-5}$  cm. in diameter.

For the performance tests and calibrations, rotor speeds between 1500 and 6000 r.p.m. were employed, and the total flow rate was varied between 5 and 19 liters per minute. Depending upon the particular aerosol inlet section used in the test, the aerosol flow rate was adjusted somewhere between 0.6 and 15% of the total flow rate.

Under most of the selected operating conditions, the test runs indicated a very good size resolution for the first half of

the foil length. In this section, all tests produced a sequence of deposits of different degrees of aggregation. The deposits could be discriminated visibly. They all had quasi-parabolic contours at the leading edge and were almost symmetrical to the center line of the foil. Figure 8 gives a typical example for high flow rates.

Because of the great regularity and similarity of the deposit patterns, it was not necessary to check the correlation between the deposit position in the pattern and the degree of aggregation for all latex sizes used in the tests. However, for a few selected sizes, the aggregates of the different deposits were identified by regular and scanning electron microscopy.

To obtain regular electron micrographs, a number of carrier grids were placed along the center line of the foil strip and covered with large sheets of formvar foils, thus holding the grids in place. Prior to the tests, the coated strips received a thin chromium layer to avoid possible charging effects from the deposited particles. After the test, the grids were removed by cutting the formvar around the edges of the grids. The grids with the deposits were shadowed with chromium under vacuum and then investigated in the electron microscope.

For studying the deposits in the scanning electron microscope, the sections of the strip foil carrying deposits were cut into small pieces (ca. 0.5 by 0.5 cm.) which were vacuum-shadowed with gold and then directly inspected with the scanning electron microscope.

The results indicated that in each major deposit, as discriminated visibly, the aggregates were all alike, and each con-

Table I. Relative Aerodynamic Diameter,  $f_n$ , of Aggregates of  $n$  Uniform Spheres

	$f_3$	$f_4$	$f_5$	$f_6$	$f_7$	$f_8$	$f_9$	$f_{10}$	$f_{11}$	$f_{12}$	
	As Used for Calibration										
	1.18	1.33	1.46	1.54	1.65	1.73	1.81	1.88	1.91	1.97	
	As Obtained by Using the Calibration Curves										
Latex sizes $>10^{-5}$ cm.	1.189	1.343	1.471	1.568	1.676	1.748	1.812	1.887	1.936	1.996	2.043
Number of tests	66	57	40	30	26	23	20	15	13	11	9
Standard deviation	0.025	0.031	0.027	0.040	0.027	0.030	0.033	0.040	0.051	0.053	0.036
Mean error	0.25%	0.31%	0.29%	0.46%	0.32%	0.36%	0.41%	0.57%	0.72%	0.80%	0.58%
Latex size $3.57 \times 10^{-5}$ cm.	1.179	1.322	1.457	1.549	1.664	1.735	1.801	1.867	1.919	1.981	2.035
Number of tests	16	16	13	12	12	12	11	10	10	9	8
Standard deviation	0.017	0.021	0.018	0.024	0.025	0.027	0.031	0.025	0.033	0.032	0.026
Mean error	0.36%	0.40%	0.34%	0.45%	0.44%	0.45%	0.55%	0.43%	0.55%	0.53%	0.45%
	$f_{13}$	$f_{14}$	$f_{15}$	$f_{16}$	$f_{17}$	$f_{18}$	$f_{19}$	$f_{20}$	$f_{21}$	$f_{22}$	$f_{23}$
Latex size $3.57 \times 10^{-6}$ cm.	2.11	2.17	2.22	2.25	2.30	2.33	2.36	2.43	2.51	2.56	2.57
Number of tests	2	2	2	2	2	2	2	2	2	2	2

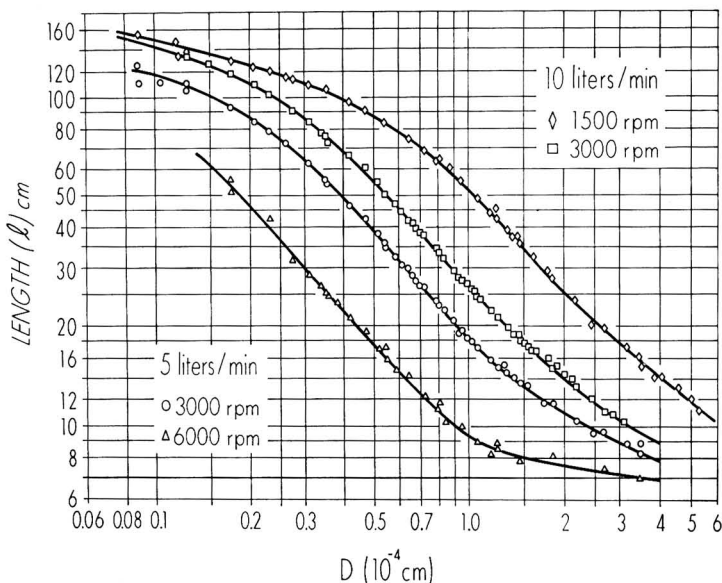


Figure 9. Calibration curve for the size separation under various operating conditions

tained one more sphere than the aggregates of the adjacent deposit at greater foil length,  $l$ . The leading deposit was always made up of single spheres. In most cases, five to seven aggregates besides the deposit of single spheres were easily discernible. The size resolution was substantially increased by using aerosol inlet sections with narrower slits at reduced aerosol flow rate. By applying the results of a recent investigation (Stöber, Berner, *et al.*, 1969) on aerodynamic diameters of aggregates of uniform spheres, all discernible deposits could be utilized for calibration purposes. Table I gives the numerical values of the relative aerodynamic diameters used for the calibrations.

Taking the maximum length of each deposit at the center line of the foil, a number of calibration curves were established. Some of them, as obtained at various rotor speeds, are plotted on logarithmic scales in Figure 9. These curves cover a size range of almost two orders of magnitude. At a flow rate of 5 liters per minute, the lower size limit apparently extends well below  $8.8 \times 10^{-6}$  cm., the smallest latex size available for calibration tests.

The deposition of this size at rotor speeds as low as 1500 r.p.m. had not been expected. In fact, the deposition occurring along the upper inflection of the curves stretching over the latter half of the length of the strip must be predominantly controlled by the secondary flow pattern in the air duct. This can be concluded from a simple theoretical estimate.

The centrifugal force pushing the particles to the outer wall of the duct is at a maximum in the sixth semicircle of the duct. In analogy to earlier calculations (Stöber and Flachsbart, 1969; Stöber and Zessack, 1964), we obtain in this section of the duct

$$\frac{dr}{dt} = \frac{D^2 \Omega^2 (r_0 + a + 4k)}{18\eta} \left( 1 + \frac{2\beta}{D} \right) \quad (15)$$

and by applying this expression to the whole duct, we overestimate

$$\Delta r \leq \int_{l_1}^{l_2} \frac{dr}{dt} \frac{dl}{\bar{v}} = \frac{D^2 \Omega^2 H_0 B_0 (r_0 + a + 4k) (l_1 - l_2)}{18\eta F} \left( 1 + \frac{2\beta}{D} \right) \quad (16)$$

at the foil length,  $l_1$ .

On the upper curve of Figure 9, we find  $l_1 = 110$  cm. for a particle size of  $3 \times 10^{-6}$  cm. Thus, at 1500 r.p.m. and 10 liters per minute, Equation 16 gives  $\Delta r \leq 0.27H_0$ . This indicates that more than 73% of the radial motion of the particle toward the outer wall was provided by a secondary flow in the air duct. The effective width was less than 27%:  $H_{eff} \leq 0.27H_0$ . Accordingly, the size resolution at this point is smaller than along the steeper section of the calibration curve. At 1500 r.p.m. and 10 liters per minute, the deposit of single latex spheres of  $3.57 \times 10^{-6}$  cm. at  $l_1 = 104$  cm. covers a section of the foil which is more than 8.5 cm. long. Under the same operating conditions, the deposit area of spheres of  $2.64 \times 10^{-6}$  cm. at  $l_1 = 114$  cm. overlaps with the doublet deposit of the same spheres at and below  $l_1 = 108$  cm., in such a way that the two deposits are barely discernible.

Reducing the aerosol flow at 1500 r.p.m. improved the resolution to some degree. However, if good resolution was desired for sizes at and below  $3 \times 10^{-6}$  cm., it was more effective to increase the rotor speed to 3000 r.p.m., thus shifting the deposits to smaller  $l$  values.

At 3000 r.p.m. and a total flow of 10 liters per minute, the resolution for spheres of  $3.57 \times 10^{-6}$  cm. at  $l_1 = 76$  cm. is still excellent. Under this operating condition, overlapping does not occur for test spheres bigger than  $1.5 \times 10^{-6}$  cm., for which  $l_1 \approx 120$  cm.

An increase of the rotor speed to 6000 r.p.m. did not further improve size resolution for the smaller particles. At this speed, distortions of the flow in the duct caused overlapping of the deposits of spheres of  $1.76 \times 10^{-6}$  cm. and their aggregates at  $l_1 < 55$  cm., although the total flow rate was reduced to 5

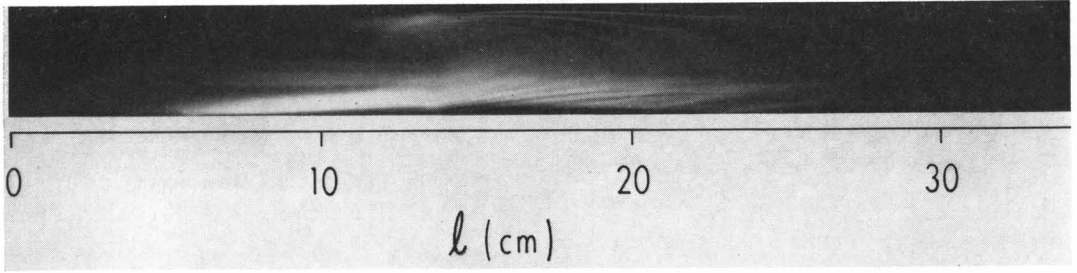


Figure 10. Irregular deposition of latex aerosol ( $3.57 \times 10^{-5}$  cm. spheres) at an aerosol flow rate of 0.2 liters per minute  
 Operating conditions: 6000 r.p.m.; total flow rate, 5 liters per minute; slit width, ca. 0.3 mm.

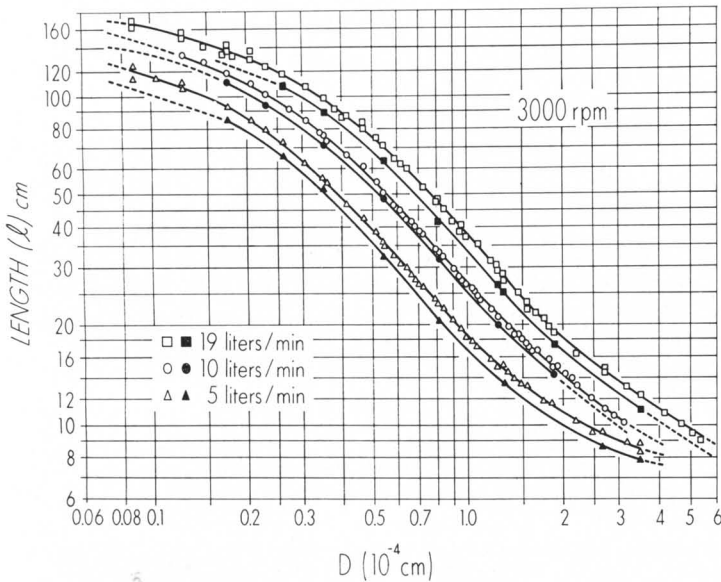


Figure 11. Calibration curves for the size separation at 3000 r.p.m. and different total flow rates

liters per minute. There were also highly irregular deposition patterns at short distances  $l_1 < 20$  cm., as shown in Figure 10.

In view of these difficulties, the rotor speed of 3000 r.p.m. was selected as standard speed for routine measurements. The calibration curves for three different total flow rates at this speed are given in Figure 11. The band width of each curve along  $l$  indicates the area on the foil as covered by deposits of single latex spheres at an aerosol flow rate of 4% of the total flow. The band width along  $D$  is then related to the actual size resolution. In fact, the resolution is better than indicated on the graph, because the latex spheres are not precisely monodisperse, so that part of the extended area of a deposit of single spheres can be attributed to the size distribution of the latex spheres.

#### Experimental Effects of the Secondary Flow in the Spiral Duct

Although it could be estimated from the calibration curves that the deposition of small particles ( $\approx 10^{-5}$  cm.) must strongly be influenced by the secondary flow pattern, the deposit areas in these tests, except for high rotor speeds of 6000 r.p.m. or high total flow rate (19 liters per minute) at low rotor

speed (1500 r.p.m.) appeared to be surprisingly regular. The leading edges seemed to be patterned after a parabolic velocity profile of the air flow in the duct, and the drawn-out shape at greater distances from the aerosol entrance could qualitatively be attributed to the image projection of the aerosol entrance slit, which must increase the length,  $\Delta l$ , of a deposit with increasing distance,  $l$ . Accordingly, the deposit length can be reduced to some degree by reducing the slit width of the aerosol entrance. Because of all this rather regular behavior, the influence of the double vortex does not readily show up in the deposition patterns. It can be revealed only by quantitative considerations, because, as long as in Equation 14  $\Delta H < H_0$ , the double vortex merely modifies the projection of the flow velocity profile, as illustrated in Figure 12b.

The situation changes drastically when the direction of rotation of the rotor is reversed. The predominant Coriolis forces in the first semicircle of the duct will, then, reverse the rotation of the double vortex, and the deposit area for uniform latex particles should degenerate into a shape as illustrated by Figure 12c. Actual deposition patterns obtained with latex at various rotor speeds confirm and exceed this expectation. Figure 13 gives some photographs of typical examples. The

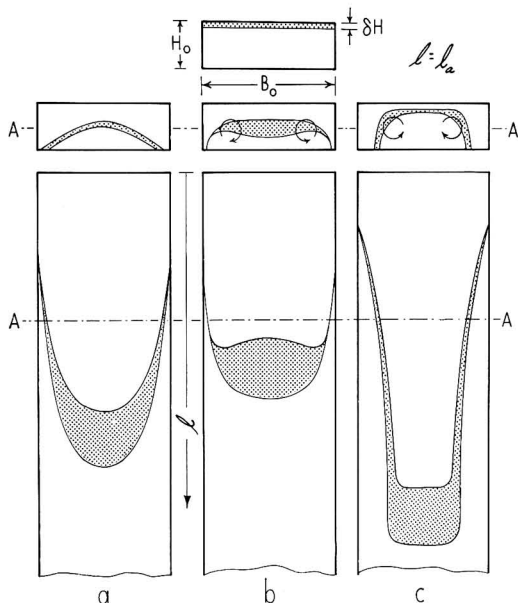


Figure 12. Schematic diagrams of the distribution of monodisperse aerosol over the cross-section of the duct and along the foil strip

- a. For a straight duct
- b. For a spiral duct with regular direction of rotation
- c. For a spiral duct with reversed direction of rotation

influence of the double vortex on the deposition pattern is now quite apparent. Along the edges of the foil there are aerosol deposits in streaks consisting of several lines with well-defined borders. These streaks taper out into narrow deposits more or less parallel to the center line of the foil. Finally, there appear some deposits across the foil between the streaks.

Electron micrographs reveal that the line structure of the streaks is due to size separation. Where the lines are no longer twisted, the inner border lines represent deposits of single spheres, whereas the sequence of lines closer to the edge of the foil is composed of latex clusters of increasing degree of aggregation. The deposits occurring in the center of the foil correspond to the regular precipitates under normal operating conditions. Thus, the leading deposit in the center consists of single spheres and the following precipitates are made up by doublets, triplets, and bigger aggregates, respectively.

In the streaks, the length of the deposit line of a given aggregate extends to some degree beyond the area of the corresponding deposit in the center of the foil. These distinct lines of deposition mark the projected location of the centers of the double vortex. Thus, from the photographs, we can conclude that the centers move closer toward the edges of the foil when the rotor speed is increased. Changing the total flow rate has a less significant influence, if any, on the vortex centers.

The deposits at 1500 and 3000 r.p.m. have some similarities. Aerosol particles deposited near the edge of the foil are found only at the beginning of the deposit close to the aerosol entrance. This indicates that the vortical velocities at these rotor speeds are not big enough to carry substantial amounts of aerosol from the center over to the edge of the foil. At 3000 r.p.m., the size-separated deposits appear eventually in the center of the foil. At 1500 r.p.m., where the centrifugal forces are substantially reduced, the vortical motion delays the

centrifugal precipitation of the utilized latex particles to the extent that no center deposit is formed within the length of the spiral duct.

At 6000 r.p.m., Figure 13 indicates strong distortions similar to those shown for regular operating conditions in Figure 10. Undoubtedly, the vortices become quite prominent at this rotor speed. The twisted deposition patterns along the edges of the foil reveal clearly that each vortex completes a full revolution at a distance  $l \approx 25$  cm. The center lines of the double vortex are close to the edges of the foil and, since the rotor speed creates great centrifugal forces on the particles used in these particular tests, there occurs still a size-separated deposition in the center of the foil, which is quite pronounced at the total flow rate of 5 liters per minute.

The observed increase of the space between the center lines of the double vortex with increasing rotor speed has some bearing on the relation between the transversal forces and the displacement,  $\Delta H$ . With the observed changes of the geometrical pattern of the secondary flow, a potential increase of the displacement,  $\Delta H$ , by increased transversal forces may be counteracted by the widening distance between the center lines of the double vortex. It is reasonable to assume that the improvement of the size resolution for fine aerosol particles as obtained at regular operating conditions by increasing the rotor speed from 1500 to 3000 r.p.m. is partly due to this influence.

An estimate of the minimum displacement,  $\Delta H$ , involved in the deposition process under routine operating conditions, where  $\Delta H < H_0$  is maintained, can be obtained experimentally by comparing test results obtained for both directions of rotation under otherwise identical operating conditions. Figure 14 shows the photograph of such tests.

Using number indices for discriminating the two experiments at opposite directions of rotation of the centrifuge, we can write for the regular case

$${}_1H_{\text{eff}} = H_0 - \Delta H_1 \quad (14a)$$

and for the reversed direction of rotation

$${}_2H_{\text{eff}} = H_0 + \Delta H_2 \quad (14b)$$

For the purpose of an estimate, let us further assume

$$\Delta H_1 \approx \Delta H_2 = \Delta H \quad (17)$$

We can, then, find a value  $\gamma$  so that

$${}_2H_{\text{eff}} = \gamma l_2 \quad (18)$$

and, since the duct is a spiral with increasing centrifugal forces,

$${}_1H_{\text{eff}} < \gamma l_1 \quad (19)$$

This gives

$$\frac{{}_1H_{\text{eff}}}{{}_2H_{\text{eff}}} = \frac{H_0 - \Delta H}{H_0 + \Delta H} < \frac{l_1}{l_2} \quad (20)$$

or

$$\Delta H \geq \frac{(l_2 - l_1)H_0}{l_1 + l_2} \quad (21)$$

where the equality is appropriate for  $l_2 - l_1 \ll l_1 + l_2$ .

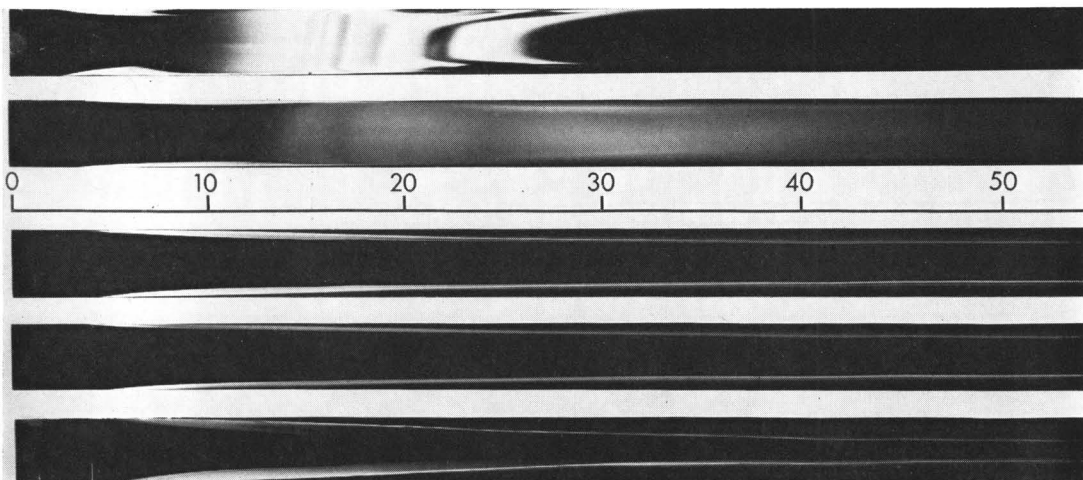
From the results at 3000 r.p.m., as shown in Figure 14, we obtain for the deposits of single spheres the actual values of  $l_1 = 47.5$  cm. and  $l_2 = 87.5$  cm. Thus, the displacement is

$$\Delta H > 0.30 H_0$$

At shorter distances, the doublet and triplet deposits give  $\Delta H > 0.24 H_0$  and  $\Delta H > 0.18$ , respectively.

For a comparison, Equation 16 can be employed. Utilizing





From top to bottom:

1. 6000 r.p.m.; total flow, 5 liters per minute; aerosol flow, 0.1 liter per minute; latex size,  $3.57 \times 10^{-5}$  cm.
2. 6000 r.p.m.; total flow, 10 liters per minute; aerosol flow, 0.1 liter per minute; latex size,  $3.57 \times 10^{-5}$  cm.
3. 3000 r.p.m.; total flow, 10 liters per minute; aerosol flow, 0.1 liter per minute; latex size,  $5.48 \times 10^{-5}$  cm.
4. 3000 r.p.m.; total flow, 19 liters per minute; aerosol flow, 0.2 liter per minute; latex size,  $8.10 \times 10^{-5}$  cm.
5. 1500 r.p.m.; total flow, 10 liters per minute; aerosol flow, 0.2 liter per minute; latex size,  $8.10 \times 10^{-5}$  cm.

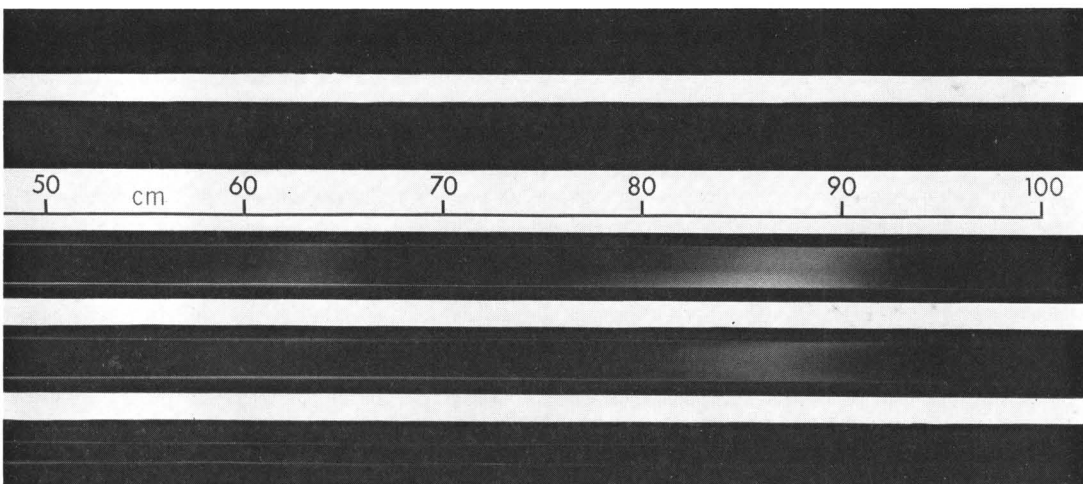


Figure 13. Foil deposits under various operating conditions with reversed direction of rotation of the centrifuge

the radius vector  $r$  of the location of the deposit of single spheres at  $l_1 = 47.5$  cm., we obtain a value of  $\Delta r < 0.80 H_0$ . In view of Figure 5, we can conclude that, for values  $l_1 \gtrsim 40$  cm., Equation 16 does not overestimate the radial particle displacement  $\Delta r$  by more than 25%, if the radius vector  $r$  at  $l_1$  is employed. Thus, we obtain

$$0.64 H_0 < \Delta r < 0.80 H_0$$

which corresponds to

$$0.20 H_0 < \Delta H < 0.36 H_0$$

Considering the approximate nature of these calculations, the results seem to be in reasonable agreement and compatible with the experiments.

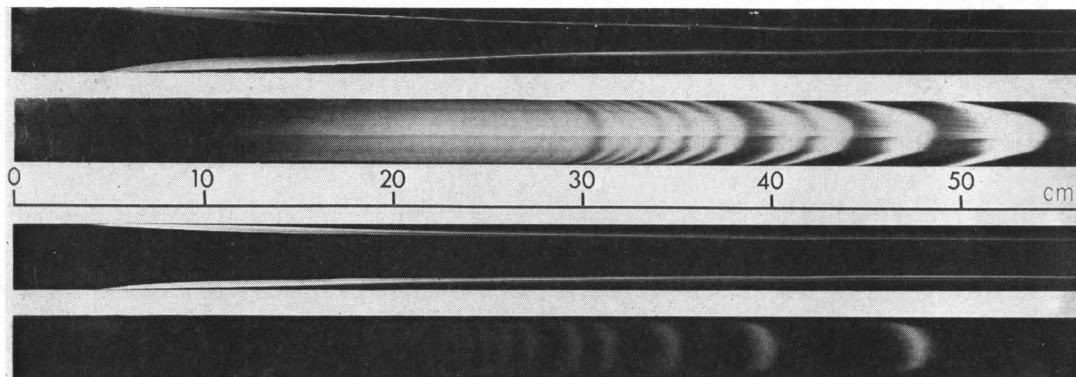
#### Experiments at Very High Size Resolution

In many of the calibration tests, the size resolution was equal to the best results so far reported (Berner, 1968). In

view of these easily obtained results, an attempt was made to further increase the size resolution by reducing the aerosol flow rate below 1% of the total flow and using a special aerosol entrance section with a 0.1-cm. center bore and a very narrow slit. Figure 15 gives a photograph of the foil of one of the successful tests under such conditions.

In these experiments, more than 20 distinct deposits can be discriminated on the foils. A weak additional deposit appears between the familiar dense deposits of doublet and triplet aggregates, and a similar additional precipitate can be discriminated in front of the dense quadruplet deposit. Electron micrographs made in these two areas showed that in the first case the deposit consisted of chain-like triplet aggregates (Figure 16, upper right), whereas in the latter case the aggregates were quadruplets in the form of branched chains (Figure 17, upper right).

A systematic electron microscopic survey of all the deposits of the high-resolution tests revealed further details about some



From top to bottom:

1. Reversed direction
2. Regular direction at 1500 r.p.m.; total flow, 10 liters per minute; aerosol flow, 0.2 liter per minute; latex size,  $8.10 \times 10^{-5}$  cm.
3. Reversed direction
4. Regular direction at 3000 r.p.m.; total flow, 10 liters per minute; aerosol flow 0.1 liter per minute; latex size,  $5.48 \times 10^{-5}$  cm.

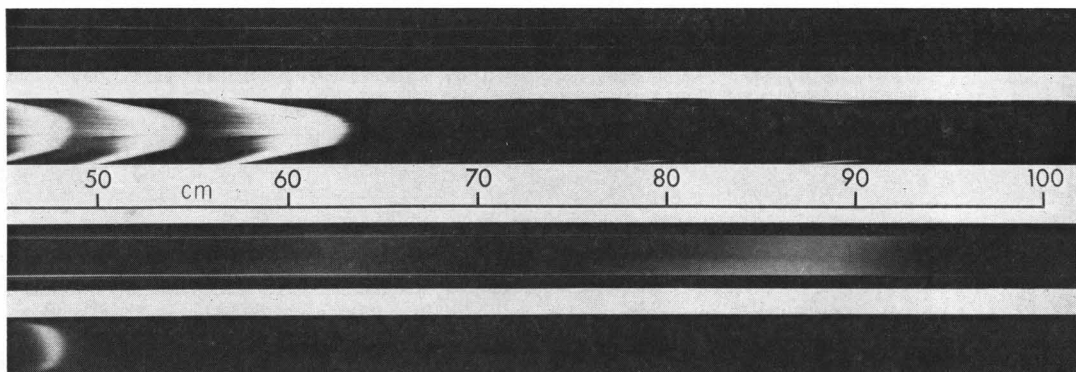


Figure 14. Comparison of foil deposits obtained under opposite directions of rotation of the centrifuge

special types of aggregates. A series of regular electron micrographs is shown in Figures 16-21. The relative aerodynamic size,  $f$ , as indicated for each micrograph, is derived from the size values taken from the calibration curves. In general, all aggregates in each major deposit have almost the same configuration. They tend toward optimum sphericity. In the size range smaller than the octahedral sextuplets (Figure 19, lower right), however, there occur also small concentrations of chain-like aggregates, which are either superimposed upon the major deposits or are found in the spaces between them. Figures 16 to 19 show a variety of straight and branched chain configurations. Average values of the relative aerodynamic size,

$f$ , for some configurations are given in Table II, together with values calculated from results by Kunkel (1948).

Chain aggregates of more than eight spheres were observed with latex spheres of  $3.57 \times 10^{-5}$  cm., but they were very rare. Deposits of sizes beyond  $f = 1.75$  generally consisted of aggregates of rather spherical shape. Figures 20 and 21 give typical examples. Up to the seventeenth major deposit, the regular size increase of the aggregates by one sphere from deposit to deposit could be verified by counting the spheres of the aggregates on micrographs taken under high-energy electron transmission, which made the latex spheres translucent. For larger aggregates, it was difficult to avoid counting errors,

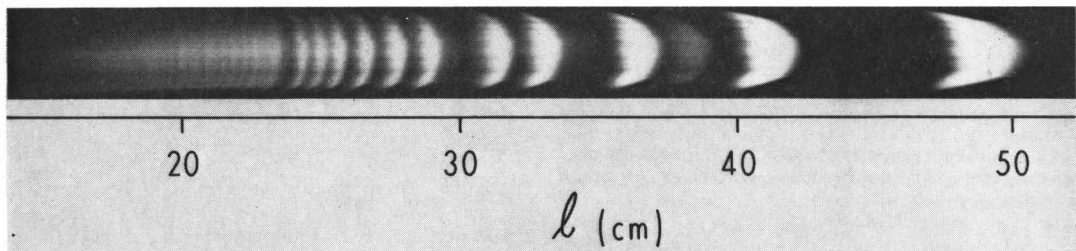


Figure 15. Foil deposit of very high resolution

Operating conditions: 2000 r.p.m.; total flow, 10 liters per minute; aerosol flow, 0.1 liter per minute; latex size,  $7.14 \times 10^{-5}$  cm.

TABLE 2  
RELATIVE AERODYNAMIC DIAMETERS,  $f$ , OF AGGREGATES  
OF  $n$  UNIFORM SPHERES OF DIFFERENT CONFIGURATION

n	configuration	as observed		reference: Kunkel (16)
		f	number of tests	
2	∞	1.19	66	1.17
3	∞∞	1.28	10	1.25
3	∞∞	1.34	57	1.28
4	∞∞∞	1.38	3	1.30
4	∞∞∞	1.42	5	
5	∞∞∞∞	1.42	2	
6	∞∞∞∞∞	1.45	1	
4	∞∞∞	1.47	40	
7	∞∞∞∞∞∞	1.48	1	
5	∞∞∞∞	1.50	2	
6	∞∞∞∞∞	1.52	1	
8	∞∞∞∞∞∞∞	1.52	1	1.37
8	∞∞∞∞∞∞	1.56	1	
5	∞∞∞∞	1.57	30	
8	∞∞∞∞∞∞∞	1.60	1	
6	∞∞∞∞∞	1.68	26	1.54

and there was reason to believe that some size increases involved more than one sphere at a time. An evaluation of the relative aerodynamic size of 23 successive major deposits obtained with latex spheres of  $3.57 \times 10^{-5}$  cm. in diameter is given in Table I. The first 11 values may be compared with the listed average values obtained by re-evaluating all latex measurements of sizes between  $1.26 \times 10^{-5}$  and  $3.49 \times 10^{-4}$  cm. by means of the established empirical calibration curves. The agreement among these data and with other results (Stöber, Berner, *et al.*, 1969; Hochrainer and Brown, 1969) is very good. The micrograph of the quintuplet aggregates (Figure 22, lower right) indicates a random deposition, rather than the "parachute" effect observed in the cylindrical conifuge (Stöber, Berner, *et al.*, 1969). This may be due to the more complex air flow pattern in the spiral duct, which could prevent the orientation of the quintuplets.

#### Aspects of Aerodynamic Size Distribution Analysis

The most desirable application of the new centrifuge is, of course, the analysis of the aerodynamic size distribution of aerosol particles. For this purpose, an additional calibration is necessary, relating the deposit concentration or the total amount of deposited particles of a given size interval to the airborne concentration prior to sampling. This can be done entirely in an empirical way either by utilizing the whole width of the strip foil or, for experiments at high resolution, by selecting a narrow strip along the center line of the foil for the correlation to the airborne concentration.

The only requirement for the feasibility of such approaches is that a significant proportion of the airborne particles will pass through the aerosol inlet section without being trapped. In other words, the entrance losses should not exceed some 10% of the total amount of the size interval under consideration. A simple estimate for the two types of aerosol inlet sections used in the tests will show that this condition is reasonably fulfilled.

