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Research and Development

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1979 Research Review

Industrial Environmental Research Laboratory

Research Triangle Park, North Carolina

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Research Triangle Park, North Carolina

March 1980

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Coal gasification plant in Westfield, Scotland, with the gasification building at left and the acid gas cleanup facility at right.

Foreword

For any organization, the beginning of a new year is a time to reflect on the year that has passed—to assess what has been accomplished and to establish goals for the future. The Industrial Environmental Research Laboratory at Research Triangle Park (IERL-RTP) in North Carolina, is no exception. It is charged with the significant task of researching, developing, and demonstrating control technologies for stationary source pollution and determining the multimedia impacts of energy and industrial processes on the environment.

IERL-RTP is pleased to present the results of its assessment of the past year's programs and accomplishments in this *1979 Research Review.* Additional information may be obtained from the appropriate program manager listed in the Information Transfer section of this report.

We trust that this *1979 Research Review* will inform the interested public of our progress toward a national goal of improved environmental quality.

John K. Burchard, Director
Industrial Environmental Research Laboratory-RTP

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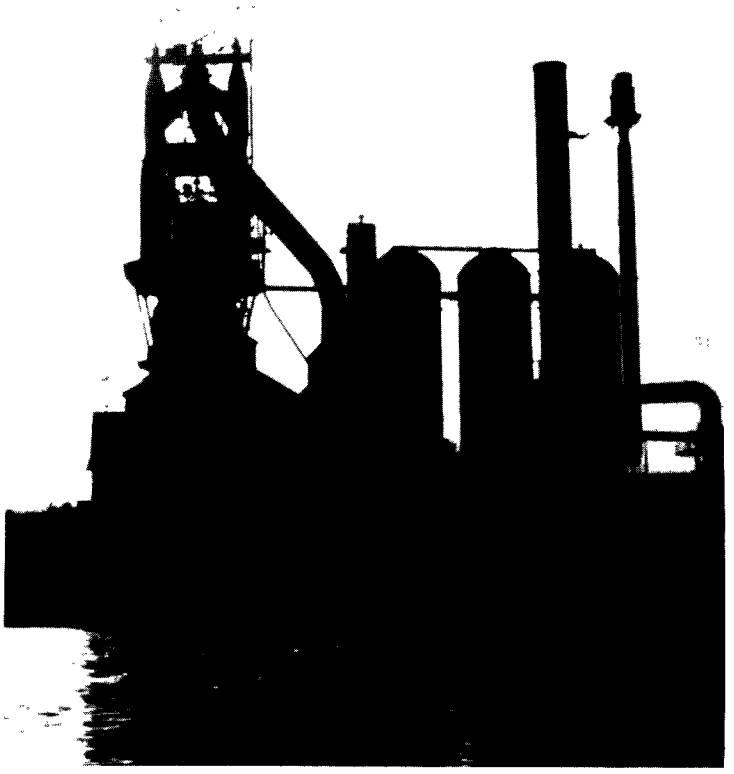
Introduction

Although mobile sources like cars and trucks contribute to our Nation's pollution problems, much of our air, land, and water pollution comes from *stationary* sources, such as power plants, oil refineries, and industries that manufacture steel, textiles, and pesticides. Today there are more than 20,000 major stationary sources in the United States and hundreds of thousands of lesser ones, including home and commercial furnaces. These sources are a primary cause of the environmental problems identified by the U.S. Environmental Protection Agency (EPA) as having "potential for widespread adverse effects on human health and welfare."

The combustion of fossil fuels—coal, oil, and natural gas—causes a large part of the pollution from stationary sources. As supplies of oil and natural gas dwindle, more power plants and industries will convert to coal, a "dirtier" fuel that emits significantly more of most major pollutants. As a result, pollution from stationary sources will increase in the years ahead unless we do something about it now.

And we are. Landmark legislation, like the Clean Air Act and the Federal Water Pollution Control Act, has made environmental quality a national policy. EPA's Industrial Environmental Research Laboratory at Research Triangle Park (IERL-RTP), North Carolina, plays an important part in carrying out this legislation. A coordinated series of research programs is underway at IERL-RTP to find the most effective and economical methods of controlling pollution from utilities and industries.

By supplying essential technical information about the pollutants that pose the most serious problems and about methods for their control, IERL-RTP supports EPA's goal of setting realistic and attainable pollution standards to improve the quality of our environment. IERL-RTP works with industry to assess the impacts of pollutants and to develop practical, cost-effective control techniques. Through research into more efficient and environmentally acceptable ways of using our fuel—especially coal—the Laboratory makes an important contribution to our national goal of energy self-sufficiency.



Blast furnaces in an integrated iron and steel plant.

Through its participation in international cooperative efforts, IERL-RTP also contributes to worldwide environmental quality. This international experience widens the Laboratory's information base and enhances the pollution control capabilities of all the nations involved.

Goals and Approach

Environmental Assessment

Effective control of pollution requires a comprehensive understanding of its source as well as the environment it affects. That is why programs at IERL-RTP begin with an in-depth analysis known as an *environmental assessment.* Environmental assessments characterize specific industrial processes much as a football scouting report sizes up the next team. The objective is to guide research and development efforts by evaluating the impacts of pollutants on our environment, economy, energy supplies, and society at large.

But what pollutants are being emitted by a source? To what extent must emissions be reduced, and how much will it cost? How will emissions of other pollutants be affected? What are the potential effects on plant operations, fuel consumption, and economics?

To answer questions like these, IERL-RTP sifts through a massive amount of information on stationary sources, pollutants, control techniques, and environmental effects. Throughout this effort, IERL-RTP works closely with other parts of EPA, with the U.S. Department of Energy (DOE) and other Federal agencies, and with manufacturers and operators of stationary sources. Where data are lacking, field tests are conducted to gather the facts.

During the environmental assessment, goals for controlling a given pollutant are defined and research needs are identified. After the best available control technology is chosen, a comprehensive analysis is conducted on the environmental, economic, and energy-related aspects of the technology.

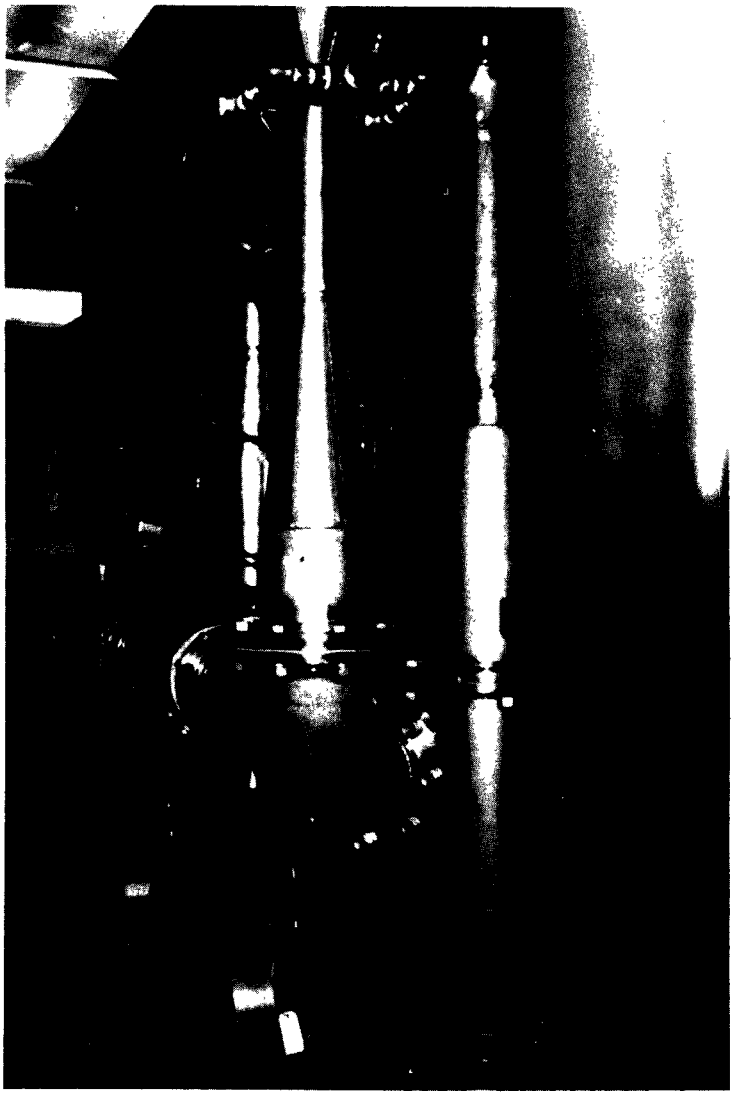
Control Technology Development

Even after an environmental assessment determines what needs to be done, the best available control technology still may be unable to bring a utility or industrial process into compliance with regulatory standards, or its costs may be prohibitive.

To solve these problems, IERL-RTP is working with utilities and industries to develop more effective and less expensive pollution control methods. This work starts in the laboratory with fundamental research into the detection and characterization of pollutants and bench-scale testing of new control techniques. The most promising techniques are evaluated in pilot-scale experiments and, finally, in full-scale field demonstrations under actual working conditions.

The two-pronged approach—environmental assessment and control technology development—allows IERL-RTP to combat pollution at *industrial process sources* and *energy-producing sources,* the two major components of stationary sources that concern the laboratory. A series of specific environmental assessment and control technology development efforts is directed at each of these sources.

This systematic approach to highly complex technical problems is paying off in improved control technologies that industries and utilities can count on, and that means a cleaner environment for all of us.



Experimental scrubber used in the IERL-RTP mobile sampling unit.

Scope of Effort

From small home furnaces to giant utility boilers, from bench-scale experiments to industrywide applications, IERL-RTP's programs to develop effective, economical pollution controls span the full range of sources and techniques. Although some of these programs are conducted in-house at the IERL-RTP laboratories in North Carolina, most are carried out through:

- Contracts with private companies
- Grants with universities
- Combined efforts with other Government agencies, such as DOE
- International cooperative agreements

IERL-RTP reviews the objectives and methodology of all its programs to prevent duplication of effort and to ensure consistency of approach. This approach promotes effective use of the limited research funds available.

As the Nation progresses toward technological breakthroughs that affect every phase of our lives, IERL-RTP is working to resolve existing problems and to identify future threats. In this way, we will be ready to make the best environmental decisions as we switch from old to new energy processes and pollution control technologies.

Controlling Pollution From Industrial Process Sources

One of IERL-RTP's concerns in its environmental assessment/control technology development efforts is the group of stationary sources known as *industrial process sources.* This category includes ferrous metallurgical processes—steelmaking and allied processes—and chemical processes—oil refining, petrochemical manufacture, and pesticide and textile production.

Ferrous Metallurgical Processes

Because steel production and finishing involve a multitude of operations, the *steelmaking industry* presents formidable challenges for assessment and control technology development.

A recent IERL-RTP study concluded that the basic oxygen process (BOP) is, and will continue to be, the dominant method for producing steel. Examination of the pollutant-producing actions in this process indicated that one of the two main operations—the injection of high purity oxygen into the hot metal mixture—was already well controlled in domestic BOP shops, whereas the second operation—charging—still allowed pollutants to escape into the air. Four promising control systems were identified for followup, thus offering four alternatives to fit the unique operating and physical setups in domestic shops.

In addition to studying the basic process of producing steel, IERL-RTP is researching the significance of some unexpected sources of pollution in the steelmaking industry. For instance, the impact of abnormal operating conditions on air and water pollution has been seriously underrated. The Laboratory reached this conclusion by analyzing existing data and inferring that these data were representative of the industry as a whole. Available data on sintering blast furnace ironmaking, open hearth furnaces, BOP steelmaking, and electric arc furnaces, and on the air and water pollution control equipment used in these operations, formed the basis for this assumption. A recent study revealed that the lubricants, oils, greases, and hydraulic fluids used by the steelmaking industry are other unexpected sources of pollutants. It has been assumed that most of these materials are recovered and recycled, but IERL-RTP's study estimated that 63 percent of the oils, greases, and hydraulic fluids used by a typical plant enter the environment as pollutants: 44 percent as solid waste, 10 percent as air pollution, and 9 percent as water pollution.

The sections that follow present highlights of the year's research accomplishments in ferrous metallurgical processes.

Symposium on Iron and Steel Pollution Abatement Technology

The first EPA symposium on iron and steel pollution abatement technology and environmental assessment was held October 30-November 1, 1979, in Chicago, Illinois. The symposium, with separate sessions on air, water, and solid waste, served as a forum for information exchange on environmental control research and development that is being conducted by EPA and the steelmaking industry.

During the 3-day symposium, government environmental officials, contractors for EPA-sponsored work, and industry personnel presented some 25 papers on all phases of environmental assessment and control in the steel industry. Overviews on the various impacts of pollution control legislation on the steel industry were presented by Donald Goodwin of EPA's Office of Air Quality Planning and Standards (OAQPS), Robert Schaffer of EPA's Effluent Guidelines Division, and Eugene Meyer of EPA's Region V Hazardous Waste Management Section. A broad analysis of environmental research and development in the steel industry was presented by Earle F. Young of the American Iron and Steel Institute (AISI). The symposium papers are included in the published proceedings of the symposium.[1]

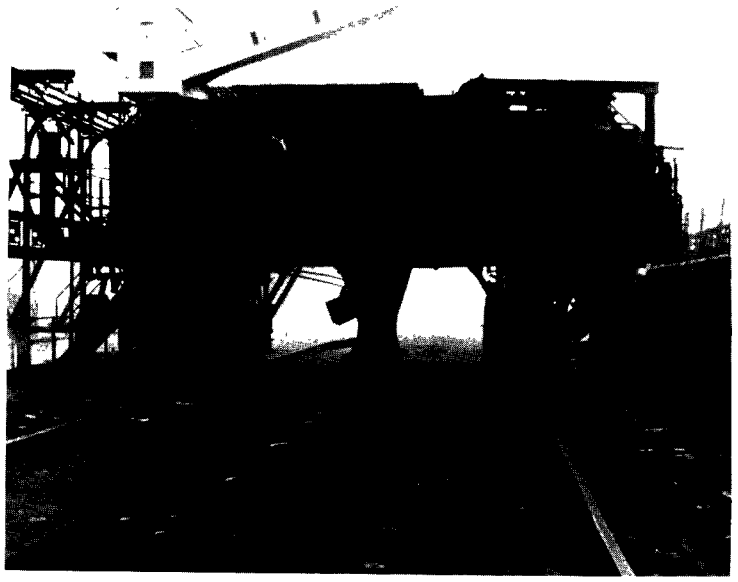
Approximately 260 people attended the symposium. The ratio of people involved in iron and steel pollution abatement was balanced, with nearly equal representation of regulatory agencies and industry. Comments received from participants indicate a continuing need for and high interest in similar symposia in the future.

Coke Battery Environmental Control Cost-Effectiveness Model

A computer model has been developed that can determine the method of lowest cost for achieving a specified emission reduction for the whole cokemaking industry or any subset. The model includes 20 air pollution sources per battery (for example larry car charging, combustion stack), 9 control options for each source, and 4 air pollutants (total suspended particulates, benzenesulfonic acid, benzo(a)pyrene, benzene). The optimization mode will minimize capital or operating cost to achieve a specified pollutant reduction or, for a specified cost, will minimize emissions of one of the pollutants. Some of the baselines that can be selected are no control, meets average State Implementation Plan (SIP), and meets most stringent SIP.

This model is currently operational on EPA's computer at IERL-RTP. Consideration is being given to expanding the model to include all major steel plant sources in addition to cokemaking on a multimedia basis.

[1] U.S. Environmental Protection Agency, *Proceedings: First Symposium on Iron and Steel Pollution Abatement Technology* (NTIS No. to be assigned), EPA 600/9-80-012, Feb. 1980



Larry car charging a coke oven from atop a coke oven battery. In the background is the coal bunker, where the larry car is loaded.

Feasibility of Total Water Recycle in the Steel Industry

An engineering study to determine how five integrated U.S. steel plants could ultimately achieve total recycle of water was recently completed. The plants represent a cross section of plant-specific factors, such as size, age, location, and available space, that are present in U.S. steel plants. Specific conceptual engineering designs were prepared to improve each plant's present water discharge situation. The goals were to meet the Clean Water Act's 1984 Best Available Technology limitations and eventually to achieve total water recycle. Potential treatment technologies for meeting these goals were evaluated; the most promising were incorporated in the plant designs. Capital and operating costs and energy requirements were estimated, and problems associated with implementation of the designs were addressed. Problems included the lack of steel plant experience with the technologies required, the high cost and energy requirements, the additional solid waste disposal problems, and the more difficult management requirements for sophisticated water systems. The report on the study is intended as a reference tool for planning and implementing programs that will enable steel plants to meet the more stringent water quality requirements of the future.

Mobile Wastewater Treatment System on Steel Plant

IERL-RTP is using a mobile wastewater treatment system to investigate and evaluate the effectiveness of advanced wastewater treatment technology for steel plant effluents. Under EPA Contract No. 68-02-2671, Rexnord, Incorporated, has designed, constructed, and is operating a mobile system for the Metallurgical Processes Branch. The work will provide data to support the development of effluent guidelines for this industry and will provide information to help the industry meet the guidelines.

The equipment is mounted in trailer vans and, because it is self-contained, requires only connection to plant utilities and the wastewater source for operation. Facilities for physical/chemical treatment and biological treatment are available. The equipment can be operated in any logical sequence and is large enough to make direct scale-up to commercial size reasonable.

The first studies using the mobile wastewater treatment system analyzed coke plant and blast furnace wastewaters, two of the most contaminated wastewaters found in steel plants. A recently completed 3-month study evaluated treatment of blast furnace wastewater using three basic physical/chemical treatment schemes—chlorination, ozonation, and reverse osmosis. Two more studies evaluating coke plant wastewater treatment are scheduled for the near future. Two separate treatment approaches—biological oxidation and chlorination/carbon adsorption—will be evaluated in the coke plant tests.

Additional work will be done over the next several years using the mobile wastewater treatment system for the steel plant sources considered most important by EPA. The Office of Research and Development (ORD) will work closely with EPA's standard-setting and enforcement branches to determine the best approach for this activity.

EPA/AISI Anticipatory Research Program

An anticipatory research program for the iron and steel industry, funded by AISI and EPA, began in 1977 and continues to provide a framework for cooperation among EPA, industry, and university technical personnel in pollution control technology concepts and communications.

These projects cover a wide spectrum of topics, including measurement and control of windblown dusts, investigation of factors influencing biological nitrification of steel industry

wastewater, removal of cyanide from cokemaking and blast furnace wastewater, removal of ammonia by filtration through polymer-coated glass matrix adsorption beds, and treatment of steel plant emissions containing small concentrations of hydrocarbon vapors. In addition to the general benefits of the overall program given above, the individual projects often show substantial potential to understand pollution problems better or to alleviate them at relatively modest cost.

The grant applications, which cover all media, are subjected to individual review and selection by both EPA and AISI. The AISI Research Committee monitors anticipatory research program projects for the industry, whereas project officers from IERL-RTP's Metallurgical Processes Branch monitor these projects for EPA.

Development of Novel Coke Oven Door Seal

One of the chronic air emission problems from byproduct coke oven batteries—leakage of organic vapors through small openings around the doors—is being addressed with development of a novel coke oven door seal.

This jointly funded EPA/industry project, which commenced in 1974 with a concepts study, has proceeded through design and development and is currently in the full-scale field demonstration phase. Four demonstration seals were fabricated and installed in July 1979 on a 6-m- (20-ft-) high battery at Bethlehem Steel's Lackawanna Plant. These seals, three of which have been in continuous operation since installation, show excellent sealing except at the corners. The fourth seal installation is being modified in light of stress data obtained by the contractor on a full-scale end segment in the contractor's laboratory. Modifications are intended to reduce stresses in the corners, which should reduce warpage to an acceptable level.

Four additional seals are currently being fabricated for a 4-m (13-ft) battery at Republic Steel Corporation's Youngstown Works. Lessons learned at Lackawanna are being factored into the seal design.

Solid Waste Disposal in the Iron and Steel Industry

The iron and steel industry is the largest single industrial producer of solid waste. A recently completed study examined the solid wastes generated by ironmaking and steelmaking, with emphasis on the impact of Section 4004 of the Resource Conservation and Recovery Act (RCRA). The quantities, properties, and origins of wastes are estimated, current waste disposal practices are discussed, and the potential for ground water pollution is identified in the final report. Cost estimates are given for collection of leachate that could endanger ground water.

A major finding of this study is that, although most iron and steel wastes are not listed as hazardous, leaching test results indicate that almost every type of iron and steel waste potentially endangers ground water. Leachate collection, which would be required for proper landfill management of these wastes under RCRA, would increase the cost of iron and steel waste disposal by approximately 40 percent.

Identification of Hazardous Pollutants by Iron and Steel Assessments

Initial studies in a broad IERL-RTP environmental assessment program have shown the presence of hazardous pollutants in several ferrous metallurgical processes. The environmental assessments include EPA Level 1 screening analysis and, in many cases, Level 2 verification analysis. Both procedures employ the latest techniques and environmental assessment methodologies. Various ferrous metallurgical processes have been selected for assessment based on the expected environmental problems created by the process, the information needs of EPA's regulatory and enforcement offices, and the opportunity to coordinate assessments with other ongoing activities.

The major results to date have been related to coke plant byproducts. Polynuclear aromatic hydrocarbons (PAH's) have been identified and quantified in coke quench tower emissions, oven door leaks, fugitive emissions from the byproduct recovery process, and coal preheater emissions. An intense sampling effort has resulted in a refined quantification of fugitive emissions from open sources in steel plants. Major quantities of volatilized oils and lubricants have been identified in the ventilation air from steel rolling operations. Various iron foundry casting operations have been examined and show unexpectedly low levels of organic air emissions; however, further efforts are proposed in the foundry area. Preliminary evaluation of an assessment of ferroalloy operations indicates that the ferroalloy process is an unexpectedly large source of PAH emissions.

Chemical Processes

In addition to ferrous metallurgical processes, IERL-RTP is examining numerous chemical processes for possible pollutant discharges.