We overestimate the initial losses of the coaxial aerosol flow

Table III. Maximum Impaction Losses in the Aerosol Inlet Section with 0.4-Cm. Center Bore at an Aerosol Flow Rate of 1 Liter per Minute

$D$ ( $10^{-4}$ Cm.)	$\sqrt{V}$	Loss, %
5	0.16	0
6	0.19	0
7	0.23	0
8	0.25	0
9	0.29	25
10	0.32	35
12	0.38	80

by considering the flow as coming from a round impactor jet. For aerosol flow rates up to 3 liters per minute, an inlet section with a center bore of 0.4 cm. in diameter was used. Aerosol flow rates of 0.2 liter per minute or less were employed in connection with an inlet section having a 0.1-cm. center bore. In both cases, the average linear velocity of the coaxial aerosol flow is about 400 cm. per second. Using these data for calculating a maximum impaction efficiency according to theoretical results reported in the literature (Ranz and Wong, 1952), we find that no impaction occurs for particle diameters up to  $4 \times 10^{-4}$  or  $2 \times 10^{-4}$  cm. with the 0.4-cm. or the 0.1-cm. center bore inlet, respectively. For a standard procedure at an aerosol flow of 1 liter per minute through the 0.4-cm. center bore inlet, Table III gives the theoretical values of impaction losses. This indicates that, within the size range of interest, impaction losses in the aerosol inlet system are rather negligible.

Of greater significance are the losses which occur in the radial extension of the aerosol inlet, as formed between the inner wall of the duct and a thin brass sheath defining the slit width,  $s$ . Figure 22 shows a cross section of the actual arrangement parallel to the rotor plane. Assuming an aerosol duct with parallel walls along the sheath length,  $l_s$ , at a distance,  $s$ , we overestimate the precipitation of particles during their radial passage toward the slit. The precipitation is caused by the Coriolis acceleration, as given by Equation 7. The residence time,  $t_s$ , inside the narrow duct is

$$t_s = \frac{l_s}{v_r} \quad (22)$$

and by Stokes' law we obtain

$$\frac{\Delta s}{t_s} = \frac{\rho D^2}{18\eta} \times 2v_r\Omega \quad (23)$$

or, after combining Equations 22 and 23,

$$\Delta s = \frac{\rho D^2 \Omega l_s}{9\eta} \quad (24)$$

This is the thickness of a layer from which all particles are removed and deposited on the brass sheath. For a standard slit width  $s = 0.1$  cm. and the regular length of the sheath  $l_s = 0.8$  cm., the maximum losses by Coriolis acceleration are listed in Table IV. These results indicate that practically all losses in the aerosol entrance section are due to the angular acceleration of the aerosol flow. The losses can be reduced by widening the slit width,  $s$ , and reducing the sheath length,  $l_s$ . Under the specified conditions of the inlet, the losses may exceed 50% for particle sizes of  $6 \times 10^{-4}$  cm. and more. Thus, the calibration of deposit concentrations in this size range becomes dependent upon the slit width. For particles smaller than  $2 \times 10^{-4}$  cm., however, such influence is rather insignificant.

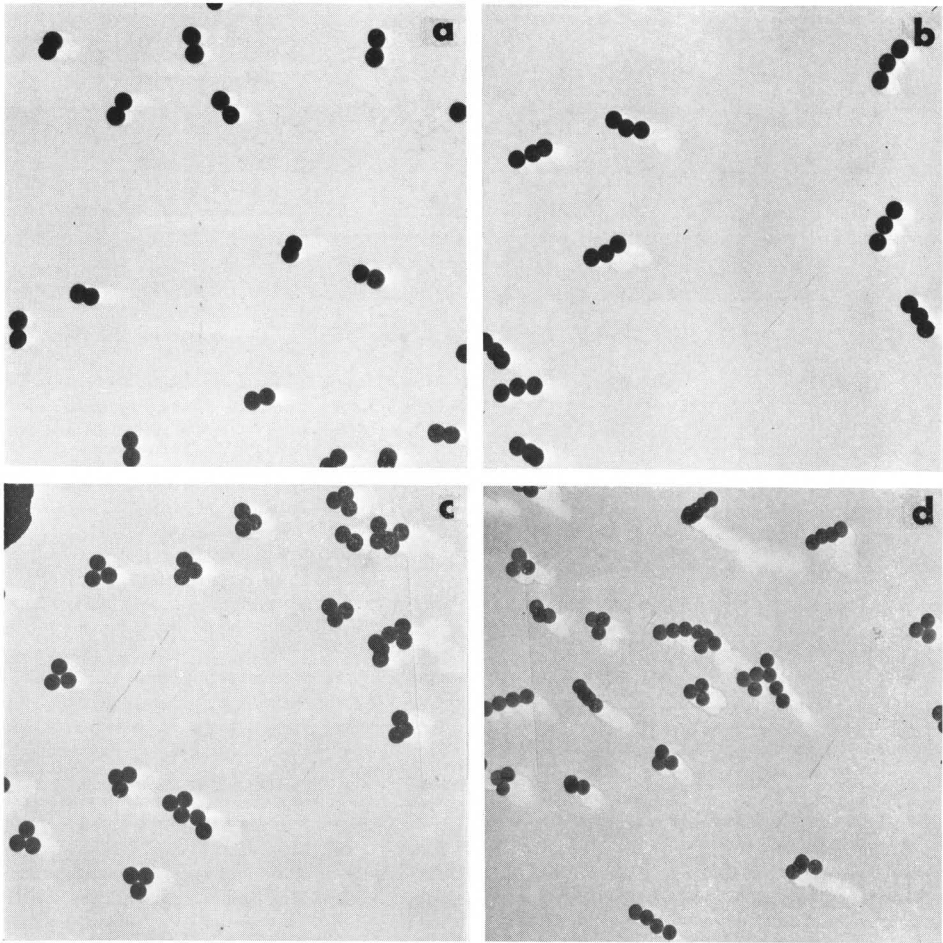


Figure 16. Electron micrographs of latex aggregates collected at foil locations at relative aerodynamic diameter  $f$

a. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 1.19$   
 b. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 1.28$

c. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 1.33$   
 d. Sphere size,  $3.57 \times 10^{-5}$  cm.;  $f = 1.37$

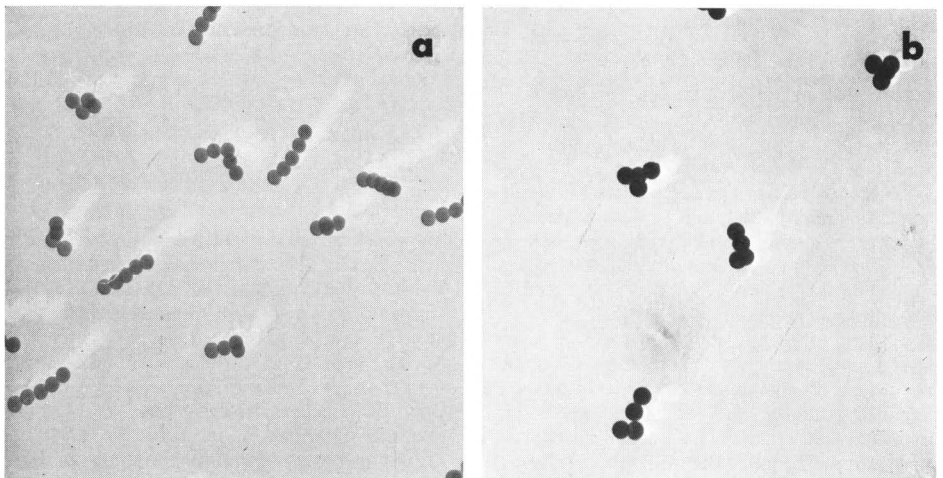


Figure 17. Electron micrographs of latex aggregates collected

a. Sphere size,  $3.57 \times 10^{-5}$  cm.;  $f = 1.42$     b. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 1.43$

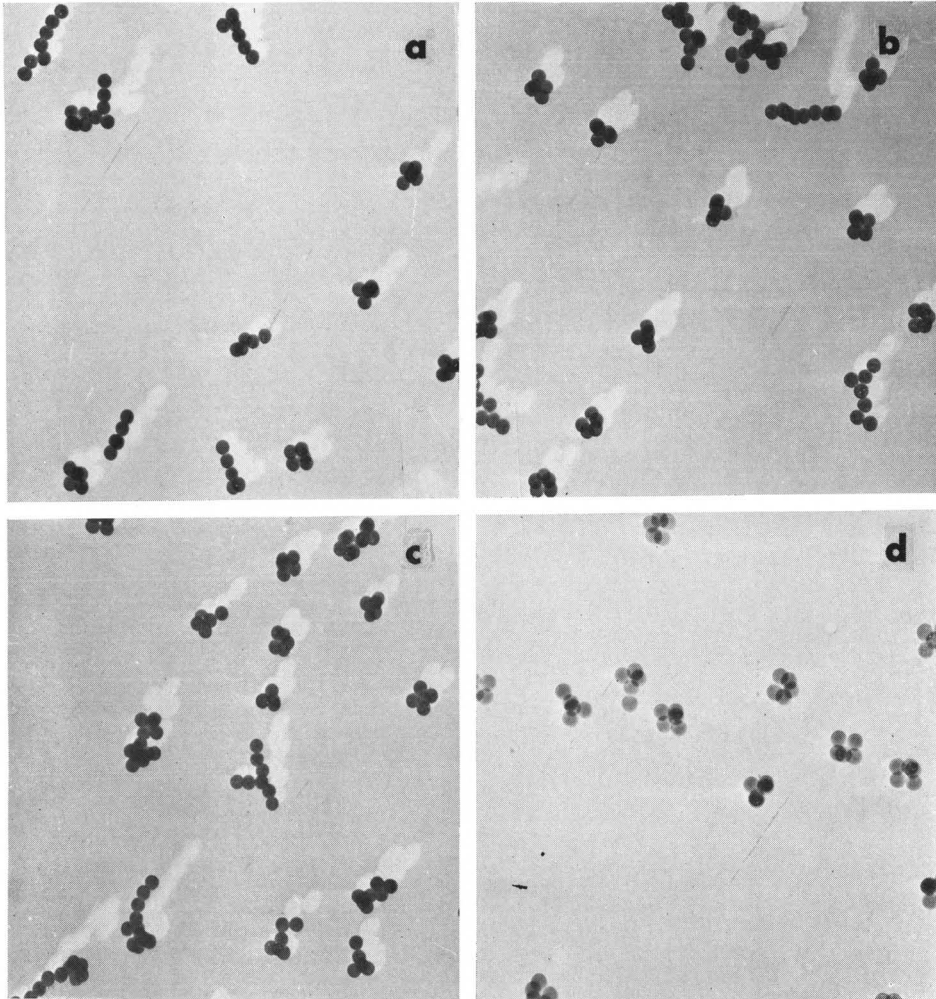


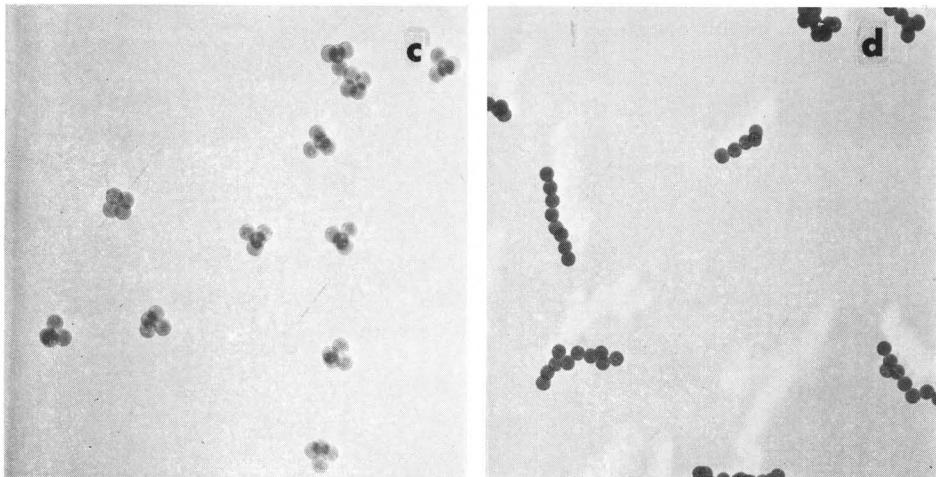
Figure 18. Electron micrographs of latex aggregates collected at foil locations of relative aerodynamic diameter  $f$

a. Sphere size,  $3.57 \times 10^{-5}$  cm.;  $f = 1.53$

b. Sphere size,  $3.57 \times 10^{-5}$  cm.;  $f = 1.55$

c. Sphere size,  $3.57 \times 10^{-5}$  cm.;  $f = 1.55$

d. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 1.56$



at foil locations of relative aerodynamic diameter  $f$

c. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 1.47$  d. Sphere size,  $3.57 \times 10^{-5}$  cm.;  $f = 1.52$

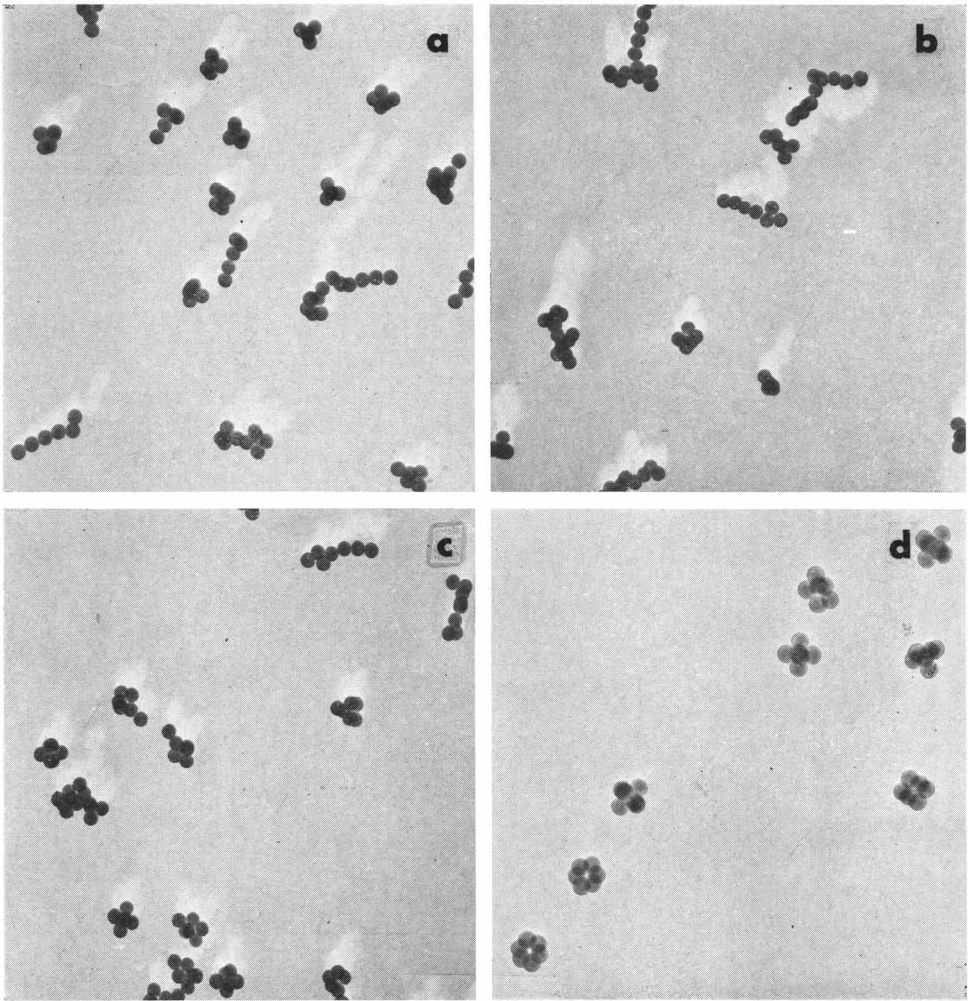


Figure 19. Electron micrographs of latex aggregates collected at foil locations of relative aerodynamic diameter  $f$

a. Sphere size,  $3.57 \times 10^{-5}$  cm.;  $f = 1.57$   
 b. Sphere size,  $3.57 \times 10^{-5}$  cm.;  $f = 1.63$

c. Sphere size,  $3.57 \times 10^{-5}$  cm.;  $f = 1.64$   
 d. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 1.67$

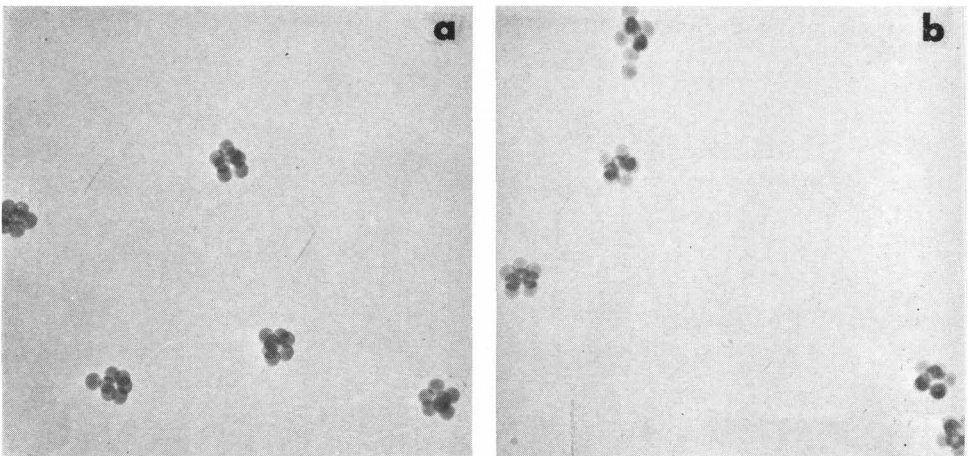


Figure 20. Electron micrographs of latex aggregates collected

a. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 1.74$     b. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 1.82$

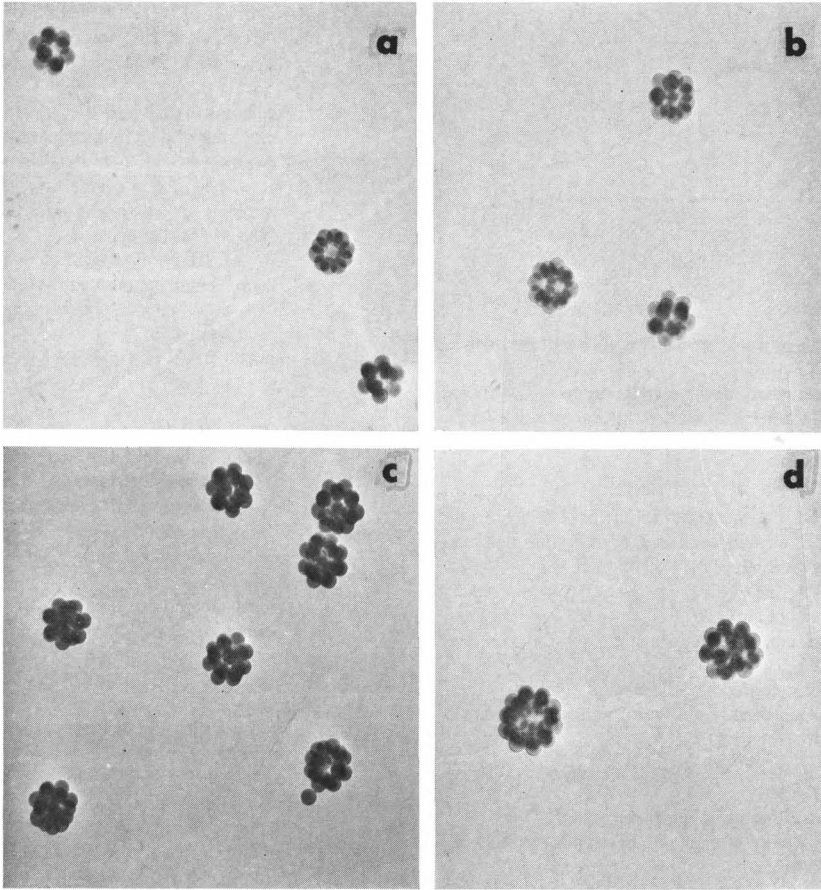
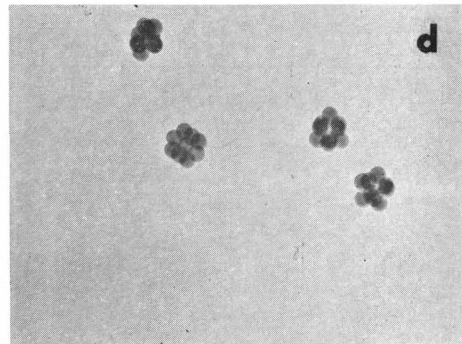
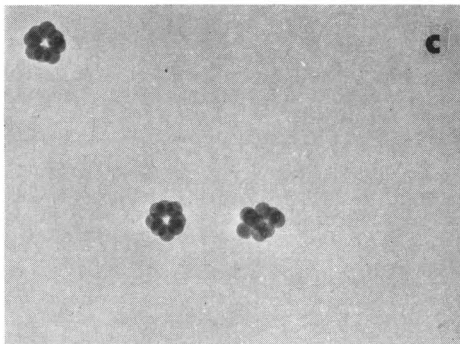


Figure 21. Electron micrographs of latex aggregates collected at foil locations of relative aerodynamic diameter  $f$

- a. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 2.00$
- b. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 2.17$
- c. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 2.30$
- d. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 2.48$



at foil locations of relative aerodynamic diameter  $f$

- c. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 1.85$
- d. Sphere size,  $7.14 \times 10^{-5}$  cm.;  $f = 1.89$

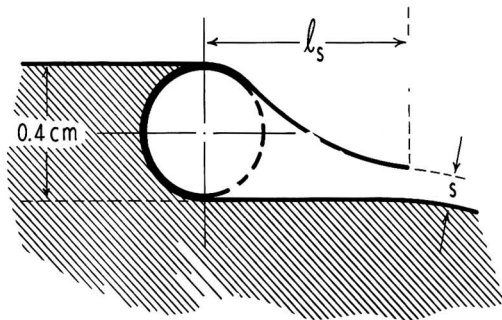


Figure 22. Cross-section of aerosol inlet at center of rotation

An experimental study of the correlation between airborne concentration of the aerosol and deposit concentration on the strip foil is presently in progress.

#### Nomenclature

$\beta$	= $8.2 \times 10^{-6}$ cm., empirical factor as related to the Cunningham correction at mean free molecular path length of $6.53 \times 10^{-6}$ cm.
$\eta$	= $1.84 \times 10^{-4}$ gram cm. <sup>-1</sup> sec. <sup>-1</sup> , viscosity coefficient of air at 20° C.
$\nu$	= 0.143 cm. <sup>2</sup> sec. <sup>-1</sup> , kinematic viscosity coefficient of air at 20° C.
$\phi$	= angular coordinate at center of rotor
$\psi$	= angle between radius vector and vector of curvature (Figure 7)
$\Psi$	= $\frac{\bar{v}}{18\eta D_c} (D^2 + 2\beta D)$ (Ranz and Wong, 1952)
$\rho$	= particle density F, gram cm. <sup>-3</sup>
$\rho_{air}$	= $1.29 \times 10^{-3}$ gram cm. <sup>-3</sup> , density of air at 20° C.
$\Omega$	= $2\pi N$ , angular velocity of rotor, sec. <sup>-1</sup>
$a$	= 3.60 cm., eccentricity of first semicircle (Figure 7)
$b$	= coordinate along height of spiral duct, cm.
$b_{cor}$	= Coriolis acceleration, cm. sec. <sup>-2</sup>
$(b_{cor})_{norm}$	= component of Coriolis acceleration perpendicular to wall of duct, cm. sec. <sup>-2</sup>
$b_{fl}$	= centrifugal acceleration in curved flow, cm. sec. <sup>-2</sup>
$b_{norm}$	= effective acceleration perpendicular to wall of duct, cm. sec. <sup>-2</sup>
$B_0$	= 3.30 cm., height of spiral duct
$D$	= aerodynamic diameter of aerosol particle, cm.
$D_c$	= diameter of center bore of aerosol inlet section, cm.
$f$	= relative aerodynamic diameter of aggregate of uniform spheres
$F$	= rate of total volume flow through spiral duct, cm. <sup>3</sup> sec. <sup>-1</sup>

$h$	= coordinate along width of spiral duct, cm.
$H_0$	= 1.00 cm., width of spiral duct
$H_{eff}$	= effective width of duct for particle size separation, cm.
$\Delta H$	= displacement of volume element of air along $h$ in center of duct by secondary flow, cm.
$k$	= 0.84 cm., eccentricity of third and fifth semicircle
$K_{fl}$	= centrifugal force in curved flow, gram cm. sec. <sup>-2</sup>
$l$	= coordinate of length along the strip foil (outer wall of duct), cm.
$l_a$	= 1.02 cm., length of straight section of strip foil
$l_s$	= 0.8 cm., length of slit sheath
$\Delta l$	= length of foil deposit area of monodisperse aerosol particles, cm.
$n$	= number of particles in an aggregate
$N$	= rotor speed of centrifuge, sec. <sup>-1</sup>
$Q$	= cross section of spiral duct, cm. <sup>2</sup>
$r$	= radius vector from center of rotor, cm.
$r_0$	= 5.12 cm., actual radius of curvature of outer wall of first semicircle (Figure 7)
$\Delta r$	= radial or transversal displacement of particles relative to air flow, cm.
$R$	= radius of curvature, cm.
$Re$	= Reynolds number
$Re_{crit}$	= critical Reynolds number for laminar flow conditions
$s$	= width of aerosol entrance slit, cm.
$\Delta s$	= transversal displacement of particles before leaving entrance slit, cm.
$t_s$	= residence time of particles in the entrance slit, sec.
$U$	= perimeter of spiral duct, cm.
$v$	= local linear flow velocity in spiral duct, cm. sec. <sup>-1</sup>
$\bar{v}$	= average linear flow velocity in spiral duct, cm. sec. <sup>-1</sup>
$v_r$	= radial linear velocity component, cm. sec. <sup>-1</sup>

#### Literature Cited

- Berner, A., in "Aerosol Research at 1st Physics Institute," University of Vienna, Status Report, January 1968.
- Boose, C., *Staub* **22**, 109-12 (1962).
- Cornish, R. J., *Proc. Roy. Soc. London A* **120**, 691-700 (1928).
- Goetz, A., Stevenson, H. J. R., Preining, O., *J. Air Pollution Control Assoc.* **10**, 378-83 (1960).
- Hauck, H., Schedling, J. A., *Staub* **28**, 18-21 (1968).
- Hochrainer, D., Brown, P. M., *ENVIRON. SCI. TECHNOL.* **3**, 830-5 (1969).
- Kast, W., *Staub* **21**, 215-23 (1961).
- Keith, C. H., Derrick, J. C., *J. Colloid Sci.* **15**, 340-56 (1960).
- Kunkel, W. B., *J. Appl. Phys.* **19**, 1056-8 (1948).
- May, K. R., *J. Sci. Instr.* **22**, 187-95 (1945).
- Ranz, W. E., Wong, J. B., *Ind. Eng. Chem.* **44**, 1371-81 (1952).
- Sawyer, K. F., Walton, W. H., *J. Sci. Instr.* **27**, 272-6 (1950).
- Stöber, W., in "Assessment of Airborne Radioactivity," Intern. Atomic Energy Agency, Vienna, pp. 393-404, 1967.
- Stöber, W., Berner, A., Blaschke, R., *J. Colloid Interf. Sci.* **29**, 710-19 (1969).
- Stöber, W., Flachsbarth, H., *ENVIRON. SCI. TECHNOL.* **3**, 641-51 (1969).
- Stöber, W., Zessack, U., *Staub* **24**, 295-305 (1964).
- Tillery, M. I., in "Assessment of Airborne Radioactivity," Intern. Atomic Energy Agency, Vienna, pp. 405-15, 1967.
- Timbrell, V., *Brit. J. Appl. Phys.* **5**, Suppl. 3, 86-90 (1954).

Received for review February 28, 1969. Accepted July 30, 1969. In part presented at the 156th Meeting, ACS, Atlantic City, N.J., September 8-13, 1968. This paper is based on work performed under contract with the United States Atomic Energy Commission at the University of Rochester Atomic Energy Project and has been assigned Publication No. UR-49-1060.

Table IV. Aerosol Losses in the Entrance Slit  
Slit Width  $s = 0.1$  Cm.

$D (10^{-4}$ Cm.)	$\Delta s$	$\frac{\Delta s}{s}$ , %
1	0.0015	1.5
2	0.0061	6
3	0.0136	14
4	0.0243	24
5	0.0380	38
6	0.0547	55
7	0.0745	75
8	0.0973	97



## Microelectrode Determination of Oxygen Profiles in Microbial Slime Systems

William J. Whalen

Division of Research, St. Vincent Charity Hospital, Cleveland, Ohio 44115

Henry R. Bungay III

Environmental Systems Engineering, Clemson University, Clemson, S.C. 29631

Walter M. Sanders III

Southeast Water Laboratory, USDI, Federal Water Pollution Control Administration, Athens, Ga. 30601

■ Dissolved oxygen profiles were measured above and within a bacterial slime mass under a continuous flow of nutrient. The microprobe tip was  $1.5 \mu$  in diameter and its location, with respect to the slime-water interface, was known to  $\pm 2 \mu$ . With dilute media, the respiration was substrate limited and high concentrations of oxygen were found throughout the slime mass. More concentrated media increased utilization so that oxygen concentrations approached zero in the depth of the slime.

The microelectrode described by Whalen *et al.* (1967) was of the polarographic type and consisted of a glass capillary tube drawn out to a long, tapering point  $1.5 \mu$  in diameter. The tube was filled, to within  $10\text{--}20 \mu$  of the tip, with a metal alloy. A layer of gold was electroplated on the alloy, and the remainder of the recess was filled with collodion. A pure silver wire coated with silver chloride served as a separate anode. A voltage of  $0.6\text{--}1.1$  was impressed across the electrodes, and changes in current were recorded with a picoammeter-servo recorder combination. Current flow between the electrodes is linear with the oxygen activity, and is relatively insensitive to stirring.

The slime film was developed in a small, continuous-culture growth chamber, with the bacteria growing attached on an especially prepared microscope slide. To protect the delicate cathode tip when probing near the lower or attaching layer of cells, predrilled holes in the Plexiglass slide were filled with 2% Difco agar.

The growth chamber was seeded with heterotrophic bacteria, including at least 18 species obtained from a polluted stream (Sanders, 1966), and sealed for 24 hours. At the end of this attachment period, a flow of 280 ml. per minute of 20 parts per million nutrient broth (*BBL*) was initiated and maintained for eight days. The substrate velocity along the slide was 1.5 feet per second and the temperature was  $27^\circ \text{C}$ .

Then the top of the chamber was removed and the bottom containing the slime was clamped onto the stage of a Leitz Panphot microscope. The chamber was connected to an inlet

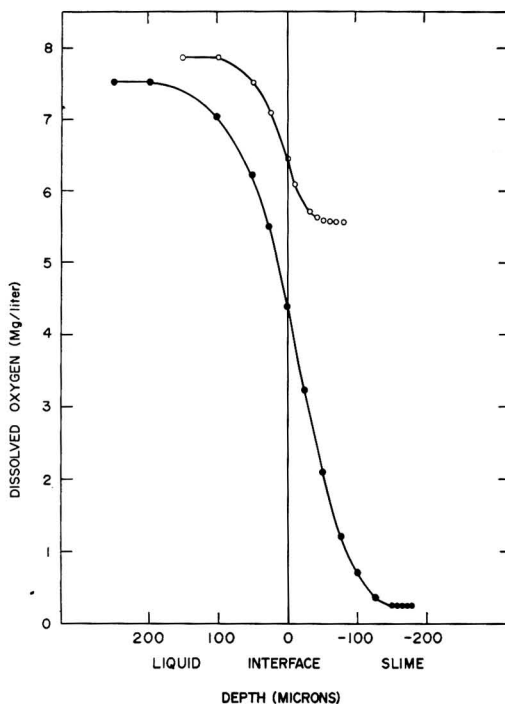


Figure 1. Dissolved oxygen profiles for bacterial slime in a continuous-flow system determined with microelectrode. Nutrient flow was 1.5 feet per second and temperature  $27^\circ \text{C}$ . With nutrient broth 20 mg. per liter (○—○), the oxygen in the slime stabilized at 5.5 parts per million below  $75 \mu$  in depth. With 500 mg. per liter nutrient broth (●—●), the profile reached  $150 \mu$  before stabilizing at 0.25 parts per million

manifold so that substrates containing 20 and 500 parts per million nutrient broth, with either high or low concentrations of dissolved oxygen, could be selected for flow through the chamber. The flow rates were adjustable, and the mean depth of flowing substrate over the slime was about  $3.3 \text{ mm}$ .

The slime film was examined optically with a 75X water immersion objective and had an average population density

of 15 cells per 100  $\mu^2$ , and ranged in depth from 150 to 200  $\mu$ .

During the probing operation, the microscope objective was replaced by the microelectrode held in the objective mount. Thus, the probe tip was positioned in the same areas as the visual observations, and the location of the probe was determined directly from the precalibrated micrometer scale on the microscope.

The slime surface was located optically with the substrate flowing, and electrically when the chamber was drained and the probe lowered until it made contact with the slime mass. Repeated probings indicated that the surface was determined within 2  $\mu$ .

After locating the surface, the microprobe was raised into the flowing liquid until the oxygen gradient stabilized. The probe was then lowered and readings taken at 25- $\mu$  increments at 30-sec. intervals, until the tip had penetrated the slime mass to a depth where the oxygen gradient stabilized.

The oxygen profile determined for the slime with air-saturated, 20-parts per million substrate flowing at 1.5 feet per second (Figure 1) shows that the oxygen concentration in the liquid and the film decreased with depth until a constant 5.5 parts per million was reached at a depth of 50  $\mu$  below the slime-nutrient interface. Thus the diffusion rate for oxygen into the slime film was higher than the respiration rate for that particular substrate concentration. These test conditions closely duplicated the growth conditions maintained during the eight days' culture period. When the substrate concentration was increased to 500 parts per million and the probe moved to an adjacent location (within 1 mm.), the new oxygen

profile was much steeper, starting 200  $\mu$  above the slime-nutrient interface and extending down to a depth of 150  $\mu$ . The oxygen concentration at this level was 0.24 parts per million, and the total slime thickness was 175  $\mu$ . Other experiments using nutrient with a lower initial oxygen concentration showed an oxygen profile approaching zero in the lower layers of the slime.