In the *petroleum industry,* IERL-RTP is concerned primarily with hydrocarbon emissions from such sources as petroleum refining, petroleum storage tanks, and gasoline service stations. Fugitive emissions are being emphasized in an ongoing environmental assessment of the petroleum refining industry. The study indicates that most of these emissions are caused

by a relatively small percentage of the refinery components (for example, pumps and valves) that might be suspected of hydrocarbon leaks. An upcoming report will contribute important data on emission factors for fugitive sources in oil refineries. Data from this study already are being used by OAQPS to establish oil refinery air pollution emission guidelines.

Manufacturers of *textiles* and *pesticides* are potential polluters of water because both industries use large volumes of water in their processing operations. In a major research project being conducted cooperatively with the American Textile Manufacturers' Institute, the Northern Textile Association, and the Carpet and Rug Institute, IERL-RTP is seeking the Best Available Technology Economically Achievable (BATEA) for the textile industry and is contributing data to EPA's Effluent Guidelines Division for use in preparing proposed 1983 guidelines for the textile industry.

For the pesticide industry, IERL-RTP is studying several means of removing pollutants from wastewater streams. One innovative and promising process employs supercritical carbon dioxide to regenerate activated carbon, a commonly used medium for cleaning wastewaters. If the process proves as effective as preliminary studies suggest, it will eliminate the need to dispose of activated carbon, a sizable task that has hampered the pesticide industry in the past.

IERL-RTP also has contributed to improved technology for disposing of organochlorine wastes, the best known of which is the highly toxic Herbicide Orange. Studies have demonstrated that incineration is the best currently available means of disposing of these wastes. Because incineration at sea presents the least threat to the environment, the laboratory has contributed its monitoring expertise over the past 4 years in a series of organochlorine test burns. Here, again, international cooperation has resulted in a wider base of knowledge. IERL-RTP, as well as France, the Netherlands, and West Germany, contributes data to the Intergovernmental Maritime Consultative Organization. Most recently, representatives from IERL-RTP and the French Government monitored an organochlorine burn aboard ship in the North Sea.

The sections that follow present highlights of the year's research accomplishments in chemical processes.

Fugitive Volatile Organic Compound Emissions

Fugitive emissions from petroleum refineries and petrochemical process units are a significant source of atmospheric volatile organic compounds (VOC's). VOC emissions contribute to the development of photochemical smog; in some cases, specific VOC's (such as benzene) are known hazardous materials.

Fugitive VOC emissions are caused by:

- Leaking components, such as valves, flanges, pump and compressor seals, and relief valves
- Spills
- Oily liquids exposed to the atmosphere, such as from open drains, wastewater ditches, cooling towers, and wastewater treatment systems

Research in fiscal year 1979 focused on two aspects of the fugitive emission problem: determination of the rate of fugitive emissions (that is, development of emission factors) and evaluation of monitoring and repair programs to control fugitive emissions.

Data were collected by Radian Corporation and Monsanto Research Corporation in petroleum refineries and petrochemical plants, respectively, to develop fugitive emission factors for various sources and to determine the frequency of leaks. In addition, data were collected by Radian to determine the effectiveness of maintenance in reducing fugitive emissions from petroleum refineries. Also, IERL-RTP cooperated with IERL-Cincinnati in developing a project to determine the effectiveness of valve maintenance in reducing emissions from petrochemical plants.

Achievements in fiscal year 1979 included:

- Development and publication of emission factors and leak frequency data for various emission sources in petroleum refineries
- Development of a method for evaluating the effectiveness of leak detection and repair programs
- Completion of all data collection associated with the assessment of atmospheric emissions from petroleum refining

Fiscal year 1980 will see the completion of the petroleum refinery assessment project, including an update of EPA's publication, "Compilation of Air Pollutant Emission Factors" (No. AP-42). The Symposium on Assessment of Air Emissions From Petroleum Refineries—held in Austin, Texas, in November 1979—presented the results of this effort. Work on emissions from petroleum refinery wastewater systems and frequency of leaks in petrochemical process units will also be conducted in fiscal year 1980.

Hyperfiltration Studies Related to Wastewater Recycle/Reuse in the Textile Industry

IERL-RTP has long supported research and development in the area of hyperfiltration as a means of wastewater pollution

control, energy recovery, and material conservation. Hyperfiltration is a rapidly growing technology now being used extensively for water desalination and boiler feedwater demineralization. Municipal treatment plants also use hyperfiltration. Its use in industry for wastewater pollution control has been limited thus far to experimental units.

Perhaps one of the most significant hyperfiltration projects managed by IERL-RTP is being conducted under an interagency agreement with the U.S. Department of the Interior, DOE, and IERL-Cincinnati. The project involves the design, construction, and operation of a hyperfiltration demonstration plant at the LaFrance Division of Riegal Textile Company, LaFrance, South Carolina. Riegal supplies approximately 30 percent of the funding in this cost-sharing project. The total cost of the project over a 3-year period is expected to be $1.7 million.

Phase I—testing of competitive membranes and design of the plant—has been completed. Phase II—construction and initial shakedown of the plant—is underway and all equipment is on order. The project will be completed by 1981.

The plant will provide for recycle of wastewater to a continuous Kuster dye range with attendant recovery of energy in the form of heat because water in the dye range exits at about 71° C (160° F). Various means for recovering concentrated dyes and salts are being examined.

Other projects on hyperfiltration completed during 1979 are: *Energy Conservation Through Point Source Recycle with High Temperature Hyperfiltration,*[2] *Evaluation of Hyperfiltration for Separation of Toxic Substances in Textile Process Water,*[3] and *Hyperfiltration Processes for Treatment and Renovation of Textile Wastewater.*[4]

Characterization of Wastewater Pretreatment Needs in Pesticide Manufacturing

Under the Clean Water Act of 1977, the pesticides manufacturing industry will be subject to effluent guidelines for toxic pollutants as well as pretreatment regulations for (other) pollutants that adversely affect publicly owned treatment works (POTW's) or are not susceptible to treatment by such works.

Because EPA must identify potential problem areas and provide avenues for their resolution, IERL-RTP has supported and continues to support laboratory and pilot studies on the treatability of pesticide manufacturing wastewaters.

A recent treatability study by the Laboratory has investigated a triazine herbicide, an organometallic herbicide, a thiocarbamate fungicide, and a nitrated aromatic herbicide.

The study methodology employed and the results obtained are based on the use of laboratory bench-scale activated carbon and activated sludge wastewater treatment units. Pesticide wastewaters, at dilutions of 1:10 and 1:100 with municipal wastewaters, were investigated. The treatability effectiveness of various pesticide wastewaters was evaluated based on the measured removal of known pesticides and their intermediates, the treatability effects on traditional wastewater treatment parameters such as chemical oxygen demand and color, and bioassays with freshwater fish and algae.

Results indicate that activated carbon pretreatment of the triazine, thiocarbamate, and nitrated aromatic pesticides can reduce pesticide levels for these wastewaters. The wastewater concentration of organometallic pesticide was not reduced significantly by activated carbon pretreatment.

Biological treatment of the four pesticides studied indicated ineffective treatment of the pesticide wastewaters. Measured levels of the triazine and organometallic pesticides were not significantly reduced by the activated sludge treatment, although the biological treatment system itself was not impaired. It was noted, however, that the retention of the metallic pesticide component could signify failure of the activated sludge unit during longer runs. Activated sludge treatment of the thiocarbamate pesticide was characterized by buildup of the pesticide in the sludge and by the identification of less desirable pesticide intermediates in the wastewater effluent. The nitrated aromatic pesticide caused loss of sludge solids in the activated sludge unit and was unaffected by the activated sludge treatment.

Catalytic Incineration of VOC Emissions

Incineration is an effective means for controlling VOC emissions, and thermal incineration is used throughout the petrochemical industry. Catalytic oxidation is a recognized means of controlling VOC emissions, but the lower energy requirements and the ability to recycle energy have caused an increase in the use of catalytic incinerators. In many cases, however, data on the efficiency of catalytic incineration are inadequate for a rigorous assessment of its overall control effectiveness. Lack of adequate data is a critical problem for OAQPS in their efforts to set emission regulations.

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[2] U.S. Environmental Protection Agency, *Energy Conservation Through Point Source Recycle With High Temperature Hyperfiltration,* NTIS No. Pb 299-183, EPA 600/7-79-131, June 1979

[3] U S. Environmental Protection Agency, *Evaluation of Hyperfiltration for Separation of Toxic Substances in Textile Process Water,* NTIS No. Pb 80113889, EPA 600/2-79-118, June 1979.

[4] U S. Environmental Protection Agency, *Hyperfiltration Processes for Treatment and Renovation of Textile Wastewater,* NTIS No. Pb 80119563, EPA 600/2-79-195, Oct. 1979.

To assess the effectiveness of catalytic incineration for controlling VOC emissions, a contract was awarded to Engelhard Industries, a major catalyst manufacturer. The project involves evaluation of catalytic incineration of emissions from two processes:

- Formaldehyde (FORMOX)—full scale
- Ink solvents, plastic sheet printing—pilot scale

Results collected in fiscal year 1979 indicate that catalytic incineration is very effective in controlling VOC emissions from these processes. An overall efficiency of greater than 99 percent has been achieved in tests to date. Further testing will enable evaluation of the catalyst's effective life.

Granular Activated Carbon Regeneration Using Supercritical Carbon Dioxide

The use of supercritical carbon dioxide for regenerating activated carbon was investigated and showed promise for reducing the cost of carbon regeneration. It was also reported that initial experimental work on pesticides, particularly alachlor and atrazine, indicated efficient regeneration.

This work has now progressed to the point that negotiations are underway with a pesticide company for construction of a demonstration plant.

In addition, the work is being expanded to include regeneration of granular activated carbon used to adsorb VOC's with special emphasis on gasoline vapors.

Offshore Incineration Feasibility Study: Phase I—Conceptual Design

Incineration at sea has been determined to be an effective and environmentally acceptable method for the destruction of organochlorine waste, that is, highly toxic chlorinated hydrocarbons including pesticides, polychlorinated biphenyls (PCB's), and polybrominated biphenyls (PBB's).

At-sea (offshore) incineration has been employed in European waters since 1969 and in the Gulf of Mexico, at intervals, since 1974. At-sea incineration is regulated by EPA under the Marine Protection, Research and Sanctuaries Act of 1972.

In January 1979 EPA and the U.S. Coast Guard responded to a proposal by Chevron Oil Company to transfer an offshore drilling platform to the Coast Guard at no cost. The platform is located approximately 100 km (60 mi) south of Mobile Point, Alabama, and 120 km (75 mi) east of North Pass, Louisiana.

A preliminary assessment of the structural integrity of the 43- by 36-m (140- by 117-ft) oil platform and its utility as an offshore incineration site led EPA and the Coast Guard to request a 2-year extension of Department of the Interior lease stipulations that would have required removal of the platform by July 1979.

EPA, in cooperation with the Coast Guard, is currently conducting a feasibility study for use of the platform. This study will provide conceptual designs for an incineration system (including hardware and operating procedures) on the platform and a shore-based support facility. As part of the study, the cost of installation and operation of the system and its effects on air and water quality will be estimated for the system.

The conceptual design is focusing on the use of a rotary kiln incinerator with a ram charger feed and afterburner. The system will handle either liquid or solid waste, burning them at 1,000° to 1,500° C (1,832° to 2,732° F) under negative pressure to prevent losses during firing.

System performance will be evaluated through the continuous monitoring of total hydrocarbons, carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2). Hazardous waste destruction efficiencies will be monitored by use of gas chromatography (GC) and gas chromatography/mass spectrometry (GC/MS) measurements for specific components.

Stack gas emissions will be monitored before and after any seawater quench for the constituents mentioned above as well as for total particulates; organic compounds and inorganic elemental emissions will be collected in solvent-filled impinger sampling trains.

Occupational exposure will be monitored by requiring ambient air quality spot tests for organics, sulfur oxides (SO_x), nitrogen oxides (NO_x), CO, and halogen acids. Facility cleanliness will be checked by extraction and analysis of wipes from environmental surfaces. GC and GC/MS analysis will be used.

Chesapeake Bay Program Toxic Point Source Assessment

The Chesapeake Bay program is designed to discover and evaluate those factors responsible for the deterioration of the Bay's ecosystem and to develop management strategies for the restoration and protection of the ecosystem. The Toxic Point Source Assessment is one aspect of the overall Bay program.

The Toxic Point Source Assessment has three objectives:

- Characterize the effluents of a broad range of industries discharging into the Bay or its tributaries to assess the impact of these discharges on the Bay ecosystem (such characterization shall particularly stress toxicity).

- Develop a plan for characterization of effluents that may be implemented by the States and EPA to support discharge control decisions.
- Support other activities sponsored by the Chesapeake Bay program in the areas of food chain accumulation of toxic materials and toxic material transport.

The Toxic Point Source Assessment is being conducted in three phases. The first phase, which has been completed, inventoried the major industrial discharges and rated each outfall in the Bay Basin for potential toxicity. This project, which was based on readily available information evaluated with engineering judgment, identified and chemically described 274 outfalls. From this list, 80 were selected for further characterization in the subsequent phases of the Toxic Point Source Assessment.

The second phase is to develop and test a chemical and biological characterization protocol while assessing 50 of the 80 outfalls. The chemical characterization includes specific analysis of those compounds believed to be present as well as a general class analysis. Biological characterization includes both health effects and acute ecological effects testing.

The methods developed and tested during the second phase will be taught to State and EPA personnel during Phase III while the remaining 30 outfalls are characterized cooperatively. The exchange of results between the Point Source Assessment and other Chesapeake Bay program activities will continue during Phases II and III, which are under contract.

Controlling Pollution From Energy Sources

Precombustion Controls

One of the most promising ways of reducing emissions of sulfur, fly ash, and trace elements is to remove them in the *precombustion* stage, that is, before the fuels are burned. For the near term, IERL-RTP is investigating a number of physical and chemical methods for cleaning fuels. In line with our Nation's energy policy, the emphasis of this research is on fuel treatment methods for coal and waste oils. For the longer term, the Laboratory is researching methods of converting coal into cleaner burning products, such as synthetic natural gas and liquefied coal.

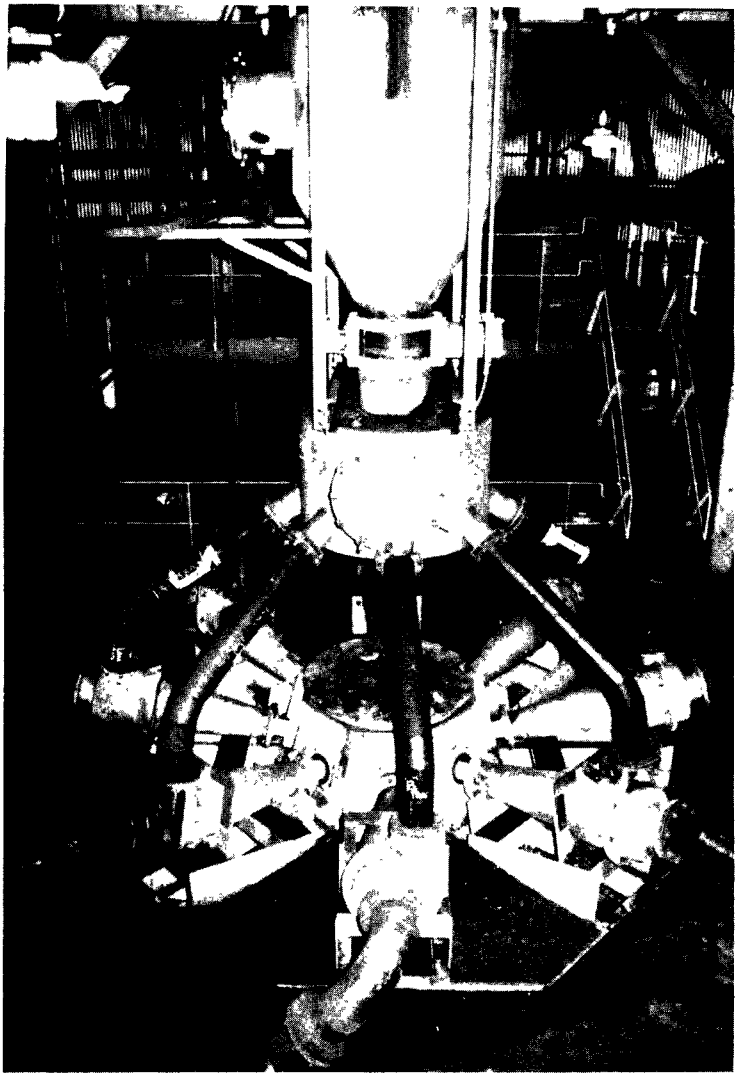
Coal Cleaning and Coal Conversion

Physical processes for coal cleaning change the physical form of coal (for example, by pulverizing) but not its molecular structure. Physical processes are especially attractive to utilities and large industries for two reasons. First, they are less costly than other sulfur dioxide (SO_2) removal alternatives, such as flue gas desulfurization; second, they do not present the corrosion/sealing problems experienced with flue gas desulfurization systems. These physical processes for coal cleaning are suitable for utilities that already are close to complying with SO_2 control regulations (those that must reduce SO_2 emissions by less than 50 percent to be in compliance), but are not effective for utilities that must reduce their SO_2 emissions by 50 percent or more to reach compliance.

At Pennsylvania Electric Power Company's Homer City facility, IERL-RTP helped to install a multistream coal-cleaning plant that can remove sulfur and ash from up to 1,100 Mg (1,200 tons) of coal per hour. Data from the Homer City study will go a long way toward improving the cost effectiveness of physical fuel treatment methods.

Selected pollutants in coal can be changed to nonpolluting substances through chemical reactions. These *chemical processes* may be a more efficient means of supplying clean coal to small combustion sources, including commercial and residential furnaces. With the support of IERL-RTP, several studies of chemical cleaning methods—including hydrothermal treatment, microwave treatment, and flash desulfurization—are underway.

Environmental assessments provide data to all these coal-cleaning projects. Current projects include analysis of the toxicity of wastes from coal cleaning and combustion, examination of the environmental effects of the steps between coal mining and burning, and assembly of detailed information on the geological factors that determine coal's mineral and elemental variations to identify the best cleaning process for each major type of coal in the United States.



"Spider" cyclone classifier at Pennsylvania Electric Company's physical coal-cleaning plant in Homer City, Pennsylvania.

Turning *solid coal* into *synthetic fuels,* such as liquefied coal and coal gas, represents a positive step toward meeting our national energy and environmental goals. These synthetics are relatively clean burning and use our most plentiful domestic fuel—the sizable deposits of lower quality coals that have been bypassed until now because of their high pollutant content. Coal conversion techniques (although very expensive) have

been available for years, but the technology needed to apply these techniques economically is still evolving. Synthetic fuels have not become cost effective because other cleaner fuels have been available. Questions remain to be answered about the emissions we can expect from the conversion of coal and from the combustion of synthetic fuels.

To determine how the widespread use of coal conversion will affect our environment, IERL-RTP is sponsoring extensive environmental assessments. For example, at Georgia Power Company's Mitchell Plant near Albany, Georgia, liquefied coal is being fired for the first time in a large utility boiler. Tests by IERL-RTP at this plant are producing a detailed inventory of the emissions that result from firing liquefied coal, as well as information about overall boiler efficiency with this synthetic fuel. At North Carolina State University in Raleigh, a pilot-scale coal gasifier is undergoing a variety of tests to supply answers to questions about the conversion process itself; for example, how can different controls reduce emissions of coal tar, particulates, and dust? Ultimately, the information for IERL-RTP programs like these will help planners to predict the environmental impact of coal conversion and to specify controls for commerical-scale application.

The sections that follow present highlights of the year's research accomplishments in coal cleaning and conversion.

Feasibility of Cleaning Ohio Coals Economically. An Ohio Edison steam electric plant with a history of noncompliance with particulate emission standards is the object of a study on the cleanability of Ohio coals. Teknekron is examining the present and potential supply of coals (both cleaned and uncleaned) to the W. H. Sammis plant in Stratton, Ohio. The study will determine the extent to which physical coal cleaning can enable Sammis to increase its use of Ohio coals and still meet existing particulate and planned SO_2 standards.

To adhere to the design parameters of its electrostatic precipitators and to meet the particulate and SO_2 emission limitations, Sammis must burn coal that, on a 24-hour average, produces ash at no more than 4.30 ng/kJ (10 lb/10^6 Btu), SO_2 at no more than 1.92 ng/kJ (4.46 lb/10^6 Btu) for 70 percent of the plant's capacity, and SO_2 at no more than 0.69 ng/kJ (1.61 lb/10^6 Btu) for the remaining capacity.

Preliminary findings indicate that, although coal cleaning is not extensively practiced, it is an economically feasible strategy. At present only about 25 percent of Ohio coals are cleaned and then only to remove mineral matter. The degree of cleaning practiced at most Ohio coal-cleaning plants is not sufficient for compliance with the standard of 1.92 ng/kJ (4.46 lb/10^6 Btu) for SO_2. A number of Ohio coals, however, *can* be economically cleaned to meet this standard as well as the ash limitation. Because few Ohio coals can meet the SO_2 requirement of 0.69 ng/kJ (1.61 lb/10^6 Btu), the most obvious compliance strategy is to clean Ohio coals to the SO_2 level of 1.92 ng/kJ (4.46 lb/10^6 Btu and purchase low sulfur Appalachian (non-Ohio) coals for the SO_2 standard of 0.69 ng/kJ (1.61 lb/10^6 Btu). Teknekron is to complete the Sammis study by performing economic analyses of alternative SO_2 emission compliance strategies.

Results of Bench-Scale Coal Gasifier Testing. In attempting to evaluate the pollution potential of coal gasification, Research Triangle Institute (RTI) has been operating a small, laboratory-scale reactor along with extensive sampling and analysis of reactor streams. A statistical analysis of the voluminous data obtained from approximately 60 gasification test runs has been performed to determine the correlations between operating parameters, coal types, and pollutant production. Some conclusions found to date are summarized in the following paragraphs.

In the production of pollutants, the coal total sulfur, sulfate, and volatile contents were the most important factors influencing pollutant yields. Although the reason is not yet clear, coal sulfur was found to correlate significantly with the production of both sulfur and nonsulfur pollutants. The most important gasifier operating variable affecting pollutant production was the steam-to-coal ratio. This variable had a significant influence on total benzene-toluene-xylene production. Heating rate was found to be influential only in the yield of the fused aromatic hydrocarbon (also known as polynuclear aromatic, or PNA) fraction of the tar.

Increases in both the air-to-steam ratio and the bed temperature decreased the yield of several of the major pollutants. However, no significant correlations existed between any of the selected independent variables and the yields of phenol and naphthalene. Because phenol is the primary pollutant in the gasifier condensate, a mechanistic rather than the statistical approach to explaining the production of phenol is warranted.

The preceding statistical correlations were based on data from gasification tests conducted in the fixed-bed mode with batch feed. Currently, a second series of tests is underway to study in greater depth the effects of varying operating conditions on pollutant generation. For this parametric test series, the reactor has been modified to operate in the fluidized bed mode with continuous coal feed. The reactor operating conditions that are being varied include coal particle size, reactor pressure, steam/air ratio, and coal additives.

In six parametric tests with three different coal types, pollutant production was observed for the product gas in the ranges shown in Table 1. The wide ranges observed, usually greater

than one order of magnitude, support an approach to emission control through process modification. Changing coal type, pressure, mesh size, and other process parameters influences pollutant output.

Synthetic Fuels Wastewater Treatability Studies. The University of North Carolina at Chapel Hill is conducting a major research effort to study treatment methods applicable to coal conversion process wastewaters. Preliminary information on the biotreatability of such waters is being gathered using a synthetic mixture representative of actual wastewaters. In addition, an actual wastewater supplied by EPA has been subjected to treatment by activated carbon adsorption, coagulation, and precipitation.

Biotreatment involves bringing the wastewater into contact with microorganisms that can use the organic contaminants as a food supply. The University of North Carolina is using a set of eight bioreactors to perform this study by allowing the synthetic wastewater to come into contact with an active biomass for various residence times. Influent and effluent streams from these bioreactors are analyzed for chemical composition, toxicity of aquatic life, and potential harmful effects to human health. Results to date indicate that wastewaters from synthetic fuel plants will be biologically treatable but that some degree of dilution may be necessary. Biological treatability improves with increased solids residence time (sludge age), but it appears that a sludge age minimum of 10 days may be necessary to achieve a reasonable degree of treatment. A mammalian cytotoxicity assay, used as an indicator of potential human health effects associated with the wastewater, shows that cytotoxicity decreases with increasing degrees of biotreatment.

Table 1.
Pollutant Production Ranges for Three Coal Types

Compound	Compound produced/ carbon converted (g/g)
Hydrogen sulfide	3,700-36,000
Carbonyl sulfide	270-4,500
Thiophene	8-670
Benzene	3,600-17,000
Toluene	1,700-5,800
Phenol	62-920
Benzofuran	8-170

Acidification of samples of actual coal gasification wastewaters obtained from EPA proved to be an effective means of removing dissolved and suspended tars. Concomitant reductions in total organic carbon and chemical oxygen demand were observed with tar reductions. The addition of strong acid—approximately 40 milliequivalents per liter of wastewater—was required to obtain about 95 percent removal of tar from the wastewater. The addition of this amount of acid to the wastewater lowered the pH of the waste to about 5.0.

Alum was found to be ineffective as a coagulant in chemical treatment of the wastewater. It is proposed that complexes formed by aluminum and ligands present in the wastewater result in the solubilization of aluminum and the inhibition of its effectiveness as a coagulant. Two organic cationic polyelectrolytes were shown to be effective coagulants, but only at high dosages. The cost of these polymers probably precludes their use on a large scale.

One result of the activated carbon adsorption study is that alkyl-substituted phenols are more strongly adsorbed by activated carbon than phenol. The degree of adsorption increases with the number of substituents and the length of the alkyl chain. The position of the substituent alkyl group has no effect on the extent of adsorption.

It is expected that when this project is completed, we will have made a good start at developing and evaluating satisfactory means of treating coal conversion wastewaters for disposal in an environmentally acceptable fashion.

Symposium on Environmental Aspects of Fuel Conversion. In response to the shift in the U.S. energy supply priorities from natural gas and oil to coal, EPA has initiated a comprehensive evaluation of the environmental impacts of promising synthetic fuel processes. During April 17-20, 1979, EPA held its fourth Symposium on Environmental Aspects of Fuel Conversion Technology in Hollywood, Florida.[5] The first of these symposia came in the wake of the 1974 oil embargo; this latest one narrowly preceded the fuel shortage of May and June. Such occurrences dramatically emphasize the need to evaluate energy alternatives carefully.

The synthetic fuel industry will require very large and complex plants that will entail great discharge quantities, large consumptions of water, air, and fuel, and massive extraction of resources in relatively small areas. The latest findings in the environmental assessment of coal gasification and liquefaction

[5]U.S. Environmental Protection Agency, *Symposium Proceedings: Environmental Aspects of Fuel Conversion Technology, IV,* NTIS No. Pb 80134729, EPA 600/7-79-217, Sept. 1979.

drew over 300 representatives of process developers, process users, environmental groups, and research scientists to the symposium.

Session I provided an overview of environmental assessment, addressing methodology as well as specific programs. Several key elements of IERL-RTP's methodology were explained, such as Multimedia Environmental Goals and Source Assessment Models. Other presentations described various environmental assessment and health programs sponsored by EPA and other agencies. Two needs surfaced during this session: eliminating process and pollution control uncertainties, and unifying the efforts of the various sponsoring groups to ensure efficiency.

Session II emphasized data and conclusions from ongoing research and field studies concerning the chemical composition and environmental impacts of coal conversion waste streams. Summaries of the solvent refined coal (SRC) plant in Fort Lewis, Washington, were given, as well as a presentation on the commercial-scale Lurgi gasifier in Kosovo, Yugoslavia, by the Yugoslav/U.S. team involved in its environmental assessment.

The final session featured evaluations of environmental control technology and discussions of possible regulations affecting coal conversion facilities and the issue of water supplies to fuel conversion plants. Water requirements for a variety of synfuel technologies were given for locations in the major coal- and oil-shale-bearing regions of the United States. Because of limited water supplies and growing demand, many such regions in the western United States cannot supply the great amounts of water necessary for synfuel production.

Although much work remains to be done, the symposium indicated that substantial progress has been made in defining the problems of fuel conversion and evaluating alternative solutions.

Assessment of Gasification Facility in Yugoslavia. In cooperation with the government of Yugoslavia, EPA is sponsoring an environmental data acquisition program that focuses on a medium-Btu Lurgi gasification facility located in the Kosovo region of Yugoslavia. The main objective of the program is to gather information that will help EPA define environmental controls needed for U.S. gasification plants.

The Kosovo test program is divided into two phases. In Phase I—completed during November 1978—approximately 40 of the plant's most significant emission streams were screened. Stream flows were analyzed to identify the major components.

The Phase II tests at Kosovo involved the sampling/analysis of a more select group of about 20 streams. The work examined detailed characterizations of trace and minor component emissions, including trace metals and organics. In addition, Phase II included fugitive emission and ambient monitoring tests. The objective of the ambient work was to develop and evaluate methods for characterizing the airborne particulates and the trace organics that originate in coal conversion processes. Five monitoring stations were set up to collect the samples. The fugitive emission work included a survey of the sources in the plant and an analytical screening of the emissions. The fugitive emission data provide an initial indication of the potential magnitude of the problem.

A summary of the Kosovo test program, including presentation of the results obtained to that date, was given at the fourth Symposium on Environmental Aspects of Fuel Conversion Technology, sponsored by EPA's IERL-RTP in 1979.

Solid Waste Problem of Proposed SRC Plant. A study of the potential pollutants from a hypothetical commercial-size SRC plant suggests that solid wastes would constitute the most toxic waste stream from the plant.

The SRC system uses a noncatalytic direct-hydrogenation liquefaction process to convert coal high in sulfur and ash into clean-burning gaseous, liquid, or solid fuels. There are two variations: SRC-I, which produces a solid coallike product of less than 1 percent sulfur and 0.2 percent ash, and SRC-II, which produces a low-sulfur (0.2 to 0.5 percent) fuel oil and naphtha product. Both produce gaseous hydrocarbons that are further processed into substitute natural gas and liquefied petroleum gas. Byproducts recovered from the hydrogenation reaction include sulfur, ammonia, and phenol.

The study, conducted by Hittman Associates, Inc., analyzed the possible environmental effects of waste streams from a proposed SRC plant in White County, Illinois. The commercial-size facility would use 28,000 Mg (31,000 tons) of Illinois No. 6 coal per day. The objectives of the study were to evaluate the pollutants identified in the *Standards of Practice Manual*[6] for the SRC facility and to provide background information for the SRC Environmental Assessment Report. Results from the analysis, detailed in the report "SRC (Solvent Refined Coal) Site-Specific Pollutant Evaluation,"[7] suggest the following:

- The most significant gaseous emissions appear to be carbon dioxide and carbon monoxide.

[6]U.S. Environmental Protection Agency, *Standards of Practice Manual for the Solvent Refined Coal Liquefaction Process,* NTIS No. Pb 283-028/AS, EPA 600/7-78-091, June 1978.

[7]U.S. Environmental Protection Agency, *SRC Site-Specific Pollutant Evaluation: Vol. 1, Discussion,* NTIS No. Pb 291-495, EPA 600/7-78-223a; *Vol. 2, Appendices,* NTIS No. Pb 291-496, EPA 600/7-78-223b, Nov. 1978.

- The most important effluents appear to contain aluminum, copper, zinc, nickel, and several organic compounds.
- The most toxic general category of waste streams will be the solid wastes.

These findings should be used with caution until more definitive data are obtained from a comprehensive pilot plant program and an operational demonstration plant. The environmental analysis procedure used was intended primarily to determine safe emission limits for major pollutants. It is difficult, however, to suggest safe discharge limits for pollutants because of the complexity of the SRC system and an incomplete understanding of such phenomena as transportation of pollutants through air, water, and land and transformation of compounds by physical, chemical, or biological means.

Environmental Assessment of Key Gasifier Discharges. During an environmental assessment, it is unwise to assume that the problems are known and then to conduct tests and evaluations that describe and solve the problem. If the problem is different from the assumption or if other problems exist, they might not be discovered in time to prevent adverse effects. To avoid this danger, IERL-RTP uses a phased environmental assessment approach. The approach includes a broad chemical and biological screening for determining potential problems (Level 1), a comprehensive investigation of the potential problems (Level 2), and long-term monitoring (Level 3) where justified.

The screening evaluation (Level 1) was conducted at a commercial Chapman low-Btu gasification facility. The Chapman facility was selected for testing because of its:

- Accessibility
- Well-defined operating history
- Single-stage, fixed-bed, atmospheric pressure gasifiers, which are representative of those currently in commercial use in this country
- Use of bituminous coal—a widely available feedstock
- Gas quenching and scrubbing system, which provides a means of evaluating tar and oil byproducts associated with a gas quenching operation
- Capability to obtain particle removal efficiency data for a hot cyclone

The specific objectives of the Chapman facility tests were threefold: to characterize the waste streams and potential fugitive emission and effluent streams, to evaluate the applicability of Level 1 sampling and analytical methodology to such a characterization, and to evaluate the particulate removal efficiency of the product gas cyclone.

Results of the chemical and bioassay testing indicated that all waste and process streams examined contained potentially harmful organic or inorganic materials, or both. In the coal feeder vent gases, examples of potentially harmful species included polycyclic aromatic hydrocarbons (PAH's), carbon monoxide (CO), and chromium. The potentially harmful species found in the separator vent gases included PAH's, amines, CO, ammonia, C_2-hydrocarbons, heterocyclic nitrogen compounds, chromium, vanadium, and silver. Potentially harmful levels of the following trace elements were found in the gasifier ash and cyclone dust: boron, phosphorus, iron, calcium, aluminum, lithium, barium, selenium, lead, copper, thallium, cadmium, antimony, vanadium, cobalt, uranium, and cesium. The product gas cyclone was found to be approximately 60 percent effective in removing particulate matter from the raw product gas stream.

To verify the existence and quantities of the specific chemicals that are identified as potential problems, a comprehensive analysis (Level 2) is required. Only a limited number of gas chromatography/mass spectrometry (GC/MS) analyses were conducted in this program. The results indicated the presence in the discharge stream of potentially harmful concentrations of aminotoluene, naphthol, alkylphenols, anisoles, and benzpyrene. Although the quantities of material, transport properties, transformation effects, end point effects, and population risk would need to be determined to ascertain accurately if a real problem exists for the population as a whole, the phased environmental assessment approach has proved beneficial in addressing the environmental assessment source characterization.

Environmental Assessment of Industrial Anthracite Gasifier. Using the phased environmental assessment approach, evaluations were conducted at a commercial coal gasification facility that uses a Wellman-Galusha gasifier to produce low-Btu fuel gas. These tests used anthracite coal and a different gasifier from another test at a Chapman facility that used bituminous coal. Objectives of the test program were to perform an environmental assessment on the facility's waste streams and fugitive emissions and to characterize the product gas cyclone's particulate removal efficiency.

Results from the chemical analyses of the plant's waste streams indicated that all waste streams contained organic or inorganic components, or both, that could have harmful health or ecological effects. In the pokehole and coal hopper gaseous emissions, CO, ammonia, and possibly iron pentacarbonyl were of major concern. Organic compounds that were not specifically identified are of potential concern in the ash sluice water. The gasifier ash and cyclone dust contained a number of trace elements and possibly organics that could be harmful. Analyses

performed on the leachate from these two solid waste streams indicated that the leachate could be harmful to health or the ecology. The possibility of risk, however, is greater from the gasifier ash and cyclone dust than from the leachate.

In general, the potential for adverse health and ecological effects was found to be significantly lower for the Wellman-Galusha facility's waste streams than for waste streams produced by gasifying bituminous coal, principally because of the much lower levels of organics in the Wellman-Galusha facility's waste streams. The results of bioassay screening tests exhibited a similar tendency.

Definition of Pollutant Categories by Bench-Scale Gasifier Tests. An important question being addressed by Research Triangle Institute (RTI) through an IERL-RTP grant is: What pollutants from coal conversion processes present the greatest environmental hazards? Figure 1 shows the estimated environmental impact of classes of compounds identified in the gaseous and condensate streams from RTI's laboratory reactor. The height of an individual bar was calculated by summing the ratios of measured concentrations to Multimedia Environmental Goal values for all compounds found to be present in that particular compound class and taking the logarithm of the sum. Thus, the higher the bar, the greater the adverse impact of that chemical class. Negative bars mean that the sum was less than 1 and therefore gave a negative logarithm. Plots are shown for four test runs using three different coals. It is interesting to note that this graphic display shows little difference among runs and coals. The most hazardous class of compounds is the phenols, followed by benzene and alkyl-substituted benzenes and, for those coals containing significant sulfur, the sulfur compounds.

Potential of Low-Btu Gasification as Control Approach. The amendments to the Clean Air Act of 1977 require EPA to coordinate and lead the development and implementation of standards of performance for new and modified sources of air pollution. Because fossil-fuel-fired steam generators are mentioned specifically in the act, EPA has undertaken a study of industrial boilers. Based on the results of this and other studies, EPA will propose standards of performance.

Many methods are available to reduce emissions from fossil-fuel-fired industrial boilers. These techniques may be broadly classified as precombustion, combustion, and postcombustion. The purpose of EPA's study was to evaluate the use of synthetic fuels from coal technologies as precombustion emission controls for new industrial boilers. The synthetic fuel technologies examined included coal gasification and liquefaction. Although major emphasis was placed on reduction of sulfur oxides, nitrogen oxides, and particulate emissions in the industrial boiler flue gases, other gaseous pollutants in the flue gases—as well as gaseous emissions, liquid effluents, and solid wastes from the synthetic fuel system—were also examined.

EPA will use the results of this evaluation to assess the need and, if appropriate, to prepare New Source Performance Standards (NSPS) for small industrial boilers. The evaluation of synthetic fuel technologies considered the following factors: development status, capital and operating costs, energy impacts, environmental impacts, and performance data.

For reasons such as cost, facility size, and capital investment required, it was concluded that low-Btu coal gasification would be an appropriate precombustion control for industrial boilers and that medium-Btu gasification, high-Btu gasification, and coal liquefaction would be less desirable.

Based on the results of detailed evaluations of various synthetic fuel systems, two representative low-Btu gasification systems were selected—a Wellman-Galusha gasifier with a Stretford process and one with a monoethanolamine acid gas removal process. Performance results of these systems indicate that they are applicable to the boiler sizes under consideration, capable of controlling major emissions, and commercially available. In addition, the cost and energy impacts are reasonable and other environmental impacts are controllable.

These study results will be combined with those of other studies on techniques for controlling pollutants from industrial boilers. A comparison among the various systems for the previously listed items of concern must be completed before conclusions can be drawn as to the most appropriate controls for the industrial boiler segment. Findings of this study represent only a part of the information that is necessary for setting NSPS for industrial boilers.

Environmental Assessment Support to DOE's Evaluation of Industrial Gasifiers. In 1977, EPA presented DOE with an environmental program that the Agency believed was necessary to demonstrate fully the feasibility of the technology. This program led to additional discussions and the performance of limited tests by EPA at DOE's first site. As a result, Oak Ridge National Laboratory (ORNL) has taken the lead role for DOE in establishing environmental and worker health programs at other sites.

EPA has continued to work with DOE and ORNL in establishing data acquisition requirements. EPA also will perform short-duration (less than 1 month) testing using the methodologies developed at EPA, whereas ORNL will conduct longer duration testing. As sites are tested, the programs will continue to

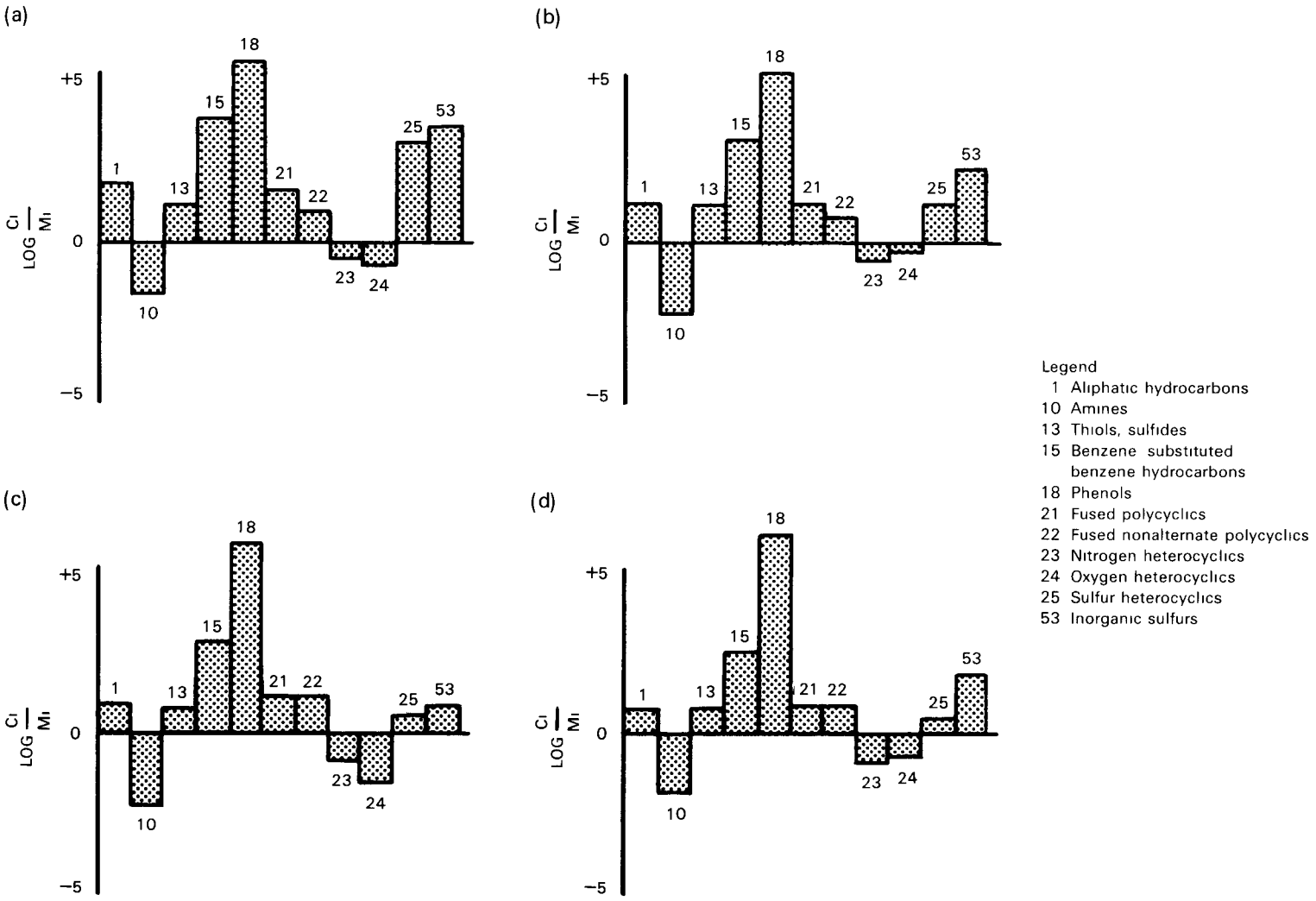


Figure 1.
Average Gas and Condensate Concentrations by Pollutant Class: (a) Run 23—Illinois Coal, (b) Run 26—Montana Coal, (c) Run 33—Wyoming Coal, and (d) Run 35—Wyoming Coal

evolve. Improvement is anticipated in sampling, analysis, data handling, multidisciplined evaluation of data, and other areas. The quantity of data from any one site will be large. The data should provide a valuable resource for determining environmental effects from low-Btu gasification facilities.