These experiments demonstrate the applicability of the microelectrode dissolved oxygen system for the direct measurement of oxygen concentrations and gradients in liquids and in microbial slime films. This should lead to direct determinations of oxygen and nutrient diffusivity coefficients for slime systems, and provides a method for studying the respiration of aquatic organisms with respect to their microenvironments.

#### *Acknowledgment*

The authors thank the Ecological Engineering staff of the Southeast Water Laboratory, Federal Water Pollution Control Administration, for their assistance in culturing the microorganisms, and the Division of Research, St. Vincent Charity Hospital, for making and supplying the microelectrodes.

#### *Literature Cited*

Sanders, W. M., III, *Air and Water Pollution International Journal* **10**, 253-76 (1966).  
Whalen, W. J., Riley, J., Nair, P., *J. Appl. Physiol.* **23** (5), 798-801 (1967).

*Received for review April 16, 1969. Accepted August 14, 1969. Mention of products and manufacturers is for identification only and does not imply endorsement by the Federal Water Pollution Control Administration or U.S. Department of the Interior.*

# ES&T READER SERVICE

If you would like to receive any of the material made available by advertisers in this issue, circle the numbers on one of the attached cards corresponding to the number shown beneath each advertisement. The New Product and New Literature Digests also have corresponding numbers for each item. This is a free service provided by ES&T.

**is your  
river  
looking  
a little green?**

Rivers turn green because they are full of algae, and the algae thrive because the water is rich in nitrate. If you would like a fast, simple method of tracking down the problem — whether it's fertilizer in run-off water, or sewage treatment effluent — Orion has a completely portable instrument system to do the job. The Specific Ion Meter and Nitrate Electrode make nitrate measurement as fast and simple as pH measurement — and the system gives laboratory determinations of nitrate just as good as any method you now use. And when water quality standards require that you check for nitrates, the system will pay for itself in no time at all with savings in laboratory analyses. Another example of the new technology for chemical analysis — from Orion.



**ORION RESEARCH INC.**  
11 Blackstone Street  
Cambridge, Massachusetts 02139

Circle No. 11 on Readers' Service Card

## DECEMBER 1969 VALID THROUGH MAY 1970

### ADVERTISED PRODUCTS:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60

### NEW PRODUCTS, NEW LITERATURE:

61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
106	107	108	109	110	111	112	113	114	115	116	117	118	119	120

Name \_\_\_\_\_

Position \_\_\_\_\_

Affiliation \_\_\_\_\_

Address \_\_\_\_\_

Zip \_\_\_\_\_

**NATURE OF BUSINESS:**  Industrial Firm  Academic  Government  
 Other \_\_\_\_\_

## DECEMBER 1969 VALID THROUGH MAY 1970

### ADVERTISED PRODUCTS:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60

### NEW PRODUCTS, NEW LITERATURE:

61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
106	107	108	109	110	111	112	113	114	115	116	117	118	119	120

Name \_\_\_\_\_

Position \_\_\_\_\_

Affiliation \_\_\_\_\_

Address \_\_\_\_\_

Zip \_\_\_\_\_

**NATURE OF BUSINESS:**  Industrial Firm  Academic  Government  
 Other \_\_\_\_\_

## DECEMBER 1969 VALID THROUGH MAY 1970

### ADVERTISED PRODUCTS:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60

### NEW PRODUCTS, NEW LITERATURE:

61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
106	107	108	109	110	111	112	113	114	115	116	117	118	119	120

Name \_\_\_\_\_

Position \_\_\_\_\_

Affiliation \_\_\_\_\_

Address \_\_\_\_\_

Zip \_\_\_\_\_

**NATURE OF BUSINESS:**  Industrial Firm  Academic  Government  
 Other \_\_\_\_\_

# ENVIRONMENTAL SCIENCE & TECHNOLOGY READER SERVICE

FIRST CLASS  
Permit No. 425  
Stamford,  
Conn. 06904

**BUSINESS REPLY MAIL**

No Postage Stamp Necessary if Mailed in the United States

POSTAGE WILL BE PAID BY—

**ENVIRONMENTAL  
Science & Technology**

READERS' INFORMATION SERVICE  
600 SUMMER STREET  
STAMFORD, CONN. 06904



If you would like to receive any of the material made available by advertisers in this issue, circle the numbers on one of the attached cards corresponding to the number shown beneath each advertisement. The New Product and New Literature Digests also have corresponding numbers for each item. This is a free service provided by ES&T.

FIRST CLASS  
Permit No. 425  
Stamford,  
Conn. 06904

**BUSINESS REPLY MAIL**

No Postage Stamp Necessary if Mailed in the United States

POSTAGE WILL BE PAID BY—

**ENVIRONMENTAL  
Science & Technology**

READERS' INFORMATION SERVICE  
600 SUMMER STREET  
STAMFORD, CONN. 06904



FIRST CLASS  
Permit No. 425  
Stamford,  
Conn. 06904

**BUSINESS REPLY MAIL**

No Postage Stamp Necessary if Mailed in the United States

POSTAGE WILL BE PAID BY—

**ENVIRONMENTAL  
Science & Technology**

READERS' INFORMATION SERVICE  
600 SUMMER STREET  
STAMFORD, CONN. 06904



# bookshelf

**Environmental Pollution Instrumentation.** Edited by Robert L. Chapman. 190 pages. Instrument Society of America, 530 William Penn Place, Pittsburgh, Pa. 15219. 1969. \$7.00, members, \$9.00, nonmembers; paper.

This monograph consists of symposia papers covering the state of the art and latest developments in air, water, and noise pollution. Monitoring air pollutants, vehicle exhaust data processing, chemical analysis by remote sensing, and the future of instrumentation in water pollution control are among topics discussed.

**Principles and Practices of Incineration.** Richard C. Corey. ix + 297 pages. Wiley-Interscience, 605 Third Avenue, New York, N.Y. 10016. 1969. \$14.95, hard cover. ■

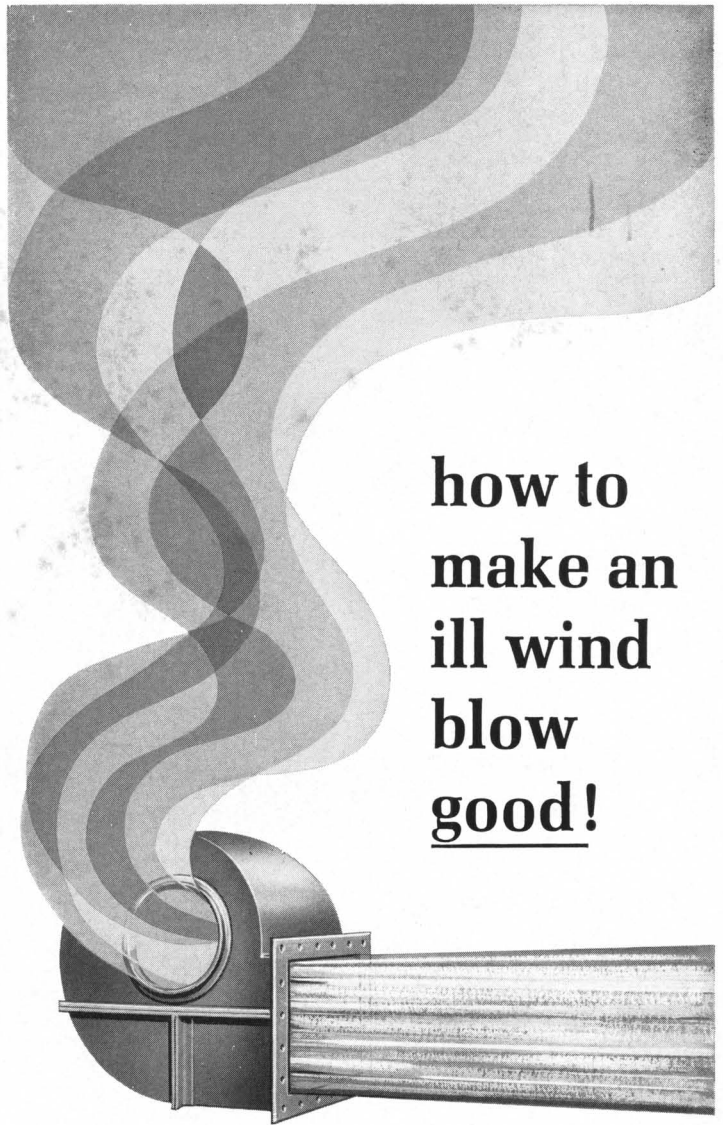
**The Biological Aspects of Water Pollution.** Charles G. Wilbur. vii + 296 pages. Charles C. Thomas, Publisher, 301-327 E. Lawrence Ave., Springfield, Ill. 1969. \$23.75, hard cover. ■

**Garbage As You Like It: A Plan to Stop Pollution by Using Our Nation's Wastes.** Jerome Goldstein. 243 pages. Rodale Books, Inc., 33 E. Minor St., Emmaus, Pa. 18049. 1969. \$4.95, hard cover. ■

**Progress in Oceanography: Volume 5** Edited by Mary Sears. xi + 191 pages. Permagon Press, Inc., Maxwell House, Fairview Park, Elmsford, N.Y. 10523. 1969. \$11.00, hard cover. ■

**Natural Resource Information for Economic Development.** Orris C. Herfindahl. A Resources for the Future Publication. ix + 212 pages. Johns Hopkins Press, Baltimore, Md. 21218. 1969. \$7.00, hard cover. ■

**An Oceanic Quest: The International Decade of Ocean Exploration.** Publication 1709. Prepared under the auspices of the Committee on Oceanography, National Research Council, and Committee on Ocean Engineering, National Academy of Engineering. 115 pages. National Academy of Sciences, 2101 Constitution Ave., N.W., Washington, D.C. 20418. 1969. \$3.75, paper. ■



how to  
make an  
ill wind  
blow  
good!

**By Call in Garden City—the air moving specialist!**

When you find yourself eyeball to eyeball with a tricky air handling job — one involving extremely high or low temperatures, corrosives, abrasives or handling difficult materials — call in the Garden City experts.

We've successfully diagnosed and treated all kinds of difficult air handling cases in processing and manufacturing industries for a long time — since 1879, in fact.

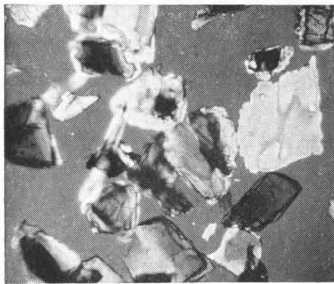
Write for bulletin: Garden City Fan & Blower Co., 803 N. Eighth Street, Niles, Michigan 49120

Standard Duty Fans to 300° F  
Thermal-Aire® Fans to 2000° F  
Alloy Fans for Corrosive Applications  
Materials Handling Fans

Circle No. 10 on Readers' Service Card



**Walter C. McCrone Associates**  
is *the* specialist group  
designed to answer any or all  
of your contamination control  
questions or requirements



Augite particles greatly magnified

## McCrone identifies particulates

Because of training, experience and instrumentation, the McCrone Laboratory is uniquely qualified to make a survey of your plant or operation to track down the source of your troubles. We determine the nature and amount of the contaminants involved.

**and/or**

## McCrone makes recommendations

If corrective measures are required, McCrone Associates will provide complete recommendations covering the type, size, and cost of equipment necessary. These recommendations are completely objective and, therefore, most economic.

**and/or**

## McCrone provides the engineering

Based on the previous information, our staff will engineer the correction . . . provide you with comprehensive drawings, and receive bids from equipment manufacturers. After submitting this material, McCrone Associates will present third person recommendations. All told, the McCrone "full circle" approach is your most efficient handling.

Talk to the McCrone specialist, phone or write today. A meeting will be arranged to meet your schedule. No obligation, of course.



**WALTER C. MCCRONE  
ASSOCIATES, INC.**  
493 East 31st Street  
Chicago, Illinois 60616  
Phone: (312) 842-7100

Circle No. 13 on Readers' Service Card

# new products digest

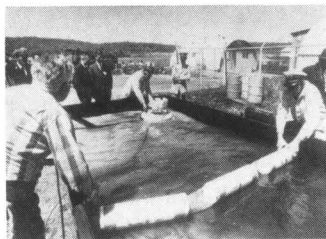
company says. Research Appliance Co. **62**

### Slime and algae suppressant

A new water treatment agent is designed to control slime deposits in recirculating cooling water systems. The company claims that dispersants contained in Nalco 209—a dry pulverized chlorine-release compound—help to remove existing deposits and prevent fouling due to buildup of new microbial or chemical deposits. Nalco Chemical Co. **63**

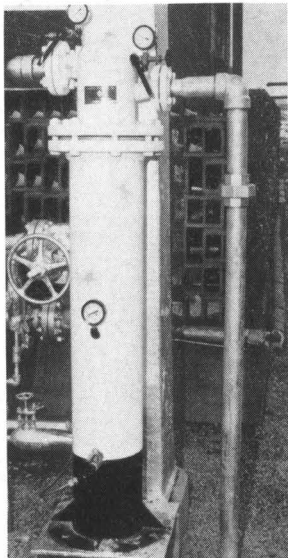
### Refuse compactor

A small, low investment refuse compactor for use in high-rise buildings is available. The PowerMite is a hydraulic stationary packer which crushes refuse inside an attached container. When the container is full, it is detached, hauled away by a truck handling unit, emptied, and returned to the PowerMite. The company says the unit can be used with any size container system—ranging from 3 cubic yards-42 cubic yards. Dempster Brothers, Inc. **64**



### Sweeping up oil spills

The Sunshine Chemical Oil Recovery Broom (SCORB)—or Seabroom—works with Slickbar (a weighted plastic curtain which surrounds an oil spill) to clean up oil spills in the sea. Seabroom, which floats on the water, has vacuumed up 170 gallons of fuel oil in minutes, according to the company. In addition, after the spill is sucked up, water settles out of the recovered mixture, and the oil can be reused. Sunshine Chemical Corp. **65**

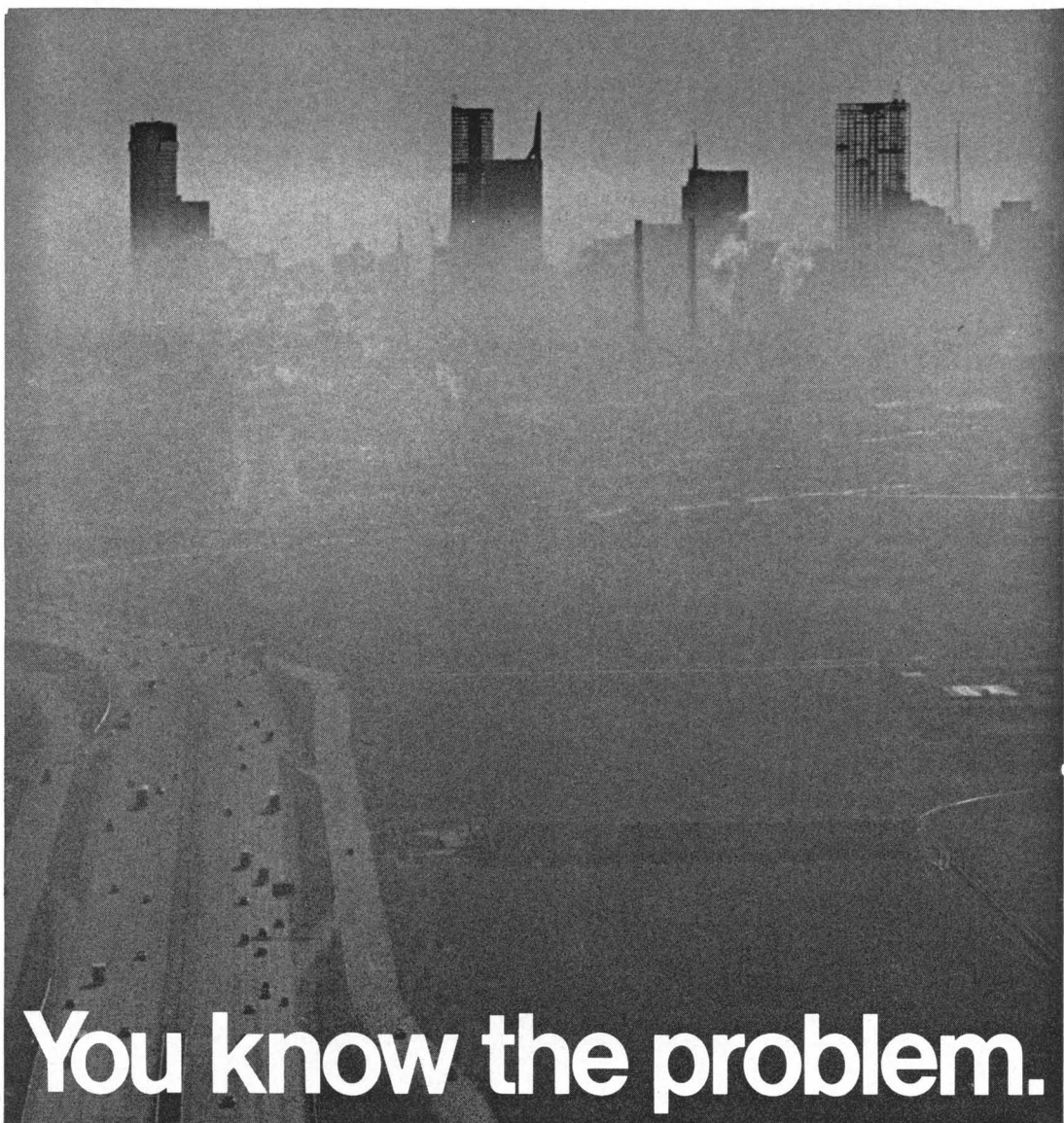


### Cyclone separator

The company claims that the Cor-Clone is ideal for removing suspended solids—mud, silt, sand, dead algae—from process cooling water in recirculating and once-through cooling systems. The continuous operating cyclone separator achieves separation by vertical inertia controlled within specific ranges. Containing no moving parts, the device is easy to maintain, and is available in light models having separator capacities of 5-300 g.p.m. which will control suspended solids of system capacities from 500-500,000 gallons. Vulcan Lab. **61**

### Automatic stack monitor

The AISI Stack Monitor—an automatic mass effluent monitoring system which can be applied as a process control device or air pollution monitor to stacks discharging particulate matter—is available. The device has specific application in such steelmaking processes as basic oxygen furnace, blast furnace, and open hearth, as well as in power generation, paper mills, cement plants, and chemical and petroleum industries, the



# You know the problem.

## Now Amsco has answers.

A full bag of answers. Including four new solvents that clear current West Coast restrictions on organic solvents: SPECIAL NAPHTHOLITE® Mineral Spirits, Naphthol Spirits, and 140 Solvent.

Each offers an approach to air pollution control, via limitation of photochemically reactive emissions.

These versatile new solvents show low aromatic content and low odor. They

mesh easily in present processing systems. Important applications show up in chemicals, coatings, adhesives, and graphic arts.

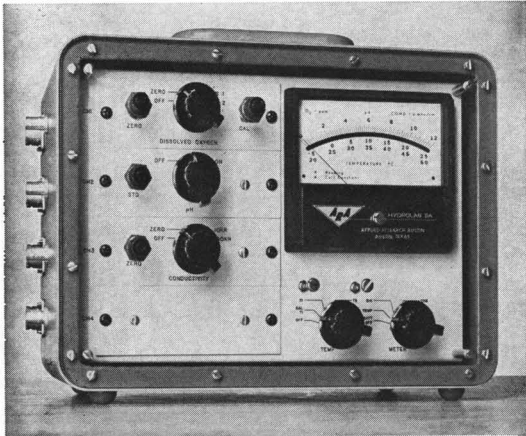
You know your problem. Now draw on the experience and the resources of the men in our Talent Bank of Experts, to help you develop answers. Ask AMSCO.

**amsco**

American Mineral Spirits Company  
Division of Union Oil Company of California  
Palatine, Illinois 60067

# portable water quality analyzer

Continuously and simultaneously measures pH, conductivity, dissolved oxygen, water temperature and concentration of various anions. Recorder output. Ideal for water studies, pollution abatement and wide-ranging field ecological studies.



## HYDROLAB IIA

This rugged field instrument is designed to provide on-the-spot data in the hostile environment of salt, brackish or fresh water. Unattended, the HYDROLAB monitors in remote areas when teamed with the ARA Field Scanner and Battery Operated Recorder to produce records of all five variables as a function of time.

Packaged to operate without interruption through dust storms, driving rain, in mud or the wet bilge of a small boat, the HYDROLAB also floats, so a trip over the side does no harm. Battery life approximates 8 hours daily use for a year. Safe maximum 9 volts. Net weight, 10 lbs.

Current delivery 30 days. Price: Main Frame (includes temperature) \$540; Modules: pH \$140; Conductivity \$170; Dissolved Oxygen \$160; Specific Ion \$150; Probe and Cable additional. Prices subject to change without notice.

Telephone 512 465-9526



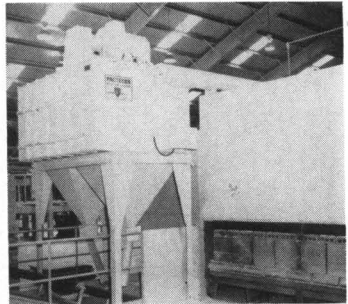
APPLIED RESEARCH AUSTIN, INC.  
P. O. BOX 9406 • AUSTIN, TEXAS 78757

*Rugged field instruments for biological studies  
and water quality analysis*

Circle No. 50 on Readers' Service Card

## Atmospheric particle counter

Accurate long-term monitoring of particulate air pollution is possible with a new analytical particle counter, according to the company. The device counts particles in the atmosphere at concentrations up to 10 million particles per cubic foot, analyzing one cubic foot of air per minute, optically detecting and registering particles as small as  $0.3 \mu$  in one of four digital counter channels. Particles detected over a one minute period are summed up in the counters and automatically printed out by an integral digital printer. Particle Technology, Inc. 66



## Dust filter

The Pactecon Dust Collector recovers dust and sand from kiln processed brick cleaned by sand blowing as the cooled brick passes through the sand blowing operation. Continuous operation and intermittent models handle volumes of 300-3000 c.f.m. at temperatures to  $250^{\circ}$  F. with 99.9% collection of particles over 1-2 micron in size, the company says. W. W. Sly Manufacturing Co. 67

## Continuous level measurement

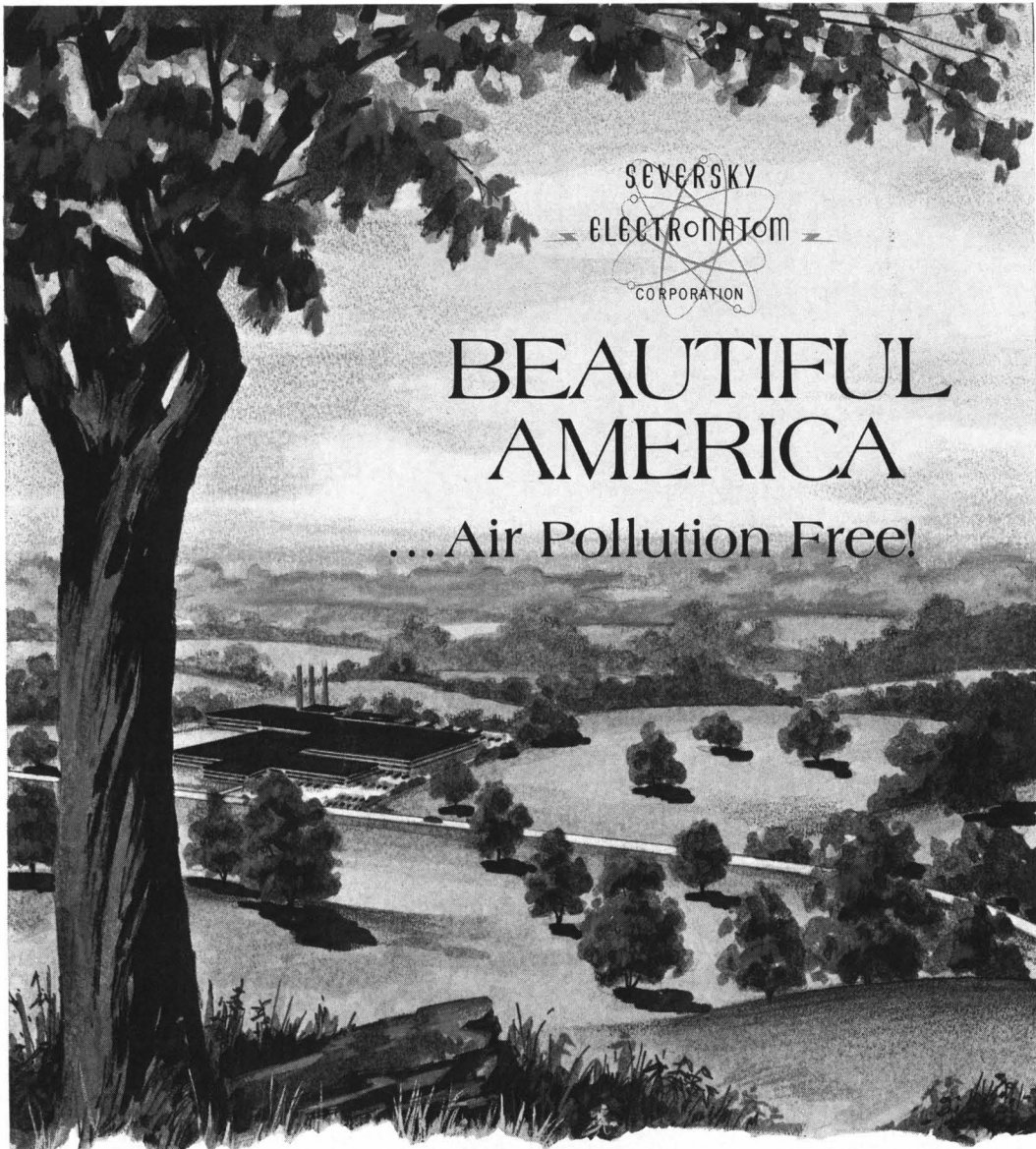
A continuous level measuring instrument, providing uninterrupted level readings under loading, unloading, and storage conditions of virtually all liquids and dry materials, is available. The Uni-Sonic-100 gage operates on sonic echo ranging principles accomplishing accurate and instant level gaging over a 0-200 foot range, regardless of container type, size, and location, according to the manufacturer. The instrument is designed to gage all liquids, including slurries and highly viscous substances, and can measure dry bulk materials used in mining, paper, cement, plastics, ceramic, food, and chemical industries. Inventron Industries, Inc. 68





# BEAUTIFUL AMERICA

...Air Pollution Free!



To help beautify America, we start at the source. Each factory and mill has its special pollution problem, and it takes a well-rounded background to find the solution to each problem. It also takes a company such as Seversky Electronatom, with a complete line of equipment to meet any contingency.

Seversky Electronatom Corporation provides not only the background, it offers equipment of every type to meet any requirement, thereby assuring an unbiased recommendation.

But, in addition to the standard equipment such as: Electrostatic Precipitators, Mechanical Collectors, Fabric Filters and Wet Scrubbers; Seversky also presents the HYDRO PRECIPITROL to industry. This major breakthrough in pollution control gives you all the combined advantages of a wet scrubber and a highly efficient electrostatic precipitator in a single unit. It provides industry with a new tool in the fight to keep America Beautiful.

For more details call or write:

## SEVERSKY ELECTRONATOM CORPORATION

One de Seversky Plaza, Garden City, N. Y. 11530

Phone: (516) 746-7400

Products and Services: HYDRO PRECIPITROL, ELECTROSTATIC PRECIPITATORS, MECHANICAL COLLECTORS, FABRIC FILTERS, FUME INCINERATORS . . . Evaluation and System Engineering Services.

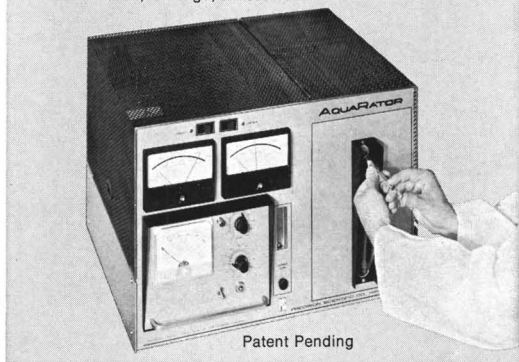
Circle No. 22 on Readers' Service Card

Volume 3, Number 12, December 1969 1305

# COD determinations in two minutes with the AquaRator!

Fast—only 2 minutes for complete test. Repeatable—to  $\pm 3\%$  or better. Low operating cost—uses inexpensive  $\text{CO}_2$ . Applicable for rapid detection of process upset or product loss.

Ask your Precision Scientific Dealer or write us for Bulletin 644 on the new AquaRator and how it works. Precision Scientific Company, 3737 W. Cortland St., Chicago, Ill. 60647.



Circle No. 38 on Readers' Service Card

for FULL CONE nozzle performance  
to meet your specifications



QUALITY, PRECISION MACHINED

*FullJet*® SPRAY NOZZLES

An unequalled Spraying Systems advantage is the far greater availability of nozzle types and capacities to meet whatever your specifications may be. For example, FullJet nozzles are supplied in over 500 types and sizes . . . 0.14 to 2130 GPM capacities . . . 15° to 125° spray angles . . . in brass, iron, steel, stainless steel, hard rubber and PVC.

**SPRAYING SYSTEMS CO.**  
3202 Randolph St., Bellwood, Ill. 60104



For complete information WRITE FOR CATALOG . . . 25A

Circle No. 18 on Readers' Service Card

## new literature digest

**Waste water treatment.** Two publications discuss possible applications and advantages of activated carbon to waste water treatment. Bulletin D-110, "Activated Carbon for Waste Water Treatment" covers such topics as when to consider activated carbon for solving pollution problems, which carbon process is best, how much is required, and expected costs. "Evaluation of Granular Carbon for Waste Water Treatment (D-111) describes powdered carbon tests, laboratory column tests, and pilot carbon tests. Both publications feature flow sketches and diagrams. Atlas Chemical Industries, Inc. **91**

**Water pollution control.** Case histories of successful application of the Mixmeter systems in treatment of industrial waste water are included in a 4 page bulletin. The continuously electronic controlled, portable, semi-permanent and permanent installations have wide application in mills, mines, water and sewage works, as well as in chemical, food, and paper processing industries, according to the manufacturer. Shirley Machine Co. **92**

**Deodorant insecticide.** A technical report describes the effectiveness of Deodorant Insectex Granules (DIG) in eliminating odors and destroying insects. The company claims that DIG ". . . releases a vapor blanket which kills flies, gnats, roaches, termites . . . and other flying and crawling insects attracted by wastes and garbage, while it inhibits the spread of odors." Eagle Chemical Co. **93**

**Air pollution instrumentation.** The company's line of instruments with application in air pollution detection and control are listed in a new catalog. Combustible gas detectors, combustion analyzers, temperature and humidity recorders, and various test devices are included. Bacharach Instrument Co. **94**

**Notes about littering.** A 19 page brochure presents basic facts about littering—what it is, who does it, why, and how it can be stopped. Illustrated with whimsical drawings, "The Litter Fact Book" aims to provide the

# If pollution control is old hat to your company, you'll like doing business with Thermal.

# If all you know is that you have a pollution control problem you'll appreciate us even more.

Thermal understands the problems of modern industrial pollution control. We talk your language — whether it involves an off-the-shelf unit to solve a conventional problem — or a complete waste management system featuring a variety of sophisticated equipment designed and built to meet your specific requirements.

Thermal didn't just discover pollution control—we've been in it since 1953. We can sell you equipment for the disposal of solid, liquid and gaseous wastes; but more important than the equipment is the skill, judgment and depth of experience which guides its application. Beyond the installation, we provide continuous advice and assistance in handling new or changing waste materials.

If you are not an expert in the field, you may be pleasantly surprised at what we can do with incineration of liquids and gases, often very simply and inexpensively. For solids we have a new "pit incinerator" that disposes of plant trash, plastics and many other materials at a fraction of the usual cost. Thermal also designs and constructs central disposal facilities for industrial complexes.

Expert or novice, big company or small — if you are looking for an efficient, economical waste disposal system — look to Thermal. Call or write today for more information regarding the use of our complete testing facility.

*Bulletin No. 132 for full details*

 **THERMAL** SUBSIDIARY  
OF COSMODYNE  
**RESEARCH & ENGINEERING CORP.**  
Conehohocken, Pa. 19428 • (215) 828-5400 • In Canada: Trecon Limited, Cookeville, Ont.

Circle No. 49 on Readers' Service Card

Volume 3, Number 12, December 1969 1307

general public with some information on a serious contemporary problem. Glass Containers Manufacturers Institute, Inc. **95**

**Evaporative losses.** "Activated Carbon for Effective Control of Evaporative Losses" is the title of a new 10 page publication. Bulletin 690086 considers the physical properties of activated carbon that affect its ability to store and then release gasoline vapors. Selection of activated carbon,

adsorptive life of the carbon, and factors affecting system design are among topics covered. The bulletin also features graphic material and a list of references. Calgon Corp. **96**

**Solving waste problems.** A 12 page illustrated brochure (Bulletin 69 WWT01-A) discusses how waste treatment systems can be designed to solve various domestic, commercial, and industrial waste problems. Secondary treatment systems, based on the Aero-

pack modified activated sludge plant, are described, and combination secondary-tertiary treatment systems are detailed. Dravo Corp. **97**

**Wet scrubbers.** The Flooded Disc wet scrubbers for dust and mist collection are detailed in Bulletin RC-975. The 12 page publication describes operating principle, features, and applications, and includes tables of dimensions. The company says the scrubber, which has no nozzles, requires no high water pressure, has a turn down ratio of more than 20:1, and is used for in process gas cleaning, product recovery, plant environmental control, and removal of gaseous pollutants. Research-Cottrell, Inc. **98**

#### Films

The National Medical Audiovisual Center has announced the availability of three films concerning the air pollution problem:

**"Beware the Wind"** (M-1707-X) is a 16 mm, 22 minute, color and sound presentation, narrated by Robert Preston. The film shows the origin and evolution of dirty air in American and European cities, stressing the threat of worldwide pollution. Principal air pollution sources, effects of air pollution on animals, people, and property, and ways of technologically cleaning the air also are illustrated.