Simplifying Complex Synfuel Pollutant Control Problems. Work at RTI is continuing on the complete characterization of gases, condensibles, and solids produced by coal gasification. This effort is being accomplished by means of a laboratory-scale gasifier and sampling system. Composite results from

preliminary screening tests with eight different U.S. coals have been analyzed to rank the various pollutants by their potential effects on the health of human subjects exposed directly to the reactor effluents.

Major pollutants of concern in the raw product gas stream are carbon monoxide, benzene, hydrogen sulfide, and other sulfur species. Eliminating these pollutants from consideration (or assuming that control technologies exist for such species) reduces the gas stream discharge severity by four to five orders of magnitude. If carbon monoxide is considered a desired fuel product rather than a pollutant, a typical gas stream discharge severity is about 10^3. This factor is reduced to about 10^0 by removing hydrogen sulfide, benzene, and other sulfur compounds.

Aqueous condensates from coal gasification are heavily contaminated by phenols, cresols, and xylenols. It appears that if the e phenolics and the other important condensate constituent, ammonia, are removed, the condensate discharge severity would be reduced to approximately a value of 10^1.

Tars present a more intractable environmental hazard. Although phenols again represent the dominant hazard, their elimination reduces the discharge severity to only 10^3 owing to the continued presence of PNA's. It should be noted that typically less than 20 percent of the total tar is identified as specific compounds in RTI's analyses. This low percentage is owed in part to restricting analyses to selected compounds that represent known high environmental hazards, but also to difficulties in characterizing the heavier fraction of the tar. Currently applied RTI techniques of gas chromatography/mass spectrometry restrict compound analysis to species boiling below about 300° C (572° F). However, from 10 to 75 percent of gasification tars have a boiling point above 400° C (752° F). Methods in high-performance liquid chromatography and other analytical techniques are being developed to extend the analytical range to the heavier tar fractions; notable success is being achieved in this area.

Ames mutagenicity tests have been performed on crude tar samples and on tar fractions. Results of these tests show that certain fractions—namely, those containing primarily the PNA's and aromatic amines—possess a higher mutagenic character than the whole tar. This phenomenon is referred to as an "unmasking effect" revealed by the tar partitioning process. The results also show that tars derived from Illinois and western Kentucky coals are more mutagenic than tars from Montana subbituminous coal or North Dakota lignite.

EPA/North Carolina State University Synfuel Environmental Control Facility. Coal gasification plays a large part in the developing synthetic fuel industry not only because of the production of fuel gas but also because it represents the first phase of all indirect coal liquefaction processes. These processes involve first gasifying coal and then catalytically reforming the gas into a variety of liquid fuels and byproducts, including gasoline. To study the environmental effects related to coal gasification and the associated purification of the raw product gas, a coal gasifier [20 kg/h (50 lb/h)] and gas-cleaning facility was constructed at North Carolina State University in 1978 under the auspices of IERL-RTP.

This project is being carried out by the faculty and staff of the North Carolina State University Chemical Engineering Department by means of an EPA grant. The goals of the project are to characterize completely the gaseous and condensed-phase emissions from the gasification/gas-cleaning process and to determine the dependence of pollutants and their emission rates on adjustable operating parameters, coal type, and method of acid gas removal.

During the first year of operation, this facility achieved fully operational plant status and completed a preliminary experimental program using a devolatilized coal char as feedstock. Several 15-hour test runs have been successful with the acid gas removal system and gasifier fully integrated and working efficiently. Specific accomplishments at this facility include:

- Excellent mass balances for the major elements around the various components
- Analyses of the major gasifier products
- Determination of major contaminants removed by adsorption in methanol refrigerated to −30° C (−22° F).

Recently the facility switched from using char to using a New Mexico subbituminous coal as feedstock. Future work will emphasize the capabilities of alternative acid gas removal methods for removing contaminants other than the major acidic species (hydrogen sulfide and carbon dioxide) and the buildup of trace contaminants in acid gas removal systems. Information developed from this project should accelerate the design of environmental control systems for what promises to be a major new U.S. industry.

Evaluation of a Lurgi Synthetic Natural Gas Coal Gasification Plant. IERL-RTP has collected, categorized, and evaluated existing information on Lurgi gasification for the production of synthetic natural gas (SNG). The report divides the Lurgi SNG systems into four operations—coal preparation, coal gasification, gas purification, and gas upgrading—and a number of auxiliary processes (such as air pollution control, raw water

treatment, and oxygen production), with each operation comprising a number of processes. The report presents the data on the characteristics of input materials, products, and waste streams associated with each process. The pollution control alternatives for air emissions, water effluents, solid wastes, and toxic substances in an integrated facility were examined for performance, costs, energy requirements, and ability to comply with current and anticipated environmental standards.

In the report, each EPA program office's areas of responsibility are addressed separately. In addition, the report provides information on the advantages and disadvantages of transferring a pollutant from one medium to another. This multimedia approach is important, but much work remains to quantify the effects. The report is intended as technical background information for establishing regulatory actions.

Residual and Waste Oils

Not all of the crude oil that enters a refinery is converted into products like gasoline, home heating oil, and aviation fuel. The remainder is called *residual oil. Waste oils,* such as motor oil drained from cars, and *residual oils* would make suitable fuel for boilers and large engines if they did not contain such high concentrations of contaminants. To turn this energy source into an environmentally acceptable fuel, IERL-RTP is exploring advanced processing methods. Demetallization, desulfurization, and removal of other trace elements are being tested as ways of increasing our supply of clean-burning fuels. Part of the work on the demetallization of residual oils is being carried out through a cooperative assessment program between the United States and the Soviet Union.

One promising technology that IERL-RTP is exploring for residual oil treatment is the Chemically Active Fluid Bed (CAFB) process. A pilot-scale CAFB plant in Abington, England, has been successful in removing 85 percent of the sulfur and all of the vanadium from residual oil without creating serious environmental problems with the spent bed material. In the near future, IERL-RTP will help support a commercial-scale CAFB demonstration at Central Power and Light's plant in San Benito, Texas. This project should provide the data and experience to put this energy-saving technology to work throughout the industry.

The sections that follow present highlights of the year's research accomplishments in residual and waste oils.

Potential Carcinogenicity of Residual Oils. The conclusion that 40 percent of residual oils may be carcinogenic came to light during an IERL-RTP project to evaluate the potential environmental hazards of using residual oil. The program was aimed at examining residual oils representing a majority of U.S. production. The Ames test results on 26 residual oils using strains TA1538, TA1537, TA98, and TA100 (with and without activation) were: 11 positive, 5 probable, and 10 negative. The 11 positive samples showed no correlation to a common denominator. The positive tests are being rerun. Yeast and *E. coli* tests were negative for all 26 samples. Obvious differences exist in the chemical nature of volatiles, at 100° C (212° F), from oils found mutagenic and those found nonmutagenic in the Ames test. The major differences in the volatiles are in the first one-third of the chromatogram and involve at least three major and several minor GC peaks. Additional funding would be required in the present contract or future advanced oil processing programs to pursue investigation of any common chemical factors that may be contributing. Joint studies with EPA's Health Effects Research Laboratory (HERL) are recommended.

Construction of CAFB Evaluation Plant. The CAFB Evaluation Plant of about 10-MWe (34×10^6 Btu/h) capacity has been constructed at the La Palma Station of Central Power and Light in San Benito, Texas. Preliminary checkout of the unit during combustion conditions is complete. Equipment modifications to the cyclones, the coal feed system, and revised instrumentation of the oil feed system are nearing completion. Hot operations will be resumed in September with 1 to 3 weeks of combustion conditions to verify the changes made, followed by gasification conditions and commencement of the test program. Operation during combustion conditions produced some fine deposits in the boiler that were loose, fluffy, and easily removed. The type of limestone used causes more dust to be formed when the stone is calcined under combustion conditions, as it was here, than when calcined under gasification conditions, as it would be in normal operation. Evaluation is continuing of the observations made and data collected during the preliminary shakedown run under combustion conditions. Emphasis was placed on evaluating and correcting operational problems, such as excessive vibration being transmitted from the coal feeders to the structure and the need for additional temperature sensors.

Combustion Controls

Fundamental research programs focus on the main factors in the formation of nitrogen oxides (NO_x): combustion chemistry and combustion aerodynamics. Work in the chemistry of combustion is answering basic questions about the chemical reactions that occur when fuels burn and how temperature, fuel,

and air affect these reactions. At the same time, research in the aerodynamics of combustion is examining the physical conditions in the flame zone and how different ways of mixing fuel and air alter these conditions.

Combustion Modification

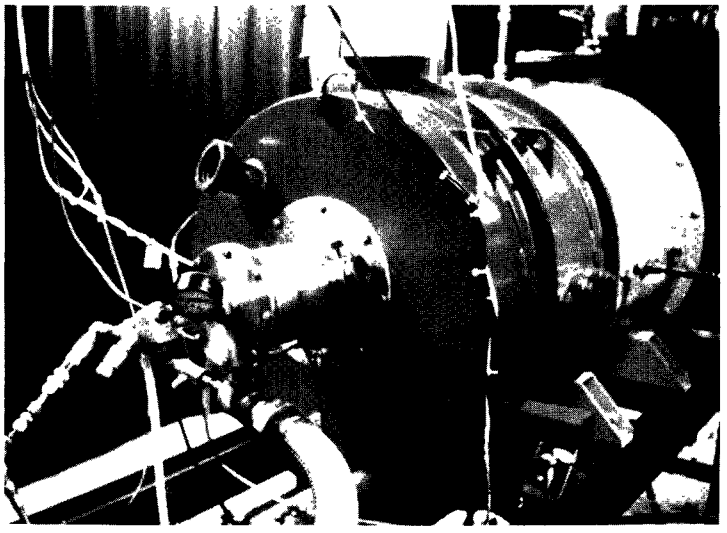
Research has shown that *combustion modification* is one of the most effective and economical methods of limiting a number of major pollutants. The combustion process can be modified by changing combustion temperatures or air/fuel ratios. Nitrogen oxide emissions can be reduced by lowering the combustion temperature if burners are situated to avoid "hot spots" in the furnace. Limiting the amount of oxygen and regulating the way air and fuel mix minimize the formation of NO_x. Currently, IERL-RTP is exploring new combustion methods in programs ranging from fundamental research to field testing.

To date, these programs have emphasized NO_x emissions, which are among the most difficult pollutants to control. Information being gathered about combustion chemistry and thermodynamics also will help us to understand how to control carbon monoxide, hydrocarbons, and other pollutants.

Using the results of fundamental research, IERL-RTP is testing several combustion modification techniques on pilot-scale equipment. New burner designs are being developed for coal-fired boilers that can cut NO_x emissions by as much as 60 to 80 percent without sacrificing fuel economy or equipment life. Pilot-scale boilers firing residual oil are being tested extensively at EPA's facilities in North Carolina. And a new low-NO_x residential oil furnace has demonstrated that advanced burner and firebox designs can reduce NO_x emissions and improve efficiency as well.

IERL-RTP also is evaluating new combustion techniques on full-scale equipment in the field. Tests under actual working conditions have been conducted on utility and industrial boilers, industrial process equipment, residential and commercial heating systems, stationary internal combustion engines, and gas turbines. At Gulf Power's Crist Plant in Pensacola, Florida, a 2-year series of tests has shown that boiler modifications can reduce NO_x emissions by as much as 40 percent without increasing corrosion, fouling, or slagging.

The sections that follow present highlights of the year's research accomplishments in combustion modification.



The experimental "rainbow furnace"—one of several pieces of in-house equipment used in combustion modification studies—provides bench-scale information on the use of staged combustion in NO_x control.

Testing Coals in EPA Low-NO_x Burner. An advanced-design, low-emission coal burner has been developed under EPA sponsorship. The goal of this development effort has been to achieve NO_x emissions of 86.0 to 129.0 ng/J (0.2 to 0.3 lb/10^6 Btu) without an increase of carbonaceous pollutants or a decrease of efficiency. Meeting this goal requires a 50 to 70 percent reduction relative to pending NSPS and a 70 to 85 percent reduction relative to uncontrolled wall-fired boilers. These goals have been achieved in pilot-scale experimental tests of the burner design at scales up to 35 MW (120 $\times$ 10^6 Btu/h), so a program has been initiated for burner field evaluations in full-scale industrial and utility boilers over the next 4 years.

As an outgrowth of this work, EPA (working through DOE) proposed a project for screening non-U.S. coals in the U.S. facility that is developing the low-NO_x burner. On May 22, 1979, a letter of intent for the proposed program was signed by the United States and five other countries. The scope of the technical effort has been negotiated among Canada, Sweden, and Denmark. The project provides for screening 15 non-U.S. coals in a small furnace followed by testing of up to 4 coals with low-NO_x burners at three scales from 3 to 30 MW (10 to 100 $\times$ 10^6 Btu/h). The possibility exists for an additional activity for field evaluation of selected coals either in the United States or the host countries. Discussions of the possibility for similar activities with four other countries are anticipated.

Environmentally Acceptable Use of Synthetic Liquid Fuels in New Gas Turbine Combustor. A new combustor configuration

for stationary gas turbine engines called the "Rich Burn/Quick Quench Combustor" has been developed by Pratt and Whitney Aircraft under EPA Contract No. 68-02-2136. The purpose of developing a new gas turbine combustor was to find a technique that would allow the NSPS for NO_x to be met without the use of water injection, and that would allow the use of high nitrogen fuels such as synthetic liquids. A design approach meeting both goals was first identified in an extensive series of bench-scale tests. Significant features of the new concept include premixing of the fuel and primary air flow, maintaining the primary combustion zone in a fuel-rich environment, and then quickly bringing the effluent from the first stage to the high excess air levels required by the gas turbine cycle.

Following bench-scale testing, the design was scaled up to a size commensurate with a single can from a multican 25-MW (85×10^6 Btu/h) gas turbine engine. Total heat release for the single can was approximately 13 MW (45×10^6 Btu/h) at full load and was designed for operation at pressures up to 1,317 kPa (13 atm). Next, the full-scale combustor was mounted in a test stand and performance was determined while burning a variety of fuels. NO_x emissions on clean No. 2 fuel, which is a standard fuel used by stationary gas turbines, was measured to be 40 ppm (at 15 percent O_2), which compares to an NSPS limit of 75 ppm. The next fuel used was a No. 2 doped to 0.5 percent bound nitrogen as pyridine, and the NO_x emissions were 75 ppm. The NSPS limit for a fuel with greater than 0.25 percent nitrogen is 125 ppm. Limited quantities of residual shale oil that contain 0.46 percent nitrogen and a coal-derived liquid fuel (SRC-II) at 1.0 percent nitrogen were secured for testing. NO_x emissions of 65 and 93 ppm were recorded on the shale oil and on the 1.0 percent SRC-II, respectively.

These results mark a major breakthrough in gas turbine combustor design. The emissions are not only well below the limits set by the NSPS, they are also achievable without water injection, owing to the new design approach. Elimination of water injection translates into a fuel saving of up to 5 percent. Even more significant is the performance of the synthetic liquids: these tests represent the first known full-scale experiments in which a stationary gas turbine combustor has been able to meet the NSPS while burning very high nitrogen fuels.

Significant additional development is required before this new gas turbine combustor concept is demonstrated in an actual engine, but if funds are made available, the probability of success is quite high.

Coal-Limestone Pellet Fuel. IERL-RTP currently is directing an R&D program for increased use of high-sulfur coal by combining the coal with limestone in a pellet fuel. This fuel would be suitable for use in a wide range of industrial stoker boilers that require control of SO_2 emissions. Recent test evaluations and economic studies indicate that coal-limestone pellet fuel can be an effective and economical SO_2 control method for industrial-sized boilers.

Research and development efforts are being conducted at Battelle-Columbus Laboratories under Contract No. 68-02-2627. Initial efforts included evaluation of a 50-percent-coal/50-percent-limestone pellet that reduced SO_2 emissions by 74 percent in a full-scale, 8-hour test. Further study was directed at optimization of the pellet formulation and combustion performance.

The basic evaluation system used is a tubular fixed-bed reactor. In this small, batch combustor, several hundred combustor experiments have been performed to evaluate rapidly a large number of parameters that affect pellet fuel performance. These parameters include limestone/coal ratio, pelletizing method, pellet size, binder material, coal type, and limestone type. Recent tests have identified binder materials that result in a pellet with compression strength and weatherability equal to or greater than the properties of the base coal. Combustion tests in the fixed-bed reactor indicate an SO_2 capture as high as 87 percent using a 70-percent-coal/30-percent-limestone formula and an organic binder material <3 percent of the pellet mass.

The next step was to conduct combustion evaluations in a 196-kW (20-hp) model spreader stoker boiler for the "best" pellet formulations developed in the fixed-bed reactor study. With a 70/30 mill-type pellet, the average SO_2 emission was reduced by 70.4 percent compared with straight coal combustion in the same system. A more fundamental study of the reaction process involved in pellet fuel combustion is being conducted concurrently to attempt further improvements in the pellet fuel formulation. This study includes computer model analysis of the data along with metallographic and scanning electron microscope examination of pellets before and after combustion to identify SO_2 capture mechanics.

A full-scale, 8- to 10-hour combustion test in a spreader stoker boiler—11,000 kg/h (25,000 lb/h) steam—was conducted in mid-December 1979. This test will be used to establish the practical performance that can be expected from coal-limestone pellet fuel under actual operating conditions. The experience gained from this test will be a guide for conducting a 30-day demonstration of pellet fuel in May 1980. The 30-day test will provide data for the industrial boiler NSPS that will be set in June 1980.

Cost analyses of production techniques have indicated a favorable outlook for the pellet fuel technology. The cost of

preparing limestone-coal pellet fuel, based on a projected 50-Mg/h (60-ton/h) processing plant located in a coal-mining region would only add $16/Mg ($15/ton) to the cost of coal. This figure is substantially below the comparative costs of wet scrubber technologies for industrial boilers with streams smaller than 160,000 kg/h (350,000 lb/h). Pellet fuel development could provide a cost-effective alternative for industrial and commercial boiler operations.

Additional Guidelines To Aid Combustion Pollution Control. Three guidelines have been issued recently by IERL-RTP for adjustment of residential and commercial heating equipment to minimize emissions and save fuel. Two of the guidelines discuss adjustment of gas burners for residential and commercial space heating and water heating, with an emphasis on safety aspects of gas combustion. The third guideline relates to domestic heating with oil.

One of the guideline publications, "Guidelines for Adjustment of Atmospheric Gas Burners for Residential and Commercial Space Heating and Water Heating,"[8] was written for use by experienced service technicians. By following the step-by-step procedures outlined in the guidelines, the skilled gas-burner service technician will be able to adjust residential and commercial space heating equipment and water heaters to minimize air pollution, attain maximal efficiency, and provide safe, reliable operation. The 30-page guideline publication, which was reviewed extensively by industry representatives, can be used as a training guide for advanced burner service courses. It is designed to be used as a supplement to the manufacturer's service instructions.

The second publication, "Get the Most From Your Gas Heating Dollar,"[9] is a brochure for homeowners who heat with gas. It is written in less technical language and describes how the layman can inspect a gas flame visually to determine whether the burner needs adjusting. The primary purpose of the brochure is to give the homeowner enough information to know whether his burner is being serviced properly.

The third publication, "Get the Most From Your Heating Oil Dollar,"[10] is actually an updated version of a brochure released in 1976. This brochure is similar to the one just described, except that it is intended for homeowners who heat with oil. Over 120,000 copies have been distributed.

In past years IERL-RTP has issued other guidelines for service technicians. One was aimed at technicians who adjust residential oil burners,[11] another at those who adjust commercial oil burners,[12] and a third guideline was written for operators of industrial boilers.[13] In addition, a guideline publication for industrial boiler manufacturers[14] explained how design affects emissions and efficiency.

A guideline for operators of coal-fired utility boilers is scheduled for publication by April 1980, and a guideline for manufacturers of those boilers is being written. A guideline publication for operators of coal-fired stoker boilers is planned.

The response to these guidelines has been overwhelming. They are widely used by industry for training, and three of them have been reprinted by magazines. *Power* magazine summarized the guidelines for industrial boiler operators and published them in a three-part series.[15,16,17] *Fueloil and Oil Heat* published articles on industrial boilers[18,19] as well as the guidelines for residential and commercial oil burning in their entirety.[20,21,22]

Symposium on Stationary Source Combustion. The Third Symposium on Stationary Source Combustion was held in San Francisco, March 5-8, 1979. The meeting, held as part of the technology transfer activity of IERL-RTP, had about 250 registered attendees. Seven sessions covered stationary

[8] U S Environmental Protection Agency, *Guidelines for Adjustment of Atmospheric Gas Burners for Residential and Commercial Space Heating and Water Heating,* NTIS No Pb 290-777, EPA 600/8-79-005, Feb. 1979. (Also available from the Government Printing Office as Report No. 055-000-00177-4.)

[9] U S Environmental Protection Agency, "Get the Most From Your Gas Heating Dollar," IERL-RTP-P-252, Aug 1979 (Free copies available from Chris L West, Public Awareness Office (MD-50), Environmental Research Center, U.S. EPA, Research Triangle Park NC 27711.)

[10] U.S. Environmental Protection Agency, "Get the Most From Your Heating Oil Dollar," IERL-RTP-P-298, Jan 1980. (Free copies available from Chris L. West, Public Awareness Office (MD-50), Environmental Research Center, U.S. EPA, Research Triangle Park NC 27711.)

[11] U.S. Environmental Protection Agency, *Guidelines for Residential Oil-Burner Adjustments,* NTIS No. Pb 248-292, EPA 600/2-75-069a, Oct. 1975.

[12] U.S. Environmental Protection Agency, *Guidelines for Burner Adjustments of Commercial Oil-Fired Boilers,* NTIS No Pb 251-919, EPA 600/2-76-088, Mar. 1976.

[13] U.S. Environmental Protection Agency, *Guidelines for Industrial Boiler Performance Improvement (Boiler Adjustment Procedures To Minimize Air Pollution and To Achieve Efficient Use of Fuel),* NTIS No. Pb 264-543, EPA 600/8-77-003a, Jan. 1977.

[14] U.S. Environmental Protection Agency, *Reference Guideline for Industrial Boiler Manufacturers To Control Pollution With Combustion Modification,* NTIS No. Pb 276-715/AS, EPA 600/8-77-003b, Nov. 1977

[15] "Tuning Industrial Boilers-1," *Power, 121*(4) (pp. 64-67), Apr. 1977.

[16] "Tuning Industrial Boilers-2," *Power, 121*(5) (pp. 76-79), May 1977.

[17] "Tuning Industrial Boilers-3," *Power, 121*(6) (pp. 110-115), June 1977.

[18] "How To Improve Industrial Boiler Performance," *Fueloil and Oil Heat* (pp. 41-44), Feb. 1978.

[19] "How To Improve Industrial Boiler Performance," *Fueloil and Oil Heat* (pp. 46-68), Mar. 1978.

[20] "Residential Oilburner Adjustments," *Fueloil and Oil Heat* (pp 49-51), June 1976.

[21] "Residential Oilburner Adjustments," *Fueloil and Oil Heat* (pp. 43-44), July 1976.

[22] "Adjusting Commercial Oilfired Boilers," *Fueloil and Oil Heat* (pp. 48-51), Oct. 1976.

combustion systems, ranging in size from residential to utility, including boilers, engines, and industrial process equipment. Advanced processes, fundamental combustion research, and environmental assessment were the subjects of other sessions.

The symposium generated a great deal of interest, as evidenced by the stimulating question-and-answer sessions that followed the 35 technical presentations. The most active discussions followed sessions on utility boilers, advanced processes, and fundamental research. It was strongly recommended that NO_x be monitored continuously during the long-term corrosion study. It was also suggested that particulate emissions be characterized more thoroughly during combustion modification tests if mass is not measured both upstream and downstream of the collector. Much interest focused on the early results from tests of an advanced low-NO_x pulverized coal burner design for use with utility and industrial boilers that, under optimal conditions, yields NO_x levels below 200 ppm for three burner scales—4, 15, and 29 MW (12, 50, and 100×10^6 Btu/h). A study of the responses of commercially available chemiluminescent NO_x analyzers to simulated combustion products and the errors introduced by the presence of certain species or conditioning systems also drew the attention of many researchers in the field.

There were many requests for copies of the recently issued "Guidelines for Adjustment of Atmospheric Gas Burners for Residential and Commercial Space Heating and Water Heating."[8]

Videotapes of selected IERL-RTP projects, which were shown continuously in a separate room at the Symposium, were very well received by the attendees. Many favorable comments were made and representatives of the California Air Resources Board, University of California, National Bureau of Standards, and VGB-Geschaffsstelle of West Germany asked to borrow copies.

Catalytic Combustion Panel Meetings. Following the format established in the low-NO_x coal burner panel meetings, two panels have been established to provide review and comment on EPA's program for the development of catalytic combustion technology. A *Technical Review Panel,* composed of representatives of equipment manufacturers and technology users, provides input on practical aspects of the research. The invited members of the panel represent four gas turbine companies, four boiler or burner manufacturers, two public utilities, and a catalyst consultant. A *Technology Transfer Panel,* composed of representatives of government and private agencies, provides guidance to the program on both technical and emission control trends. This panel also provides a forum for agencies sponsoring research to discuss areas of program coordination. The panel has invited representatives of EPA (Office of Environmental Engineering and Technology, IERL-RTP and Office of Air Quality Planning and Standards), DOE, Department of Defense, National Aeronautics and Space Administration, Electric Power Research Institute (EPRI), California Air Resources Board, California Energy Commission, Gas Research Institute, and American Boiler Manufacturers Association.

Two panels are used to maintain a small size (less than 15) suitable for maximal interchange and to highlight the somewhat different interests of each group.

The first meetings of the Technical Review and Technology Transfer Panels were held on May 22 and 23, 1979, respectively, in Atlanta, Georgia. All members of the Technical Review Panel and most members of the Technology Transfer Panel were present. An informal atmosphere promoted active discussion of the materials presented. Following an introduction by the project officer, representatives of the contractor (Acurex Corporation) made presentations on various program aspects, including overall program plan, catalyst development and screening, auxiliary system testing, system concept evaluation, and fundamental processes. A general discussion period was concluded with a summary by the project officer. In the case of the Technology Transfer Panel, a discussion of ongoing and planned research activities was conducted in a session to which Acurex was not admitted.

The main points of the technical presentation were as follows:

- Effort is concentrated on achieving very low emission levels for stationary sources, especially boilers.
- Catalyst development has led to the development of the graded cell concept (patented by EPA) that offers a significant performance advantage over conventional catalysts (additional work is needed in catalyst structural durability and life testing).
- A number of system concepts have been developed that have the potential to achieve very low levels of thermal and fuel NO_x with high system efficiency.
- For practical application, several auxiliary systems are required—flame safety and control, ignition, and fuel injection for both light and heavy metals.
- The various components will be integrated into several prototypes of the most promising system concepts; these will be tested in the laboratory to simulate practical operating requirements.

The pretreatment resulted in considerable discussion. Several of the most pertinent comments follow (the first three comments are supportive of the program direction):

- Emphasis should be placed on dual-flame systems capable of burning both gaseous and liquid fuels.

- The concepts should be capable of burning fuels containing heavy nitrogen (especially residual oil and synthetic liquids) and, therefore, should strongly address fuel NO_x control.
- Safety systems are of great concern and may be a problem for conventional approaches because of the flameless nature of catalytic combustion.
- A list of definitions and descriptive terms should be compiled to explain the jargon (this has been done).
- Catalytic combustion has the potential for being a much lower cost option than postcombustion treatment where very low NO_x levels are required, such as in California. This also indicates the need for the retrofit concepts that are being considered in the program.

The panels are scheduled to meet again in February 1980.

Conference on Coal Combustion Technology and Emission Control. A conference on Coal Combustion Technology and Emission Control was held February 5-7, 1979, in Pasadena, California, to present an integrated view of all aspects of coal combustion technology from fundamental processes and practical system aspects to long-term environmental impacts.

The program was organized into the following four major topic areas:

- *Conference Theme* dealt with an overview of the problems, including health effects of pollutant species, projected emissions trends and control technology requirements, and atmospheric interactions of pollutants.
- *Kinetic Processes* covered fundamental processes in coal combustion, including devolatilization, homogeneous kinetics, heterogeneous kinetics, and ash formation.
- *Combustion Control of Pollutants* covered a wide range of pilot-scale activities related to operating characteristics and emissions of coal combustors.
- *Full-Scale Applications* described low-NO_x emission and operating experience for three major U.S. boiler manufacturers and one German manufacturer. The EPA low-NO_x burner program was covered for both industrial and utility boilers.

The most significant conclusions of the meeting are presented in the following paragraphs.

Even though existing ambient standards may be sufficient from the standpoint of health, improved control technology is needed to offset the projected growth of mass emissions and to reduce effects of secondary pollutants, such as aerosols, SO_4^{-2}, and SO_3^{-2}.

In recent years, significant progress has been made in understanding key elements of coal combustion fundamentals, particularly in the areas of devolatilization and heterogeneous reactions.

Reactor studies are particularly promising as a quick and relatively inexpensive way of screening the effects of fuels on emission performance. Although additional work is needed, attempts to correlate results qualitatively with fundamental data (for example, devolatilization rates) and with pilot-scale burner data have been informative.

Combustion control of NO_x and other pollutants has been successful in the past on practical pulverized coal-fired boilers, and pilot-scale advanced burner designs show promise for further control.

The presentations provided new insights into the work of both research and applications people. The conference also was the basis for the Fundamental Combustion Session at the Combustion Research Third Stationary Source Symposium. Several promising areas were identified for further work on integrating the two types of activities.

Effect of Coal Properties, Other Than Nitrogen Content, on NO_x Emissions. Small-scale fuel screening experiments for EPA's low-NO_x staged combustion burner show that coal properties, apart from nitrogen content, significantly affect NO_x emissions. In the premixed (nonstaged) mode, the NO_x emissions for five coals having the same nitrogen content (percentage of dry, ash-free nitrogen) vary by a factor of 1.5. For 15 coals tested, NO_x emissions do not correlate with nitrogen content. These findings support the hypothesis that other factors, such as the nitrogen distribution, have important roles in determining emissions.

The premixed mode is expected to maximize the differences caused by high conversions of volatile nitrogen compounds. Experiments under staged conditions, however, show the same relative ranking of most coals, even though the absolute emission differences are smaller (about 100 ppm) for coals of the same nitrogen content. In addition, limited testing of two coals at 3 and 30 MW (10 and 100×10^6 Btu/h) suggests that burner results will correlate with the screening results. Large-scale testing of a number of coals is planned.

Flow Field Test Cases To Aid Fundamental Combustion Research. The ability to predict flow patterns in the swirling environment of a flame has long been sought because variations in the mixing rate of fuel and air streams within a boiler can markedly influence formation of such pollutants as NO_x and CO. Attempts to develop computer programs for flow field predictions have been hampered by the complexity and mathematical characteristics of the governing equations as well as by a

basic lack of knowledge concerning the physics of the flow. The governing equations form a set of coupled, nonlinear, stiff, partial differential equations that are elliptic in nature. Questions concerning the physics of the flow deal mainly with how the turbulence can be described as a function of mean flow variables.

Several research organizations have developed or modified numerical techniques that purport to solve these governing equations. The computer programs to perform the calculations, however, contain a group of correlation parameters that are experimentally determined, as well as procedures to ensure convergence or stability under difficult conditions. Comparing predictions with experimental data has produced mixed results; some comparisons are excellent, others are unacceptable. Practitioners usually respond to unacceptable comparisons by calling for more advanced turbulence models, assuming that the numerical procedures used by the computer programs are sound.

Under the Fundamental Combustion Research (FCR) Program (EPA Contract No. 68-02-2631), Energy and Environmental Research Corporation has carefully reviewed the numerical techniques used by these computer programs. Conclusions from this analysis are not yet definitive but indicate the possibility of error in using the numerical techniques. Two possibilities exist. First, as suggested by the practitioners, the numerical procedures could be correct, and discrepancy between predictions and experimental findings could result from inadequate turbulence modeling. Second, numerical errors could be substantial, with agreement between prediction and measurement reflecting merely a fortuitous choice of input correlation parameters.

To investigate these two possibilities and to establish a rational course of action in refining predictive capabilities, the FCR program has compiled a set of test cases. Prominent practitioners in the formulation of these computer programs will be invited to apply their techniques to these cases. Each test case will have a known solution for a specified turbulence model, thus restricting possible sources of discrepancy to the numerical procedures.

Conventional Combustion Environmental Assessment: Oil-to-Coal Conversion. An area of recent and growing concern has been the environmental consequences of extensive conversion from oil-firing to coal-firing industrial and utility boilers. IERL-RTP has issued a report showing that the differences in environmental impacts between coal and oil combustion emissions from industrial boilers controlled only by FGD (scrubbers) are potentially significant. The comprehensive environmental assessment of a 10-MW (34×10^6 Btu/h) industrial boiler, conducted by the Laboratory's Conventional Combustion Environmental Assessment Program, suggests several differences between coal firing and oil firing. The following eight paragraphs present some of these differences.

First, before the scrubber, the quantity of particles from coal firing was about 56 times as great as the quantity from oil firing, but the oil-fired particles are generally smaller and more difficult to remove. As a result, the quantity of particles from coal firing was only 1.4 times as great as the quantity from oil firing after the scrubber.

Second, the data indicate that little or no removal of particles in the 1- to 3-μm (4 to 12×10^{-5} inch) range occurred in the scrubber. In fact, the net increase in emissions of these particles suggests that particles in this size range are generated, as well as not effectively removed, by the scrubber. Up to 40 percent of the fine particle emissions at the scrubber outlet could result from scrubber-generated sodium bisulfate ($NaHSO_4$).

Third, as expected, NO_x and CO emissions before and after the scrubber during coal firing were about triple those during oil firing. This finding is typical because the scrubber does not remove these pollutants, and no other controls were used. As a result, it has been estimated that coal firing would produce NO_x levels that exceed the National Ambient Air Quality Standards (NAAQS) in the range of 1 to 3 km (0.6 to 1.9 mi) from the source under typical weather conditions.

Fourth, SO_3 emissions from both coal firing and oil firing before the scrubber are low—0.8 to 1.0 kg/h (1.8 to 2.3 lb/h). However, SO_3 emissions from oil firing were about 1.3 times as great as SO_3 emissions from coal firing at the scrubber inlet and 1.4 times as great at the scrubber outlet.

Fifth, sulfate emissions were about 9 kg/h (20 lb/h) at the scrubber inlet for coal firing and about 3 kg/h (7 lb/h) for oil firing. At the scrubber outlet, sulfate emissions for both fuels were about 1.1 kg/h (2.5 lb/h).

Sixth, although coal firing produced greater quantities of trace elements in the scrubber cake than oil firing, quantities of heavy metals and toxic substances in the scrubber cake from both fuels would require the use of environmentally acceptable disposal techniques to prevent contamination of ground water by leaching.

Seventh, after the scrubber, most trace element emissions (except vanadium, cadmium, lead, cobalt, nickel, and copper) were higher during coal firing. Oil firing produced cadmium emissions 60 times greater than coal firing.

Eighth, among the trace element emissions, cadmium and molybdenum were predicted to produce the greatest burdens in living plant tissues. Oil firing was predicted to produce a tenfold increase in cadmium concentrations in living plants, and coal firing was predicted to result in a thirtyfold increase

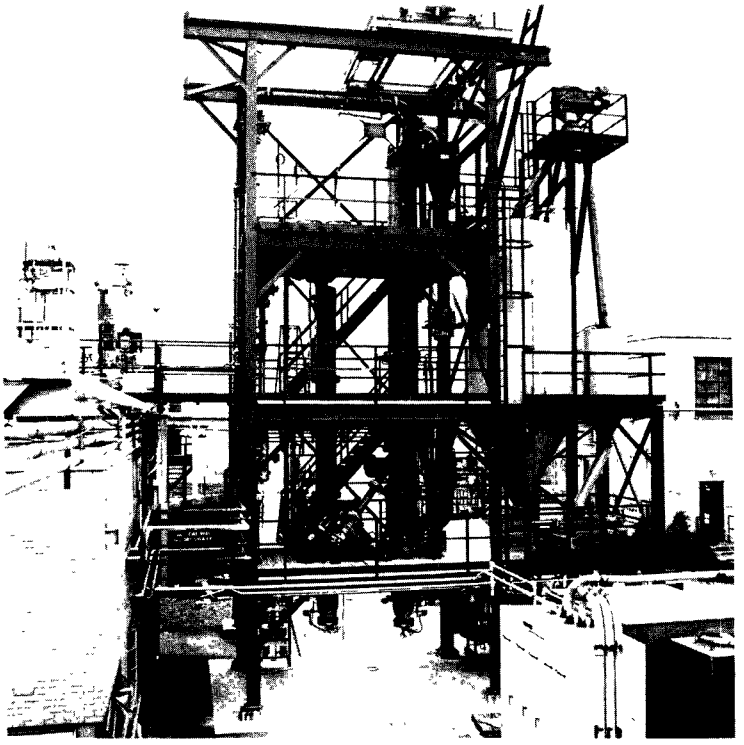
in molybdenum concentrations. Because cadmium is considered highly toxic and accumulates in mammals, its emission to the environment is a serious problem. Although molybdenum is much less toxic than cadmium, it has caused injury to farm animals at very low concentrations; therefore, the emission of molybdenum to the environment is also of concern.

Even though the differences outlined in the preceding paragraphs are significant, it was concluded that other factors may override fuel choice in determining the environmental acceptability of controlled industrial boilers. These other factors include location, type, and number of other emission sources, background pollution levels, and the potential long-term accumulation of pollutants to unacceptable levels in the environment.

The comparative assessment of coal firing and oil firing was conducted under IERL-RTP direction by TRW, Inc., of Redondo Beach, California, with the cooperation and participation of Firestone Tire and Rubber Company at the Firestone plant in Pottstown, Pennsylvania. The study, which is EPA's most comprehensive assessment of a conventional combustion source to date, involved the following:

- Sampling and analysis of gas, liquid, and solid emissions from the boiler and its pollution control equipment
- Estimation of multimedia environmental impacts of the emissions
- Comparison with best estimates of acceptable levels of impacts
- Evaluation of techniques for mitigating unacceptable impacts

Details of the comparative assessment are presented in a three-volume EPA report published in August 1978.[23]



IERL-RTP's 0.63-MW pressurized FBC Miniplant, which burns up to 500 lb/d of coal, is operated by Exxon to study emissions and control options.

Advanced Combustion Processes

Along with work on conventional combustion equipment, IERL-RTP is evaluating *advanced combustion processes* like fluidized bed combustion (FBC), catalytic combustion, and combined-cycle coal combustion.

Comprehensive sampling and analysis of emissions from fluidized bed combustors have been completed at four units in the United States and Great Britain. A pilot-scale test of emission control techniques at DOE's FBC-fired plant [30 MW (102×10^6 Btu/h)] in Rivesville, West Virginia, is scheduled for the near future.

Extensive tests are being conducted at a pilot-scale catalytic combustor to develop scale-up criteria for different kinds of stationary combustion equipment. These tests already have shown that catalytic combustors substantially reduce emissions of nitrogen oxides, carbon monoxide, and hydrocarbons from a variety of fuels.

To unify all combustion modification work, IERL-RTP's environmental assessment of NO_x control is evaluating the broader environmental and economic consequences of controlling pollutants from stationary sources. Information on pollutants, control techniques, and environmental effects is being weighed and analyzed carefully. When the 3-year study is completed, EPA will be in a much better position to make intelligent choices about controlling NO_x and other pollutants in the years ahead.

The sections that follow present highlights of the year's research accomplishments in advanced combustion processes.

[23] U.S. Environmental Protection Agency, *Environmental Assessment of Coal- and Oil-Firing in a Controlled Industrial Boiler: Vol. I, Executive Summary,* NTIS No. Pb 289-942, EPA 600/7-78-164a, *Vol. II, Comparative Assessment,* NTIS No. Pb 289-941, EPA 600/7-78-164b; *Vol. III, Comprehensive Assessment and Appendices,* NTIS No. Pb 291-236, EPA 600/7-78-164c, Aug. 1978.

Classification of FBC Solid Residue. Solid residues from FBC have been evaluated by the criteria and procedures proposed in the *Federal Register* of December 18, 1978,[24] for determining whether a material is to be considered "hazardous" under the Resource Conservation and Recovery Act (RCRA). Materials found to be hazardous will be subject to special requirements for handling and disposal, to be specified under RCRA. The evaluation of FBC residues indicated that, in general, FBC residues will not be hazardous according to the RCRA criteria and procedures as currently proposed.

Four criteria have been proposed for determining whether a material is hazardous: toxicity (as determined by a proposed leaching test referred to as the Extraction Procedure), corrosivity, reactivity, and ignitability. Several FBC residues (including both spent bed material and carryover/fly ash) have been tested to date by the Extraction Procedure; none of the residues was found to be hazardous in terms of toxicity (that is, in no case did any trace metal concentration in the Extraction Procedure leachate exceed 10 times the National Interim Primary Drinking Water Standards). Also, it is EPA's current judgment that the residue would not be considered corrosive, reactive, or ignitable. The conclusion, therefore, is that FBC residue generally would not be found to be hazardous under the currently proposed RCRA procedures.

In certain cases—perhaps if an FBC plant is burning a coal or using a sorbent having a high content of trace metals—it is possible for an individual FBC residue to be found hazardous. It is likely that any such residue would be included in the same "special waste" category that has been defined for any electric utility wastes considered hazardous.

Activities are underway by EPA's Office of Solid Waste to expand the RCRA test procedures. Biological testing for toxicity and a fifth criterion (radioactivity) for determining whether a residue is hazardous are under consideration. In addition, changes in the test procedures are possible. Further testing of FBC residue will be conducted as necessary employing any new or revised procedures.

Potential of FBC as One Control Approach for Industrial Boilers. GCA Corporation's Technology Division has prepared a comprehensive Technology Assessment Report (TAR) that assesses the environmental control options, the "best" control systems, the cost, and the environmental and energy impacts of the FBC process. This report was prepared to assist EPA's Office of Air Quality Planning and Standards (OAQPS) in determining the technological basis for NSPS being considered for industrial boilers. The TAR concludes that, after the costs and reliability have been demonstrated, atmospheric FBC should be a candidate for any new coal-fired boiler installation. The results from this report, together with results from similar reports prepared on alternative control technologies (such as flue gas desulfurization), will be rigorously examined by OAQPS in conjunction with several regulatory options to facilitate the setting of standards for industrial boiler emissions.

Results of the FBC TAR suggest that the following should be technically achievable at a cost only moderately above that of an uncontrolled conventional boiler:

- SO_2 removals as high as 90 percent
- NO_x emissions as low as 0.2 ng/kJ (0.5 lb/10^6 Btu)
- Particulate emissions as low as 0.01 ng/kJ (0.03 lb/10^6 Btu)

Although it was not in the scope of the TAR to compare alternative control options, a preliminary comparison concludes that FBC should be able to achieve the indicated control levels at a cost competitive with conventional boilers using flue gas desulfurization.

The large volume of soild residue (spent SO_2 control sorbent and fly ash) generated by the FBC process could become an important environmental concern. Further consideration is needed of means for handling and disposing of this residue, the leachate from which is very basic and has a high total dissolved solids content.

The costs and reliability of this emerging energy technology must be demonstrated in commercial-scale applications before the process receives wide commercial acceptance.

Followup Testing for Mutagenic FBC Fine Particulates. Because positive Ames (mutagenicity) results were obtained with fly ash from the pressurized FBC (PFBC) Miniplant, IERL-RTP and HERL-RTP are working together to evaluate Miniplant samples further. This effort may be considered a methodology development effort to identify Level 2 bioassay approaches. Samples from three Miniplant runs have been provided to HERL-RTP so far; two more sample sets will be provided in the future. During these runs, the Laboratory's trailer-mounted partial control devices (electrostatic precipitator or fabric filter) were on the Miniplant flue gas so that the fine fly ash responsible for the previous Ames result is captured in relatively large quantities. HERL-RTP will repeat the Ames test with these samples, using different extraction solvents and procedures. Whole animal tests may be conducted if the early work warrants.