**"On a Clear Day You Can Almost See Terminal Tower"** (M-1712-X) is a 16 mm, 22 minute, color and sound film produced by a Cleveland (Ohio) TV station. In addition to presenting the principal sources of the city's air pollution and their impact on city life, the film stresses the need for taking preventive action, and contrasts the level of air pollution in Cleveland with that of Cleveland, Tenn.

**"Beware of Ill Winds"** (F-1745-X) is a 35 mm, 39 frame filmstrip with accompanying manual, which describes the regional approach to air pollution control under provisions of the Air Quality Act. The role of public hearings prior to state adoption of federal standards is discussed.

Films are available for free, short-term loan. Order by title and number from: National Medical Audiovisual Center (Annex), Station K, Atlanta, Ga. 30324 (Write direct).

**THINK SMALL... For a Better Solution to Air Pollution**

**BELCO Electric Precipitators** are designed to **CLEAN** any process gas by entrapping dust as fine as **1/10<sup>th</sup> MICRON**

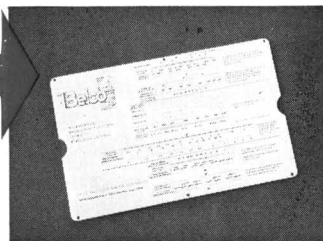
BELCO Electric Precipitators collect particles so small that a cluster of seven million would just cover the head of a pin. By using potential as high as 60,000 volts to charge the molecules of the entraining gas, billions of negatively charged gas ions flood the spaces between the Belco Electric Precipitator Collectrodes to block the escape of invisible dusts.

Whether your dust is coarse or fine, consult BELCO's experienced staff of Application Engineers who will recommend the most practical solution to **your** problem by skilled selection from BELCO's complete line of electric precipitators, mechanical cyclone collectors, and wet scrubbers. There is no obligation of course.

Write for Interesting Catalog

**FREE**

The Belco Sizer-Calculator will help in Calculating Requirements for the Solution to Air Pollution . . . Write for this helpful tool, today. It's Free.



**BELCO POLLUTION CONTROL CORPORATION**

185 PENNSYLVANIA AVE.  
PATERSON, N. J. 07509  
201 - 525-2200



Processes for Removal of Water and Air Pollutants

Circle No. 19 on Readers' Service Card

# meeting guide

## **December 15-17 American Petroleum Institute and Federal Water Pollution Control Administration**

Joint Conference on the Prevention and Control of Oil Spillage

Americana Hotel, New York City

Included in the 3 day session are a review of recent major oil spill incidents; discussion of the federal government's plan for dealing with such incidents; and industry's plan to deal with oil spills. In addition, such topics as harvesting techniques and fate and behavior of oil in water will be covered. For information: W. A. Burhouse, American Petroleum Institute, 1271 Avenue of the Americas, New York, N. Y. 10020

## **December 26-31 American Association for the Advancement of Science**

136th Annual Meeting  
Boston, Mass.

Featured at this year's meeting will be a 1 day symposium, Power Generation and Environmental Change: Reconciling man's desire for power with the needs of his environment. Another 1 day session will be devoted to a symposium on undergraduate education in environmental science. Information available through AAAS, 1515 Massachusetts Ave. NW, Washington, D.C. 20005

## **January 15-16 TAPPI, Michigan Division of the Paper Industry, and Western Michigan University**

14th Annual Pulp and Paper Conference  
Western Michigan University Student Center, Kalamazoo

Chemical additives—application, theory, and control is the theme of the conference. Papers and discussion will treat such topics as wet strength, sizing, retention aids, and the effects of such chemicals on effluent abatement control. For information, contact: Department of Paper Technology, Western Michigan University, Kalamazoo, Mich. 49001

## **January 25-30 Engineering Foundation**

Research Conference on Waste Water Engineering in the Food Industry

Asilomar Conference Grounds, Pacific Grove, Calif.

Purpose of the conference is to investigate the management of waste water in the food industry, pollution abatement, treatment procedures, and cost reduction as related to the food industry. Topics to be discussed include pollution abatement, planning with people; economics of managing waste water; solids handling from waste water treatment; and FWPCA demonstration grants.

## **February 2-5 Weed Science Society of America**

Annual Meeting

Queen Elizabeth Hotel, Montreal, Canada

Weed science and food—Canada, Britain, and the U.S. is the theme of the meeting. Leading authorities from government and industry will present papers dealing with various aspects of weed science and vegetation control.

## **February 11-12 Illinois Department of Public Health, and Department of Civil Engineering, University of Illinois**

12th Sanitary Engineering Conference  
Urbana, Ill.

The conference is aimed toward engineers and scientists in government, industry, or private practice, as well as water works managers and operators. Sessions will include papers and discussion topics under the general theme: Nitrate and water supply: source and control.

## **March 18-19 U.S. Bureau of Mines and IIT Research Institute**

2nd Mineral Waste Utilization Symposium

Chicago, Ill.

This year's symposium will be divided into four sections, covering utilization of mining wastes; industrial wastes; municipal refuse; and scrap. Papers will be presented by investigators representing research centers, resources centers, and contractors. For information: Murray A. Schwartz, IIT Research Institute, 10 W. 35th St., Chicago, Ill. 60616

## **March 24-26 University of Houston and Environmental Control Administration**

National Industrial Solid Wastes Management Conference

University of Houston, Tex.

Papers will be presented on such topics as research and development on organic and mineral industrial wastes characterizations; collection, handling, processing, conversion, or utilization; byproduct production processes from wastes; secondary material processes; economics; and resource recovery techniques from urban and industrial solid wastes. For further information: H. Nugent Myrick, Cullen College of Engineering, University of Houston, 3801 Cullen Blvd., Houston, Tex. 77004

# America's first membrane coated filter paper... **Bac-T-Kote®**

For use in clarification and sterilization of liquids such as drugs, wines and beverages. The advantage of these membrane coated filters is their ease of handling in press operations. BAC-T-KOTE, with proper support, withstands pressures up to 88 psi.

A uniformly thin and porous cellulose nitrate coating is fused to heavy, boil-proof paper. This gives the film layers strength necessary for handling in operation. Stable even against pulsating flow currents, they are fully permeable to relatively large proteins, such as serum globulin.

In circles or sheets, plain or punched, BAC-T-KOTE is available in...

### Three clarification grades:

**No. 1118.** High permeability. Complete separation of minute particles or suspended matter, even from viscous fluids. Yeast and mold content effectively reduced.

**No. 1119.** Stabilization of wines, fruit juices, beer and similar beverages. Change in taste, color or chemical composition prevented. Microorganisms in solutions, at room temperature, clarified and reduced.

**No. 1120.** Removal of microorganisms.

### And in one sterilization grade:

**No. 1121.** Highest degree of safety. Freedom from sorption, and good filtration performance. Formation of pyrogenic matter in ampoule filling plants eliminated.

Use coupon for additional information and free samples.



the first name in filtration...  
**SCHLEICHER & SCHUELL**  
(603) 352-3810

Schleicher & Schuell, Inc.  
Keene, New Hampshire 03431

Please send Bulletin #144, and Free  
BAC-T-KOTE sample. (Specify size.....)

Name \_\_\_\_\_

Address \_\_\_\_\_

City \_\_\_\_\_

State \_\_\_\_\_ Zip \_\_\_\_\_

ES-1269

# professional consulting services directory

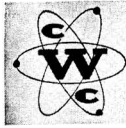


**Alpine Geophysical Associates, Inc.**  
Oak St., Norwood, N.J. 07648 • (201) 768-8000 Cable: "ALPGEO"  
**Consulting Geophysicists • Oceanographers • Engineers**

Oceanographic Studies • Ecological Studies • Land and Marine Seismic Surveys • Dye Diffusion Studies • Soil Mechanics and Foundation Engineering • Beach and Shore Erosion Reports

**THE BEN HOLT CO.**  
521 E. Green Street, Pasadena, Calif. 91101

**ENVIRONMENTAL SURVEYS**  
• **POLLUTION CONTROL** •



**CWC INDUSTRIES, INC.**  
2750 Grand Ave.  
Cleveland, Ohio 44104  
(216) 721-4747

*Chemical & Bacteriological  
Laboratory  
Feasibility Studies—  
Registered Engineers*

**DAMES & MOORE**  
**CONSULTING ENGINEERS IN APPLIED EARTH SCIENCES**

Air Pollution Water Pollution  
Solid and liquid Waste Disposal  
Environmental Studies For Nuclear Power Plants

**100 CHURCH STREET, NEW YORK, NEW YORK 10007**

ATLANTA	CHICAGO	CINCINNATI	DENVER	HONOLULU
HOUSTON	LOS ANGELES	PORTLAND	SALT LAKE	
SAN FRANCISCO	SEATTLE	WASHINGTON, D. C.		
LONDON	MADRID	SYDNEY	TEHRAN	TORONTO

**LIMNETICS, INC.**

**ENVIRONMENTAL ENGINEERS**  
**CONSULTING AND RESEARCH IN  
WATER POLLUTION CONTROL**

**Water Quality Investigations**

**A**nalytical and Economic Studies  
**T**otal Systems Engineering Programs  
**E**nvironmental Data Collection Systems  
**R**esource Planning and Development

**LIMNETICS, INC.** (414) 461-9500  
6132 W. Fond du Lac Ave., Milwaukee, Wis. 53218  
A Subsidiary of U.I.P. CORPORATION



phone (216) 248-0770

**environmental pollution control inc.**

30405 SOLON ROAD

CLEVELAND, OHIO 44139

**YORK RESEARCH CORP.**

- Air & Water Pollution Control
- Complete Analytical Laboratory
- Source Testing & Stack Sampling
- Industrial Plant Investigations
- Noise Level Studies

Phone or write for our brochure.

One Research Drive  
Stamford, Connecticut 06904  
(203) 325-1371

**DECCA SURVEY SYSTEMS, INC.**

Hydrographic Surveyors

provide a water pollution  
survey service, in  
estuaries and offshore

3410 Mercer, Houston, Texas 77027  
(713) 622-0736

**NARVON CONSULTING SERVICES**

• MUNICIPAL AND INDUSTRIAL WATER •  
• TRADE WASTES •

Narvon Mining and Chemical Co.,  
P.O. Box 1592, Lancaster, Pa., 17604  
Telephone 717/393-0761

**Specialists in  
Air & Water Quality Problems**

**RESOURCES RESEARCH, INC.**

1916 Newton Square West  
Reston, Virginia 22070  
Phone: 703-471-7234

3705 New Dade City Highway  
Lakeland, Florida, 33802  
Phone: 813-858-4408

A Subsidiary of TRW, Inc.



Sciences and Systems Division  
Ocean Science and Water Resources Section  
6500 Tracor Lane, Austin, Texas 78721

**WATER RESOURCES SYSTEMS**

- Computer Simulation and Modeling of System Hydraulics and Water Quality
- Comprehensive Planning, Design, and Engineering for Large-Scale Water Resources Systems
- Optimal Design of Waste Treatment Systems, Laboratory, Field Studies and Surveys
- Estuarine and Oceanographic Research and Development
- Data Management Systems

3065 Rosecrans Place  
San Diego, Calif.

19 Thames Street  
Groton, Conn.

1601 Research Blvd.  
Rockville, Md.

1735 Eye Street, N.W.  
Washington, D.C.



**ENVIRONMENTAL  
SERVICES**

**CONSULTING ENGINEERS  
IN INDUSTRIAL AIR AND  
WATER POLLUTION ABATEMENT**

P. O. BOX 40160

HOUSTON, TEXAS 77040 • TELEPHONE: (713) 462-4501



## Oceanonics, Inc. A Subsidiary of the Rucker Co.

Consulting & Research in Estuarine and Marine Waste Disposal Problems

6210 Evergreen, Houston, Texas 77036  
Phone: 771-5731 (Area Code 713)

P.O. Box 1095, Morgan City, La. 70380  
Phone: 384-3362 (Area Code 504)

## Kem-Tech Laboratories, Inc.



**AIR AND WATER POLLUTION CONSULTANTS**  
**ENVIRONMENTAL STUDIES • INDUSTRIAL PLANT INVESTIGATIONS • MOBILE LABORATORY SURVEYS • PRE-PLANT STUDIES**

16550 Highland Rd.

Baton Rouge, La. 70808



Source emission inventories • Air quality monitoring • Air resource simulation modeling • Cost/benefit analysis of abatement alternatives • Stack sampling • Diffusion meteorology

The Travelers Research Corp. 250 Constitution Plaza, Hartford, Conn. 06103 203 277-4388

## R<sup>2</sup> ASSOCIATES

**Environmental Consultants**

914-471-6738

5 Maryland Ave.

914-462-3974

Poughkeepsie, N. Y. 12603

## ENVIRONMENTAL DEVELOPMENT, INC.

Consultation-Research  
Development-Surveillance  
Laboratory Services

in  
Air and Water Pollution, Industrial, Domestic,  
Solid Waste, Occupational Health

L. C. McCabe S. Megregian  
1246 Taylor St., N.W., Washington, D. C. 20011  
(202) 291-9300

## SWIFT LABORATORIES, INC.

**SPECIALISTS IN METAL PROCESSING AND FINISHING FUME AND RINSE POLLUTION CONTROL TURNKEY SYSTEMS**

14 Spring Street, Waltham, Mass. 02154  
Telephone (617) 894-2995

## NUS CORPORATION

Consulting Engineering

Air Pollution

Water Pollution

Environmental Analyses

Process Design and Evaluation

Environmental Safeguards Division

2351 Research Blvd.

Rockville, Md. 20850

Area Code: 301-948-7010

## BETZ

TREVOBE, PENNSYLVANIA 19047

CONSULTING SERVICES DIVISION

Air Pollution • Process Water • Industrial Wastes

Analyses Evaluations Design  
Specifications  
Treatability and Reuse Studies

AIR and WATER POLLUTION CONTROL  
WASTE DISPOSAL • EMISSION ANALYSES  
PROCESS DESIGN • ENGINEERING  
SOLID WASTE MANAGEMENT • CONSULTING

**Environat Engineers**

1155 W. Chestnut St.  
Union, N. J. 07083  
(201) 688-1172

## Charles R Velzy Associates, Inc.

Consulting Engineers

Water Pollution Control—Water Supply—  
Drainage—Solid Waste Disposal—  
Industries Wastes

300 Martine Ave., White Plains, N.Y. 10601  
Mineola, N.Y. New City, N.Y.

## REYNOLDS, SMITH AND HILLS ENGINEERING DIVISION



**environmental engineering, inc.**

Offer diversified services in Pollution Control, Resource Management and Process Development

Problem Evaluation • Research and Development • Planning • Reports • Design • Supervision • Program Management

HOME OFFICE

Box 4850, Jacksonville, Florida 32201

## BUFFALO TESTING LABORATORIES, INC.

902 Kenmore Ave.

Buffalo, N. Y. 14216

Phone: 716-873-2302

TESTING AND CONSULTING SERVICES

AIR & WATER POLLUTION

SOURCE SAMPLING AND ANALYSIS

INDUSTRIAL WASTE TREATMENT STUDIES

## TRACE INORGANICS IN WATER

ADVANCES IN CHEMISTRY  
SERIES NO. 73

Twenty-one papers from a symposium by the Division of Water, Air, and Waste Chemistry of the American Chemical Society chaired by Robert A. Baker. Includes:

Five surveys on broad topics—

- Transport properties of electrolytes
- Anions in aqueous solution
- Effects of trace inorganics on the ice/water system
- Aluminum species in water
- The role of hydrous Mn and Fe oxides in fixation of metals in soils and sediments

Eleven papers on analytical developments, such as:

- Atomic absorption (3 papers)
- Atomic fluorescence
- Flame emission
- Neutron activation

And five research reports.

396 pages with index

Clothbound (1968)

\$12.50

Postpaid in U.S. and Canada; plus 20 cents elsewhere.

Set of L.C. cards free with library orders.

Order from

SPECIAL ISSUES SALES DEPT.  
AMERICAN CHEMICAL SOCIETY  
1155 SIXTEENTH ST., N.W.  
WASHINGTON, D.C. 20036

## USE THE CONSULTANTS' DIRECTORY

New rates effective January 1970 issue

Size	RATES PER MONTH	
	6 months	12 months
1" X 1 col.	\$20.00	\$19.00
1" X 2 col.	40.00	36.00
1" X 3 col.	58.00	52.00
2" X 1 col.	40.00	36.00
2" X 2 col.	75.00	68.00

Your card may appear in every issue for one year, every issue for six months (consecutive issues), or every other issue for one year. Send your copy to Joseph P. Stenza, ENVIRONMENTAL SCIENCE & TECHNOLOGY, 600 Summer St., Stamford, Conn. 06904, or call him at 203-348-7531.

**March 31-April 3  
International Association for  
Great Lakes Research**

13th Conference on Great Lakes  
Research

Statler Hotel, Buffalo, N.Y.

The program consists of five half day sessions of technical papers and a half day general session including a symposium of contributed papers on Great Lakes of the World. Purpose of the meeting is the promotion of all aspects of research and dissemination of research information on the Great Lakes and their basins.

**April 19-22  
American Association for  
Contamination Control**

9th Annual Technical Meeting and  
Exhibit

Convention Center, Anaheim, Calif.

Technical sessions will feature presentation of papers on new work or developments for contamination control in industrial manufacturing or processing related to products and environment, or related to biological, pharmaceutical, hospital, or other applications in the life sciences. Subject areas include standards, control of environment, quality control, and packaging. For further information, contact: William T. Mahoney, AACC, Six Beacon St., Boston, Mass. 02108

**Call for papers**

**December 31 deadline  
American Society of Civil Engineers,  
and Department of Civil Engineering  
and the Water Resources Research  
Center, University of Massachusetts**

3rd National Symposium on Sanitary  
Engineering Research

Abstracts may be submitted for a Special Conference on Disinfection, to be held July 13-15, 1970, at the University of Massachusetts, Amherst. Topics to be covered in the symposium are mode of biocidal action by disinfectants and other agents; kinetics of disinfection; water disinfection; effect of waste water disinfection on natural streams. Further details available from: Tsuan H. Feng or Lawrence N. Kuzminski, Department of Civil Engineering, University of Massachusetts, Amherst 01002

**January 31 deadline  
International Union of Air Pollution  
Prevention Associations**

2nd International Air Pollution  
Conference

Proposals to present papers may be filed with the sponsors of the meeting, to be held Dec. 6-11, 1970, Washington, D.C. Six concurrent sessions will include air pollution chemistry and physics; air pollution meteorology; air pollution medicine and biology; air pollution engineering; air pollution control administration; air pollution surveys. Proposals may be submitted in the language of the author. For information: Arthur C. Stern, Department of Environmental Sciences and Engineering, University of North Carolina, P.O. Box 630, Chapel Hill, N.C. 27514

**INDEX TO ADVERTISERS IN THIS ISSUE**

Alpine Geophysical Associates Inc....	1310	Schleicher & Schuell, Inc.....	1309
Ted Peck, Inc.		Wildrick & Miller, Inc.	
American Mineral Spirits Co., Div. of Union Oil Co., of California....	1303	Seversky Electronom Corp.....	1305
Leo Burnett Co., Inc.		Dereamus & Co.	
Applied Research Austin, Inc.....	1304	Spraying Systems, Inc.....	1306
David G. Benjamin, Inc.		Advertising Producers Associated, Inc.	
Aqua Test Corp.....	1220	Swift Laboratories, Inc.....	1311
Wm. Edins & Son Advertising Agency			
Atlas Electric Devices Co.....	1224	Technicon Corp.....	IFC
Kreicker & Meloan, Inc.		Mediad, Inc.	
		Thermal Research & Engineering Corp.	1307
Bartlett-Snow, A Bangor Punta Co....	1223	William Jenkins Advertising, Inc.	
Jack Herrick Advertising, Inc.		Torit Mfg., Co.....	1240
Bausch & Lomb, Inc., Analytical Sys- tems Div.....	OBC	Kerker & Associates, Inc.	
Wolf Associates, Inc.		Tractor, Inc.....	1310
Belco Pollution Control Corp.....	1308	The Travelers Research Corp.....	1311
W. N. Hudson			
Betz Laboratories, Inc.....	1311	Charles R. Velzy Associates, Inc....	1311
Buffalo Testing Laboratories, Inc.....	1311		
		Wheelabrator Corp.....	1232
Calgon Corp.....	1234	The Jaqua Co.	
Ketchum, MacLeod & Grove, Inc.		York Research Corp.....	1310
Geo. D. Clayton & Assoc., Inc.....	1236	Thomas A. Blanchard Associates	
Martin Herman Advertising			
Cleveland Water Conditioning Inc....	1310		
Clow Corp.....	1246		
Herbert Baker Advertising Inc.			
Curtin Scientific Co.....	1228		
Robinson-Gerrard, Inc.			
		▼ ▼ ▼	
Dames & Moore.....	1310		
Decca Survey Systems, Inc.....	1310	Advertising Management for the American Chemical Society Publications	
		REINHOLD PUBLISHING CORP.	
Engineering-Science, Inc.....	1310	A subsidiary of Litton Publications, Robert N. Sillars, Jr., General Manager, ACS Publications Division; 600 Summer St., Stamford, Conn. 06904. Phone: 203-348-7531. Cable Address: REINPUB STAMFORDCONNECTICUT	
Evronal Engineers.....	1311	ADVERTISING SALES MANAGER-WEST Laurence O. Roberts	
Seymour Charles Advertising, Inc.		ADVERTISING SALES MANAGER-EAST J. Barry Stanford	
Environmental Development, Inc.....	1311		
Environmental Pollution Control Co....	1310	SALES REPRESENTATIVES	
		Chicago 60603 . . . Laurence O. Roberts, Reinhold Publishing Corp., 10 S. LaSalle St., (Area Code 312) 726-1282	
Garden City Fan & Blower Co.....	1301	Dallas 75207 . . . Parker Harris, George Thompson, Roy McDonald Associates, 714 Stemmons Tower West, (Area Code 214) 637-2444	
Paxon Advertising, Inc.		Denver 80203 . . . Robert H. Heidersbach, Roy McDonald Associates, Inc., 846 Lincoln St., (Area Code 303) 826-3325	
Hercules Incorporated.....	1310	Houston 77006 . . . Frank N. Vickrey, Richard Clothier, Roy McDonald Associates, Inc., 3130 Southwest Freeway, (Area Code 713) 529-6711	
Fuller & Smith & Ross, Inc.		Los Angeles 90045 . . . Clay S. Holden, Lynn Gaskill, Reinhold Publishing Corp., 8939 S. Sepulveda Blvd., Suite 528, (Area Code 213) 776-0552	
The Ben Holt Co.....	1310	San Francisco . . . Clay S. Holden, Lynn Gas- kill, (Area Code 415) 421-8080	
Kem-Tech Laboratories, Inc.....	1311	Stamford 06904 . . . J. Barry Stanford, James C. Maywalt, Reinhold Publishing Corp., 600 Summer St. (Area Code 203) 348- 7531	
Herbert S. Benjamin Associates, Inc.		SALES SERVICE MANAGER Robert L. Voepel	
Limnatics, Inc.....	1310		
Litton Industries, Inc.....	IBC		
Jordan Advertising & Marketing Ser- vices, Inc.			
Maxon Premix Burner Company, Inc..	1230		
R. J. Poorman & Associates, Inc.			
Walter C. McCrone Associates, Inc..	1332		
Leonard Primer Advertising, Inc.			
Monsanto Co.....	1226-1227		
Poote, Cone & Belding, Inc.			
Narvon Mining & Chemical Co.....	1310		
Andes Advertising Agency			
NUS Corp.....	1311		
Oceanonics, Inc.....	1311		
Stevenson Advertising Agency			
Orion Research, Inc.....	1299		
Visual Research & Design Corp.			
Precision Scientific, Subsidiary of GCA Corp.....	1306		
Tri-State Advertising Co., Inc.			
R2 Associates.....	1311		
Research Appliances Co.....	1219		
George Hill Co. Inc.			
Resources Research Inc.....	1310		
Reynolds Smith and Hills.....	1311		



# ENVIRONMENTAL SCIENCE & TECHNOLOGY

## NAMES INDEX VOLUME 3—1969

January	1-94	July	607-688
February	95-192	August	689-782
March	193-290	September	783-868
April	291-410	October	869-1132
May	411-500	November	1133-1218
June	501-606	December	1219-1324

All authors' names and all names appearing in articles are indexed, except for those names appearing in meeting programs, feature articles, research papers, bibliographies, book reviews, and the Pollution Control Directory portion of the October issue.

### A

Abel, I. W., 429  
 Abrahams, John H., Jr., 17  
 Abrams, J. I., 235, 240, 508  
 Abramson, H. I., 1216  
 Adams, D. F. See Bamesberger, W. L., 258  
 Agnew, Allen F., 279  
 Agnew, Spiro T., 1249  
 Allen, Herbert E., and Hahn, Richard B. Determination of phosphate in natural waters by activation analysis of tungstophosphoric acid, 844  
 Allen, Lawrence H. See Matijević, Egon, 264  
 Altshuller, A. P., 497, 629  
 See also Bufalini, J. J., 469  
 Amaral, Joseph, Jr., 223  
 Applegate, Howard G., and Durrant, Lane C. Synergistic action of ozone-sulfur dioxide on peanuts, 759  
 Armiger, Walter H. See Barrows, Harold L., 261  
 Ascher, Michael C., 623  
 Ash, Roy L., 803  
 Ashley, Thomas L., 1243  
 Astrom, Sverker, 9  
 Atkinson, Bruce W., 1211  
 Austin, J. B. See Steiner, R. L., 1192  
 Austin, John H., 79, 87  
 Awpling, Howell, 697

### B

Bacon, Vinton, 209  
 Bailod, C. Robert, and Boyle, William C. Instruments in response time in an analytical system for continuous glucose measurement, 1205  
 Baker, William O., 787  
 Ballance, W. C., 110  
 Bamesberger, W. L., and Adams, D. F. Improvements in the collection of hydrogen sulfide in cadmium hydroxide suspensions, 258  
 Barber, William D., 1155  
 Barrows, Harold L., Caro, Joseph H., Armiger, Walter H., and Edwards, William M. Contribution of aerial contamination to the accumulation of dieldrin by mature corn plants, 261  
 Bartlett, D., Jr., 1224  
 Basier, J. A., 110  
 Baugh, J. O. See Thein, Myint, 667  
 Baumgartner, Wilfrid, 1241  
 Baurer, Theodore. See Kummier, R. H., 248  
 Beard, Carl G., II, 624  
 Beard, R., 1223

Beck, J. N. See Thein, Myint, 667  
 Begemen, Charles R. See Colucci, Joseph M., 41  
 Bellamy, W. Dexter, 883  
 Bennett, Carrie F. See Chow, Tsaihua, J., 737  
 Bennett, Gary F., 858  
 Bennett, Ivan T., 18  
 Berlandi, Frances J. See Mark, Harry B., Jr., 165  
 Bernstein, Ralph H., 676  
 Besley, H. E., 881  
 Bessilveire, Edmund B., 399  
 Bhatia, M. N., 701  
 Black, Ralph, 707  
 Blanc, F., 214  
 Bloom, Ralph, Jr., 214, 217, 1143  
 Bogen, S. A., 521  
 Bolduc, Michael J., 1258, 1260  
 Bond, Aaron, 321  
 Borchers, Doyle J., 103  
 Bortleson, Gilbert C. See Delfino, Joseph J., 1189  
 Bortner, M. H. See Kummier, R. H., 248, 944  
 Bott, Roderick F., 75  
 Boucher, Frank, 1152  
 Bowditch, Fred W., 890  
 Bowen, D. H. Michael, 400, 513, 695, 787, 879, 1225  
 Bower, Blair T., 80  
 Bowman, Wallace D., 1139  
 Boyd, Alan S., 11  
 Boyle, Harvey W. See Mount, Donald I., 1183  
 Boyle, William C. See Bailod, C. Robert., 1205  
 Bradley, R. M., 677  
 Braman, James D., 1251  
 Bregman, Jacob I., 336, 340  
 Breidenbach, Andrew, 707  
 Brenchley, David L., 605, 865  
 Brenner, Theodore E., 101  
 Brewer, R. F., Sutherland, F. H., and Guillemet, F. B. Effects of various fluoride sources on citrus growth and fruit production, 378  
 Briggs, Robert O., 205  
 Brock, James R. See Hidy, George M., 563  
 Brooks, David B., 487  
 Brooks, Douglas L., 594  
 Brooks, Harvey, 305  
 Brown, Paul M. A modification of the Bausch and Lomb aerosol dust counting system to automatically measure aerosol size distributions, 768  
 See also Hochrainer, Dietrich, 830  
 Brown, Robert V., 213  
 Bruce, J. P., 179  
 Bryan, Edward H., 179  
 Buckley, John L., 1160, 1249  
 Bueche, Arthur M., 787  
 Bufalini, J. J., and Altshuller, A. P. Oxidation of nitric oxide in the presence of ultraviolet light and hydrocarbons, 469

Bungay, Henry R., III. See Whalen, William J., 1297  
 Burcar, P. J. See Wershaw, R. L., 271  
 Burchinal, Jerry C., 1170, 1173  
 Burd, Patricia A., 80  
 Burd, Robert S., 120  
 Burhouse, W. A., 1216, 1309  
 Burnett, William E. Air pollution from animal wastes. Determination of malodors by gas chromatographic and organoleptic techniques, 744  
 Burnham, Carole D., Moore, Carl, Kanabrocki, Eugene, and Hattori, Don M. Determination of lead in airborne particulates in Chicago and Cook County, Illinois, by atomic absorption spectroscopy, 472  
 Butrico, Frank A., 191  
 Byerly, Theodore C., 1251

### C

Cadle, Richard D., 73  
 Campbell, J. E. See Schafer, J. T., 1261  
 Campbell, J. Phil, 701  
 Campbell, Thomas H., 586  
 Caro, Joseph H. See Barrows, Harold L., 261  
 Carpenter, Richard A., 1139  
 Carter, Melvin W. See Rehnberg, Georgia L., 171  
 Case, Clifford P., 615  
 Castagno, Joe L. See Collins, A. Gene, 274  
 Cavanagh, Leonard A., Schadt, Conrad F., and Robinson, Elmer. Atmospheric hydrocarbon and carbon monoxide measurements at Point Barrow Alaska, 251  
 Chapman, Robert L., 1301  
 Charlson, Robert J. Atmospheric visibility related to aerosol mass concentration. A review, 913  
 See also Friend, James P., 1181; Yamada, Victor, M., 483  
 Chass, Robert L., 1224  
 Cheek, C. H. See Swinnerton, J. W., 836  
 Cheney, Richard L., 17  
 Chen, S. K. See Mateles, R. I., 569, 769  
 Cholak, Jacob. See Noweir, Madbuli, H., 927  
 Chow, Tsaihua, J., Earl, John L., and Bennett, Carrie F. Lead aerosols in marine atmosphere, 737  
 Chow, V. T., 858  
 Church, Franklin W., 542  
 Clark, R. S. See Thein, Myint, 667  
 Clayton, George D., 80

Cliath, M. M. See Spencer, W. F., 67  
 Cline, Joel D., and Richards, Francis A. Oxygenation of hydrogen sulfide in seawater at constant salinity, temperature, and pH, 838  
 Collins, A. Gene, Castagno, Joe L., and Marcy, V. M. Potentiometric determination of ammonium nitrogen in oilfield brines, 274  
 Collins, George F. See Turk, Amos, 44  
 Collins, George R., 179  
 Collins, J. W., Webb, A. A., Didwania, H. P., and Lueck, B. F. Components of wood pulp bleach effluents, 371  
 Colucci, Joseph M., and Begeman, Charles R. Carbon monoxide in Detroit, New York, and Los Angeles air, 41  
 Connally, Hugh H., 707  
 Cook, E. E., 279  
 Cooke, Lloyd M., 787  
 Cooper, W. W. See Thein, Myint, 667  
 Copley, Charles M., Jr., 21  
 Corbett, Don M., 279  
 Corey, Richard C., 1301  
 Coughlin, Robert L., 213  
 Coulter, James B., 123  
 Craine, Lyle E., 1211  
 Crailley, Lester V., 80, 721  
 Crailley, Lewis J., 80  
 Cunningham, Newton, 524  
 Curry, James A., 793  
 Curtis, Jesse W., 890

### D

Daddario, Emilio Q., 417  
 Daines, R. H., 720  
 Dale, William J., 80  
 Daniels, Stacy L. See Teot, Arthur S., 825  
 Darnay, Arsen J., Jr., 328, 333  
 Dasman, R. F., 80  
 Davis, Larry G., 618  
 Davis, Robert K., 80  
 Dean, Karl, 717  
 Dean, Robert B., 820, 824  
 DeCastro, Jose Fernandez, 1141  
 Decker, George H., 301  
 Delfino, Joseph J., Bortleson, Gilbert C., and Lee, G. Fred. Distribution of Mn, Fe, P, Mg, K, Na, and Ca in the surface sediments of Lake Mendota, Wisconsin, 1189  
 Delfino, Joseph J., and Lee, G. Fred. Colorimetric determination of manganese in lake waters, 761  
 Chemistry of Manganese in Lake Mendota, Wisconsin, 1094