[24] U.S. Environmental Protection Agency, "Hazardous Waste Proposed Guidelines and Regulations and Proposal on Identification and Listing (Part IV)," 43 F.R., No. 243, Dec 18, 1978.

Operation of FBC Unit With Baghouse. Two 36-hour runs on the Sampling and Analytical Test Rig have been completed successfully. The purpose of these test runs was to evaluate the performance of low-temperature baghouse fabric filters as particulate control for FBC. The first 24 hours of each run was for bag conditioning, and the remainder of the time was used for sampling the effluent gas streams. Data reduction is incomplete at this time but will be reported as soon as available. Other scheduled test programs include: evaluation of electrostatic precipitators, environmental assessment of all emissions and waste streams, and control of nitrogen oxides.

Continuation of Test Preparation for DOE on Georgetown Atmospheric FBC Boiler. EPA continues to prepare for environmental tests on the DOE 50,000-kg/h (100,000-lb/h) steam atmospheric FBC (AFBC) boiler at Georgetown University. Testing plans include: Level 1 (and possibly Level 2) comprehensive analysis, characterization of the performance of the fabric filter on the unit, and 30-day continuous monitoring in support of the industrial boiler NSPS development effort. DOE cooperation continues to be excellent. Shakedown of this FBC is proceeding well, giving encouragement that EPA's testing may indeed be possible on the currently anticipated schedule. The Georgetown unit originally burned coal, but since late June it has had several reasonably successful coal combustion runs of 8 hours or more. The unit eventually will be turned over to the university for routine operation.

FBC Support to Program Offices. To ensure that the IERL-RTP FBC program is fully supportive of the program offices, the Laboratory has initiated communication with all the offices in an effort to define their real needs. The results of these dialogues will be used to develop the Standards Support Plan for FBC and to design the FBC program to provide the information that the program offices require. To date, brief individual documents have been prepared for each program office. These documents raise issues to stimulate discussions that should help define the goals of the IERL-RTP program. It is now planned to follow through with a visit to each office to discuss these issues with program office staff. In addition, further action is underway in connection with some of the offices: for the Office of Solid Waste (OSW), IERL-RTP (through GCA Corporation) is attempting to define the precise tasks that should be undertaken to support OSW's mandate under RCRA; for the Office of Radiation Programs (ORP), specific radioassays on FBC samples have been undertaken. Program offices contacted, in addition to OAQPS, include the Office of Water Planning and Standards, OSW, ORP, the Office of Toxic Substances, and the Office of Noise Abatement and Control.

Reducing NO_x Emissions From PFBC by 30 to 50 Percent Through Combustion Modifications. A test program on the PFBC bench-scale unit—burning coal at 11 kg/h (25 lb/h)—at Exxon Research and Engineering Company indicated that up to 50 percent reduction in emissions of NO_x can be achieved in PFBC through the use of two-stage combustion, ammonia injection, or flue gas recirculation. Combinations of these combustion modification techniques, however, do not provide reductions beyond those obtained using one of the techniques alone.

Two-stage combustion runs were made with primary air being 75 to 90 percent of stoichiometric conditions and with enough secondary air injected into the bed, near the top, to raise the total air to an excess of 15 to 30 percent. Operating at 800 kPa (8 atm) total pressure, this approach reduced NO_x emissions from the range of 86 to 129 ng/J (0.2 to 0.3 lb/10^6 Btu), with an average reduction of 45 percent. Two-stage operation also had the adverse effect of increasing SO_2 and CO emissions. More testing would be required to optimize two-stage operation and to address the impact of such operation on other FBC performance parameters.

Ammonia injection tests investigated the effect of ammonia injection location and temperature, ammonia feed rate (NH_3/NO ratio), and the injection of hydrogen with the ammonia. Injection location was found to have the predominant effect. When the ammonia was injected near the top of the bed (at a temperature of about 704° C (1,300° F), NO_x emissions were reduced by 30 to 50 percent to about 0.04 ng/kJ (0.10 lb/10^6 Btu).

Simulated flue gas recirculation tests were conducted by mixing nitrogen with the combustion air feed to simulate the effects of recirculation. Tests simulating different degrees of recirculation (10 percent and 20 percent of the air feed) showed no substantial reduction in NO_x emissions as a result of the simulated recirculation.

These results are considered preliminary; further testing is required to confirm the results and perfect the process.

Potential of Conventional Cyclones and Ceramic Filters for High-Temperature/High-Pressure Particle Control. High-temperature/high-pressure particle control devices have been tested on IERL-RTP's 0.63-MW (2.15 × 10^6 Btu/h) PFBC Miniplant at Exxon. The goal of this testing has been to achieve the revised EPA NSPS for utility boiler emissions—0.01 ng/kJ (0.03 lb/10^6 Btu). This goal was achieved using a ceramic fiber filter, consisting of Saffil alumina, on a 0.85-m^3/min

(30-ft^3/min) slipstream of Miniplant flue gas. Emissions somewhat higher than 0.01 ng/kJ (0.03 lb/10^6 Btu) were achieved using three stages of conventional cyclones. These results are encouraging.

Approximately 30 tests were conducted using the slipstream ceramic fiber filter, representing about 90 hours of operation. At 815° C (1,500° F) and 900 kPa (9 atm), the filter captured between 90 and 99+ percent of the particulate in the entering flue gas. The inlet particle loading was between 0.2 and 0.5 ng/kJ (0.4 and 1.2 lb/10^6 Btu), with a mass mean particle size of about 7 μm (2.8 $\times$ 10^{-4} inch); the outlet loading ranged from 0.86 to 12.90 ng/J (0.002 to 0.03 lb/10^6 Btu), which is equal to or below the standard. Operation of the ceramic fiber filter was generally smooth and stable. Reverse air pulses, employed to clean the filter, maintained a reasonable pressure drop across the filter.

About 2,000 hours of Miniplant operation have been completed with three stages of conventional cyclones in series treating the full flue gas flow—up to 14 m^3/min (500 ft^3/min). The three cyclones typically reduced particulate emissions to 0.02 to 0.1 ng/kJ (0.04 to 0.2 lb/10^6 Btu), with a mass mean particle size of about 1 to 2 μm (0.4 to 0.8 $\times$ 10^{-4} inch). Of particular interest was the performance of the third cyclone, which reduced the particle loading from the inlet value of 0.2 to 0.7 ng/kJ (0.4 to 1.6 lb/10^6 Btu)—mass mean particle size 5 to 7 μm (2 to 2.8 $\times$ 10^{-4} inch)—to the outlet levels indicated previously. This performance of the cyclone on such fine particulate is superior to that which would be expected based on traditional cyclone performance equations. The reason for this superior performance is not fully understood.

Improving SO_2 Removal by Increasing Gas Residence Time. IERL-RTP has projected that improved sorbent performance in removing SO_2 can be achieved in FBC's by increasing gas residence time. A recent test program on the 0.63-MW (2.15 $\times$ 10^6 Btu/h) PFBC Miniplant confirmed that projection, demonstrating SO_2 removals greater than 90 percent while limiting NO_x emissions to 0.02 to 0.1 ng/kJ (0.05 to 0.2 lb/10^6 Btu).

In a series of tests run with a gas residence time of about 1.6 seconds, SO_2 removals ranged from 94 to 98 percent while varying the dolomite sorbent feed rate calcium-to-sulfur molar ratio between 1.5 and 2. When the gas residence time was increased to 2.1 seconds, the SO_2 removals at the same dolomite feed rates were increased to 97 to 99.8 percent.

In addition to confirming the important effect of gas residence time, these runs demonstrated that almost any level of sulfur capture is technically achievable in PFBC. The control levels that may be employed in practice will have to be assessed for:

- Overall economic impact of buying, handling, and disposing of increased quantities of sorbent
- Impact on overall plant performance
- Environmental impact of disposing of increased quantities of solid residue

Suitable selection of such key parameters as gas residence time and sorbent particle size may be critical in determining the level of SO_2 control that is economically achievable.

Postcombustion Controls

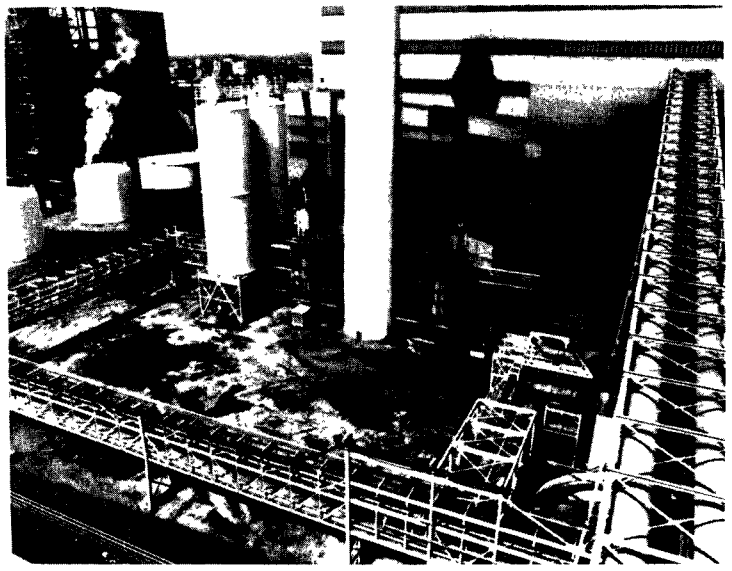
To complete its coverage of possible combustion options, IERL-RTP is seeking more efficient means of controlling sulfur oxides (SO_x), particulates, and nitrogen oxides after fuel is burned, that is, in the *postcombustion* stage. Postcombustion controls use a variety of technologies to remove these pollutants from the discharge streams of combustion processes.

Flue Gas Desulfurization

For the immediate future, *flue gas desulfurization* (FGD) promises to be technically and economically the most feasible method of reducing sulfur emissions from utility and industrial boilers. To improve this technology, IERL-RTP is sponsoring a number of FGD evaluation and demonstration projects.

Lime/limestone scrubbers are being evaluated in pilot-scale programs at IERL-RTP laboratories in North Carolina and at Tennesee Valley Authority's (TVA's) Shawnee Station near Paducah, Kentucky. Long-term reliability and verification tests currently are being conducted on two 10-MW (34 $\times$ 10^6 Btu/h) prototypes at the Shawnee site, and options are being evaluated for treating and recycling the sludge created by the scrubbers. This program is an important step in the development of environmentally safe, cost-effective ways to dispose of the sulfur wastes and other materials from flue gas cleaning processes. At Northern Indiana Public Service Company's Dean H. Mitchell Station near Gary, Indiana, IERL-RTP is investigating the Wellman-Lord/Allied Chemical process, in which SO_x are removed from flue gases and used to produce elemental sulfur.

In a project funded with the Air Force at Rickenbacker Air Force Base near Columbus, Ohio, IERL-RTP is testing another FGD process, the Swedish Bahco lime-scrubbing process. Dual-alkali and alkaline ash-scrubbing processes also are being investigated.



Magnesium oxide FGD plant at Philadelphia Electric Company's Eddystone facility in Philadelphia, Pennsylvania. Pictured from left to right are magnesium oxide storage silos, Boiler No. 2 stack, magnesium sulfite dryer, and coal conveyor.

The Laboratory is gaining further valuable insight into SO_2 scrubber technology through its cooperative efforts with Japan, where success in the application of scrubber technology has been impressive. Under the terms of the U.S.-Japan Agreement on Cooperation in the Field of Environmental Protection, IERL-RTP is widening its base of knowledge in the whole area of FGD technology for combustion sources.

The sections that follow present highlights of the year's research accomplishments in FGD.

Utility Dual-Alkali FGD Demonstration. IERL-RTP's full-scale, cost-shared demonstration of the dual-alkali process at Louisville Gas & Electric's 280-MW (960×10^6 Btu/h) Cane Run No. 6 Station entered the startup phase in late spring 1979. The unit was tested successfully for compliance with SO_2 and particulate removal requirements imposed by Jefferson County, Kentucky, and EPA Region IV.

The EPA demonstration acceptance tests designed to establish system performance with respect to key contract guarantees were scheduled for late November 1979. These tests have been delayed somewhat by a number of mechanical problems that have hindered continuous operation. Most of these problems, however, have been resolved as evidenced by a 96-percent system availability factor for October.

Following completion of the acceptance tests, a 1-year test program will be undertaken to characterize completely the system performance, reliability, and economics.

Dry SO_2 Control Program. IERL-RTP initiated its dry SO_2 control program early in 1979 through support of two surveys. One survey concerns the economics of dry scrubbing and is being performed by TVA. The main objective of this study was to provide an expeditious economic comparison of the most promising application of a lime sorbent dry-scrubbing system treating flue gas from western coal (0.7 percent sulfur, high alkalinity) with state-of-the-art wet limestone scrubbing. The report on this objective was received in early September 1979, and its revised version serves as an interim in-house reference. The final report, which is to be completed by TVA in late 1980, will include process information from vendors and will cover the three methods of dry FGD technology—spray-dryer baghouse, dry sorbent duct injection (before baghouse), and dry sorbent (limestone) boiler injection into a low-NO_x burner.

The second survey summarizes the status of dry FGD processes in the United States for both utility and industrial applications. Radian Corporation completed the report in late 1979.[25] Quarterly updates of this survey for this rapidly developing technology field are planned during fiscal year 1980.

Three demonstrations of dry FGD systems are in the planning stages with three different vendors. One demonstration would involve a full-scale industrial-size boiler—generating steam at 50,000 kg/h (100,000 lb/h)—using eastern coal (1 to 2 percent sulfur) and a spray dryer baghouse system with lime as sorbent. This system at Celanese's Amcelle Plant in Cumberland, Maryland, is under construction and is expected to be operational in March 1980. A testing waiver is needed for parametric testing because the plant must remove SO_2 to meet Prevention of Significant Deterioration (PSD) requirements. Full-load tests are expected to precede the parametric tests and to provide data relevant to NSPS for industrial boilers.

Two pilot-scale projects at western utilities involve spray dryer baghouse systems. In addition to scrubber waste characterization for both systems, waste disposal options for sodium salts resulting from using sodium compounds in both dry injection and spray dryer processes are being studied for the project now underway at the Martin Drake plant in Colorado

[25] U.S. Environmental Protection Agency, *Survey of Dry SO_2 Control Systems* (NTIS No. to be assigned), EPA 600/7-80-030, Feb. 1980.

Springs. For a second site, negotiations are underway for comprehensive testing of an optimized system using lime as sorbent in a system handling 140 to 280 actual m^3/min (5,000 to 10,000 actual ft^3/min) of flue gas.

If the work proceeds as planned, the full-load data for the full-scale industrial boiler scrubber tests should be available by June 1980, and the final report should be completed in September 1980. Reports for the two pilot demonstrations at utility sites are expected to be completed near the end of 1980.

Aqueous Carbonate Process FGD Demonstration. In early May 1979, the EPRI and Empire State Electric Energy Research Corporation (ESEERCO) boards approved funding for the demonstration of Rockwell International's Aqueous Carbonate Process (ACP). This regenerable FGD process will be installed at the 100-MW (340 X 10^6 Btu/h) coal-fired unit at Huntley Station in Tonawanda, New York. Unlike most current commercial FGD systems, which produce a throwaway sludge product, the ACP produces elemental sulfur, a marketable byproduct.

In the ACP, flue gas is brought into contact with Na_2CO_3 in a spray dryer. Na_2CO_3 is formed as a dry product, which is collected and sent to a molten salt bath where it is reduced with coal or coke. The resulting Na_2S "smelt" is quenched and dissolved, and the resulting "green liquor" reacts with the CO_2 evolved during the preceding reduction. The reaction regenerates Na_2CO_3 and evolves SO_2, which is sent on to a Claus plant where elemental sulfur is produced.

Among the various sulfur-producing FGD processes, ACP is unique because of its direct use of coal or coke as a reductant. Other processes require natural gas, reductant gas produced by gasifying coal, or hydrogen. Low energy consumption is another advantage. Typically in sulfur-producing processes, a sorbent regeneration step requires energy and produces an SO_2 stream, which is then reduced. The reduction also consumes energy.

Negotiations have been completed among EPA, ESEERCO, Rockwell International, EPRI, and Energy Research and Development Authority of New York State to sponsor the demonstration jointly. Ground breaking took place in September 1979, and laying of foundations and caissons was completed in November.

Dry Scrubbing of Key Interest to Attendees at Fifth FGD Symposium. Approximately 800 representatives from industry, utilities, and regulatory agencies attended 3.5 days of papers, presentations, and panel discussions on such subjects as health effects of SO_2, status and possible impact of pending legislation, recent operating history of several significant FGD installations, and recent technological breakthroughs. Symposium participants included personnel from TVA, EPRI, DOE, and the U.S. Bureau of Mines.

The Symposium's keynote speaker, Leon Ring, General Manager of TVA, stated that TVA "does not view environmental protection and energy technology as opposing factors." In their view, "they are two sides to the same coin." Ring continued by describing TVA's $1 billion capital investment program for SO_2 control.

During the panel discussion on the impact of recent legislation, Walter C. Barber, EPA's Deputy Assistant Administrator for Air Quality Planning and Standards, described current Agency thinking on the Clean Air Act amendments. He discussed alternatives such as 24-hour vs. 30-day averaging times, 85 percent vs. 90 percent SO_2 removal, and partial vs. full scrubbing. Gary N. Dietrich, Associate Deputy Assistant Administrator for Solid Waste, and James Agee, Regional Coordinator for Office of Water Planning and Standards, discussed RCRA and the Clean Water Act, respectively. This 1.5-hour session was marked by active audience participation.

The symposium devoted 1.5 days to utility applications. In the area of operating experience, Don Ross of Davy Powergas spoke on Wellman-Lord at Northern Indiana Public Service Company and Public Service of New Mexico; Harlan Head of Bechtel described recent Shawnee lime/limestone results, particularly the dramatic success to date with adipic acid enhancement. These two programs are EPA sponsored. In addition, attendees heard about Cholla Station, LaCygne, Martin Lake, and sludge disposal at Cane Run.

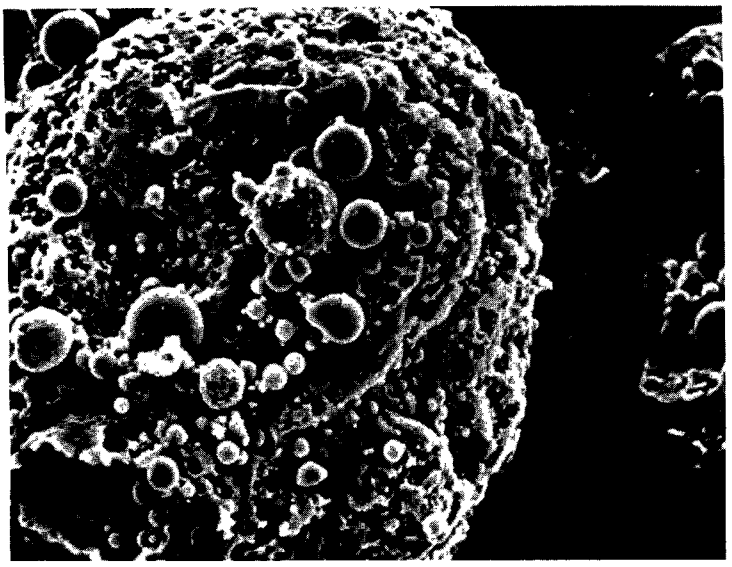
Dry scrubbing was the topic that generated the most interest. Two papers described the technology, recent testing experience, and plans for large-scale power plant applications. Dry scrubbing was also the primary focus at the evening panel discussion on the current status and future prospects of FGD.

A half-day session devoted to industrial applications included papers on significant industrial boiler FGD installations and a panel discussion on FGD for potential industrial boiler NSPS.

Fine Particulates

Fine particulates—less than 3 μm (1.2 X 10^{-4} inch) in diameter—include some of the most dangerous pollutants. These tiny particles bypass the natural filters in our nasal passages and penetrate deep into our lungs, where they may cause respiratory disease and cancer.

IERL-RTP is helping to solve the problem of fine particulate pollution by studying novel and advanced techniques and



Photomicrograph of fly ash from a coal-fired power plant (magnified 200 times).

by improving the efficiency and cost effectiveness of the three main particulate control devices in use today—electrostatic precipitators (ESP's), wet scrubbers, and fabric filter systems.

At present, three techniques are being tested to improve the performance of ESP's: increasing the specific collection area, redesigning devices to operate at higher temperatures, and adding conditioning agents to the exhaust gases.

Tests on new, low-cost designs for wet scrubbers are underway at TVA's Shawnee Station near Paducah, Kentucky. Both a mobile bed scrubber and a venturi/spray tower system are being studied.

For the future, fabric filter systems, called baghouses, may be the most attractive technique for controlling fine particulates—especially from boilers firing low-sulfur western coal. This is true for two reasons. First, these tiny particles are less likely to escape through fabric filters than through ESP's. Second, the particles emitted when burning low-sulfur western coal exhibit a high resistance to obtaining a charge and thus are difficult to collect using an ESP. (Ordinarily particles would have no charge of their own and would be attracted to the electrically charged elements in the ESP.) To improve baghouses, IERL-RTP is using materials like silica and zirconia to develop advanced filters that can withstand extremely high temperature corrosive environments for long periods of time.

The sections that follow present highlights of the year's research accomplishments in fine particulates.

Significant Cost Savings for Control of Fly Ash Projected From Pilot Scale Test of Novel Two-Stage ESP. In response to the need for cost-effective technology for controlling the particulate emissions from utility boilers burning low-sulfur coal, a novel two-stage ESP has been developed by Southern Research Institute under the sponsorship of IERL-RTP. The precharger stage employs a novel method for control of back corona. This precharger provides well-controlled electrical conditions and rapid particle charging in spite of the high electrical resistivity of the fly ash produced by most low-sulfur coals. The downstream collector stage is operated at high electric field strength and low current density to permit efficient collection of the charged particles and to avoid any substantial back discharge.

A pilot scale precharger-collector system was fabricated and tested on a slipstream of approximately 28 actual m^3/min (1,000 actual ft^3/min) at a coal-fired power plant where a high-resistivity fly ash was present. To compare the system with the conventional ESP technology, the IERL-RTP mobile ESP was operated simultaneously on a parallel slipstream. During a test period of approximately 2 weeks, measurements were made to characterize the particulate matter and the flue gas, to determine the effectiveness of the precharger in charging high-resistivity particles, and to assess the particle collection efficiency.

Although the inlet mass loading was about twice the expected loading, the precharger worked well. No operational problems were encountered during the test period. The average of the overall mass collection efficiency of the precharger-collector system was 97.7 percent, as determined by daily measurements during the test period. This rate compares with the average overall mass collection efficiency of about 90 percent for the mobile conventional ESP with the same specific collector area. Thus, the particulate emissions from the precharger-collector system were nearly one-fifth of the emissions from a conventional ESP with the same specific collector area. A preliminary engineering analysis indicates that the precharger produces an effect equivalent to more than doubling the total specific collector area of the downstream collector. This result is in agreement with previous laboratory tests and theoretical studies. Because the cost of an ESP is nearly proportional to the specific collector area, a substantial economic benefit can be projected for the two-stage system.

The field data and previous pilot plant work were used to estimate the specific collector area and costs of a precharger

system installed on a utility boiler burning low-sulfur coal and capable of meeting the particulate emission NSPS—0.01 ng/kJ (0.03 lb/10^6 Btu). The estimated specific collector area for a precharger system is 18.3 m^2/1,000 actual m^3/s (335 ft^2/1,000 actual ft^3/min), which compares with an estimated specific collector area of 38.3 m^2/1,000 actual m^3/s (700 ft^2/1,000 actual ft^3/min) for a conventional ESP. Order of magnitude turnkey capital costs for the precharger system are $44/kW to $50/kW compared with about $80/kW for the conventional ESP. The field data and previous pilot plant data indicate that the particulate collection efficiency of a properly designed precharger system is little affected by increases in the electrical resistivity of the fly ash (at least in the range of 1×10^{11} to 3×10^{12} ohm-cm). Thus, a precharger system with a specific collector area of 20.7 m^2/1,000 actual m^3/s (380 ft^2/1,000 actual ft^3/min) should meet NSPS for even worst case coals. A comparison of estimated costs for meeting NSPS with various ash resistivities for precharger systems and conventional technology is shown in Table 2.

The outlook for retrofit applications for the precharger also shows promise. The electrical characteristics and performance of the IERL-RTP mobile ESP, representing the conventional technology, were very similar to those found for the downstream collector in the two-stage system. Therefore, the addition of a precharger to such a conventional ESP can be expected to produce a similar magnitude of improvement in collection efficiency.

Diesel Emission Control. To representatives of EPA-Research Triangle Park, EPA-Ann Arbor, the U.S. Department of Transportation (DOT), and DOE, Southern Research Institute and Battelle Columbus presented results of recent diesel control development. The purpose of their presentations was to review significant progress under IERL-RTP contracts. These contracts are intended to assess and develop concepts for aftertreatment of diesel emissions. The Southern Research Institute contract also has assessed the application of stationary source particulate control devices to mobile sources.

Southern Research Institute found that diesel particulate is difficult to collect because of its small particle size and low bulk density. Application of scrubbers was ruled out entirely by high evaporation losses. Traps, filters, and electrostatic devices could be used to achieve 60 to 90 percent collection efficiencies at pressure drops less than that in current mufflers. Specific designs for future study were recommended, including a fiber filter, a two-stage electrostatic collector, and a trap similar to the one proposed by Eikosha Company.

Battelle Columbus found that a number of approaches for oxidation of diesel particles were feasible and that catalytic oxidation on some type of filter or trap holds the greatest promise. The key to successful operation would be frequent ignition combined with filter media that maintain integrity at high temperature.

Other discussion was provided by Senichi Masuda of Tokyo University and Tom Baines of EPA-Ann Arbor. Senichi Masuda reviewed the current activity of Eikosha Company in developing the Aut-Ainer trap. Better cooling of the trap by ram air ducted from the front of the vehicle had increased efficiency during a recent road test. Tom Baines reported that work on the contract with Michigan Technical University had started and that there were plans to evaluate a series of control approaches on a heavy duty diesel.

Table 2.
Order of Magnitude Cost Estimates for Meeting Utility NSPS for Particulate Matter of 12.90 ng/J

Resistivity (ohm-cm)	SCA of precharger system (ft^2/actual 1,000 ft^3/min)[a]	Cost of precharger system ($/kW)	SCA of conventional ESP (ft^2/actual 1,000 ft^3/min)[a]	Cost of conventional ESP ($/kW)
1×10^{11}	355	44-50	700	80
2×10^{11}	355	44-50	800	91
5×10^{11}	380	47-53	850	97
10^{12}	380	47-53	930	106

[a]Specific collector area (SCA) is measured in square feet of collector area per actual 1,000 cubic feet of gas per minute (ft^2/actual 1,000 ft^3/min). To convert SCA from English to metric units (m^2/1,000 m^3/s), multiply by 0.055.

Evaluation of a Baghouse for Collection of Fly Ash From Low-Sulfur Coal. A contract has been funded with Southwestern Public Service (SWPS) to provide a full-scale demonstration of a fabric filter for control of particulates on a large utility boiler burning western low-sulfur coal. A new fabric filter began operation in June 1978 on a 356-MW (1,214 $\times 10^6$ Btu/h) boiler at the Harrington Station of SWPS in Amarillo, Texas. IERL-RTP has provided funding for installation and operation of continuous monitors to track filter operation and performance. Also, three 1-month detailed emission tests are scheduled to be completed during the first 2 years of operation to characterize the fabric filter. Results of these emission tests will provide a sound basis for NSPS, State Implementation Plan (SIP), and PSD determinations. The contract will continue until 1984 to determine the technical and economic feasibility and the long-term reliability of the fabric filter.

Shortly after the fabric filter unit began operating, the pressure drop began to increase rapidly. At full load the pressure drop reached 25 to 31 cm (10 to 12 inches). Design pressure drop is about 13 cm (5 inches). Also, after about 3 months of operation, bag failures began to occur at an alarming rate. In June 1979 the fabric filter unit was rebagged after several modifications to the cleaning system failed to reduce the high pressure drop. Since rebagging was completed, the pressure drop has improved and is now operating at 18 to 20 cm (7 to 8 inches) at full load. No bag failures caused by wear have been observed.

Before the new bags were installed, one of the three 1-month detailed tests was completed. The average outlet loading for this test series was 0.01 ng/kJ (0.02 lb/10^6 Btu), and the average collection efficiency was 99.4 percent.

Testing To Develop Emission Factors for Inhalable Particulate Program. In response to the amendments to the Clean Air Act of 1977, EPA is considering an ambient standard for inhalable particles—those particles having aerodynamic diameters <15 μm (<59 $\times 10^{-5}$ inch). Consequently, it will be necessary to have emission factors for inhalable particles to provide for implementation of the standard. IERL-RTP is assisting OAQPS in determining emission factors based on cutoff size for inhalable particles for both controlled and uncontrolled sources.

A multiple-award competitive procurement was issued by IERL-RTP in fiscal year 1979 for three contractors to test inhalable particulate emissions. The continental United States was divided into the following three geographical areas for contract award:

- Area A: EPA Regions I, II, III, and IV
- Area B: EPA Regions V, VI, and VII
- Area C: EPA Regions VIII, IX, and X

The contractors selected were GCA Corporation for Area A, Midwest Research Institute for Area B, and Acurex Corporatior for Area C. Contracts were awarded in September 1979; testing begins early in fiscal year 1980.

Some inhalable particulate (IP) testing was initiated in fiscal year 1979 under existing EPA contracts for secondary lead smelters, the iron and steel industry, and paved and unpaved roads Draft copies of sampling protocols for IP emission testing hav been prepared and issued to IP emission testing contractors for both ducted and fugitive emissions. The protocols will be published early in 1980.

A computer program has been developed to extrapolate dat from the Fine Particle Emissions Information System to the IP range. The user can extract data for up to 50 sample runs from a given source and fit a curve to the data points. From thi curve, the fraction below 15 μm (59 $\times 10^{-5}$ inch) or the fractio below any particle size less than 15 μm (59 $\times 10^{-5}$ inch) can be estimated.

Particulate Symposium. The Particulate Control Technology Annual Symposium was held in July in Denver, Colorado, with 80 attendees from a wide variety of companies, including 17 utility companies. Approximately 120 papers were presented at the 4-day meeting, which started with a keynote speech by Frank T. Princiotta and a plenary session on enforcement questions.

The attendees were polled to determine areas of interest. The most popular topic was operation and maintenance, with ESP's and fabric filters running a close second. Interest in particulate scrubbers appears to be waning.

Technical presentations drawing great interest were the application of precipitators and baghouses to power plants and the development of novel precipitators. Examples of nove precipitators discussed are the Buell Trielectrode Electrostatic Precipitator, the University of Denmark Pulse Generator/Precip tator, and the Wide Plate Spaced Electrostatic Precipitator. Also discussed were two-stage precipitators using novel chargin sections, such as the Southern Research Institute Precharger, the Air Pollution Systems, Inc., High Intensity Ionizer, and the University of Tokyo Boxer Charger. As an important alternativ to ESP's, baghouses were shown, in papers given, to have had general success in controlling emissions from coal-fired power plants. Current baghouse installations include units of th Cameo, Harrington, Holtwood, Kramer, Martin Drake, Nucla, an Sunbury power stations. When operating properly, baghouses are capable of limiting emissions to less than 5 mg/normal m (5×10^{-6} oz/stdft^3) at pressure drops of less than 2 kPa (0.3 lb/in^2 Not all baghouse installations have been completely successfu

Both high pressure drop and bag loss have been encountered at the Harrington station, but these problems appear to be solved.

Flux Force/Condensation Scrubber Demonstration. A flux force/condensation (F/C) scrubber system has been developed by Air Pollution Technology under the sponsorship of IERL-RTP. An F/C scrubber is any wet scrubber designed to take advantage of water vapor condensation effects to enhance particle collection. Some of the water vapor condenses on the particles, causing their mass and diameter to increase and thereby making them easier to collect. The rest of the condensing vapor sweeps particles with it as it moves toward the cold surface and condenses. To a lesser extent, particle collection is also enhanced by thermal forces resulting from the temperature gradient between the gas and the cold surface. The diffusion and thermal forces are termed "flux" forces.

A full-scale F/C scrubber has been demonstrated on an iron cupola. The 400-dry-normal-m^3/min (14,000-dry-stdft^3/min) gas-atomized spray F/C scrubber was installed on the iron melting cupola at the Cleveland, Ohio, plant of Metalblast, Inc. A 6-month period of extensive study under a variety of conditions is nearing completion. The tests have shown that the F/C scrubber system uses only 70 percent of the power that a conventional scrubber system needs to achieve the same collection efficiency.

NO_x Flue Gas Treatment

Along with postcombustion controls for SO_x and particulates, IERL-RTP is sponsoring research on *flue gas treatment* (FGT) for reducing NO_x emissions from utility and large industrial sources. Although both dry and wet FGT processes are being investigated, IERL-RTP's program focuses on dry techniques, such as selective catalytic reduction of NO_x with ammonia, because they avoid many of the sludge disposal problems associated with wet FGT processes.

The Laboratory's international cooperative program with Japan has been particularly important in evaluating FGT technology. Japan already has a number of FGT systems in operation, and IERL-RTP draws heavily on their utility/industrial experiences in applying the technology.

In addition, IERL-RTP is performing both an economic and a control technology assessment of FGT processes. As part of these assessments, data from the Chicago Air Quality Control Region are being used in a modeling study comparing the economic and environmental impacts of currently available NO_x control technologies.

The sections that follow present highlights of the year's research accomplishments in NO_x FGT.

FGT Technology for NO_x and Simultaneous NO_x/SO_x Control. The objective of this research and development program is to demonstrate the applicability of FGT technology to coal-fired sources for the highly efficient removal of NO_x and SO_x emissions. The goal of the program is to remove 90 percent of the NO_x or 90 percent of both the NO_x and SO_x emissions. Significant progress was made in 1979 toward meeting the program's objective.

Construction was completed on a pilot plant to evaluate Hitachi Zosen's process for the selective catalytic reduction of NO_x with ammonia. Chemico Air Pollution Control Corporation, Hitachi Zosen's American licensee, operated the unit, which was installed at Georgia Power Company's Mitchell plant. Preliminary measurements indicate NO_x removal was in the range of 80-90 percent at an $NO:NH_3$ mole ratio of 1:1 and a temperature of 393° C (740° F).

Final results from the program should be available in 1980. The pilot plant was the first application of the technology on a coal-fired source in the United States.

Construction was also completed on a pilot plant to evaluate the Shell-Universal Oil Products (UOP) copper oxide process for the simultaneous removal of NO_x and SO_x emissions. The unit was installed at Tampa Electric Company's Big Bend station. Preliminary results indicated NO_x and SO_x removal in the 90-percent range for a 30-minute acceptance time and an $NO:NH_3$ mole ratio of 1:1. Final results from the program should be available in 1980. The pilot plant was the first application of the technology on a coal-fired source in the world.

The Japanese are the leaders in developing FGT technology for NO_x and simultaneous NO_x/SO_x control. To apprise interested U.S. parties of the latest developments, EPA published *NO_x Abatement for Stationary Sources in Japan.*[26] The report cited considerable advances with selective catalytic reduction technology for NO_x control. Catalysts resistant to sulfur species and reactors free from particulate plugging have been commercialized. Many large plants have been constructed, mainly for boilers that burn gas and oil. Demonstration plants for coal-fired boilers were under construction.

To estimate the cost of applying selective catalytic reduction technology in the United States, an economic study was undertaken by TVA. This study was cosponsored by EPRI and EPA. A 90-percent NO_x reduction system for a 500-MW ($1{,}700 \times 10^6$ Btu/h) coal-fired plant was estimated to have a capital cost of about $42/kW and an annual revenue requirement of about 2.7 mills/kWh. The dry simultaneous NO_x/SO_x process

[26]U.S. Environmental Protection Agency, *NO_x Abatement for Stationary Sources in Japan,* NTIS No. Pb 80-113673, EPA 600/7-79-205, Aug 1979.

(Shell-UOP) appeared competitive with the NO_x control process followed by a conventional FGD unit. The final report, *Preliminary Economic Analysis of NO_x Flue Gas Treatment Processes,* should be available in early 1980.

A study was conducted by Radian Corporation to assess the applicability of NO_x FGT technology to industrial boilers. The study was one of a series of technology assessment reports to help determine the technological basis for NSPS for industrial boilers. This study was the first serious consideration of the technology for a Federal standard. The study assessed the status of development and performance of alternative NO_x FGT control techniques and identified the cost, energy, and environmental impacts of the most promising processes. The final report, *Technology Assessment Report for Industrial Boiler Applications: NO_x Flue Gas Treatment,* should be available in early 1980.

Because results of the pilot plants and other studies will be available in 1980, a significant advancement should occur in NO_x and NO_x/SO_x FGT technology in the United States. This progress will enable EPA to move ahead with its assessment of the feasibility of applying the technology to coal-fired sources in the United States.

IERL-RTP Support to the Industrial Boiler NSPS. The amendments to the Clean Air Act of 1977 required that emission standards be developed for the fossil-fuel-fired steam generators. Accordingly, EPA has undertaken a study of industrial boilers to propose NSPS for this category of sources. The study is being directed by OAQPS; technical support is being provided by EPA's Office of Research and Development (ORD). As part of this support, IERL-RTP prepared a series of technology assessment reports for determining the technological basis for the NSPS for industrial boilers. The complete report series is listed in Table 3.

The reports in Table 3 will be combined with other information into the document, "Industrial Boilers—Background Information for Proposed Standards," which will be issued by OAQPS.

Emission testing is being conducted by IERL-RTP contractors to establish 30-day performance levels of emission control technology on industrial boilers. The following testing was conducted in 1979 or is planned for 1980:

- NO_x combustion modification, 7 sites
- FGD, 3 sites
- FBC, 2 sites

In addition, IERL-RTP project officers and contractors assisted in the development of computerized algorithms to estimate cost, energy, and environmental impacts of applying emission control techniques to industrial boilers. The algorithms were used in the Industrial Fuel Choice Analysis Model of OAQPS t predict nationwide impacts of various alternative regulatory option

The support of the industrial boiler NSPS activity is the mo extensive and significant commitment to a regulatory action undertaken by the IERL-RTP. This high level of involvement is expected to continue in 1980.

Table 3.
IERL-RTP Technology Assessment Report Series

Title	EPA No.
The Population and Characteristics of Industrial/Commercial Boilers in the U.S.[a]	600/7-79-178
Technology Assessment Report for Industrial Boiler Applications: Oil Cleaning	600/7-79-178
Technology Assessment Report for Industrial Boiler Applications: Coal Cleaning and Low Sulfur Coal	600/7-79-178
Technology Assessment Report for Industrial Boiler Applications: Synthetic Fuels	600/7-79-178
Technology Assessment Report for Industrial Boiler Applications: Fluidized-Bed Combustion	600/7-79-178
Technology Assessment Report for Industrial Boiler Applications: NO_x Combustion Modification	600/7-79-178
Technology Assessment Report for Industrial Boiler Applications: NO_x Flue Gas Treatment	600/7-79-178
Technology Assessment Report for Industrial Boiler Applications: Particulate Collection	600/7-79-178
Technology Assessment Report for Industrial Boiler Applications: Flue Gas Desulfurization[b]	600/7-79-178

[a]NTIS No. Pb 80150881.

[b]NTIS No. Pb 80150873.

Power Plant Waste and Water Management

IERL-RTP is conducting a comprehensive program to find environmentally acceptable methods of dealing with the *waste*

and the *water pollution* problems created in energy production. The Laboratory is seeking means of disposing of, or using, FGD byproducts and coal ash, as well as means of minimizing the adverse effects of cooling tower blowdown, coal pile runoff, boiler cleaning wastes, ash pond effluents, and the like. The program has been given additional impetus by the Resource Conservation and Recovery Act (RCRA); it is part of the Interagency Energy/Environment Program.

EPA's Effluent Guidelines Division has requested IERL-RTP's assistance to develop background data for power plants. This assistance includes some pilot field tests and studies to assess technology for meeting effluent guidelines for boiler cleaning wastes, chlorinated cooling system effluents, and fly ash sluice discharges.

To improve *thermal pollution control* technology, IERL-RTP is analyzing the performance of current wet and dry cooling systems in cooperative programs with TVA near Charlotte, North Carolina, and with the town of Braintree, Massachusetts. Control technology also is being developed for more effective treatment and recycling of cooling system effluent streams.

For better waste heat use, IERL-RTP is exploring applications in both agriculture and aquaculture. With cooperation from the Northern States Power Company and the University of Minnesota, waste heat has been used successfully to grow flowers, trees, and vegetables in greenhouses. In another cooperative program with TVA, waste heat is helping to speed the growth of algae to feed fish in commercial hatcheries.

The sections that follow present highlights of the year's research accomplishments in power plant waste and water management.

IERL-RTP Support of RCRA Regulation Development

The RCRA requires EPA to issue regulations for identifying and listing hazardous wastes as well as for handling, storing, treating, and disposing of both hazardous and nonhazardous wastes. At least part of the high-volume wastes from coal-fired power plants—coal ash and FGD waste—could fall in the hazardous category. Coal ash or FGD waste from a specific power plant would be designated as hazardous or nonhazardous depending on whether it fails the tests for toxicity required in the final RCRA regulations. The RCRA regulations proposed on December 18, 1978, include the proposed toxicity tests. The proposed regulations also recognize that coal ash and FGD waste are low in their potential toxicity and therefore have assigned them a "special waste" status, temporarily exempting them from many disposal site standards until additional data are available.

IERL-RTP is playing a key role in generating these additional data. Three projects have been initiated in support of the RCRA regulation development. First, a study was conducted for OSW to develop data on the coal-fired electric utility industry for a long-term waste management plan. Although this study was based on the assumption that most coal ash and FGD waste will be designated nonhazardous, the following results have general applicability:

- Hydrological data on existing power plant waste disposal sites are insufficient to determine whether the RCRA performance criteria (such as prevention of ground water contamination) are being met.
- Greater use of western coal would result in less waste generation.
- Power plant waste utilization should be encouraged.

The second effort, which is ongoing, involves testing of power plant wastes for toxicity. The proposed RCRA Extraction Procedure, followed by chemical analysis and biological testing of the extract, has been used on initial samples of fly ash, bottom ash, and FGD waste from a TVA plant. Results showed all three samples to be nonhazardous. The fly ash sample came closest to failing the test; therefore, fly ash from another TVA plant is currently being tested.

The third (and largest) effort, involves characterizing and monitoring approximately 16 coal-fired electric utility coal ash and FGD waste disposal sites. The purpose of this effort, now in the final stages of planning, is to obtain sufficient full-scale field data on environmental effects and costs to enable promulgation of RCRA regulations for management of these wastes. The sites to be studied will represent a cross section of the industry, including the prevalent disposal methods as well as those likely to represent the best disposal technology. This multimillion-dollar project is underway and should be completed in the fall of 1981.

Publication of Power Plant Cooling System Manual

Steam-electric power plants use large quantities of water for condensing steam and other in-plant purposes. This heated water, frequently containing other pollutants stemming from in-plant uses, can have adverse environmental effects, especially on aquatic organisms when the water is returned to a natural water body or stream. Many studies and reports have addressed environmental impacts related to aquatic or atmospheric effects of these discharges, particularly since passage of the Federal Water Pollution Control Act Amendments of 1972; however, no single document provides a broad perspective of

power plant cooling systems or their associated impacts. A state-of-the-art manual[27] on closed-cycle cooling systems for steam-electric power plants is intended to be a practical, user-oriented handbook that synthesizes the information reported in many specialized studies.