Demint, R. J. See Frank, P. A. 69  
 Dennis, Richard, 676  
 Denny, Charles S., 80  
 Devaney, Joseph J., 322  
 Didwania, H. P. See Collins, J. W., 371  
 Dingell, John D., 803  
 Dixon, J. K., and Zielky, M. W. Control of the bacterial content of water with synthetic polymer flocculants, 551  
 Docking, Robert B., 120  
 Dominick, David D., 615, 1139, 1241  
 Dow, Donald H., 80  
 Dow, R. L., 1233  
 Dravnieks, Andrew, 624  
 Dubey, George A., 1148  
 Dubos, Rene, 9  
 DuBridge, Lee A., 611, 890, 1241, 1249  
 Duce, Robert A. See Hoffman, Gerald L., 1207  
 Dunham, W. H., 1233  
 Dunning, Harrison F.  
 Durham, Clarence O. Jr., 1252, 1257  
 Durrant, Lane C. See Applegate, Howard G., 759  
 Duttweiler, David W., 709

## E

Earl, John L. See Chow, Tsaihua J., 737  
 Eaton, E. D., 699  
 Eckardt, Robert E., 543  
 Eckenfelder, W. W., Jr., 685  
 Edmonds, Sylvan M. See Turk, Amos, 44  
 Edwards, Max N., 120, 197  
 Edwards, William M. See Barrows, Harold L., 261  
 Egleson, G. C., and Querio, C. W. Variation in the composition of brine from the Sylvania Formation near Midland, Michigan, 367  
 Eisenbud, Merril, 882  
 Eisner, Uri. See Mark, Harry B., Jr., 165  
 Eldredge, Richard, 707  
 Eliassen, Roif, 18, 536, 541, 1160  
 Ensminger, L. G., 605, 865  
 Epstein, S. S., 105  
 Evans, David M., 105

## F

Fair, Gordon M., 798  
 Fairweather, John H., 430  
 Falch, Edward, 699  
 Farvar, Taghi, 619  
 Faust, Samuel D. See Nelson, Nancy H., 1186  
 Fay, James A., 497  
 Feldmann, Charles R. See Saltzman, Bernard E., 1275  
 Feng, Tsuan H., 1216, 1312  
 Finch, Robert H., 517, 1160, 1229, 1249  
 Fish, Birney R. See Smith, Benjamin M., 558  
 Fisher, Ellsworth, 15  
 Fisher, James, 858  
 Fisher, Joseph L., 11  
 Flachsbarth, Hermann. See Stöber, Werner, 641, 1280  
 Flinn, James E., 866  
 Folkerts, G. See MacLean D. C., 1201  
 Follett, R. H., 279  
 Fort, Tomlinson, Jr., 602  
 Fox, Robert A., 79  
 Frank, Evelyn R. See Spurny, Kvetoslav R., 453, 464  
 Frank, Marilyn L. See Witkamp, Martin, 1195  
 Frank, P. A., and Demint, R. J. Gas chromatographic analysis of dalapon in water, 69  
 Franz, Roger L., 510  
 Fraser, Douglas, 179  
 Frear, Donald E. H., 858  
 Friedlander, S. K., 74  
 Friedlander, S. K., and Sinfeld, J. H. A dynamic model of photochemical smog, 1175  
 Friedman, L. D., 214, 217

Friend, James P., and Charlson, Robert J. Double tracer techniques for studying air pollution, 1181  
 Frietsch, William, 707  
 Fung, Kochy. See Glater, Julius, 580  
 Funkhouser, John T., 624

## G

Galetti, Bernard J., 34, 37  
 Gallagher, Brian J., 798  
 Galley, John E., 399  
 Gardner, W. S. See Schafer, M. L., 1261  
 Gates, George O., 1231  
 Gaudy, A. F., Jr., 279  
 See also Storer, F. F., 143  
 Gaulding, Clark L., 431  
 George, Ralph E., 897  
 Gilbertson, Wesley E., 228  
 Glasser, Marvin, 1235  
 Glater, Julius, and Fung, Kochy. Calcium sulfate hemihydrate scaling thresholds in natural waters from 100° to 150° C., 580  
 Glaze, William H. See Henley, Don E., 268  
 Gleason, Marion N., 399  
 Glenn, Thomas R., Jr., 203  
 Gloyna, Ernest F., 859  
 Godfrey, Arthur, 403  
 Goetz, Alexander. A new instrument for the evaluation of environmental aerocolloids, 154  
 Goldberg, Edward D., 74  
 Goldberg, M. C. See Wershaw, R. L., 271  
 Goldsmith, J. R., 1224  
 Goldstein, Jerome, 1301  
 Goodenough, Robert D., Mills, Jack R., and Place, John. Anion exchange resin (polybromide form) as a source of active bromine for water disinfection, 854  
 Goodwin, Harold Leland, 588  
 Gosselin, Robert E., 399  
 Grant, Edmund J., 103  
 Gray, Oscar S., 11  
 Greenburg, Leonard, 1235  
 Gregor, Harry P., 74  
 Griswold, S. Smith, 699  
 Guillemet, F. B. See Brewer, R. F., 378

## H

Haar, Charles M., 303  
 Hageopian, H. G. Blue tetrazolium reduction by whole tobacco smoke and gas phase components, 567  
 Hahn, Richard B. See Allen, Herbert E., 844  
 Haley, T. J., 529  
 Hallstein, Frank, 189, 404  
 Hansen, Chris A., 28  
 Hardin, Clifford M., 303, 1249  
 Hardy, Jorge, 179  
 Harper, K. T., 717  
 Harris, A. J., 487  
 Harris, Robert L., Jr., 103  
 Hart, Philip A., 417  
 Hattori, Don M. See Burnham, Carole D., 472  
 Hauck, Andrew R., and Sourirajan, S. Performance of porous cellulose acetate membranes for the reverse osmosis treatment of hard and waste waters, 1269  
 Havens, Richard, 717  
 Hawes, Alexander B., 203  
 Hayden, John A., 812, 819  
 Heffner, Hubert B., 885  
 Heine, Walter, 1239  
 Heller, Austin N., 301, 882  
 Henley, Don E., Glaze, William H., and Silvey, J. K. G. Isolation and identification of an odor compound produced by a selected aquatic actinomyces, 268  
 Henriksen, Rein, 1241  
 Herfindahl, Orris C., 1301  
 Herwig, R. S., 703  
 Hibbs, James R., 1251

Hickel, Walter J., 791, 881, 1141, 1145, 1231, 1241, 1249  
 Hickey, H. R., 720  
 Hickey, Joseph J., 15  
 Hickman, H. Lanier, 707  
 Hidy, George M., and Brock, James R. Lung deposition of aerosols—a footnote on the role of diffusio-phoresis, 563  
 Hildebrandt, Peter W., 226  
 Hill, A. Clyde, and Littlefield, Neil. Ozone. Effect on apparent photosynthesis, rate of transpiration, and stomatal closure in plants, 52  
 Hirsch, Allan, 103  
 Hochrainer, Dietrich, and Brown, Paul M. Sizing of aerosol particles by centrifugation, 830  
 Hochstetler, Arthur D. See Smith, Hermes D., 169  
 Hodge, Harold C., 399  
 Hoelscher, H. E., 235, 240, 508  
 Hoffman, Gerald L., Duce, Robert A., and Zoller, William H. Vanadium, copper, and aluminum in the lower atmosphere between California and Hawaii, 1207  
 Holley, C. Wayne. See Howe, Lyman H., III, 478  
 Holmer, Freeman, 224  
 Holmes, Timothy, 531  
 Hopkins, Charles B., 214, 216, 1143  
 Hostman, James W., 858  
 Howe, Lyman H., III, and Holley, C. Wayne. Comparisons of mercury (II) chloride and sulfuric acid as preservatives for nitrogen forms in water samples, 478  
 Howison, Charles N., 895  
 Hudgins, Mildred R., 677  
 Hughes, Harold, 121  
 Hughes, J. Martin. See Soo, Shao L., 386  
 Hughes, Richard, 895  
 Hulbert, Samuel F., 18  
 Huls, Thomas A., 627

## I

Iddings, Frank A., 132, 140  
 Ilder, D. R., 811  
 Ildard, Frank N., 13  
 Iliff, Neil, 1241  
 Isaac, Peter C. G., 677

## J

Jackson, Henry M., 207, 611, 701, 803  
 Jaeger, Walter, 806  
 Jannasch, H. W. See Mitchell, Ralph, 941  
 Jarrett, Henry, 859  
 Jayson, Lester S., 1139  
 Jenkins, Charles R., 1170, 1173  
 Jenkins, David. See Medsker, Lloyd L., 476  
 Jensen, James H., 613  
 Jewell, John P., 721  
 Johari, Om, 1211  
 Johnson, Charles C., Jr., 28  
 Johnson, Edwin L., 213  
 Johnson, H. C., 711  
 Johnson, Horace. See Thein, Myint, 667  
 Johnson, James A., 213  
 Johnson, Lyndon B., 803  
 Johnson, Vernon G., 446, 451  
 Jones, Emmet E., 87  
 Jones, H. Mason, 1247  
 Jopling, William F., 75  
 Joseph, R. T., 214, 217  
 Josephs, Melvin J., 5, 201, 295, 400

## K

Kalinske, A. A., 229, 234  
 Kammerer, Phil A., Jr., and Lee, G. Fred. Freeze concentration of organic compounds in dilute aqueous solutions, 276

Kanabrocki, Eugene. See Burnham, Carole D., 472  
 Katko, Albert, 75  
 Katz, M., 677  
 Kaufman, D. D., 1211  
 Kawahara, Fred K. Identification and differentiation of heavy residual oil and asphalt pollutants in surface waters by comparative ratios of infrared absorbances, 150  
 Kearney, P. C., 1211  
 Keilpart, Ted, 807  
 Kennedy, Edward M., 207  
 Kennedy, John F., 803  
 Khan, Ansan U. See Pitts, J. N., Jr., 241  
 Kincannon, D. F., 279  
 Kirk, Claude E., 881  
 Kittredge, George D., 623  
 Klee, Albert J., 898, 902  
 Klein, Carl L., 699, 885, 891, 1231, 1241  
 Klein, Elias. See Spears, Larry G., 576  
 Kleinert, Stanton J., 15  
 Kneese, Allen V., 80, 174  
 Koch, Edward I., 890  
 Koch, C. See Medsker, Lloyd L., 476  
 Komolrit, K., 279  
 Kornberg, H. A., 487  
 Krutilla, John V., 487  
 Kuettnner, Joachim P., 305  
 Kummier, R. H., and Bortner, M. H. Production of O<sub>3</sub>(Ag) by energy transfer from excited benzaldehyde, 944  
 Kummier, R. H., Bortner, M. H., and Baurer, Theodore. The Hartley photolysis of ozone as a source of singlet oxygen in polluted atmospheres, 248  
 Kunze, G. W., 399  
 Kunzid, R. L., 1143  
 Kuroda, P. K. See Thein, Myint, 667  
 Kuzninski, Lawrence N., 1216, 1312

## L

LaFarge, Aubrey, 191, 287, 405  
 Laird, Melvin R., 5, 29  
 Lampi, Paul, 179  
 Landaw, S. A., 1224  
 Lander, D. W. See Steiner, R. L., 1192  
 Landsberg, H. E., 1211  
 Lang, Otto E., 885  
 Larson, Thurston O., 787  
 Ledbetter, Joe O., 859  
 Lee, G. Fred. See Delfino, Joseph J., 761, 1189, 894; Kammerer, Phil A., Jr., 276; Tranquillo, J. S., 393; Wentz, Dennis A., 750, 754  
 Leman, Charles, 224  
 Lenher, Samuel, 893, 894  
 Leonard, Fred B., 508  
 Levy, Arthur, and Merryman, Earl L. Sulfur-oxide formation in carbonyl sulfide flames, 63  
 Ley, Herbert L., Jr., 28  
 Lindsay, John V., 882  
 Ling, Joseph T., 1258, 1260  
 Linnembon, V. J. See Swinnerton, J. W., 836  
 Linton, Ron M., 29, 885  
 Littlefield, Neil. See Hill, A. Clyde, 52  
 Liu, B. Y. H., Marple, V. A., and Yazdani, H. Comparative size measurements of monodisperse liquid aerosols by electrical and optical methods, 381  
 Livengood, Charles D., 403  
 Locandro, Roger, 498, 602  
 Lodge, James P., Jr., 787  
 See also Spurny, Kvetoslav R., 453, 464; Wartburg, Arthur F., 767  
 Löf, George O. G., 174  
 Lombardo, Louis V., 626  
 Lonegram, Richard, 707  
 Long, Franklin A., 787  
 Longley, M. Y., 1224  
 Luce, Charles F., 303, 697, 885, 1241  
 Ludwig, John H., 103  
 Luck, B. F. See Collins, J. W., 371  
 Lyon, W. A., 1239  
 Lysly, Ihor, 709

## M

- McCormick, Brooks, 1241  
 McCoy, Charles B., 1241  
 McCoy, James W., 676  
 McCune, D. C., 720  
 McIntyre, Michael V., 606, 682, 780  
 McKee, Herbert C., 542, 858  
 McKee, Jack E., 75  
 McKinley, Daniel, 677  
 McLean, Louis A., 15  
 McMahon, W. A., 858  
 McNamara, B. J., 897  
 McNulty, James A. See Moore, Robert T., 741  
 McWhirter, John, 109  
 Maasland, D. E. L., 179  
 MacDougall, Daniel, 787  
 MacFarland, H. N., 543  
 Machle, Willard, 543  
 MacLean, D. C., Roark, O. F., Folkerts, G., and Schneider, R. E. Influence of mineral nutrition on the sensitivity of tomato plants to hydrogen fluoride, 1201  
 Magnuson, Warren G., 417  
 Mahoney, William T., 312  
 Mangan, George F., 904, 911  
 Manjikian, Serop, 299  
 Manny, E. H., 808  
 Marcy, V. M. See Collins, A. Gene, 274  
 Mark, Harry B., Jr., Eisner, Uri, Rottschaffer, J. Mark, Berlandi, Francis J., Mattson, James S. Application of semipermeable ion exchange membranes to *in situ* determination of trace metal ions in aqueous systems by electrochemical and neutron activation techniques. Critical evaluation of techniques, 165  
 See also Mattson, James S., 161, 484; Snoeyink, Vernon L., 918  
 Mark, Howard L. See Turk, Amos, 44  
 Marple, V. A. See Lui, B. Y. H., 381  
 Marshall, James, 399  
 Martin, Dean F., 586  
 Martin, D. O., 434  
 Martinez, Joseph D., 1252, 1257  
 Martinson, R. Kahler, 677  
 Mateles, R. I., and Chian, S. K. Kinetics of substrate uptake in pure and mixed culture, 569, 769  
 Matijević, Egon, and Allen, Lawrence H. Interactions of colloidal dispersions with electrolytes, 264  
 Matsumura, Fumio, 15  
 Mattson, James S., and Mark, Harry B., Jr. Application of internal reflectance spectroscopy to water pollution analysis, 161, 484  
 See also Mark, Harry B., Jr., 165  
 Mayers, May R., 588  
 Medsker, Lloyd L., Jenkins, David, Thomas, Jerome F., and Koch, C. Odorous compounds in natural waters. 2-exo-hydroxy-2-methylbornane, the major odorous compound produced by several actinomycetes, 476  
 Meeker, James E. See Stanley, Thomas W., 1198  
 Megonell, William H., 103, 430, 626  
 Merrell, John C., Jr., 75  
 Merryman, Earl L. See Levy, Arthur, 63  
 Merten, Ulrich, 72  
 Meyer, J. Theodore, 624  
 Meyer, John M., Jr., 904, 911  
 Middleton, Francis M., 891  
 Middleton, John T., 28, 429, 431, 611, 615, 791  
 Miller, George P., 417  
 Mills, Jack F. See Goodenough, Robert D., 854  
 Mills, Kenneth D., 625  
 Milton, John, 619  
 Mishkin, Ralph, 315  
 Mitchell, John N., 890  
 Mitchell, Ralph, and Jannasch, H. W. Processes controlling virus inactivation in seawater, 941  
 Mitchell, Ralph, and Yankofsky, Shlomit. Implication of a marine ameba in the decline of *Escherichia coli* in seawater, 574  
 Modesitt, D. E., 279  
 Moeller, Dade W., 87, 88, 191, 192, 408, 685

- Moore, Carl E. See Burnham, Carole D., 472  
 Moore, Joe G., Jr., 105, 121, 299  
 Moore, Robert T., and McNulty, James A. Determination of total nitrogen in water by micro-coulometric titration, 741  
 Morgan, James J., 72, 787  
 Morgan, Myrna J. See Stanley, Thomas W., 1198  
 Moser, Charles E., 72  
 Moss, Frank E., 615  
 Mount, Donald L., and Boyle, Harvey W. Parathion—use of blood concentration to diagnose mortality of fish, 1183  
 Moynihan, Daniel P., 885  
 Mrak, Emil M., 613, 1229  
 Muhlich, Anton J., 228, 707  
 Mumford, L. Quincy, 1139  
 Murphy, Paul, 1157  
 Muskie, Edmund S., 101, 203, 207, 305, 417, 430, 517, 519, 706, 1139, 1157, 1160, 1251  
 Myers, L., 110  
 Myrick, H. Nugent, 1309

## N

- Nader, John S., and White, Norman. Volumetric measurement of ultraviolet energy in an urban atmosphere, 848  
 Nelson, Gaylord, 205, 207, 419, 1229  
 Nelson, Nancy H., and Faust, Samuel D. Acidic dissociation constants of selected aquatic herbicides, 1186  
 Neufeld, Ronald D., and Thodos, George. Removal of orthophosphates from aqueous solutions with activated alumina, 661  
 Newsom, Leo D., 619  
 Nicholson, H. Page, 709  
 Nicosia, John B., 430  
 Ninomiya, J. S. See Weaver, E. E., 57  
 Nixon, Richard M., 611, 803, 1249  
 Norris, Lester, 2  
 Norwood, W. D., 487  
 Noweir, Madbuli H., and Cholak, Jacob. Gas chromatographic determination of beryllium in biological materials and in air, 927

## O

- O'Connor, Donald J., 73, 191, 407, 605  
 Ogilvie, Richard B., 320  
 O'Keefe, A. E. See Stevens, R. K., 652; Saltzman, Bernard E., 1275  
 Okun, Daniel A., 197  
 Oppenheimer, Jack C., 103  
 Ortmann, G. C. See Stevens, R. K., 652  
 Overman, Michael, 859, 1211

## P

- Palmes, Edward D., 72  
 Papa, Louis J. Colorimetric determination of carbonyl compounds in automotive exhaust as 2,4-dinitrophenylhydrazones, 397  
 Pate, John B. See Wartburg, Arthur F., 767  
 Peeler, J. T. See Schafer, M. L., 1261  
 Pell, Claiborne, 588  
 Perloff, Harvey S., 859  
 Permat, Robert, 803  
 Peterson, Eugene K., 1162, 1169  
 Peterson, Henry K., 446, 451  
 Piccard, Ralph, 120  
 Pierrard, John M. Photochemical decomposition of lead halides from automobile exhaust, 48  
 Pintner, Herbert E., 75  
 Pitts, J. N., Jr., 74

- Pitts, J. N., Jr., Kahn, Ashan U., Smith, E. Brian, and Wayne, Richard P. Singlet oxygen in the environmental sciences. Singlet molecular oxygen and photochemical air pollution, 241  
 See also Steer, R. P., 946  
 Place, John. See Goodenough, Robert D., 854  
 Podell, Bertram L., 419  
 Podzimek, J., 605, 779, 865  
 Porter, Charles R. See Rehnberg, Georgia L., 171  
 Preining, O., 605, 779  
 Price, Leighton A., 103  
 Purcell, Thomas C. See Rogers, Charles J., 764  
 Purdy, Ralph W., 882

## Q

- Quase, Harold A., 697  
 Querio, C. W. See Egleson, G. C., 367  
 Quigley, Stephen T., 787

## R

- Ramanathan, M., 279  
 Ramey, James T., 425  
 Ramo, Simon, 859  
 Ray, Robert D., 120  
 Reagan, Ronald, 793  
 Reese, Kenneth, 787  
 Rehnberg, Georgia L., Strong, Ann B., Porter, Charles R., and Carter, Melvin W. Levels of stable strontium in milk and the total diet, 171  
 Reilly, William R., 322  
 Reynolds, David P., 1157  
 Reynolds, M. A. See Thein, Myint, 667  
 Rhodes, James A., 1141  
 Ribicoff, Abraham A., 5  
 Richards, Francis A. See Cline, Joel D., 838  
 Richmond, Joseph L., 894  
 Rihm, Alexander, Jr., 430  
 Riseborough, Robert, 15  
 Roark, O. R. See MacLean, D. C., 1201  
 Robens, Lord Alfred, 615, 719  
 Robinson, Elmer. See Cavanagh, Leonard A., 251  
 Rockefeller, Laurance S., 611  
 Rockefeller, Winthrop, 885  
 Roddis, Louis H., 719  
 Rogers, Charles J., and Purcell, Thomas C. Identification of bacteria by rapid spectrophotometric methods, 764  
 Rohlich, Gerard A., 101  
 Romer, Harold, 711  
 Romney, George, 1160, 1249  
 Roosevelt, Theodore, 695  
 Rose, John K., 1139  
 Roth, Tom, 713  
 Rottschaffer, J. Mark. See Mark, Harry B., Jr., 165  
 Ruof, C. H. See Weaver, E. E., 57  
 Rust, R. H., 399  
 Ryan, Michael J. Apparatus for continuous solids-liquid separation, 674  
 Ryant, Charles J., Jr., 319, 624

## S

- Saalman, Howard, 179  
 Saltzman, Bernard E., Feldman Charles R., and O'Keefe, Andrew E. Volumetric calibration of permeation tubes, 1275  
 Sand, Paul F., 207  
 Sanders, Walter M., III. See Whalen, William J., 1297  
 Satterthwaite, Ann, 24  
 Sax, Joseph L., 205  
 Schadt, Theodore M., 303

- Schadt, Conrad F. See Cavanagh, Leonard A., 251  
 Schafer, M. L., Peeler, J. T., Gardner, W. S., and Campbell, J. E. Pesticides in drinking water. Water from the Mississippi and Missouri Rivers, 1261  
 Schmon, Robert M., 1241  
 Schneider, R. E. See MacLean, D. C., 1201  
 Schroeder, William H., 436, 445  
 Schuessler, R. G., 713  
 Schulte, J. H., 877  
 Schwartz, Murray A., 1309  
 Sears, Mary, 1301  
 Seinfeld, J. H. See Friedlander, S. K., 1175  
 Sellers, Gary, 1229  
 Sewell, W. R., Derrick, 179  
 Shafer, Raymond P., 699  
 Shea, T. G., 191, 287, 405  
 Sheesley, David C. See Spurny, Kvetoslav R., 453, 464  
 Shepherd, Paul, 677  
 Sherman, William F., 1223  
 Shields, Maynard, 189, 404  
 Shupe, James L., 721  
 Silver, Francis, 876  
 Silver, Sidney A., 697  
 Silvey, J. K. G. See Henley, Don E., 268  
 Simon, Herbert A., 305  
 Simon, Noel, 858  
 Simpson, Roland W., 523  
 Singer, S. Fred, 124, 131, 198, 891  
 Sinha, Evelyn, 487  
 Stittig, Marston, 399  
 Skewes, L. M. See Weaver, E. E., 57  
 Skopp, A., 808  
 Slade, D. H., 433, 441  
 Slansky, Cyril M., 446, 451  
 Smith, Alexander F., 523  
 Smith, Benjamin W. Wagman, Jack, and Fish, Birney R. Interaction of airborne particles with gases, 558  
 Smith, David D., 1231  
 Smith, E. Brian. See Pitts, J. N., Jr., 241  
 Smith, Hermes O., and Hochstetler, Arthur D. Determination of odor thresholds in air using C<sup>14</sup>-labeled compounds to monitor concentrations, 169  
 Smith, Ralph G., 628, 876  
 Smith, Ralph J., 319, 624  
 Smith, Raymond, 103  
 Smith, Richard, 706  
 Smith, Roger P., 399  
 Snoeyink, Vernon L., Weber, Walter J., Jr., and Mark, Harry B., Jr. Sorption of phenol and nitrophenol by active carbon, 918  
 Snowden, F. Curtis, 34, 37  
 Soo, Shao, Stukel, James J., and Hughes, J. Martin. Measure-ment of mass flow and density of aerosols in transport, 386  
 Sourirajan, S. See Hauck, Andrew R., 1269  
 Spears, Larry G., Stone, James H., and Klein, Elias. Electrolysis of copper screening: A technique for the prevention of marine fouling, 576  
 Speer, Edgar B., 519, 895, 1241  
 Speiser, Arnold, 506  
 Spencer, W. F., and Cliath, M. M. Vapor density of dieltrin, 670  
 Springer, Karl J., 624  
 Sprung, J. L. See Steer, R. P., 946  
 Spurny, Kvetoslav R., Lodge, James P., Jr., Frank, Evelyn R., and Sheesley David C. Aerosol filtration by means of nucleopore filters. Structural and filtration properties, 453  
 Aerosol filtration by means of nucleopore filters. Aerosol sampling and measurement, 464  
 Stahman, Ralph C., 624, 627  
 Stanley, Kenneth G., 287  
 Stanley, Thomas W., Morgan, Myrna J., and Meeker, James E. Rapid estimation of 7H-benz[e]anthracene-7-one and phenanthrene-1-one in organic extracts of airborne particulates from 3-hour sequential air samples, 1198  
 Stans, Maurice H., 1249  
 Steer, R. P., Sprung, J. L., and Pitts, J. N., Jr. Singlet oxygen in the environmental sciences. Evidence by the production of O<sub>2</sub> (<sup>1</sup>Δg) by energy transfer in the gas phase, 946  
 Steigerwald, Bernard J., 103  
 Stein, Fred, 213  
 Stein, Murray, 103, 120

- Steiner, R. L., Austin, J. B., and Lander, D. W. Rapid direct-reading spectrographic determination of elements in industrial waste water, 1192
- Stephan, David G., 103, 421, 891
- Stern, Arthur C., 588, 605, 1312
- Stevens, R. K., O'Keefe, A. E., and Ortman, G. C. Absolute calibration of a flame photometric detector to volatile sulfur compounds at sub-part-per-million levels, 652
- Stevens, Richard, 706
- Stickel, Lucille F., 677
- Stöber, Werner, Flachsbar, Hermann. Aerosol size spectrometry with a ring split centrifuge, 641
- Size-separating precipitation of aerosols in a spinning spiral duct, 1280
- Stone, James H. See Spears, Larry G., 576
- Storer, F. F., and Gaudy, A. F., Jr. Computational analysis of transient response to quantitative shock loadings of heterogeneous populations in continuous culture, 143
- Stratton, Julius A., 117, 118
- Strong, Ann B. See Rehnberg, Georgia L., 171
- Stukel, James J. See Soo, Shao L., 386
- Sullivan, Richard J., 226, 301, 793, 897
- Sullivan, William T., and Swisher, R. D. MBAS and LAS surfactants in the Illinois River, 1968, 481
- Sussman, Victor H., 895
- Sutherland, F. H. See Brewer, R. F., 378
- Swader, Fred., N., 780
- Swearingen, John E., 1241
- Swift, Jack F., 322
- Swinnerton, J. W., Linnenbom, V. J., and Cheek, C. H. Distribution of methane and carbon monoxide between the atmosphere and natural waters, 836
- Swisher, R. D. See Sullivan, William T., 481
- Sylvester, Robert O., 586
- Synder, Keith, 213
- and ionic strengths up to 0.15M and at 25° C., 656
- Tate, James H. J., 1231
- Taylor, O. C. See Thompson, C. Ray, 934
- Tchobanoglous, George, 536, 541
- Teeple, H. O., 191, 287, 405
- Teot, Arthur S., and Daniels, Stacy L. Flocculation of negatively charged colloids by inorganic cations and anionic polyelectrolytes, 825
- Thein, Myint, Beck, J. N., Johnson, Horace, Cooper, W. W., Reynolds, M. A., Clark, R. S., Baugh, J. O., and Kuroda, P. K. Fractionation of bomb-produced rare-earth nuclides in the atmosphere, 667
- Thodos, George. See Neufeld, Ronald D., 661
- Thomas, Jerome F. See Medsker, Lloyd L., 476
- Thomas, Moyer D., 629
- Thompson, C. Ray, and Taylor, O. C. Effects of air pollutants on growth, leaf drop, fruit drop, and yield of citrus trees, 934
- Tiernan, Robert O., 517
- Tikvart, J. A., 434
- Toro, Richard F., 30, 33
- Train, Russell E., 27, 303, 1145, 1241
- Tranquillo, J. S., and Lee, G. Fred. Concentration of dilute aqueous phenol solutions utilizing methylsulfinylmethane (DMSO), 393
- Tuerk, Edward F., 103, 430
- Turk, Amos, Edmonds, Sylvan M., Mark, Howard L., and Collins, George F. Sulfur hexafluoride as a gas-air tracer, 44
- Turkes, W. R., 235, 240, 508
- U**
- Udall, Stewart L., 107, 115, 120, 426
- Urone, Paul, 436, 445
- V**
- Valentyne, J. R., 1245
- Valerio, Giorgio, 1241
- van den Bosch, Robert, 15
- VanderPlank, J. E., 487
- Vanderveld, John, Jr., 706
- Vaughan, Richard D., 13, 228, 705
- Vijan, Prem N. Rapid combustion method for determination of sulfur in lead dioxide candles exposed to atmospheric pollution, 931
- Vincent, Jack, 858
- Volzler, James F., 677
- Vollenweider, R. A., 1244
- Volpe John, 207, 881, 1249
- vonKann, Clifton F., 897
- W**
- Wagman, Jack. See Smith, Benjamin M., 558
- Wallcave, Lawrence. Gas chromatographic analysis of polycyclic aromatic hydrocarbons in soot samples, 948
- Warren, Charles R., 80
- Warren, John, 319
- Wartburg, Arthur F., Pate, John B., and Lodge, James O., Jr. An improved gas sampler for air pollutant analysis, 767
- Watson, William T., 487
- Watt, E. F., 1211
- Wayne, Richard P. See Pitts, J. N., Jr., 241
- Weaver, E. E., Ninomiya, J. S., Skewes, L. M., and Ruof, C. H. Oxidation of gaseous hydrocarbons in concentrations of parts per million in flow systems. Oxidation of 1-butene in type 410 stainless steel tubes, 5
- Webb, A. A. See Collins, J. W., 371
- Weber, Walter, J., Jr., 73, 1143; See also Snoeyink, Vernon L., 918
- Weinstein, Norman J., 30, 33
- Weinstock, Bernard, 628, 877
- Weise, Ursula, 79
- Weitzel, William, 315
- Weitzel, Basil Q., 713
- Wendell, Mitchell, 223
- Wentz, Dennis A., and Lee, G. Fred. Sedimentary phosphorus in lake cores—analytical procedure, 750
- Sedimentary phosphorus in lake cores—observations on depositional pattern in Lake Mendota, 754
- Wershaw, R. L., Burcar, P. J., and Goldberg, M. C. Interaction of pesticides with natural organic material, 271
- Wertheim, G., 1223
- Whalen, William J., Bungay, Henry R., III, and Sanders, Walter M., III. Microelectrode determination of oxygen profiles in microbial slime systems, 1297
- Whipple, William, Jr., 174
- White, Charles E., 305
- White, Gilbert F., 677
- White, J. L., 399
- White, Lee C., 303
- White, Norman. See Nader, John S., 848
- Wilbur, Charles G., 1301
- Wiley, Averil J., 508, 1148
- Wilkening, G. M., 628
- Wilson, Billy Ray, 400, 588
- Wilson, C. J., 603, 682
- Wilson, Herbert S., 1248
- Wilson, Katherine W., 896
- Wimmer, D. B., 629
- Wingerd, Dan, 894
- Wingert, Jerold D., 623
- Witkamp, Martin, and Frank Marilyn L. Loss of Weight, <sup>14</sup>C, and <sup>137</sup>Cs from tree litter in three subsystems of a watershed, 1195
- Wittgenstein, Casmir Prinz, 1241
- Witzell, S. A., 881
- Wolffe, Lenard L., 399
- Wollman, Nathaniel, 80
- Wolozin, Harold, 770
- Wright, Colin, 770
- Wurster, Charles F., 15
- Y**
- Yamada, Victor M., and Charlson, Robert J. Proper sizing of the sampling inlet line for a continuous air monitoring station, 483
- Yankofsky, Shlomit. See Mitchell, Ralph, 574
- Yannacone, Victor J., 15
- Yazdani, H. See Luf, B. Y. H., 381
- Z**
- Zandi, Iraj, 706, 812, 819
- Zeisel, Arthur, 1231
- Zielyk, M. W. See Dixon, J. K., 551
- Zoller, William H. See Hoffman, Gerald L., 1207

January	1-94
February	95-192
March	193-290
April	291-410
May	411-500
June	501-606

July	607-688
August	689-782
September	783-868
October	869-1132
November	1133-1218
December	1219-1324

Information is indexed under specific terms wherever possible. Information on specific subjects may also be found under broader entries, particularly information in general articles in which all specific subjects cannot be indexed. Entries are alphabetized word by word.

Publications reviewed, listed, or discussed at length are listed alphabetically by title under the heading **Books**. Books, films, charts, items appearing in the New literature digest, and similar sources of information are indexed by subject. New literature is also listed by company name.

Page numbers may be followed by a superior letter, according to the following code:

- <sup>1</sup> Page reference to sources of information
- <sup>2</sup> Page reference to new products digest listing
- <sup>3</sup> Page reference to book reviews

## A

- Accepyrene**, isolation from coal tar pitch, 948
- Acid mine water**, pollution control efforts, 1237  
treatment plants, 699, 883
- Actinomycetes**, odorous compounds, 268, 476
- Activated alumina**, phosphate removal from aqueous solutions, 661
- Activated carbon**, regeneration by dispersed-phase technique, 214  
sorption of phenols, 918  
treatment costs, 1143  
treatment of industrial waste water, 314  
treatment of municipal waste water, 797, 809  
treatment of pulp mill effluents, 703
- Activated sludge process**, aerator performance, 229  
growth of bacteria, 569, 769  
response to external changes, 143  
solids-liquid separation with Millipore filter, 674
- Aerators**, biological oxidation of organic wastes, 229  
oxygen controller, 861<sup>2</sup>
- Aerial contamination**, contribution to plant accumulation of dieldrin, 261
- Aerial photography**, geologic features, 80<sup>1</sup>
- Aerocolloids**, evaluation by moving slide impactor, 154
- Aerogel General Corp.**, DDT decomposition in soil, 701  
reverse osmosis membrane, 678<sup>2</sup>
- Aerosols**, See also Lead aerosols; Mono-disperse aerosols  
deposition in lungs, 563  
determination of particle size distribution 641, 768, 830, 1280  
filtration by Nuclepore filters, 453, 464  
measurement of mass flow and density, 386  
relationship to atmospheric visibility, 913
- Agriculture**, See also Animal wastes  
pollution problems, 107  
waste disposal, 85<sup>1</sup>
- Agriculture Department**, agricultural wastes, 85<sup>1</sup>  
animal waste disposal studies, 831  
"Control of Agriculture-Related Pollution," 107  
DDT usage, 521  
Nebraska water system grant, 303  
off-flavor of dried milk products, 305  
pesticide buildup in soils, 207, 521  
pesticide use suspension, 701
- Air analysis**, 677<sup>1</sup>, 777<sup>1</sup>, 1306<sup>1</sup>  
mobile laboratory, 403<sup>1</sup>  
NASA monitoring instruments, 676<sup>1</sup>  
nuclear methods, 132  
self-calibrating instruments, 590<sup>2</sup>
- Air cushion vehicle**, monitoring of Lake Erie, 324
- Air monitoring**, See Continuous air monitoring station
- Air pollution**, 588<sup>1</sup>, 594<sup>1</sup>, 399<sup>1</sup>, 862<sup>1</sup>  
See also Photochemical air pollution  
automobile control devices litigation, 890  
economics, 770<sup>1</sup>  
New Mexico, 321  
New York City, 301  
physician's guide, 187<sup>1</sup>  
research 80<sup>1</sup>  
steel industry, 429
- Air pollution abatement**, 79<sup>1</sup>, 84<sup>1</sup>, 179<sup>1</sup>  
actions by federal facilities, 203  
equipment, 596<sup>1</sup>  
gray iron foundries, 299  
potential market for catalysts, 30  
regional approach, 431  
secondary nonferrous metals industry, 697
- Air Pollution Control Association**, Cleaner Air Week, 895
- Air purifiers**, 283<sup>1</sup>, 488<sup>2</sup>
- Air quality**, Illinois standards, 319
- Air quality control regions**, designation, 299, 431
- Air quality criteria**, 280<sup>1</sup>  
guidelines, 299  
issuance by HEW, 99  
Japan, 99
- Air quality standards**, guidelines for development, 615  
progress on regional programs, 1141  
technical significance, 542, 628, 720
- Air Reduction Co.**, gas separation, 776<sup>1</sup>  
ozonation of sewage plant effluents, 883  
specialty gases, 284<sup>1</sup>
- Air samplers**, 402<sup>2</sup>  
National Center for Atmospheric Research, 101
- Airborne particulates**, air quality criteria, 99  
air quality standards, 542  
beryllium determination, 927  
control technology, 1149  
counters, 182<sup>2</sup>, 1304<sup>2</sup>  
estimation of 7H-benz[de]anthracene-7-one and phenalen-1-one, 1198  
evaluation of aerocolloids, 154  
global transport, 1207  
interaction with gases, 558  
lead determination by atomic absorption spectroscopy, 472  
measurement of size distributions, 768
- Aircraft**, engine exhaust emissions, 219  
jet emissions control, 897  
jet fuel conditioner, 488<sup>2</sup>  
noise research, 697
- Airports**, dispersal, 617
- Alabama**, strip mines legislation, 793  
water laws, 487<sup>1</sup>
- Alaska**, petroleum pipeline, 1141
- Albert Einstein College of Medicine**, deaths from sulfur dioxide in air, 1235
- Aldehydes**, determination in automobile exhaust, 397
- Alumina**, See Activated alumina
- Aluminum**, analysis in airborne particulates, 1207  
reclamation programs, 1157
- Ameba**, implication in *E. coli* decline in sea water, 574
- American Asphalt Co.**, odor emissions, 793
- American Chemical Society**, environment report, 787
- American Hydrotherm Corp.**, central heating system for Sapporo, Japan, 515
- American Machine & Foundry Co.**, metal finishing wastes, 596<sup>1</sup>  
radioactive waste packager, 492<sup>2</sup>
- American Medical Association**, air pollution, 187<sup>1</sup>
- American Museum of Natural History**, exhibit, 534
- American Mutual Insurance Alliance**, noise control services, 863<sup>1</sup>
- American Petroleum Institute**, pollution abatement expenditures, 13
- American Precast Corp.**, leaching unit, 494<sup>1</sup>
- American Public Works Association**, surface drainage survey, 527
- American Society of Civil Engineers**, soil mechanics, 599<sup>1</sup>
- American Standard, Inc.**, dust collectors, 680<sup>1</sup>  
scrubber, 83<sup>1</sup>
- American Water Works Association**, virus disease transmission in water, 1235
- American Waterways Operators, Inc.**, regulation of watercraft discharges, 203
- Amicon Corp.**, ultrafiltration, 862<sup>1</sup>
- Ammonium nitrogen**, determination in saline waters, 274
- Animal fodder**, production from solid wastes, 883
- Animal wastes**, disposal studies, 881  
disposal system for slaughterhouses, 281<sup>2</sup>  
odorous compounds, 744
- Animals**, toxic effects of fluorides, 721
- Anodic stripping voltammetry**, trace metal ion analysis, 165
- AnPol Chemical Corp.**, jet fuel conditioner, 488<sup>2</sup>
- Appalachia**, strip and surface mining, 1211<sup>1</sup>  
surface mining reclamation project, 881
- Applied Concepts, Inc.**, litter cleanup, 494<sup>1</sup>
- Applied Science Laboratories, Inc.**, laboratory supplies, 185<sup>1</sup>
- Aqua-Chem, Inc.**, radioactive wastes concentrator, 1143
- Aqua Systems Corp.**, water pollution control services, 83<sup>1</sup>
- Aquatic Controls Corp.**, aquatic vegetation removal, 283<sup>2</sup>
- Aquatronics, Inc.**, conductivity meter, 591<sup>2</sup>  
pH meter, 81<sup>2</sup>
- Arco Industries Corp.**, air pollution control equipment, 596<sup>1</sup>
- Arctic air**, trace gas measurement, 251
- Arizona Public Service Co.**, air pollution from power plant, 321
- Asphalt**, identification in oil spills, 150  
watershed treatment, 110
- Atlas Chemical Industries, Inc.**, waste water treatment, 1306<sup>1</sup>
- Atlas Electric Devices Co.**, air analyzers, 590<sup>2</sup>
- Atmosphere**, measurement of ultraviolet energy, 848  
carbon dioxide buildup, 1162
- Atmospheric fractionation**, bomb-produced fission products, 667
- Atmospheric sciences**, See Global Atmospheric Research Program
- Atomic absorption**, 399<sup>1</sup>
- Atomic absorption spectroscopy**, lead determination in airborne particulates, 472<sup>2</sup>
- Atomic Energy Commission**, endorsement of thermal pollution legislation, 425  
natural gas recovery by Project Gasbuggy, 85<sup>1</sup>
- Auger spectroscopy**, 680<sup>1</sup>
- Author's guide**, *Environmental Science & Technology*, 39
- Automated Environmental Systems, Inc.**, total organic carbon analyzer, 1152  
water quality monitor, 282<sup>2</sup>
- Automobile emissions**, California standards, 517  
enforcement of federal regulations, 625

polynuclear aromatic content, 858<sup>1</sup>  
**Automobile exhaust**, catalytic control, 30  
determination of carbonyl compounds, 397  
oxidation of hydrocarbons, 57  
photolysis of inorganic lead compounds, 48  
**Automobile Manufacturers Association**, odor research project, 1223  
**Automobile tires**, scrap reprocessing, 119  
**Automobiles**  
See also Steam cars  
air pollution, 486<sup>1</sup>  
control devices litigation, 890  
disposal, 1211<sup>1</sup>  
driver habits study, 798  
federal labeling requirement, 791  
Federal Low Emission Vehicle Procurement Act, 1229  
fueling by natural gas, 699, 1143  
scrap processing, 1235  
**Awards**, Consulting Engineers Council, 521  
Dollinger, Lewis L., Pure Environment, 798

## B

**BSP Corp.**, Lake Tahoe project, 403<sup>1</sup>  
licensing of waste water technology, 419  
Porteous process, 285<sup>1</sup>  
**Bacharach Instrument Co.**, air pollution instruments, 1306<sup>1</sup>  
**Bacteria**  
See also *Escherichia coli*: Intestinal bacteria cellulose digestion in solid wastes, 883  
identification by spectrophotofluorometric methods, 764  
removal from water by flocculation, 551<sup>1</sup>  
**Baltimore Gas & Electric Co.**, sulfur dioxide recovery unit, 421  
**Barbados Oceanographic Meteorological Experiment**, objectives, 305  
**Barnes Engineering Co.**, infrared analysis, 185<sup>1</sup>  
spectroscopy accessories, 403<sup>1</sup>  
**Barringer Research, Inc.**, air monitoring in Los Angeles, 797  
**Bartlett-Snow**, incinerator, 491<sup>1</sup>  
**Basic, Inc.**, sulfur oxides recovery process, 703  
**Batavia, N.Y.**, sewage treatment demonstration, 109  
**Batch controller**, 861<sup>1</sup>  
**Beckman Instruments, Inc.**, electrodes, 403<sup>1</sup>  
electronic instruments, 185<sup>1</sup>  
oxygen analyzer, 284<sup>1</sup>  
pH meters, 186<sup>1</sup>, 776<sup>1</sup>  
phosphorus detector, 861<sup>1</sup>  
**Beet sugar industry**, water utilization, 174<sup>1</sup>  
**Belco Pollution Control Corp.**, electric precipitators, 599<sup>1</sup>  
power supply for electrostatic precipitators, 703  
slide rule for air pollution calculations, 599<sup>1</sup>  
**Bell Aerosystems Co.**, air cushion vehicle, 324  
**7H-Benz[de]anthracen-7-one**, estimation in airborne particulates, 1198  
**Benzaldehyde**, production of singlet oxygen, 944  
**Benzene**, production of singlet oxygen, 946  
**Beryllium**, gas chromatographic determination, 927  
**Bessie, Okla.**, desalination plant, 515  
**Biochemical oxygen demand**, 279<sup>1</sup>, 679<sup>1</sup>  
**Biological materials**, beryllium determination, 927  
**Biological waste treatment**, aerator performance, 229  
effects of colloids, 820  
**Biometeorology**, 1211<sup>1</sup>  
**BioNuclear Division, American Biomedical Corp.**, industrial tracers, 494<sup>1</sup>  
**Blast furnaces**, scrubber effluent treatment, 860<sup>1</sup>  
**Bleaching wastes**, properties, 371  
**Bliss, E. W., Co.**, street cleaning equipment, 594<sup>1</sup>

**Blue tetrazolium**, reduction by tobacco smoke, 567  
**Boats**  
See Watercraft  
**Books**, "Advances in Hydrosience," 858  
"Air Pollution Abatement by Federal Facilities," 203  
"Air Pollution Control," 179  
"Air Pollution Monitoring Instrumentation—A Survey," 676  
"Air Pollution, Volume III—Sources of Air Pollution and Their Control," 588  
"The Air We Live In—Air Pollution: What We Must Do About It," 399  
"An Appraisal of Oceanic Disposal of Solid Wastes and Industrial Sludge from U.S. Coastal Cities," 1231  
"Atomic Absorption Volume II—Petrochemistry. Methods Manual," 399  
"Automobile Disposal: A National Problem," 1211  
"Bibliography of Books on the Environment—Air, Water, and Solid Wastes," 858  
"The Biological Aspects of Water Pollution," 1301  
"Biological Effects of Pesticides in Mammalian Systems," 858  
"Canney Waste Treatment, Utilization and Disposal," 586  
"Capital and Operating Costs of Sewage Treatment," 677  
"Challenge of the Seven Seas," 588  
"Chemical Analysis of Industrial Water," 676  
"Chlorine Facts," 486, 588  
"Cities and Planning in the Ancient Near East," 179  
"Cleaning Our Environment—The Chemical Basis for Action," 787  
"Clinical Toxicology of Commercial Products—Acute Poisoning," 399  
"Coal Mining Effect on Busseron Creek Watershed, Sullivan County, Indiana," 279  
"Control of Agriculture-Related Pollution," 107  
"Control Techniques for Particulate Air Pollutants," 1149  
"The Cost of Clean Water and Its Economic Impact," 213  
"Curse for Chaos—Fresh Solutions to Social Problems Through the Systems Approach," 859  
"Degradation of Herbicides," 1211  
"A Descriptive Catalog of Selected Aerial Photographs of Geologic Features in the United States," 80  
"Design and Operation for Air Pollution Control," 79  
"Diagnosis and Treatment of Deposited Radionuclides," 487  
"Discussions of ASME Standard ASP-1 on Dust Emission for Indirect Heating Furnaces," 1211  
"Disease Resistance in Plants," 487  
"Ecology and Resource Management: A Quantitative Approach," 1211  
"Economic Impact of Air Pollution Controls on the Secondary Nonferrous Metals Industry," 1211  
"The Economics of Air Pollution," 770<sup>1</sup>  
"The Economics of Water Utilization in the Beet Sugar Industry," 174<sup>1</sup>  
"Engineering Study of Removal of Sulfur Oxides from Stack Gases," 676  
"Environment, the University, and the Welfare of Man," 400, 588  
"Environmental Conservation," 80  
"Environmental Pollution Instrumentation," 1301  
"Garbage As You Like It: A Plan to Stop Pollution by Using Our Nation's Wastes," 1301  
"Guidelines for the Development and Implementation of Air Quality Standards," 615  
"Has the United States Enough Water?," 1211  
"Index to Air Pollution Research—A Guide to Current Government and Industry Supported Air Pollution Research," 80

"Industrial Hygiene High-Lights," 80  
"The Industrial Waste Guide on Thermal Pollution," 105  
listing in environmental field, 949, 1105  
"A Major Program of Water Resources Research in Canada," 179  
"Managing Water Quality: Economics, Technology, Institutions," 80  
"Marine Chemistry. Volume I—Analytical Methods," 586  
"Measurement of Air Pollutants—Guide to the Selection of Methods," 677  
"Medieval Cities," 179  
"Methods for Evaluating the First Order Constants  $k_1$  and  $L_0$  for BOD Exertion," 279  
"Microorganic Matter in Water," 588  
"Mineralogy in Soil Science and Engineering," 399  
"The Nation's River," 399  
"The Nation's Water Resources," 9, 115  
"Natural Resource Information for Economic Development," 1301  
"Nature and Control of Aircraft Engine Exhaust Emissions," 219  
"New Zoning Landmarks in Planned Urban Developments," 399  
"1967 Domestic Refinery Effluent Profile," 676  
"Occupational Health—Hazards of the Work Environment," 588  
"Oceanic Patents, 1959-1968," 487  
"An Oceanic Quest: The International Decade of Ocean Exploration," 1301  
"Organochlorine Pesticides in the Environment," 677  
"Our Nation and the Sea: A Plan for National Action," 1211  
"Paints and Protective Coatings for Wastewater Treatment Facilities," 677  
"Panel Reports of the Commission on Marine Science, Engineering and Resources," 1211  
"Peaceful Uses for Nuclear Explosives," 487  
"Perspectives on Conservation: Essays on America's Natural Resources," 859  
"Pesticide Handbook—Entoma 1969," 858  
"Planning and Cities," 179  
"Polynuclear Aromatic Content of Vehicle Emissions," 858  
"A Primer on Ground Water," 486  
"A Primer on Oil Spill Cleanup," 399  
"A Primer on Water," 486  
"A Primer on Water Quality," 486  
"Principles and Practices of In-ter-nation," 1301  
"Principles of Radiological Health," 859  
"Proceedings of the ASCE Specialty Conference on Current Research into the Effects of Reservoirs on Water Quality," 588  
"Proceedings of the 1st Annual North Eastern Regional Anti-Pollution Conference," 399  
"Proceedings of the Sixteenth Southern Water Resources and Pollution Control Conference," 179  
"Proceedings of the Symposium on Air Quality Criteria, New York, N.Y., June 4-5, 1968," 280  
"Progress in Oceanography: Volume 5," 1301  
"Proposal for a Ten-Year National Earthquake Hazards Program—A Partnership of Science and the Community," 280  
"The Quality of the Urban Environment—Essays on 'New Resources' in an Urban Age," 859  
"Recommended Guide for Control of Dust Emission—Combustion for Indirect Heat Exchangers," 588  
"The Regulation of Pesticides in the United States," 79  
"Saline Water Conversion Report for 1967," 279  
"Santee Recreation Project, Santee, California, Final Report," 75<sup>1</sup>  
"Scanning Electron Microscopy/1969," 1211

"Scanning Electron Microscopy/1969," 1211  
"The Search for a Low-Emission Vehicle," 419  
"Selected Analytical Methods for Research on Water Pollution Control," 279  
"Simplified Laboratory Procedures for Wastewater Examination," 859  
"Solid Waste Research and Development II," 280  
"Special Studies for Incinerators for the Government of the District of Columbia," 859  
"Strip and Surface Mining in Appalachia," 1211  
"Subsurface Disposal in Geologic Basins—A Study of Reservoir Strata," 399  
"The Subversive Science—Essays Toward an Ecology of Man," 677  
"Surface Mining and Our Environment," 1211  
"Symposium on Radioecology," 486  
"The Range of Choice in Water Management: A Study of Dissolved Oxygen in the Potomac Estuary," 80  
"Technical Aspects of Joint Waste Treatment," 1211  
"Toward a Clean Environment," 301  
"The Treatment of Industrial Wastes," 399  
"The Universities and Environmental Quality—Commitment to Problem Focused Education," 1229  
"Urban Air Pollution, with Particular Reference to Motor Vehicles," 486  
"Urban Planning in Pre-Columbian America," 179  
"Village Planning in the Primitive World," 179  
"Water and Choice in the Colorado Basin," 487  
"Water Disposal from Water and Wastewater Treatment Processes," 79  
"Water, Health, and Society—Selected Papers by Abel Wolman," 677  
"Water in the Modern World: Solutions to a Problem of Supply and Demand," 859  
"Water Laws of Alabama," 487  
"Water Management Innovations in England," 1211  
"Water Pollution Aspects of Urban Runoff," 527  
"Water Pollution Control and Solid Wastes Disposal," 399  
"Water Resources Management and Public Policy," 586  
"The Water Resources of Chile: An Economic Method for Analyzing a Key Resource in Nation's Development," 80  
"Water Resources Research Catalog," 80  
"Water Resources Research in Canada," 179  
"Water: Solutions to a Problem of Supply and Demand," 1211  
"Water Treatment Plant Design," 399  
"Waterfowl Status Report, 1968," 677  
"Weather and Health—An Introduction to Biometeorology," 1211  
"The Weather Bureau and Water Management," 179  
"The Weather Business Observation, Analysis, Forecasting, and Modification," 1211  
"Wildlife in Danger," 858  
**Brines**  
See also Saline water composition in Midland, Mich., field, 367  
**Bromine**, use for water disinfection, 854  
**Brooks Instrument Division**  
See Emerson Electric Co.  
**Budget**, Federal Government, 113  
**Buoy**, monitoring of Lake Michigan, 798  
**Bureau of Commercial Fisheries**, estuarine resources, 403<sup>1</sup>  
**Bureau of Indian Affairs**, careers in land resources, 863<sup>1</sup>  
**Bureau of Mines**, coal pollution, 85<sup>1</sup>  
garbage conversion to hydrocarbons, 1233  
gasoline composition changes, 515  
mineral recovery from solid wastes, 84<sup>1</sup>  
scrap tire reprocessing, 119

vegetative stabilization of mine wastes, 717

**Bureau of Solid Waste Management**, current programs, 705

**Des Moines, Iowa**, solid waste management program, 681<sup>1</sup>

**Bureau of Sport Fisheries and Wildlife**, pesticide residues in fish, 613

**Burr-Brown Research Corp.**, soil water analyzer, 1212<sup>p</sup>

**Buses**, experimental propulsion systems, 207

**Business and Defense Services Administration**, industrial air pollution surveys, 299, 697

**Busseron Creek Watershed**, effects of coal mining, 279<sup>1</sup>

**Butene**, oxidation in stainless steel tubes, 57

## C

**Cabot Piping Systems**, valves 492<sup>p</sup>

**Calcium hydroxide suspension**, improved hydrogen sulfide collection, 258

**Calcium sulfate**, prediction of solubility, 656  
scaling threshold of hemihydrate form, 580

**Calgon Corp.**, activated carbon for evaporation loss control, 1308<sup>1</sup>  
activate carbon treatment of waste water, 300  
industrial waste water reclamation process, 314

**California**, motor vehicle emission standards, 517  
water pollution control law, 791

**Camera**, pipe inspection, 1212<sup>p</sup>

**Canada**, Centre for Inland Waters' monitoring of Lake Erie, 324  
chemical companies' pollution abatement spending, 301  
cooperative attack on pollution in Lambton County, 1247  
industrial waste facility, 13  
phosphorus plant closing, 811  
water pollution control legislation, 885  
water quality in U.S.-Canada waters, 107, 1243  
water resources, 179<sup>1</sup>

**Canadian National Committee of the IHD**, films on water, 494<sup>1</sup>

**Candles**, See Lead dioxide candles

**Cannery wastes**, 586<sup>1</sup>

**Capital Controls Co., Inc.**, chlorination, 284<sup>1</sup>, 591<sup>p</sup>

**Carbon**, See Activated carbon; Total organic carbon

**Carbon dioxide**, effects on global ecology, 1162  
removal from air, 1181

**Carbon disulfide**, determination by flame photometric detector, 652

**Carbon-14-labeled compounds**, determination of odor thresholds, 169

**Carbon monoxide**, Arctic air, 251  
detector, 679<sup>p</sup>  
distribution between atmosphere and surface waters, 836  
rate of removal from air, 1181  
role in air pollution, 628, 876, 1223  
urban air, 41

**Carbonyl compounds**, determination in automobile exhaust, 397

**Carbonyl sulfide flames**, sulfur oxide formation, 63

**Career opportunities**, Environmental Science Services Administration, 777<sup>1</sup>  
land management, 863<sup>1</sup>

**Carle Instruments, Inc.**, thermal analysis system, 402<sup>p</sup>

**Carter-Day Co.**, scrubber, 590<sup>p</sup>

**Carver-Greenfield Corp.**, solid waste disposal, 862<sup>1</sup>

**Catalysts**, air pollution control markets, 30

**Catalytic oxidation**, control of gaseous emissions, 1159

**Cellulose**, conversion to animal fodder, 883

**Cellulose acetate membranes**, water treatment by reverse osmosis, 1269

**Center for the Study of Responsive Laws**, evaluation of federal environmental programs, 1229

**Centrifuge**, determination of aerosol particle size distribution, 641, 830, 1280

**Cesium-137**, release from leaf litter, 1195

**Chemical & Pollution Sciences, Inc.**, solvent recovery, 862<sup>1</sup>

**Chemical Construction Corp.**, sulfur oxides recovery process, 703

**Chemical industry**, See also Organic chemicals industry  
pollution abatement spending, 301

**Chemical Mfg. Corp.**, filter papers, 774<sup>p</sup>

**Chemical technology**, need for pollution-free planning, 513

**Chemicals**, listing of manufacturers for environmental field, 89, 949, 971

**Chemico-Basic Corp.**, sulfur oxides recovery process, 703, 1213<sup>1</sup>

**Chemistry**, environmental approach, 508

**Chemtrix, Inc.**, nitrate analyzer, 494<sup>1</sup>

**Chicago, Ill.**, deep tunnel storage of storm runoff, 209  
lead in airborne particulates, 472  
odor abatement enforcement, 793  
sludge disposal project, 699

**Chicago River**, oil spill cleanup, 417

**Chile**, water management, 80<sup>1</sup>

**Chlorination**, 284<sup>1</sup>, 591<sup>p</sup>, 774<sup>p</sup>

**Chlorine**, 486<sup>1</sup>, 588<sup>1</sup>

**Chromatography**, 83<sup>1</sup>  
See also Gas chromatography;  
Thin layer chromatography

**Chromium plating fumes**, 861<sup>p</sup>

**Cities**, planning, 179<sup>1</sup>

**Citrus trees**, effects of air pollutants, 934  
effects of fluoride accumulation, 378

**Cleaner Air Week**, annual observance, 895

**Cleveland, Ohio**, Dow Chemical Co. operation of sewage plant, 797  
water system planning, 303

**Climet Instruments, Inc.**, particle counter, 182<sup>p</sup>

**Clo Corp.**, waste water aeration, 861<sup>p</sup>

**Coagulants**, See Polymeric flocculants

**Coagulation**, See Flocculation

**Coal**, fluid bed combustion, 615, 719  
pollution problems, 85<sup>1</sup>

**Coal mines**, effects on Busseron Creek watershed, 279<sup>1</sup>

**Coal tar pitch**, isolation of accepyrene, 948

**Cobalt-60**, release from leaf litter, 1195

**Colloidal dispersions**, interactions with electrolytes, 264

**Colloids**, effect on biological waste treatment, 820  
flocculation by metal ions and polyelectrolytes, 825

**Colorado Basin**, water resources, 487<sup>1</sup>

**Colorado River**, salinity control, 883

**Colorimetry**, manganese determination in lake waters, 761

**Combined sewers**, See Storm runoff

**Combustion**, See Fluid bed combustion

**Combustion Engineering, Inc.**, incinerator, 1213<sup>1</sup>

**Combustion Equipment Assoc., Inc.**, dust collectors, 774<sup>p</sup>  
combustion units, 860<sup>p</sup>

**Commercial products**, clinical toxicology, 399<sup>1</sup>

**Commission on Marine Sciences, Engineering, and Resources**, reorganization of federal marine programs, 117

**Companies**, listing in environmental field, 89, 949, 1111

**Composting**, 187<sup>1</sup>

**Computer**, forecasting water requirements, 904

**Comtro, Inc.**, packaged combustion units, 860<sup>p</sup>

**Concentration**, See also Freeze concentration  
evaporation procedure using DMSO, 393

**Conductivity meter**, 591<sup>p</sup>

**Conference of City Health Officers**, review of environmental health problems, 885

**Congress**, environmental committee proposal, 305

**Conifuge**, ring slit design for increased aerosol sampling rates, 641

**Conservation**, 80<sup>1</sup>, 859<sup>1</sup>, 1301<sup>1</sup>  
industrial use of air resource, 1258  
squandering of natural resources, 695

**Conservation and Environment Department**, congressional action, 615

**Conservation Foundation**, Rookery Bay development plan, 24

**Consolidated Edison Co. of New York, Inc.**, noise control, 1145

**Consolidated Technology, Inc.**, BOD bottle, 679<sup>p</sup>

**Consulting Engineers Council**, engineering excellence awards, 821

**Consulting services**, directory for environmental field, 89, 949, 961

**Consumer Protection and Environmental Health Service**, See also Names of specific agencies  
congressional inquiry, 417  
environmental goals, 28

**Continuous air monitoring station**, sampling inlet line, 483

**Contracts**, See Grants and contracts

**Controls Co., Inc.**, chlorination kit, 774<sup>p</sup>

**Coolers**, 596<sup>1</sup>

**Cooling towers**, fans, 592<sup>p</sup>  
water treatment, 678<sup>p</sup>

**Copper**, analysis in airborne particulates, 1207

**Copper screening**, prevention of marine fouling, 676

**Corn**, accumulation of dieldrin from aerial contamination, 261

**Corning Glass Works**, demineralizer, 592<sup>p</sup>  
gas chromatograph, 284<sup>1</sup>

**Costs**, air pollution, 770<sup>1</sup>  
pollution abatement, 5  
water pollution abatement, 213  
water use by beet sugar industry, 174<sup>1</sup>

**Coulometric titration**, nitrogen determination in water, 741

**Council of Ecological Advisers**, congressional action, 207

**Crane Co.**, licensing agreement with La Compagnie des Eaux et de l'Ozone, 1145  
water clarification, 776<sup>1</sup>

**Culligan, Inc.**, water purifiers, 180<sup>p</sup>, 282<sup>p</sup>

**Curtain, W. H., & Co.**, air sampler, 402<sup>p</sup>

**Cyclone separator**, 1302<sup>p</sup>

## D

**DDT**, ban in Wisconsin, 15  
ban of U.S. sales, 1229  
concentration in salmon, 419, 613  
congressional banning proposal, 419  
decomposition in soil, 710  
Swedish restrictions, 419  
usage pattern, 521

**DMSO**, See Methylsulfinylmethane

**Dalapon**, analysis in water, 69

**Dallas, Tex.**, Freon-powered buses, 207

**Deep tunnels**, storage of storm runoff, 209

**Deep well injection**, 399<sup>1</sup>, 776<sup>1</sup>  
ground water contamination, 105

**Degussa, Inc.**, water purifier, 282<sup>p</sup>

**De Laval Separator Co.**, slaughterhouse waste disposal system, 281<sup>p</sup>

**Delaware River Basin Commission**, regional waste treatment system, 521

**Delta Scientific Corp.**, water analysis, 402<sup>p</sup>, 680<sup>1</sup>

**Demier Equipment Co.**, samplers, 596<sup>1</sup>

**Dempster Brothers, Inc.**, refuse compactor, 1302<sup>p</sup>

**Density**, aerosol suspensions, 386

**Denver Equipment Co.**, flotation machines, 184<sup>1</sup>

**Des Moines, Iowa**, solid waste disposal, 681<sup>1</sup>

**Desalination plants**, ion exchange processes, 336  
reverse osmosis membrane, 299  
salinity control of Colorado River, 883

**Desalination plants**, acid mine water, 883  
prevention of sulfate scaling, 883  
reverse osmosis unit in Bessie, Okla., 515

**Detergents**, illusive river levels, 481

**Detroit, Mich.**, carbon monoxide in air, 41

**Devco Engineering, Inc.**, gas detectors, 679<sup>p</sup>

**Diamond Shamrock Chemical Co.**, ion exchange resins, 186<sup>1</sup>, 401<sup>p</sup>

**2,2-Dichloropropionic acid**, See Dalapon

**Dieldrin**, accumulation in corn from aerial contamination, 261  
vapor density, 670

**Differential pressure transmitters**, 401<sup>p</sup>

**Diffusiophoresis**, role in liquid deposition of aerosols, 563<sup>1</sup>

**Dillingham Corp.**, solid waste disposal in oceans, 205, 1231

**Directory**, pollution control, 89, 949

**Disease resistance**, plants, 487<sup>1</sup>

**Dissociation constants**, aquatic herbicides, 1186

**Dissolved oxygen**, measurement of profiles in microbial slime systems, 1297  
Potomac Estuary, 80<sup>1</sup>

**Dissolved solids**, 84<sup>1</sup>, 590<sup>p</sup>

**Ditch**, See Oxidation ditch

**Dollinger Corp.**, pipe line filters, 184<sup>1</sup>

**Dollinger, Lewis L.**, Pure Environment Award, 798

**Domes**, waste water processing units, 186<sup>1</sup>

**Dorr-Oliver, Inc.**, sludge treatment process licensing, 611

**Dow Chemical Co.**, operation of Cleveland sewage plant, 797  
plastic domes, 186<sup>1</sup>

**Dravo Corp.**, waste water treatment, 691<sup>1</sup>, 1308

**Drew Chemical Corp.**, antisalts, 282<sup>p</sup>

**Drinking water**, See Potable water

**Dryers**, 596<sup>1</sup>

**Dual water systems**, use in future cities, 197

**Duke Power Co.**, radioactive wastes concentrator, 1143

**Du Pont, E. I. de Nemours & Co., Inc.**, plastic pipe, 402<sup>p</sup>  
pollution control program, 893

**Dust collectors**, 82<sup>p</sup>, 83<sup>1</sup>, 591<sup>p</sup>, 680<sup>1</sup>, 774<sup>p</sup>, 1304<sup>p</sup>

**Dust control**, 588<sup>1</sup>, 1211<sup>1</sup>

**Dust counter**, measurement of aerosol size distribution, 768

**Dynamic model**, photochemical air pollution, 1175

## E

**EG&G, Inc.**, deep-sea probe, 81<sup>p</sup>  
fog dispersal in airports, 617

- Eagle Chemical Co.**, deodorant insecticide, 1306<sup>1</sup>
- Eagle-Picher Industries, Inc.**, water pollution hearing, 881
- Earthquake hazards**, 280<sup>1</sup>
- Eastman Kodak Co.**, reverse osmosis membrane, 185<sup>1</sup>
- Ecological Science Corp.**, ultraviolet purification of water, 1143
- Ecology**, 486<sup>1</sup>, 677<sup>1</sup>, 1211<sup>1</sup> pesticide effects in Louisiana, 619
- Ecotech Research Inc.**, carbon treatment of waste water, 797
- Economics**  
See Costs
- Editorials**, ACS environment report, 787 natural resource preservation, 695 pollution abatement costs, 5 Pollution Control Directory, 879 pollution-free chemical technology, 513 pollution terminology, 201 population growth, 1225 unified approach to environment, 295
- Education**  
See also Training development of environmental engineering programs, 235, 508 expansion of environmental programs, 1229 Ford Foundation grants, 205
- Emco Corp.**, carbon treatment of waste water, 797
- Electric power**, forecast for northeastern states, 303
- Electric Power Council on Environment**, establishment, 1145
- Electric power plants**, Arizona Public Service Co. pollution problem, 321 pollution-free designs, 523
- Electric Power Reliability Act**, congressional action, 207
- Electric Reduction of Canada, Ltd.**, phosphorus plant closing, 811
- Electrodes**, 403<sup>1</sup>  
See also Microelectrodes; Specific ion electrodes
- Electrodialysis**, pulp wastes, 1147
- Electrolysis**, prevention of marine fouling, 576
- Electrolytes**, interactions with colloidal dispersions, 264
- Electron capture**, detection of sulfur hexafluoride, 484
- Electronic Assistance Corp.**, refuse compactor, 488<sup>1</sup>
- Electrostatic precipitators**, 594<sup>1</sup>, 599<sup>1</sup> installation on New York City incinerator, 882
- Elgin Softener, Inc.**, gravity filters, 184<sup>1</sup> metal finishing wastes, 285<sup>1</sup>, 493<sup>1</sup> water neutralization systems, 596<sup>1</sup>
- Elgin-Waltham Corp.**, chemical feeder, 860<sup>1</sup>
- Emerson Electric Co.**, batch controller, 861<sup>1</sup> flow meters, 185<sup>1</sup>, 776<sup>1</sup>
- Empire Abrasive Equipment Corp.**, dust collector, 82<sup>1</sup>
- Engine exhaust**, purifiers, 185<sup>1</sup>
- Engineering**, role in solving environmental problems, 235, 508
- Environment**, 400<sup>1</sup>, 588<sup>1</sup>, 594<sup>1</sup> ACS report, 787 bibliography, 898<sup>1</sup> federal expenditures, 113 impact of science and technology, 9 management, 285<sup>1</sup> national policy legislation, 611, 701, 803 need for national commitment, 803 pollution instrumentation, 1301<sup>1</sup> proposal for Congressional committee, 305 unified approach, 295
- Environmental Control Administration**  
See also Bureau of Solid Waste Management composting evaluation, 187<sup>1</sup> home refuse storage, 494<sup>1</sup> landfill stabilization, 494<sup>1</sup> packaging in solid waste management, 681 reorganization, 103 Washington, D.C., incinerator, 681<sup>1</sup>
- Environmental Defense Fund**, DDT ban testimony, 15
- Environmental engineering**, role in society, 235, 508
- Environmental equipment**, 285<sup>1</sup>
- Environmental Mutagenesis Society**, establishment, 105
- Environmental Quality Council**, current activities, 1249 establishment, 611
- Environmental Quality Preservation Act**, congressional action, 205
- "Environmental Science & Technology," advisory board**, 72 authors' guide, 39 staff, 400
- Environmental Science Services Administration**, meteorological data for air pollution control agencies, 417 science careers, 777<sup>1</sup>
- Environmental Science Services Corp.**, air pollution, 84<sup>1</sup>
- Environmental Sciences, Inc.**, pollution control services, 285<sup>1</sup>
- Environmental Studies Board**, grant, 11
- Equipment**  
See also Specific kinds of equipment industrial air pollution control needs, 89, 299, 697 listing of manufacturers for environment field, 949, 971
- Escherichia coli**, decline in sea water, 574
- Esso Research and Engineering**, nitrogen oxides removal from flue gas, 808
- Estuaries**, 403<sup>1</sup> federal involvement, 124
- Europe**, solid waste practices, 187<sup>1</sup>, 777<sup>1</sup>
- Eutrophication**, algal assay procedure, 101 analysis via available phosphorus distribution, 754
- Everglades National Park**, jetport controversy, 881
- Exhaust**  
See also Automobile exhaust; Engine exhaust
- 2-Exo-hydroxy-2-methylbornane**, production by actinomycetes, 476
- Explosions**  
See Nuclear explosions
- F**
- FMC Corp.**, dryers and coolers, 596<sup>1</sup>
- Fairbanks Morse**, sewage pumps, 182<sup>1</sup>
- Fallout**  
See Radioactive fallout
- Farrer, William E., Ltd.**, sludge treatment process licensing, 611
- Federal Aviation Administration**, noise research contracts, 697
- Federal Government**  
See also Names of specific agencies Department of Conservation and the Environment, 615 environmental expenditures, 113 involvement in estuaries, 124 noise control in contractors' plants, 1145 pollution abatement by federal facilities, 203, 517 superagency for environment, 28 water enhancement priorities, 891
- Federal Power Commission**, electric power forecast for northeastern states, 303 pollution from power industry, 19
- Federal Water Pollution Control Administration**, clean water costs, 213 grants and contracts, 299, 521, 615, 697, 699, 701, 703, 797, 883, 1233 Lake Ontario-St. Lawrence River pollution control, 403<sup>1</sup> national priorities, 891 Ohio Basin pollution, 777<sup>1</sup> Potomac River enforcement conference, 421 program review, 804 pyrographic analyzer, 709 reorganization, 103
- thermal pollution control guide**, 105
- training of waste treatment plant operators**, 615, 1155
- waste water treatment costs for organic chemicals**, 311
- "Water Pollution Aspects of Urban Runoff,"** 527
- water quality standards progress**, 139
- Feeder**, 860<sup>1</sup>
- Fiber optics probe**, determination of mass flow and density of aerosol suspensions, 386
- Films**, 85<sup>1</sup>, 285<sup>1</sup>, 403<sup>1</sup>, 494<sup>1</sup>, 599<sup>1</sup>, 863<sup>1</sup>, 1308<sup>1</sup>
- Filter papers**, 774<sup>1</sup>
- Filters**, 184<sup>1</sup>
- Filtration**, Nucleopore filters, 453, 464
- Firestone Tire & Rubber Co.**, scrap tire reprocessing, 119
- Fish**, DDT-contaminated salmon, 419 pesticide residues, 186<sup>1</sup>, 613
- Fish kills**, blood concentrations of parathion, 1185 Pennsylvania regulation, 15
- Fisher-Klosterman, Inc.**, dust collectors, 83<sup>1</sup> mist collector, 401<sup>1</sup>
- Fisher Scientific Co.**, pH controller, 862<sup>1</sup> pH meter, 596<sup>1</sup> spectrometer, 493<sup>1</sup>
- Flame photometric detector**, air monitoring for sulfur compounds, 652
- Flames**  
See Carbonyl sulfide flames
- Flavor**  
See Off-flavor
- Flocculants**  
See Polymeric flocculants
- Flocculation**, anionic colloids by metal ions and polyelectrolytes, 825
- Florida**, industrial pollution actions, 1141 Rookery Bay development plan, 24
- Flotation**, 184<sup>1</sup>, 862<sup>1</sup>
- Flotation waste treatment system**, 775<sup>1</sup>
- Flow meters**, 185<sup>1</sup>, 402<sup>1</sup>, 490<sup>1</sup>, 776<sup>1</sup>, 862<sup>1</sup>, 1212<sup>1</sup>
- Flue gas**  
See Stack emissions
- Fluid analyzer**, 490<sup>1</sup>
- Fluid bed combustion**, coal, 615, 719
- Fluor Products Co.**, cooling tower fans, 592<sup>1</sup>
- Fluorides**, accumulation in citrus trees, 378 analysis in air, 82<sup>1</sup> effects on tomato plants, 1201 toxicity to plants and animals, 720
- Fluorocarbon Co.**, pumps, 59<sup>1</sup>
- Fluorometry**, estimation of 7H-benz[de]anthracene-7-one and phenanthrene-1-one in airborne particulates, 1198
- Fog**, seeding of warm banks, 617
- Food and Drug Administration**, seizure of contaminated salmon, 419
- Ford Foundation**, grants, 11, 205
- Fouling**  
See Marine fouling
- Foundries**  
See Gray iron foundries
- Foxboro Co.**, differential pressure transmitters, 401<sup>1</sup>
- Fractionation**  
See Atmospheric fractionation
- Franklin Institute**, Dollinger, Lewis L., Pure Environment Award, 798
- Freeze concentration**, organic compounds in dilute aqueous solutions, 276
- Freon**, use as bus fuel, 207
- Fume incineration**, 492<sup>1</sup>, 493<sup>1</sup>
- Fund for New Priorities in America**, environmental conference, 1229
- G**
- GAF Corp.**, phenol complexing agent, 590<sup>1</sup> Gas analyzer, 180<sup>1</sup>
- Gas chromatograph**, 183<sup>1</sup>, 284<sup>1</sup>
- Gas chromatography**, beryllium determination, 927 dalapon determination, 69
- polycyclic aromatic hydrocarbons determination**, 948
- sulfur hexafluoride determination**, 484
- Gas cleaning equipment**, particulate air pollutants, 1149
- Gas detectors**, 181<sup>1</sup>, 403<sup>1</sup>, 679<sup>1</sup>
- Gas sampler**, air pollution analysis, 767
- Gas separation**, 766<sup>1</sup>
- Gases**, interaction with airborne particulates, 558
- Gasoline**, composition changes to reduce pollution, 515 federal registration of additives, 791
- Gelman Instrument Co.**, particle counters, 182<sup>1</sup>
- Gem Rad, Inc.**, fluid analyzer, 490<sup>1</sup>
- General Accounting Office**, water pollution control assessment, 1229
- General American Transportation Corp.**, demineralizers, 599<sup>1</sup>
- General Electric Co.**, microbial digestion of cellulose, 883
- General Monitors, Inc.**, gas detectors, 181<sup>1</sup>
- General Radio Co.**, plant noise survey form, 1145, 1231<sup>1</sup>
- General Services Administration**, natural gas fueling of automobiles, 1143
- Geochemistry**, brines, 367
- Geological Survey**, U.S. water usage, 301 watershed asphalt-treatment project, 110
- Geology**, aerial photographs, 80<sup>1</sup>
- Gilbert Associates, Inc.**, mine-mouth power plants, 523
- Glass Container Manufacturers Institute**, litter, 1306<sup>1</sup> waste disposal program, 17
- Global Atmospheric Research Program**, Barbados Oceanographic Meteorological Experiment, 305
- Glucose**, uptake rates by biological systems, 1205
- Goodfellow Enterprises**, industrial waste facility, 13
- Grace, W. R. & Co.**, cooling water treatment, 678<sup>1</sup>
- Grants and contracts**, Agriculture Department, 303, 881 carbon treatment of waste water, 797 Federal Aviation Administration, 697 Federal Water Pollution Control Administration, 299, 521, 615, 697, 699, 701, 703, 797, 883, 1233 Ford Foundation, 11, 205 Housing and Urban Development Department, 303 Kellogg, W. K., Foundation, 11 National Air Pollution Control Administration, 703, 797 Office of Water Resources Research, 699
- Gray iron foundries**, air pollution control, 299
- Great Britain**, coal combustion information exchange with U.S., 615, 719 water management, 1211<sup>1</sup>
- Great Lakes**, pollution in U.S.-Canadian waters, 1243 U.S. Steel Corp. pollution abatement efforts, 519
- Ground water**, 486<sup>1</sup>
- Ground Water Resources Institute**, seminar, 885
- Gulf General Atomic, Inc.**, desalination plant, 515 reverse osmosis, 1213<sup>1</sup>
- Gypsum**  
See Calcium sulfate
- H**
- Hach Chemical Co.**, turbidity measurement, 184<sup>1</sup> water analysis, 776<sup>1</sup>
- Havens International**, reverse osmosis system, 508
- Hawtryk Research Corp.**, air purifier, 488<sup>1</sup>
- Heat**, effects of air pollutants, 494<sup>1</sup> effects of water pollution, 677<sup>1</sup> local environmental programs, 885



- virus disease transmission in water, 1235
- Health, Education, and Welfare Department**  
See also Names of specific agencies  
air quality criteria, 99
- Heating system**, Sapporo, Japan, 515
- Hemeon Associates**, gas sampler, 488<sup>o</sup>
- Herbicides**, 1211<sup>o</sup>  
acidic dissociation constants, 1186
- Hercules, Inc.**, flocculant polymers, 403<sup>o</sup>
- Hinde Engineering Co.**, stream pollution, 494<sup>o</sup>
- Hollytex Carpet Mills, Inc.**, waste water reclamation process, 314
- Horton Process**, water treatment, 1213<sup>o</sup>
- Hotpack Corp.**, environmental equipment, 285<sup>o</sup>
- Housing and Urban Development Department**, grant for Cleveland water system, 303  
San Francisco planning study, 1231
- Houston Atlas, Inc.**, gas detectors, 403<sup>o</sup>
- Human Ecology Symposium**, recommendations to HEW, 28
- Humic acid**, interaction with pesticides, 271
- Hurricanes**, continuous weather watch, 791
- Hydrocarbons**.  
See also Polycyclic aromatic hydrocarbons  
effect on oxidation of nitric oxide, 469  
gasoline composition, 515  
measurement in Arctic air, 251  
oxidation in auto exhaust, 57  
production from garbage, 1233  
urban air concentrations, 629
- Hydrogen chloride**, Kellogg, M. W., process, 519
- Hydrogen sulfide**, determination by flame photometric detector, 652  
improved collection in cadmium hydroxide suspension, 258  
oxygenation in sea water, 838
- Hydroscience**, 858<sup>o</sup>
- I**
- Illinois**, air pollution legislation, 319
- Illinois Institute of Technology Research Institute**, odor studies, 623
- Illinois River**, surfactant levels, 481
- Incineration**, 1301<sup>o</sup>  
European practices, 777<sup>o</sup>  
use of catalysts, 30
- Incinerators**, 491<sup>o</sup>, 1212<sup>o</sup>, 1213<sup>o</sup>  
New York City improvements, 882  
operator training, 798  
Washington, D.C., 681<sup>o</sup>, 859<sup>o</sup>
- India**, water resources, 599<sup>o</sup>
- Industrial Filter & Pump Mfg., Co.**, water treatment system, 774<sup>o</sup>
- Industrial hygiene**, 80<sup>o</sup>
- Industrial waste water**, reclamation process, 314  
separator, 81<sup>o</sup>  
spectrographic determination of metals, 192  
treatment, 1306<sup>o</sup>
- Industrial waste water treatment plant**, equalization basin, 521
- Industrial wastes**, 399<sup>o</sup>  
Canadian disposal facility, 13  
disposal by deep well injection, 105  
thermal pollution, 105
- Industrial water**, chemical analysis, 676<sup>o</sup>
- Industry**,  
designing for air conservation, 1258  
National Executives' Conference on Water Pollution Abatement, 1241  
particulate control techniques, 1149
- Infrared absorbances**, identification of pollutants in oil spills, 150
- Infrared analysis**, pyrolysis, 185<sup>o</sup>
- Institute of Scrap Iron and Steel, Inc.**, junk auto processing, 1235
- Instruments**, 185<sup>o</sup>  
air pollution, 676<sup>o</sup>, 777<sup>o</sup>, 1306<sup>o</sup>  
environmental control, 1301<sup>o</sup>
- listing of manufacturers for environmental field, 89, 949, 971
- Interior Department**  
See also Names of specific agencies  
San Francisco planning study, 1231
- Interlake Steel Co.**, water pollution hearing, 881
- Internal reflectance spectroscopy**, water pollution analyses, 161, 484
- International Biological Program**, congressional support of U.S. program, 417
- International Boiler Works Co.**, European incineration practices, 777<sup>o</sup>
- International Joint Commission**, pollution of lower Great Lakes, 1243  
water quality in U.S.-Canada waters, 107
- International Pollution Control, Inc.**, industrial wastes, 680<sup>o</sup>
- Intestinal bacteria**, decline in sea water, 574
- Inventur Industries, Inc.**, level-measuring gage, 1304<sup>o</sup>
- Ion association**, calcium sulfate in aqueous electrolytes, 656
- Ion exchange**, desalination processes, 336, 883  
resin in polybromide form for water disinfection, 854  
resins, 185<sup>o</sup>, 401<sup>o</sup>  
sulfate and phosphate determination in water, 396  
trace metal ion analysis, 165
- Iowa**, federal sewage treatment standard, 1231
- Isokinetic sampling**, determination of mass flow and density of aerosol suspensions, 386
- J**
- Japan**, air quality criteria, 99  
Sapporo central heating system, 515
- Jet aircraft**  
See Aircraft
- Johns-Manville**, marine fence, 489<sup>o</sup>
- Johnson, S. C. & Son**, exhaust vapor control, 1159
- Joint Industry-Government Task Force on Eutrophication**, executive director, 101
- Joint waste treatment**, 1211<sup>o</sup>  
current developments, 887
- Jones and Laughlin Steel Co.**, water pollution hearing, 881
- Joy Mfg. Co.**, flotation processes, 862<sup>o</sup>
- K**
- KSF Chemical Processes, Ltd.**, agreement with Wean Industries, Inc., 1235
- Keep America Beautiful, Inc.**, antislitter campaign, 187<sup>o</sup>
- Kellogg, M. W., Co.**, hydrogen chloride process, 519
- Kellogg, W. K., Foundation**, grant to Environmental Studies Board, 11
- Ketones**, determination in automobile exhaust, 397
- Kinetics**.  
See Microbial kinetics
- Krypton-85**, generation from nuclear power reactors, 446
- L**
- La Compagnie des Eaux et de l'Ozone**, licensing agreement with Crane Co., 1145
- Laboratory supplies**, 185<sup>o</sup>
- Lake Erie**, monitoring via air cushion vehicle, 324  
Ohio clean-up actions, 1141  
Pennsylvania clean-up actions, 882
- Lake Mendota**, manganese chemistry, 835  
sedimentary phosphorus depositional pattern, 754  
surface sediments analysis, 1189
- Lake Michigan**, DDT-contaminated fish, 419, 613  
instrumented buoy, 798  
pesticides study, 521, 797
- Lake Ontario**, pollution control, 403<sup>o</sup>
- Lake sediments**, analysis of Lake Mendota, 1189  
available phosphorus, 750, 754
- Lake Superior**, pollution abatement conference, 107
- Lake Tahoe**, reclamation project, 403<sup>o</sup>
- Lake waters**, manganese analysis, 761
- Lambton Industrial Society**, cooperative attack on pollution problems, 1247
- Landfill**  
See Sanitary landfill
- Lasers**, Pennsylvania regulation, 15
- Latexes**, flocculation by metal ions and polyelectrolytes, 825
- Leaching unit**, 494<sup>o</sup>
- Lead**, air pollution aspects, 529  
determination in airborne particulates, 472  
halides from auto exhaust, 48
- Lead aerosols**, concentration in marine air, 737
- Lead dioxide candles**, determination of sulfur in air, 93
- Leaf litter**, mineral release, 1195
- Leigh Instruments, Ltd.**, fluoride analyzer, 82<sup>o</sup>
- Letters**, automobile industry projects, 1223  
carbon monoxide hazards, 876, 1223  
dual water systems, 197  
environmental approach to chemistry and physics, 508  
pulp waste water processing, 506, 508  
tax credits for pollution control facilities, 196  
trichloroethylene and smog, 1224  
water quality standards, 506
- Leupold & Stevens Instruments, Inc.**, telemetering system 493<sup>o</sup>  
Level-measuring gage, 1304<sup>o</sup>
- Library of Congress**, Environmental Policy Division, 1139
- Licensing**, sludge treatment process, 611  
waste water technology, 419, 1145
- Limnatics, Inc.**, instrumented buoy, 798
- Linear alkylated sulfonates**, Illinois River levels, 481
- Liquid**  
See Solids-liquid separation
- Literature search**, 83<sup>o</sup>
- Litter clean-up**, 187<sup>o</sup>, 494<sup>o</sup>, 1306<sup>o</sup>
- Little, Arthur D., Inc.**, odor research, 623
- Loenco, Inc.**, gas chromatograph, 183<sup>o</sup>
- LogElectronics, Inc.**, strip photo printer, 186<sup>o</sup>
- Los Angeles, Calif.**, carbon monoxide in air, 41  
nitrogen oxide monitoring, 797  
organic solvents regulation, 896, 1224
- Louisiana**, ecological effects of pesticides, 519
- Lungs**, deposition of aerosols, 563
- Lurgi Gesellschaft fur Wärme-und Chemotechnik m.b.H.**, licensing of waste water technology, 419
- Lycos Systems, Inc.**, sewage treatment systems, 690<sup>o</sup>
- M**
- M&T Chemicals, Inc.**, chromium plating fume treatment, 861<sup>o</sup>
- Mack Co.**, flow meter, 402<sup>o</sup>
- Magnetic Engineering Assoc.**, treatment of blast furnace scrubber effluent, 860<sup>o</sup>
- Magnetohydrodynamics**, use by coal-fired electric utilities, 719
- Maine Yankee Atomic Power Co.**, shellfish cultivation study, 1233
- Mammals**, effects of pesticides, 858<sup>o</sup>
- Manganese**, chemistry in Lake Mendota, Wis., 835  
colorimetric determination in lake waters, 761
- Manpower**  
See Training
- Manufacturers**, listing in environmental field, 89, 949, 1111
- Manufacturing Chemists Association**, chemical industry pollution abatement spending, 301
- Marine Advisers**, stream flow monitor, 1212<sup>o</sup>
- Marine Electro Mechanical, Inc.**, flow meters, 862<sup>o</sup>
- Marine fouling**, prevention by copper electrolytic technique, 576
- Marine sciences**  
See Oceanography
- Marsan Corp.**, oil barrier, 82<sup>o</sup>
- Martek Instruments, Inc.**, marine metering system, 180<sup>o</sup>
- Maryland**, Patuxent River Basin planning grant, 299
- Mass flow**, aerosol suspensions, 386
- Meeting guides**, 87, 188, 287, 404, 597, 601, 682, 779, 885, 1215, 1309
- Meetings**, calendar, 949, 1063  
National Pollution Control Conference and Exposition, 343  
U.N. Conference on Human Environment, 9
- Melpar, Inc.**, sulfur dioxide analyzer, 590<sup>o</sup>
- Membrane processes**, treatment of pulp wastes, 1147
- Membranes**, reverse osmosis, 185<sup>o</sup>, 299, 1269
- Mercury (II) chloride**, preservation of nitrogen forms in water, 478
- Metal finishing wastes**, 184<sup>o</sup>, 185<sup>o</sup>, 284<sup>o</sup>, 493<sup>o</sup>, 596<sup>o</sup>, 599<sup>o</sup>
- Metal ions**, flocculation of anionic colloids, 825
- Metals industry**, air pollution control, 299, 697, 1211<sup>o</sup>
- Meteorological tracers**, rate of pollutant loss, 1181  
sulfur hexafluoride, 484, 591<sup>o</sup>
- Meteorology**, 1211<sup>o</sup>
- Methane**, distribution between atmosphere and surface waters, 836
- Methyl mercaptan**, determination by flame photometric detector, 652
- Methylsulfinylmethane**, use in concentrating dilute aqueous phenol solutions, 393
- Mibis Co.**, licensing agreement with Ozonator Corp., 1145
- Michigan**, certification of waste treatment plant operators, 882
- Microbial kinetics**, mathematics of transient state, 143  
substrate uptake in pure and mixed culture, 569, 769
- Microbial slime systems**, determination of oxygen profiles, 1297
- Microelectrodes**, determination of oxygen profiles in microbial slime systems, 1297
- Microorganic matter**, water, 588<sup>o</sup>
- Microscopy**, 1211<sup>o</sup>
- Midland, Mich.**, composition of brines from Sylvania formation, 367
- Midland Ross Corp.**, fume incinerators, 493<sup>o</sup>
- Midwest Research Institute**, staff publications, 285<sup>o</sup>
- Milk**, off-flavor in dried products, 305  
strontium levels, 171
- Millipore Corp.**, water analysis, 862<sup>o</sup>
- Millipore filter**, separation system for activated sludge process, 674
- Mine Safety Appliance Co.**, air pollution instruments, 777<sup>o</sup>
- Mine wastes**, chemical-vegetative stabilization, 717
- Mineral nutrition**, tomato plants exposed to fluo-rides, 1201
- Mining**  
See also Acid mine water: Coal mines; Strip mines; Surface mines

Mississippi River, environmental planning in delta region, 1252  
pesticides in drinking water, 1261

Missouri River, pesticides in drinking water, 1261

Mist collector, 401P

Models  
See Dynamic model; Theoretical models

Modern Learning Aids, water in India, 599<sup>1</sup>

Molecular sieves, 84<sup>1</sup>

Monochloroacetic acid, odor threshold, 169

Monochlorobenzene, odor threshold, 169

Monodisperse aerosols, electrical sizing method, 381

Monsanto Biodize Systems, Inc., water pollution control, 776<sup>1</sup>

Montrose Chemical Co. support of Lake Michigan study, 797

Mortality, relationship to sulfur dioxide in air, 1235

Motor vehicles  
See Automobiles

Moving slide impactor, evaluation of aerocolloids, 154

Mutagens, identification in environment, 105

Myron L. Co., salts measurement, 84<sup>1</sup>, 590P

## N

NATO, cooperation in environmental problems, 885

Nalco Chemical Co., desalination of acid mine water, 883  
slime and algae suppressant, 1302P

National Academy of Engineering Environmental Studies Board, 11

National Academy of Sciences, Environmental Studies Board, 11

National Academy of Sciences-National Research Council, Committee on Persistent Pesticides, 613

National Air Pollution Control Administration, air quality control regions, 299  
air quality standards guidelines, 299  
aircraft emissions, 219  
enforcement of automobile emission regulations, 625  
grants and contracts, 703, 797  
"Guidelines for the Development and Implementation of Air Quality Standards," 615  
labeling of new automobiles, 791  
odor research programs, 623  
Organic Solvents Advisory Committee, 611  
pollution from New Mexico power plant, 321  
registration of gasoline additives, 791  
reorganization, 103  
steel industry pollution, 429

National Center for Atmospheric Research, high-altitude air sampler, 101

National Executives' Conference on Water Pollution Abatement, meeting with federal officials, 1241

National Institute of Environmental Health Sciences, establishment, 103

National Instrument Laboratories, Inc., air sampler, 774P

National Medical Audio-Visual Center, pollution films, 599<sup>1</sup>, 863<sup>1</sup>, 1308<sup>1</sup>

National Oceanographic and Atmospheric Agency, proposed establishment, 117

National Pollution Control Conference and Exposition, program, 343

National Starch and Chemical Co., paper waste clarifier, 591P

National Water Commission, conferences, 697  
five-year plan, 303

National Wildlife Federation, air pollution, 862<sup>1</sup>

Natural gas, recovery by atomic explosion, 85<sup>1</sup>  
use in automobiles, 699, 1143  
use in New York City, 301

Natural Gas Vehicles, Inc., fuel unit for internal combustion engines, 699

Natural organic material, interaction with pesticides, 271

Natural waters, calcium sulfate hemihydrate scaling thresholds, 580  
determination of phosphate by activation analysis, 844  
dissolved carbon monoxide and methane, 836  
odoriferous compounds, 268, 476

Nebraska, water and sewer system planning, 313

Neutron activation analysis, phosphate in natural waters, 844  
trace metal ions, 165

New Jersey  
See also New York-New Jersey metropolitan area  
air pollution emergency powers, 1141  
court ruling on air pollution code, 301  
plastics plant closing, 793

New Mexico, air pollution from power plant, 321

New York, grant to Ecotech Research, Inc., 797  
watercraft waste disposal law, 203

New York City, carbon monoxide in air, 41  
deaths from sulfur dioxide in air, 1235  
driver habits, 798  
health aspects of air pollution, 494<sup>1</sup>  
municipal incinerator improvements, 882  
open burning of solid wastes, 711  
sulfur dioxide removal from air, 882  
training of incinerator operators, 798  
use of natural gas, 301

New York-New Jersey metropolitan area, air pollution, 599<sup>1</sup>, 863<sup>1</sup>

Nitrates, analysis in water, 494<sup>1</sup>

Nitric oxide, oxidation in presence of ultraviolet light and hydrocarbons, 469

Nitrogen, See also Ammonium nitrogen  
determination in water by coulometric titration, 741  
removal from waste water, 536

Nitrogen forms, preservation in water samples, 478

Nitrogen oxides, monitor, 774P  
monitoring in Los Angeles air, 797  
rate of removal from air, 1181  
removal from flue gas, 808  
urban air concentrations, 629

Nitrophenol, sorption by activated carbon, 918

Noise, control, 863<sup>1</sup>  
Federal Aviation Administration contracts, 697  
federal contractors' plants, 1145  
plant guide, 1213<sup>1</sup>

Norstel and Templewood Hawksley, licensing of waste water technology, 419

North American Rockwell Corp., pyrographic analyzer, 709

North Carolina State University, textile mill wastes, 403<sup>1</sup>

Northeastern states, electric power forecast, 303

Nuclear explosions, 487<sup>1</sup>  
atmospheric fractionation of fission products, 667

Nuclear methods, pollution analysis, 132

Nuclear power plants, thermal pollution, 425  
waste management problems, 446  
wastes concentrator, 1143

Nuclear wastes  
See Radioactive wastes

Nucleopore, filtration of aerosols, 453, 464

Nutrients, removal from waste water, 536

Nutrition  
See Mineral nutrition

## O

Occupational health, 588<sup>1</sup>

Oceanography, 588<sup>1</sup>, 1211<sup>1</sup>, 1301<sup>1</sup>  
marine metering system, 180P

patents, 487<sup>1</sup>  
reorganization of federal efforts, 117  
sonar probe, 81P

Oceans, dissolved carbon monoxide and methane in surface waters, 836  
solid waste disposal, 205, 1231

Odors, animal wastes, 744  
control system, 401P  
current research, 623  
production in water by actinomycetes, 268, 476  
threshold determination in air, 169

Off-flavor, dried milk products, 305

Office of Saline Water, desalination developments, 883

Office of Science and Technology, "Control of Agriculture-Related Pollution," 107

Office of Water Resources Research, research projects, 699

Ohio, restrictions on Lake Erie pollution, 1141

Ohio Agricultural Research and Development Center, tree deficiencies, 594<sup>1</sup>

Ohio Basin, water pollution, 777<sup>1</sup>

Oil, Alaskan pipeline, 1141  
Chicago River spill, 417  
clean-up of spills, 82P, 399<sup>6</sup>, 489P, 1302P  
identification of specific products in spills, 150

Oil industry, pollution abatement expenditures, 13

Oil refining, catalyst markets, 30  
waste water, 676<sup>1</sup>

Oilfield brines, determination of ammonium nitrogen, 274

Olin Matheson Chemical Corp., sulfur oxides recovery unit, 703

Organic chemicals industry, waste water treatment costs, 311

Organic materials  
See also Natural organic material  
recovery from water by freeze concentration, 276

Organic solvents, emissions control by catalytic oxidation, 1159

National Air Pollution Control Administration committee, 611  
recovery, 185<sup>1</sup>, 862<sup>1</sup>  
smog promotion by trichloroethylene, 896, 1224

Osmosis  
See Reverse osmosis

Overview, establishment, 107

Owens-Illinois, Inc., glass paving material, 1233

Oxidation  
See also Catalytic oxidation  
nitric oxide in presence of ultraviolet light and hydrocarbons, 469

Oxidation ditch, waste treatment, 1170

Oxy-Catalyst, Inc., engine exhaust purifiers, 185<sup>1</sup>

Oxygen  
See also Biochemical oxygen demand; Dissolved oxygen; Singlet molecular oxygen  
analyzer, 81P, 284<sup>1</sup>  
secondary sewage treatment, 109

Ozonator Corp., licensing agreement with Mibis Co., 1145

Ozone, effect on peanut plants, 759  
flavor defects in dried milk, 305  
Hartley photolysis, 248  
licensing of water treatment processes, 1145  
plant growth suppression, 52  
sewage effluent treatment, 883  
toxicity to animals, 629

## P

Pacific Pumping Co., flow control device, 490P

Packaging materials, glass containers as paving material, 1233  
solid waste disposal problems, 328, 681<sup>1</sup>

Packard Bell Environmental Sciences, air newsletter, 594<sup>1</sup>

Packard Instrument Co., Inc., bibliographic service, 83<sup>1</sup>

Paints, waste water treatment plants, 677<sup>1</sup>

Paper  
See Pulp

Parathion, blood concentrations in fish, 11

Particle sizing, aerosols, 641, 768, 830, 1280

Particle Technology, Inc., particulate monitor, 1304P

Particulates  
See Airborne particulates

Patents, oceanography, 487<sup>1</sup>

Peabody Engineering Corp., refuse compactor, 591P

Peanuts, synergistic action of ozone-sulfur dioxide, 759

Pennsylvania, accidental pollution regulation, 15  
acid mine drainage, 699, 1237  
Lake Erie clean-up actions, 882  
laser regulation, 15  
mine-mouth power plants, 523

Pennsylvania Glass Sand Corp., filter sands for water treatment, 860P

Permeation tubes, calibration of flame photometric detector, 652  
volumetric calibration, 1275

Permutit Co., flotation waste treatment system, 775P  
flow control system, 1212P  
metal finishing wastes, 185<sup>1</sup>, 284<sup>1</sup>, 599<sup>1</sup>  
water softener, 594<sup>1</sup>

Pesticides, 858<sup>1</sup>, 1306<sup>1</sup>  
See also DDT; Dalapon; Dieldrin; Herbicides; Parathion  
Agriculture Department suspension, 701  
buildup in soils, 207  
determination in drinking water, 1261  
ecological effects, 619  
interaction with natural organic material, 27  
Lake Michigan study, 521, 797  
persistence in environment, 613, 677<sup>1</sup>  
regulations, 791  
residues in fish, 186<sup>1</sup>, 419, 613

Petrochemistry, 391

Petro-Tex Chemical Corp., aerobic waste decomposition process, 401P

pH, control system, 862<sup>1</sup>  
Meters, 186<sup>1</sup>, 596<sup>1</sup>, 776<sup>1</sup>

Phenanthrene, estimation in airborne particulates, 1198

Phenol, complexing agent, 590P  
concentration of dilute aqueous solutions by evaporation, 393  
sorption by activated carbon, 918

Philadelphia, Pa., air pollution code, 1231

Phosphates, control in lower Great Lakes, 1243  
determination in water, 396, 844  
evaluation of removal techniques, 701  
removal from aqueous solutions by activated alumina, 661

Phosphorus, detector, 861P  
determination in lake sediments, 750, 754  
removal from waste water, 536

Phosphorus plant, closing due to pollution, 811

Photochemical air pollution, current developments, 629  
decomposition of lead halides from auto exhaust, 48  
dynamic model, 1175  
promotion by trichloroethylene, 896, 1224  
role of singlet oxygen, 241, 248, 84, 946

Photographic printer, 186<sup>1</sup>

Photolysis, ozone, 248

Photomation, Inc., smoke indicator, 860P

Photosynthesis, effects of ozone, 52

Physics, environmental approach, 508

Pipe  
See Plastic pipe

Pipelines, construction in Alaska, 1141  
secondary sewage treatment, 531  
solid waste collection, 812

Pipes, inspection camera, 1212P

**Planning,**  
cities, 179<sup>1</sup>, 399<sup>1</sup>  
Mississippi River delta region,  
1252

**Plants,**  
dieldrin accumulation in corn,  
261  
disease resistance, 487<sup>1</sup>  
effects of air pollutants, 52,  
720, 759, 934, 1201  
removal from lakes, 283<sup>2</sup>

**Plastic pipe,** 402<sup>2</sup>

**Poisoning,**  
commercial products, 399

**Pollution abatement,** 399<sup>1</sup>  
chemical industry spending,  
301  
economic impact, 5  
federal spending, 113  
oil industry spending, 13  
role of state governments, 223

**Pollution control,** 285<sup>1</sup>  
directory, 89, 949

**Pollution episode,**  
proper terminology, 201

**Polycyclic aromatic hydrocarbons,**  
gas chromatographic analysis  
in soot samples, 948

**Polyelectrolytes,**  
flocculation of anionic colloids,  
825

**Polymeric flocculants,** 403<sup>1</sup>  
bacteria removal from water,  
551  
waste water treatment role,  
713

**Polynuclear aromatic compounds,**  
vehicle emissions, 858<sup>1</sup>

**Population growth,**  
effect on environment, 1225

**Potable water,**  
pesticides analysis, 1261  
separate supply system, 197

**Potomac River,** 399<sup>1</sup>  
clean-up program, 421, 891  
dissolved oxygen, 80<sup>1</sup>

**Power plants,**  
emissions, 436  
thermal pollution, 425

**Precipitair Pollution Control, Inc.,**  
flue gas process, 797

**Precision Scientific Co.,**  
nitrogen oxide monitors, 774<sup>2</sup>  
water analyzer, 81<sup>2</sup>

**Pressure transmitters**  
See Differential pressure transmitters

**Pritchard, J. F., & Co.,**  
licensing of waste water technology, 419

**Pulp Manufacturers' Research League, Inc.,**  
wastes processing, 203, 506,  
508, 1147

**Pulp wastes,**  
bleaching properties, 371  
clarifier, 591<sup>2</sup>  
processing, 203, 506, 508, 703,  
1147

**Pulverizing Machinery Division, Slick Corp.,**  
scrubber, 861<sup>2</sup>

**Pumps,** 182<sup>2</sup>, 402<sup>2</sup>, 596<sup>1</sup>, 861<sup>2</sup>

**Pyrographic analyzer,**  
waste water, 709

**Pyrolysis**  
See also Reductive pyrolysis  
infrared analysis, 185<sup>1</sup>

## R

**Radiation**  
See Ultraviolet radiation

**Radioactive fallout,**  
atmospheric fractionation, 667

**Radioactive tracers,** 494<sup>1</sup>  
mineral release from leaf litter, 1195

**Radioactive wastes,**  
nuclear power industry, 446  
packager, 492<sup>2</sup>

**Radiological health,** 859<sup>1</sup>

**Radionuclides,** 487<sup>1</sup>

**Reaction rates,**  
atmospheric sulfur dioxide, 436

**Recreational lake,**  
use of renovated water, 75<sup>1</sup>

**Red Lake Lab,**  
pipe inspection camera, 1212<sup>2</sup>

**Reductive pyrolysis,**  
conversion of total bound nitrogen to ammonia, 741

**Refining**  
See Oil refining

**Regional approach,**  
air pollution abatement, 431

**Republic Steel Corp.,**  
water pollution hearing, 881

**Research,**  
air pollution, 80<sup>1</sup>

**Research Analysis Associates, Inc.,**  
*Research Analysis Notes*, 83<sup>1</sup>

**Research and development,**  
Science Information Exchange services, 99

**Research Appliance Co.,**  
stack monitor, 1302<sup>2</sup>

**Research-Cottrell, Inc.,**  
scrubbers, 1308<sup>1</sup>

**Reservoirs,** 588<sup>1</sup>

**Residual oil,**  
identification in oil spills, 150

**Resource Recovery Act,**  
congressional action, 517, 1160

**Resources for the Future,**  
grant from Ford Foundation, 11

**Reverse osmosis,**  
membranes, 185<sup>1</sup>, 299, 678<sup>2</sup>  
safety control in Colorado River, 883

**treatment of pulp wastes,** 203,  
506, 508, 1147

**water treatment,** 515, 1213<sup>1</sup>,  
1269

**Reynolds Metals Co.,**  
aluminum reclamation programs, 1157

**Rhodia, Inc.,**  
odor correction system, 401<sup>2</sup>  
623

**Ritter-Pfaudler Corp.,**  
electrolytic plating wastes,  
184<sup>1</sup>

**Rivers**  
See Names of specific rivers

**Roads,**  
glass paving material, 1233

**Rocky River, Ohio,**  
sewage treatment plant, 809

**Rookery Bay, Fla.,**  
development plan, 24

**Runoff**  
See Storm runoff

**Rutgers University,**  
animal waste disposal study,  
881

**Ryckman, Edgerley, Tomlinson, and Associates,**  
industrial waste treatment plant, 521

## S

**SCM Corp.,**  
air purification system, 283<sup>2</sup>

**St. Lawrence River,**  
pollution control, 403<sup>1</sup>

**St. Regis Paper Co.,**  
activated carbon treatment of mill effluents, 703

**Saline water,** 279<sup>1</sup>

See also Brines; Desalination;  
Sea water  
ammonium nitrogen determination, 274

**Salmon,**  
DDT-contamination, 419, 613

**Samplers,** 281<sup>1</sup>, 488<sup>2</sup>, 596<sup>1</sup>, 774<sup>2</sup>  
air pollutant analysis, 767

**Sampling inlet line,**  
continuous air monitoring station, 483

**San Francisco, Calif.,**  
open burning of solid wastes,  
711  
regional planning study, 1231  
steam buses, 207

**Sanitary landfill,** 494<sup>1</sup>

**Santee Recreation Project,** 75<sup>1</sup>

**Scaling thresholds,**  
measurement of calcium sulfate hemihydrate, 580

**Scanning electron microscopy,**  
1211<sup>1</sup>

**Science and technology,**  
impact on environmental quality, 9

**Science Information Exchange,**  
research and development services, 99

**Science Pump Corp.,**  
gas sampling pump, 861<sup>2</sup>

**Scientific Pollution Control Corp.,**  
refuse compactor, 491<sup>2</sup>

**Scientific Systems Corp.,**  
sulfur hexafluoride analyzer,  
591<sup>2</sup>

**Screening**  
See Copper screening

**Scrubbers,** 83<sup>1</sup>, 590<sup>2</sup>, 678<sup>2</sup>, 775<sup>2</sup>,  
861<sup>2</sup>, 1308<sup>1</sup>  
sulfur dioxide recovery, 806

**Sea water,**  
decline of *E. coli*, 574  
inactivation of viruses, 941  
oxygenation of hydrogen sulfide, 838

**Sediments**  
See Lake sediments

**Separation**  
See Solids-liquid separation

**Sequential air samples,**  
particulate analysis, 1198

**Sewage,**  
flocculation by metal ions and polyelectrolytes, 825

**Sewage treatment**  
See also Activated sludge process; Biological waste treatment  
costs, 677<sup>1</sup>  
Nebraska planning grant, 303  
ozonation, 883  
packaged systems, 680<sup>1</sup>  
pipeline reactor, 531  
Porteous process, 285<sup>1</sup>  
use of oxygen in biological processes, 109

**Shell Chemical Co.,**  
support of Lake Michigan study, 797

**Shellfish,**  
cultivation using power plant discharge water, 1233

**Ships**  
See Watercraft

**Shirley Machine Co.,**  
industrial waste water treatment, 1306<sup>1</sup>

**Shock loads,**  
increase in feed concentration,  
143

**Singlet molecular oxygen,**  
mechanism of production, 248,  
944, 946  
role in photochemical air pollution, 241

**Slide rule,** 599<sup>1</sup>

**Slime systems,**  
determination of oxygen profiles, 1297

**Sludge,**  
Chicago disposal project, 699  
heat treatment process, 611

**Sly, W. W., Mfg. Co.,**  
gas scrubber, 775<sup>2</sup>  
dust collectors, 591<sup>2</sup>, 1304<sup>2</sup>

**Smog**  
See Photochemical air pollution

**Smoke**  
See Tobacco smoke

**Smoke meters,** 592<sup>2</sup>, 860<sup>2</sup>

**Sodium bicarbonate,**  
sulfur dioxide removal from flue gas, 797

**Soils,** 399<sup>1</sup>, 599<sup>1</sup>  
pesticide buildup, 207  
volatilization of dieldrin, 670  
water analysis, 1212<sup>2</sup>

**Solid state power supply,**  
electrostatic precipitators, 703

**Solid waste disposal,** 399<sup>1</sup>, 862<sup>1</sup>  
See also Incineration  
bulk transport in pipelines, 812  
compactors, 488<sup>2</sup>, 491<sup>2</sup>, 591<sup>2</sup>,  
1302<sup>2</sup>  
composting, 187<sup>1</sup>  
Des Moines, Iowa, study, 681<sup>1</sup>  
Glass Container Manufacturers Institute program, 17  
household practices, 494<sup>1</sup>  
open burning, 711  
problems of throwaway packages, 328, 681<sup>1</sup>  
Resource Recovery Act, 517,  
1160  
sanitary landfill, 494<sup>1</sup>  
survey of U.S. practices, 13  
use of oceans, 205, 1231

**Solid wastes,** 280<sup>1</sup>, 1301<sup>1</sup>  
See also Mine wastes  
digestion of cellulose, 883  
federal program, 705  
garbage conversion to hydrocarbons, 1233  
insecticide, 1306<sup>1</sup>  
management by systems analysis, 898  
mineral recovery, 85<sup>1</sup>  
remover, 183<sup>2</sup>

**Solids**  
See Dissolved solids

**Solids-liquid separation,**  
activated sludge process, 674

**Solvents**  
See Organic solvents

**Soots**  
identification and determination of polycyclic aromatic hydrocarbons, 948

**Sorption,**  
phenols by activated carbon,  
918

**Southbridge Plastics Co.,**  
plant closing, 793

**Southwest Research Institute,**  
odor research, 623

**Specialty gases,** 284<sup>1</sup>

**Specific ion electrodes,**  
water analysis, 34

**Spectrochemical analysis,**  
metals in industrial waste water, 1192

**Spectrometers,** 493<sup>1</sup>  
aerosol sizing, 641, 830, 1280

**Spectrometry,**  
See Telescopic correlation spectrometry

**Spectrophotofluorometric methods,**  
identification of bacteria, 764

**Spectroscopy,** 83<sup>1</sup>  
See also Atomic absorption spectroscopy; Auger spectroscopy; Internal reflectance spectroscopy  
accessories, 403<sup>1</sup>

**Stack emissions,**  
nitrogen oxides removal, 808  
particle monitor, 1302<sup>2</sup>  
sulfur oxides removal, 30, 82<sup>2</sup>,  
421, 676<sup>1</sup>, 703, 797, 806,  
1213<sup>1</sup>

**Standards**  
See also Air quality standards; Water quality standards  
auto emissions, 517

**Stanford Research Institute,**  
aircraft noise studies, 697  
smog promotion by trichloroethylene, 896, 1224

**Staplex Co.,**  
air samplers, 281<sup>2</sup>

**States**  
See also Names of specific states  
regulation of sulfur emissions,  
19  
role in pollution abatement,  
223  
water quality standards, 15  
water quality standards summary, 120, 506, 1139

**Steam buses,**  
use in San Francisco, 207

**Steam cars,**  
Senate committee evaluation,  
419

**Steel industry,**  
air pollution, 429  
pollution control technology for pickling lines, 1235  
water pollution control efforts,  
1145

**Stomates,**  
effects of ozone, 52

**Storm runoff,**  
storage in deep tunnels, 209  
water pollution aspects, 527

**Streams,**  
flow monitor, 1212<sup>2</sup>  
pollution, 494<sup>1</sup>

**Street cleaning equipment,** 594<sup>1</sup>

**Strip mines,** 1211<sup>1</sup>  
Alabama legislation, 793

**Strontium,**  
determination in milk, 171

**Styrene,**  
odor threshold, 169

**Subsurface disposal**  
See Deep well injection

**Suburbia Systems, Inc.,**  
flotation treatment systems,  
862<sup>1</sup>

**Sugar industry,**  
water utilization, 174<sup>1</sup>

**Sulfate,**  
determination in water, 396

**Sulfur,**  
determination in air by lead oxide candles, 931  
environmental cycle, 436  
New Jersey fuel restrictions,  
301

**Sulfur dioxide**  
See also Sulfur oxides  
atmospheric reactions, 436  
determination by flame photometric detector, 652  
effect on mortality, 1235  
effect on peanut plants, 759  
monitor, 590<sup>2</sup>  
rate of removal from air, 1181  
removal processes, 30, 82<sup>2</sup>,  
797, 806  
role in photochemical reactions, 882

**Sulfur hexafluoride,**  
analyzer, 591<sup>2</sup>  
meteorological tracing, 484

**Sulfur oxides, 777<sup>1</sup>**  
air quality criteria, 99  
air quality standards, 543  
formation in carbonyl sulfide  
flames, 63  
power industry pollution, 19  
removal from stack gases, 421,  
676<sup>1</sup>, 703, 1213<sup>1</sup>

**Sulfuric acid,**  
preservation of nitrogen forms  
in water, 478

**Sunshine Chemical Corp.,**  
oil spill clean-up, 1302<sup>2</sup>

**Surface drainage**  
See Storm runoff

**Surface mines, 1211<sup>1</sup>**  
reclamation project, 881

**Surface-water runoff,**  
harvesting for potable water  
supplies, 110

**Surfactants,**  
Illinois River levels, 481

**Sweco, Inc.,**  
waste water separator, 81<sup>2</sup>

**Sweden,**  
DDT restrictions, 419

**Synergism,**  
role in peanut plant damage,  
759

**System Development Corp.,**  
driving habit study, 798

**Systems analysis, 859<sup>1</sup>**  
use in solid waste manage-  
ment, 898

## T

**Taxes,**  
credits for pollution control fa-  
cilities, 196

**Technicon Corp.,**  
mobile air laboratory, 403<sup>1</sup>

**Technology**  
See Chemical technology; Sci-  
ence and technology

**Telemetering system, 493<sup>1</sup>**

**Telescopic correlation spectrom-  
etry,**  
nitrogen dioxide monitoring,  
797

**Tennessee Valley Authority,**  
Alabama strip mines legisla-  
tion, 793

**Terpene separation, 284<sup>1</sup>**

**Textile wastes, 403<sup>1</sup>**

**Theoretical models,**  
manganese in Lake Mendota,  
835

**Thermal analysis system, 402<sup>2</sup>**

**Thermal pollution,**  
control guide, 105  
power plants, 425  
use in shellfish cultivation,  
1233

**Thin layer chromatography,**  
separation of 7H-benz[de]lan-  
thracen-7-one and phenalen-  
1-one in airborne particu-  
lates, 1198

**Tires**  
See Automobile tires

**Tobacco smoke,**  
monitoring of effluents 567

**Toledo, Ohio,**  
water pollution hearing, 881

**Tomatoes,**  
effects of fluorides, 1201

**Total organic carbon,**  
continuous monitor, 1152

**Trace metals,**  
determination using ion ex-  
change membranes, 165

**Tracers**  
See Meteorological tracers; Ra-  
dioactive tracers

**Trade names,**  
listing for environmental field,  
949, 1073

**Training,**  
incinerator operators, 798  
waste treatment plant opera-  
tors, 615, 1155

**Transient state,**  
changes in logarithmic growth  
rate and cell yield, 143

**Transpiration,**  
effects of ozone, 52

**Transportation Department**  
See also Federal Aviation Ad-  
ministration  
Office of Environmental Im-  
pact, 11

**Travelers Research Corp.,**  
environmental quality, 594<sup>1</sup>

**Trees**  
See also Citrus trees  
nutrient deficiencies, 594<sup>1</sup>

**Trichloroethylene,**  
smog-forming capabilities, 896  
1224

**Trucks,**  
solid waste collection, 812

**Tubes**  
See Permeation tubes

**Tunnels**  
See Deep tunnels

**Turbidity, 184<sup>1</sup>**

## U

**UOP Air Correction Division,**  
burner, 492<sup>2</sup>

**UOP Johnson Division,**  
well screens, 599<sup>1</sup>

**Ultrafiltration, 862<sup>1</sup>**  
municipal wastes, 1147

**Ultraviolet radiation,**  
effect on oxidation of nitric ox-  
ide, 469  
volumetric sensor, 848  
water purification, 1143

**Underwater Storage, Inc.,**  
storage of vessel sewage, 697

**Underwater tanks,**  
storage of vessel sewage, 697

**Union Carbide Corp.,**  
molecular sieves, 84<sup>1</sup>  
oxygen in sewage treatment,  
109  
scrubber, 678<sup>2</sup>

**Union of Soviet Socialist Repub-  
lics,**  
Ural River pollution, 701

**Unions**  
See United Steelworkers of  
America

**Uniroyal, Inc.,**  
wastewater treatment plant,  
521

**United Air Specialists, Inc.,**  
electrostatic precipitators, 594<sup>1</sup>

**United International Research,  
Inc.,**  
sulfur dioxide removal, 82<sup>2</sup>

**United Nations,**  
Conference on Human Environ-  
ment, 9

**United States,**  
coal combustion information  
exchange with United King-  
dom, 615  
solid waste survey, 13  
water quality in U.S.-Canada  
waters, 107, 1243  
water resource regions, 9, 115  
water usage, 301

**U.S. Steel Corp.,**  
water pollution abatement ef-  
forts, 519  
water pollution hearing, 881

**United Steelworkers of America,**  
air pollution conference, 429

**Universal Interloc, Inc.,**  
water treatment systems, 403<sup>1</sup>

**Universal Water Corp.,**  
membrane for reverse osmosis  
process, 299

**University of Delaware,**  
pipeline treatment of sewage,  
531

**University of Missouri,**  
pollution conference proceed-  
ings, 777<sup>1</sup>

**University of Wisconsin,**  
animal waste disposal study,  
881  
Eutrophication Information  
Center, 101

**Unpolluted atmospheres,**  
lead aerosols, 737  
trace substances, 251

**Ural River,**  
pollution, 701

**Urban areas, 859<sup>1</sup>**  
forecasts of water require-  
ments, 904  
measurement of ultraviolet en-  
ergy in air, 848

**Urban runoff**  
See Storm runoff

**Valves, 492<sup>2</sup>**

**Vanadium,**  
analysis in airborne particu-  
lates, 1207

## V

**Vapor density,**  
dieldrin and dieldrin-soil mix-  
tures, 670

**Varian Associates,**  
Auger spectroscopy, 680<sup>1</sup>  
automated gas analyzer, 180<sup>2</sup>  
spectrometers, 493<sup>1</sup>

**Vegetation**  
See Plants

**Velsicol Chemical Corp.,**  
support of Lake Michigan  
study, 797

**Vessels**  
See Watercraft

**Viruses,**  
inactivation in sea water, 941  
transmission by water, 1235

**Visibility,**  
relationship to aerosol mass  
concentration, 913

**Voltammetry**  
See Anodic stripping voltam-  
metry

**Vulcan, Inc.,**  
solvent recovery, 185<sup>1</sup>

**Vulcan Laboratories, Inc.,**  
cyclone separator, 1302<sup>2</sup>  
water treatment, 679<sup>2</sup>

## W

**Wade Co.,**  
wet scrubber, 806

**Wager, Robert H., Co.,**  
smoke indicator, 592<sup>2</sup>

**Wallace & Tiernan, Inc.,**  
pumps, 402<sup>2</sup>

**Warf Institute,**  
study of Lake Michigan pesti-  
cides, 797

**Washington, D.C.,**  
advanced waste treatment dem-  
onstration plant, 1233  
incinerators, 681<sup>1</sup>, 859<sup>1</sup>  
Kenilworth dump, 599<sup>1</sup>, 863<sup>1</sup>

**Waste Techniques, Inc.,**  
incinerator, 1212<sup>2</sup>

**Waste treatment plants,**  
construction by federal agen-  
cies, 517  
domes, 186<sup>1</sup>  
federal construction grants,  
791, 1139, 1229  
joint industry-municipal use,  
887  
nonbiological process, 1233  
operator certification in Michi-  
gan, 872  
operator training, 615, 1155  
oxidation ditch, 1170  
paints, 677<sup>1</sup>  
phosphate removal processes,  
701

**Waste water**  
See also Industrial waste water  
analysis, 859<sup>1</sup>

**Waste water treatment, 79<sup>1</sup>, 681<sup>1</sup>,**  
776<sup>1</sup>, 1308<sup>1</sup>  
activated carbon, 314, 797,  
809, 1143, 1306<sup>1</sup>  
aerobic decomposition process,  
401<sup>2</sup>  
controller for aeration basins,  
861<sup>1</sup>  
creation of recreational lake,  
75<sup>1</sup>  
licensing agreements, 419,  
1145  
nitrogen and phosphorus re-  
moval, 536  
organic chemicals industry  
costs, 311  
polymeric flocculants, 713  
reverse osmosis, 1269

**Wastes**  
See also Specific kinds of  
wastes  
New York regulations for wa-  
tercraft, 203

**Water**  
See Specific kinds of water

**Water analysis, 279<sup>1</sup>, 282<sup>2</sup>, 586<sup>1</sup>,**  
402<sup>2</sup>, 680<sup>1</sup>, 776<sup>1</sup>, 863<sup>1</sup>  
internal reflectance spectros-  
copy, 161, 484  
nuclear methods, 132  
pyrographic method, 709  
specific ion electrodes, 34  
sulfate and phosphate, 396

**Water pollution abatement, 83<sup>1</sup>,**  
179<sup>1</sup>, 399<sup>1</sup>  
federal priorities, 891  
Lake Superior conference, 107  
national costs, 213  
regional review, 804  
steel industry efforts, 1145  
U.S. Steel Corp. efforts, 519

**Water quality, 486<sup>1</sup>, 1301<sup>1</sup>**  
requirement for dual supply  
system, 197

**Water Quality Improvement Act  
of 1969,**  
congressional action, 101, 421,  
519, 1139  
thermal pollution control pro-  
vision, 425

**Water quality standards,**  
action on state programs, 15,  
120, 506, 1139  
federal enforcement actions,  
881  
federal standard for Iowa, 1231

**Water resources, 80<sup>1</sup>, 179<sup>1</sup>, 486<sup>1</sup>,**  
586<sup>1</sup>, 859<sup>1</sup>, 1211<sup>1</sup>  
Canada, 179<sup>1</sup>  
U.S. survey, 9, 115

**Water Resources Council,**  
U.S. water needs, 9, 115

**Water sampling,**  
Lake Erie, 324

**Water systems,**  
Cleveland planning grant, 303  
forecasting municipal require-  
ments, 304  
Nebraska planning grant, 303

**Water treatment, 79<sup>1</sup>, 403<sup>1</sup>, 1213<sup>1</sup>**  
antiscalants, 282<sup>2</sup>, 679<sup>2</sup>  
chlorination, 284<sup>1</sup>, 591<sup>2</sup>, 774<sup>2</sup>  
clarifier, 776<sup>1</sup>  
deionizers, 282<sup>2</sup>, 592<sup>2</sup>, 599<sup>1</sup>  
desalination, 336  
disinfection by bromine, 854  
filter sands, 860<sup>2</sup>  
home water purifier, 180<sup>2</sup>  
ion exchange system, 774<sup>2</sup>  
neutralization systems, 596<sup>1</sup>  
organics removal, 282<sup>2</sup>  
plant design, 399<sup>1</sup>  
reverse osmosis, 1213<sup>1</sup>  
slime and algae suppressant,  
1302<sup>2</sup>  
softener, 594<sup>1</sup>  
ultraviolet radiation, 1143

**Water utilization,**  
beef sugar industry, 174<sup>1</sup>  
U.S. increases, 301

**Watercraft,**  
underwater storage of wastes,  
697  
waste disposal regulation in  
New York, 203

**Waterfowl, 677<sup>1</sup>**

**Watershed,**  
water harvest from asphalt  
treatment, 110

**Wean Industries, Inc.,**  
agreement with KSF Chemical  
Processes, Ltd., 1235

**Weather Bureau,**  
water management, 179<sup>1</sup>

**Weather data,**  
regional air pollution control  
agencies, 417

**Weather forecasting, 1211<sup>1</sup>**  
Global Atmospheric Research  
Program, 305

**Weather modification, 1211<sup>1</sup>**  
warm fog dispersal, 617

**Welles Product Corp.,**  
oil spill recovery unit, 417  
solid waste remover, 183<sup>2</sup>

**Wellman-Lord, Inc.,**  
sulfur oxides recovery process,  
99, 421, 703

**Wells**  
See also Deep well injection  
screens, 599<sup>1</sup>

**Westinghouse Electric Corp.,**  
acid mine drainage treatment  
plant, 699

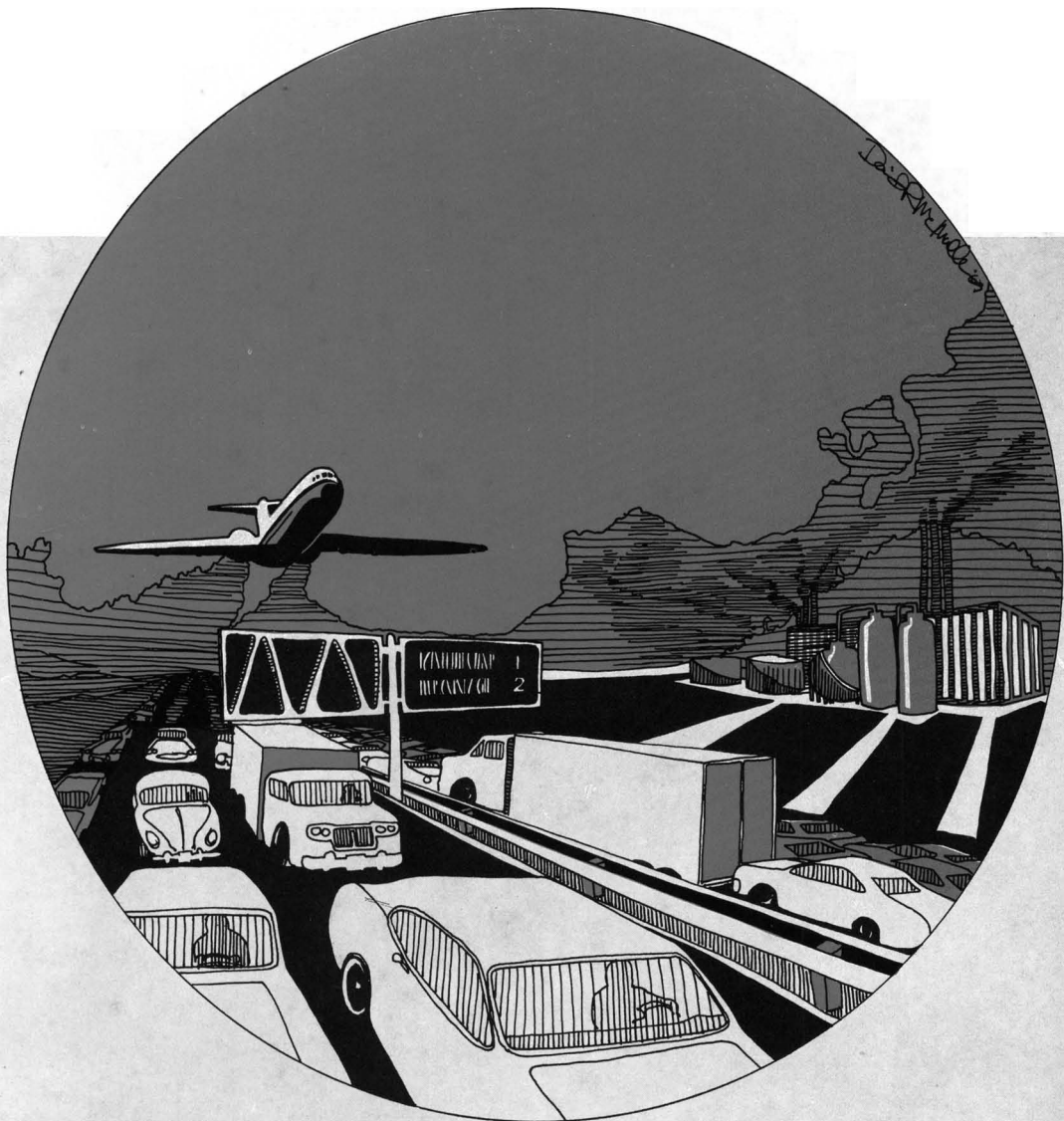
**Weston, Roy F., Co.,**  
phosphate removal studies,  
710

**Wildlife, 858<sup>1</sup>**

**Wisconsin,**  
DDT ban, 15  
pesticide residue survey, 186<sup>1</sup>

**Wood**  
See Pulp wastes

**Wyle Laboratories,**  
aircraft noise studies, 697



If You Want To  
MEASURE  
ANALYZE  
DOCUMENT  
the environment  
we live in


Let Litton Men Help You:

- Study Your Problem
- Specify Proper Hardware
- Set Up An Optimum Telemetry/Data System
- Maintain the System
- Interpret the Data Meaningfully

For the environment *you* want to measure, analyze and document, Litton can provide a meaningful, practical study, design a complete instrumentation system, and specify hardware; then produce the system, install it, calibrate it, start it up, keep it working, and help you train routine operating personnel. What more could you ask for? Lots of details, that's what — plus examples of successful environmental monitoring

systems presently installed and operating. Write or call for immediate in-depth information.

AIR & WATER QUALITY  
METEOROLOGY / OCEANOLOGY

 **Environmental  
Systems**

Litton Systems Inc.  
354 Dawson Drive,  
Camarillo, California 93010  
Phone (805) 482-0711

# high performance water pollution monitors



## SPECTRONIC® 100

Automated simplicity... set wavelength (325-925nm)—automatic system drives grating, interchanges phototubes and filters. Four place readout in three modes—0.00.0% to 100.0%T, 0.000A to 2.000A, 0000 to 2000 in concentration, with selectable positioning of decimal point. Options of single, multiple and micro flow-thru cell compartments—accept test tubes, standard rectangular or cylindrical cells, or micro flow-thru cells. Has 8.0nm optical resolution. BCD output for recording and printout devices—analogue or digital. Catalog 33-6031.

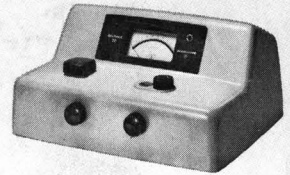
Circle No. 41 on Reader's Service Card



## SPECTRONIC® 70

Easy operation—set wavelength, adjust for 100% T or 0.0A with reference, introduce sample and read. Wide, continuous 325-925nm range. All solid-state electronics with latest integrated circuit technology assure high stability, reliability, exceptional precision. Broad sampling flexibility for up-to-50 mm path length cylindrical cells and rectangular cells—semi-micro, short path or constant temperature. Takes a variety of readouts. Catalog 33-6030.

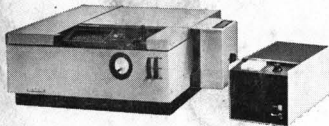
Circle No. 42 on Reader's Service Card



## SPECTRONIC® 20

The world's most widely used spectrophotometer. Extremely easy operation, wide 340-950nm range, remarkable stability, low stray light, high sensitivity. Versatility further extended by a variety of accessories including the Concentration Computer for direct concentration readings. There are over 60,000 in use all over the world. Catalog 33-266.

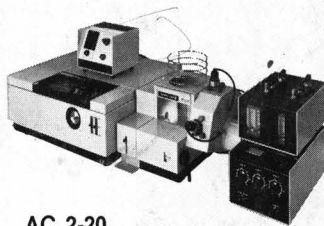
Circle No. 43 on Reader's Service Card



## PRECISION SPECTROPHOTOMETER

Precision performance and accuracy. Single beam. 190-800nm wavelength range. Most versatile, convenient, easily operated instrument on the market, with complete line of accessories. Oversize sample compartment accommodates sample cells up to 200mm long. Built-in mercury lamp for positive wavelength calibration. Choice of bandpass—2A, 5A, or 20A—constant over entire range. Catalog 33-2151.

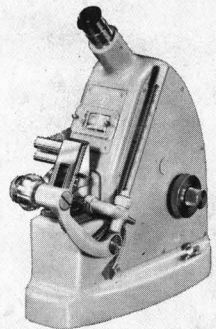
Circle No. 44 on Reader's Service Card



## AC 2-20 ATOMIC ABSORPTION SPECTROPHOTOMETER

The AC 2-20 combines all the best features of up-to-the minute AA technology. Delivers top sensitivity and accuracy; combines safety, versatility, operator convenience with exceptional performance. The finest monochromator (two 1200 grooves/mm Certified-Precision Gratings) assures superior linear dispersion, eliminates adjacent interference lines. Catalog 33-2225.

Circle No. 45 on Reader's Service Card



## REFRACTOMETERS

World's most complete line for precision testing in every index range from  $n_D$  1.20 to  $n_D$  1.71, or percent total solids from 0-85%. Operation is fast, easy and so comfortable there's no fatigue... even after all day production use. Abbe 3-L, High Range Abbe 3-L, Precision, Hand, and Juice models. Catalog 33-202.

Circle No. 46 on Reader's Service Card