The manual provides an assessment of current, near-term, and future technologies used or anticipated with closed-cycle cooling systems. Intended to provide a broad understanding of the subject rather than to be a design or specification manual, the manual discusses the design and operation, capital and operating costs, methods of evaluation and comparison, water treatment, environmental assessment of water and nonwater quality impacts, permits for construction and operation and benefit-cost analyses of closed-cycle cooling systems (primarily cooling towers and cooling lakes/ponds).

Sufficient information is provided to allow an understanding of the major parameters that are important to the design, licensing, and operation of closed-cycle cooling systems. Consequently, the manual is expected to be a useful reference for engineers, technical managers, and Federal and State regulatory agencies that must evaluate and judge the application and relative merit of these systems.

[27] U S. Environmental Protection Agency, *Closed-Cycle Cooling Systems for Steam-Electric Power Plants: A State-of-the-Art Manual,* NTIS No Pb 299-290, EPA 600/7-79-001, Jan 1979.

Supporting Programs

Process Measurements

Because every phase of IERL-RTP's work depends on reliable data, the Laboratory ensures the quality of its data through a process measurements program that coordinates and monitors measurement and sampling techniques. Through this program, IERL-RTP has made important advances in particulate measurement and sampling procedures as well as in new analysis techniques for determining organic and inorganic pollutant concentrations.

In addition to evaluating and developing measurement methods, reviewing test programs, evaluating test results, and on-site troubleshooting, the current major thrust of the process measurements program is the support of IERL-RTP's environmental assessment program. To provide a comprehensive base of comparable data on emissions from industrial and energy sources, IERL-RTP developed a three-level sampling and analytical strategy.

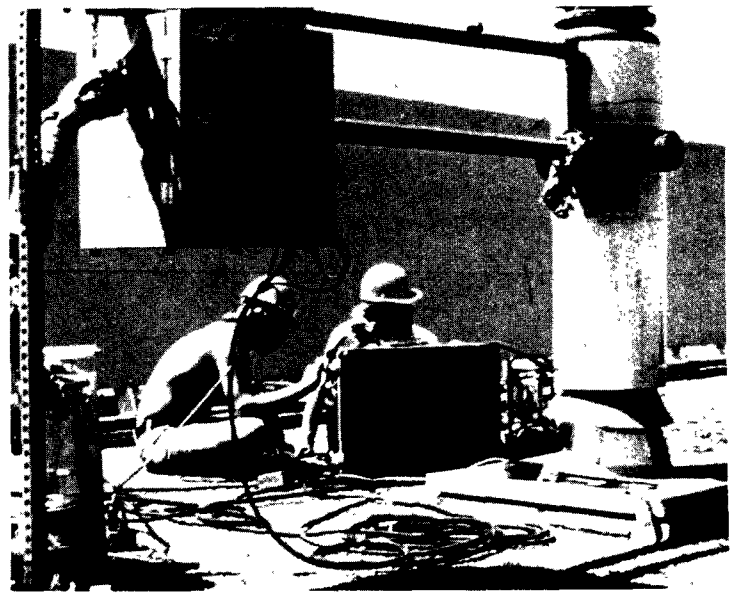
Level 1 is a screening phase for the detection of any effluent stream that might be detrimental to the environment. This phase uses a series of short-term bioassays for the detection of acute biological effects. Health-related biotests measure for presumptive carcinogenicity and general toxicity, whereas ecological biotests measure toxic effects of an effluent on soil microflora, plants, freshwater or marine fish, and freshwater or marine invertebrates.

Level 2 involves verification of the hazardous properties of the effluent streams identified in the Level 1 screening, followed by specific identification of chemical components of the effluent stream.

Level 3 focuses on long-term monitoring to determine the time-related variations of the hazardous materials in an effluent stream.

To support its three-level environmental assessment approach, the process measurements program is publishing a series of technical and procedural manuals oriented toward IERL-RTP project requirements.

The sections that follow present highlights of the year's research accomplishments in process measurements.



A process measurements team setting up source assessment sampling equipment for field studies.

Massive Volume Source Sampler for Health Effects Studies

A critical need exists for information pertaining to the health effects of the particulates emitted from emerging alternative energy sources. A portion of this information can be obtained from bioassays and animal inhalation studies conducted on samples of these emissions. However, these studies require large quantities—1 kg (2 lb) or greater—of particulate sample. The purpose of this program was to design, fabricate, and test a sampling system that would collect sufficient quantities of particulate samples for health studies in relatively short time periods. A sampling rate of 340 normal m^3/h (200 $stdft^3/min$) was estimated to be adequate.

The system consists of a probe, a cyclone dust collector, a fabric filter, a flowmeter, a blower, and a sampling/interconnecting line. The probe is 2 m (7 ft) long and has an adjustable opening at its inlet to establish isokinetic sampling. The probe is capable of traversing and, although it is designed for a 10-cm (4-inch) port, it can be easily adapted to fit larger ports.

A Fisher-Klosterman XQ-5 cyclone with a calibrated 50-percent-efficiency cut point (D_{50}) for a 2.5-μm (9.8×10^{-5} inch) aerodynamic diameter at 340 normal m^3/h (200 $stdft^3/min$) is the initial particle collector. Immediately following the cyclone is a single chamber fabric filter. The filter chamber can accommodate from 1 to 20 envelope bags. The filtration surface of the bags is composed of Gore-Tex porous Teflon™ laminate backed by Nomex. Each bag has 0.5 m^2 (5.0 ft^2) of collection surface. The fabric filter is equipped with a manual shaker and

can be easily modified to a double-chambered, automatic shaker design.

An orifice plate flowmeter is used to monitor the 340 normal m^3/h (200 $stdft^3/min$) flow rate selected for the sampler. The flow rate must be stable to maintain the 2.5-μm (9.8×10^{-5} inch) D_{50} cut point of the cyclone. A hand-operated damper attached to the outlet of the blower is used to adjust the flow rate. The entire sampler is heat traced from the probe to the outlet of the fabric filter. Design operating temperature of the sampler is 204° C (400° F).

This system was used on a 500-MW ($1,700 \times 10^6$ Btu/h) utility boiler firing low-sulfur (1 percent) No. 6 fuel oil. No emission control devices were used on the unit. Sampling began on August 6, 1979, and was completed on August 30, 1979. During this period the sampler operated for a total of 413 hours to gather 2,640 g (90 oz) of particulate in the <2.5-μm (9.8×10^{-5} inch) size fraction. The nominal total particulate loading in the stack was 28 mg/normal m^3 (28×10^{-6} oz/$stdft^3$) during the test.

Development of New Five-Stage Cyclone Particle Sizing System

Most measurements to determine the particle-size distribution in process streams are made with cascade impactors. Impactors, however, have several limitations:

- The stage capacity to retain particulates is low and operation requires skilled personnel and significant trial-and-error effort to obtain accurate values.
- When the mass concentration is high, sampling times are undesirably short.
- Impactors are used with lightweight collection substrates that can be unstable in mass when exposed to certain process streams.
- There is not enough mass collected for chemical analysis of the particles in each size fraction.
- Particle bounce and reentrainment cause an unpredictable but significant error in the stage and backup filter catches.

A series of small cyclones with progressively decreasing cut points will perform similarly to impactors, but without many of these associated problems. Therefore, IERL-RTP has developed, fabricated, and evaluated a sampling system containing five small cyclones and a backup filter in series. The cyclones were calibrated using monodisperse aerosols over ranges in temperature, flow rate, and particle density similar to those expected for field sampling. In addition to demonstrating the utility of cyclones for in situ particle-size analysis, it was intended that the experimental data supplement data already available to serve as the basis for the development of a more accurate theory of cyclone performance.

The system was designed to operate in stack at a sample flow rate of 28.3 l/min (7.5 gal/min), and is compact enough to fit through a 10-cm- (4-inch-) diameter port. The objective was to obtain five cut points equally spaced on a logarithmic scale within the range of 0.1 to 10 μm (0.4×10^{-5} to 40×10^{-5} inch). Because no theory is sufficiently accurate to serve as a basis for small cyclone design, the individual cyclones of the system were designed empirically. The final system has cut points of approximately 0.3, 0.7, 1.5, 2, and 5 μm (1.2×10^{-5}, 2.8×10^{-5}, 5.9×10^{-5}, 8×10^{-5}, and 20×10^{-5} inch) at 25° C (77° F) and a particle density of 1.0 g/cm^3 (0.5 oz/in^3).

Limestone Scrubber Slurry Automatic Control

An examination of processes for flue gas desulfurization by wet limestone scrubbing has led to consideration of process automation methods. These methods have the potential for increasing scrubber reliability, improving economy of operation, and reducing the variance of controlled variables, including SO_2. Under an EPA grant sponsored by IERL-RTP with the University of Cincinnati, control loops crucial to the performance of the slurry circuit of limestone scrubbers have been identified, mathematically modeled, and computer simulated to evaluate their dynamics. A preliminary analysis of expected scrubber performance under automatic control has been completed. Results indicate that maintaining a high process gain (defined as the ratio of slurry pH change per unit of limestone and buffer addition) under varying scrubber operating conditions is the primary objective of automatic control.

For limestone scrubbers it is generally acknowledged that scrubber operating reliability is a significant area of concern. Reliability is strongly influenced by internal scaling attributed to two circulating slurry species—sulfite and sulfate. The solubility of the sulfite can be increased by maintaining low pH, which also enhances alkali utilization. The solubility of the sulfate is controlled by the fraction of slurry solids recirculated. The objective of automatic pH control of the scrubber slurry via the limestone addition rate is to maintain the efficiency of high alkali utilization while accommodating varying scrubber SO_2 loading conditions. Based on the modeling and computer simulations, it was determined that a feedback approach to pH control would accommodate the scrubber geometric limestone dissolution characteristic. During computer dynamics studies, both feedforward and linear predictor compensators were found to offer only negligible control improvement over pH feedback because of the inherent damping effect of the

scrubber process. These approaches, therefore, do not warrant mechanization considering the additional complexity required.

The pH control system was installed on an operating limestone scrubber and maintained the pH set point within the desired operating range. The major problem experienced was reliability of the pH sensing electrode in the limestone slurry stream.

Bioassay Testing in Environmental Assessment

The assessment of potentially harmful biological effects caused by industrial and energy waste streams is the object of IERL-RTP's biological testing program. These biological tests have been chosen to conform to the three-phased approach for performing environmental source assessment.

The first level in the phased approach, Level 1, provides preliminary screening information for the assessment. The biological tests at this level identify problem areas and indicate potential need for further analysis. Level 1 tests provide a means of rapidly screening a large number of waste streams and establish priorities for these streams according to the relative need for more extensive analysis at the next level.

To ensure that an adequate and acceptable battery of tests is used, the Subcommittee on Biological Analysis was formed. This subcommittee is made up of senior EPA biologists with expertise in health, aquatic, and terrestrial bioassays. From inputs and reviews by the subcommittee, IERL-RTP has established a matrix of procedures for biological testing at Level 1.

The tests can be divided into three groups according to the biological response provided by each test organism. The subgroup representing health effects tests is composed of a mutagenicity test, cytotoxicity tests, and a rodent acute toxicity test. The aquatic ecological subgroup contains biological tests of marine and freshwater origin. A vertebrate (fish), an invertebrate (daphnia or shrimp), and an algal test are used in this subgroup. The terrestrial ecological subgroup contains two bioassays. The first, the stress ethylene assay, is performed on gas samples and uses soybean plants as the test organism. The second, the soil microcosm assay, measures response of intact soil cores to effluent samples.

The bioassay procedures were evaluated in three pilot studies involving textile wastewater after secondary treatment, fluidized bed combustion emissions, and coal gasification emissions. Level 1 chemical sampling and analysis procedures were used as guidance for sampling and chemical analyses. The results of these pilot studies revealed the applicability of the procedures, allowed ranking of the relative hazard of each effluent stream, and identified areas in the procedures that required additional development.

The success of the biological program at Level 1 on complex environmental samples has resulted from the experience gained performing these three pilot studies and from additional studies conducted under other IERL-RTP contracts. The program is continuing, and a revised Level 1 procedures manual will be issued in mid-1980. This manual will contain improvements in test application and data interpretation resulting from the pilot study experience.

Spot Test for Detection of Polynuclear Aromatic Hydrocarbons

Polynuclear aromatic hydrocarbons (PAH's) are among the many polycyclic organic materials (POM's) commonly encountered as trace level environmental contaminants in effluents associated with combustion, pyrolysis, and other thermal degradation processes. The PAH category, defined as containing hydrocarbon species with three or more fused aromatic rings, includes some compounds suspected of being carcinogens as well as many isomeric noncarcinogenic compounds. Therefore, determination of PAH emission levels is important in environmental assessment.

Procedures such as gas chromatography/mass spectrometry (GC/MS) are used to obtain compound-specific information on potential health hazards associated with PAH-containing effluents. These procedures, however, are necessarily sophisticated (because of the large number of possible PAH species) and require state-of-the-art equipment and extensive investment of expert analysts' time. It is not cost effective to apply them routinely to samples that may not contain any detectable levels of PAH.

A rapid, inexpensive spot test for preliminary screening of samples to determine the presence or absence of PAH has been developed. Basically, the test involves marking three 0.25-cm-diameter spots on a filter paper, applying 1 μl of sample extract to spots 1 and 2, applying 1 μl of naphthalene (sensitizer) reagent solution to spots 2 and 3, and visually observing all three spots under 254-nm UV light. The following criteria can be used to estimate the PAH content in the 1 μl of sample (diluted if necessary):

- Nonfluorescent with sensitizer: ≤ 1 pg
- Weakly fluorescent with sensitizer: 1-10 pg
- Strongly fluorescent with sensitizer, but not fluorescent alone: ≥ 100 pg
- Fluorescent without sensitizer: $\geq 10^4$ pg

From such estimates, the decision to proceed with further analysis can be made.

The sensitized fluorescence spot test has been used during ongoing IERL-RTP environmental assessment programs, including coal- and wood-burning furnaces, ferroalloy processes, and conventional combustion sources. Experience has shown that the test is easy to use and is valuable for preliminary screening. Results could be relied on to identify samples that contain no PAH and therefore require no GC/MS analysis and to rank samples by relative abundance of PAH. The users found that levels of 10 to 100 pg/μl of PAH, well below the usual GC/MS detection limits, were readily detectable by the spot test.

In Situ Fine Particle Stack Spectrometer System

Measurement of the particle size distribution in stacks and other hot emission sources is of fundamental importance in understanding the nature and quantity of particulate matter emitted. By combining upstream and downstream measurements, control device effectiveness can be characterized as a function of size. Particle size distribution measurements by conventional methods (for example, impaction) require a great deal of effort. Additionally, the low rate of collection precludes observations of transient phenomena such as rapping pulses associated with precipitators.

Particle Measuring Systems, Inc. (PMS), under EPA Contract No. 68-02-2668, recently developed an in situ particle size spectrometer using single particle light scattering from a helium-neon gas laser source. The Fine Particle Stack Spectrometer System (FPSSS), in addition to its in situ measuring properties, provides real-time data acquisition and both size and time resolutions that are significantly higher than with other methods.

The FPSSS has four size ranges covering 0.4 to 1.15, 0.5 to 2.0, 1.15 to 5.65, and 2.0 to 11.0 μm (1.6 to 4.5 $\times 10^{-5}$, 2.0 to 7.9 $\times 10^{-5}$, 4.5 to 22.2 $\times 10^{-5}$, and 7.9 to 43.2 $\times 10^{-5}$ inch). Each size range has 15 size classes. In normal operation, two size ranges are sampled concurrently—for example, 0.5 to 2.0 and 2.0 to 11.0 μm (2.0 to 7.9 $\times 10^{-5}$ and 7.9 to 43.2 $\times 10^{-5}$ inch)—producing 30 classes from 0.5 to 11.0 μm (2.0 to 43.2 $\times 10^{-5}$ inch). The maximum number density that can be measured is 5×10^4 cm^{-3}. The water-cooled head can operate continuously at temperatures above 250° C (482° F). The head contains the laser, condensing and imaging optics, and programmable preamplifiers. The instrument's internal velocimeter is not as accurate as conventional methods but can provide 10 to 20 percent accuracy over a 1- to 30-m sec^{-1} range.

Data acquisition is accomplished using a microcomputer with firmware programs and random access memory. Both cathode-ray tube (CRT) and hardcopy displays are generated. Sufficient memory capacity exists to generate size, area, mass, and accumulative mass distribution for up to 10 individua samples. In addition, numerical listings and time series plots of selected parameters, such as mass loading and number density, may be generated.

The prototype FPSSS has undergone testing at coal-fired generating stations and at PMS and IERL-RTP laboratory test facilities. It has performed well in laboratory tests, showing good size agreement with polystyrene spheres of known size and good agreement with mass measurements of fly ash by gravimetric methods.

Issuance of Revised Level 1 Methods Manual

Level 1 environmental assessment studies are designed as a comprehensive, predictive survey of the potential impacts on health and the environment from various industrial and energy-generating activities. A revised sampling and analytical methods manual[28] has been published and is available for future environmental assessment studies. This manual incorporates changes from the environmental assessment experience gained over the last 2 years with the original methodology selected by IERL-RTP for this data collection. It also incorporates many of the technological advances in both sampling and analytical capabilities that will facilitate or improve data gathered for these studies. New techniques include acceptance of ion chromatography for inorganic analysis, the addition of total chromatographable organics to the organic analytical scheme, and new sampling capabilities with the Fugitive Air Sampling Train system.

Special Studies

Because IERL-RTP directs its efforts at a wide range of pollution control problems, it maintains the special studies program as a means of ensuring that these complex problems are approached from all angles, systematically and efficiently. In it overview/support capacity, the special studies program has emphasized developing and implementing a computerized information system on fine particle emissions, continuing an integrated assessment of coal-based technologies, and formulating standard cost-estimating procedures for use in control technology demonstration projects.

In support of the Laboratory's environmental assessment

[28] U.S. Environmental Protection Agency, *IERL-RTP Procedures Manual: Level 1 Environmental Assessment* (2nd ed.), NTIS No. Pb 293795/AS, EPA 600/7-78-20 Oct. 1978.

program, the special studies program is developing an Environmental Assessment Data System (EADS) that will include data bases on fine particle emissions (already implemented), gaseous emissions, liquid effluents, and solid discharges. The fine particle emissions data base is already supplying important data to regulatory groups.

Participation continues in an integrated Coal Technology Assessment (CTA) that will offer policy options on the social, economic, and environmental impacts that may arise from the development and deployment of coal-based energy technologies until the year 2030.

To meet the need for complete, consistent economic evaluation methodology for pollutant emission control facilities, the special studies program also has developed a standard procedure for the use of the Laboratory's project officers in estimating capital and operating costs and in assessing the economic feasibility of proposed control options.

In addition to the above emphases, the special studies program performs technical evaluations of projects at the request of Laboratory management, manages engineering services contracts, and consults on the technical aspects of IERL-RTP's data processing applications.

The sections that follow present highlights of the year's research accomplishments in special studies.

Preparation of a Uniform Procedure for Preparing Engineering Cost Estimates

The two-volume work, *A Standard Procedure for Cost Analysis of Pollution Control Operations,*[29] was completed in 1979. Volume I, *User Guide,* provides both general and "boilerplate" information for a cost analysis for projects in all three economic sectors: private, regulated, and public. The general information delineates the need for and the characteristics of a complete, sound, appropriate, and understandable estimate. The core of Volume I, however, is the boilerplate material:

- The guidelines for information on the type of estimate, the desired measures of merit, and the financial and operation factors (these are usually designated by the requestor of a cost estimate)
- Specifications for the uniform format, which consists of three segments—descriptive, cost analysis, and reliability assessment (the format specifications are to be adhered to by those who make the cost estimate)

Volume II, *Appendices,* contains nine independent monographs and two examples of the use of the procedure:

A. Capital Investment Estimation
B. Annual Expense Estimate
C. The Cash Flow Concept
D. Discrete and Continuous Interest Factors
E. Measures of Merit
F. Cost Indices and Inflation Factors
G. Rates of Return and Interest Rates
H. Methods of Reliability Assessment
I. Sensitivity Analysis
J. Example I—Cost Analysis of Flue Gas Desulfurization (FGD) Retrofit Facility
K. Example II—Cost Analysis of Chlorolysis Plant

Courses covering fundamentals of cost analysis and an explanation of the procedure were presented to IERL-RTP personnel and the Office of Air Quality Planning and Standards on three separate occasions in 1979.

Environmental Assessment Data Systems as a Major Source of EPA Research Data

The EADS is a group of interrelated computerized data bases that describe multimedia discharges from energy systems and industrial processes and provide reference information on potentially hazardous chemicals that may be found in the discharge streams. The EADS has been developed by IERL-RTP to consolidate the increasing volume of environmental data, to provide uniform data reporting protocols, and to provide current information and methods for evaluating sampling data.

The EADS waste stream data bases consist of:

- Fine Particle Emissions Information System
- Gaseous Emissions Data System
- Liquid Effluents Data System
- Solid Discharges Data System

In conjunction with the waste stream data bases are two reference data bases—one that provides detailed toxicological and health effects data for more than 1,000 chemical compounds, and a second that records reported ambient concentrations of unmonitored multimedia pollutants. These reference data bases will allow users to compare sampled pollutant concentration with known values to aid in the determination of any hazard potential.

[29] U.S. Environmental Protection Agency, *A Standard Procedure for Cost Analysis of Pollution Control Operations: Vol 1, User Guide,* NTIS No. Pb 80108038. EPA 600/8-79-018a; *Vol II, Appendices,* NTIS No. Pb 80108046, EPA 600/8-79-018b, June 1979.

The EADS data bases are currently available to process waste stream sampling data. Detailed data input forms have been developed and distributed to allow the comprehensive encoding of data, which include source/process conditions, fuel/feed material characteristics, control technology characteristics, and the results of chemical, biological, or radiological assays. The EADS has been designed to accommodate full Level 1 and Level 2 reporting of sampling data. An extensive program library is being developed that will enable users to perform statistical analyses, calculate control technology efficiency, and model the data in a variety of ways.

The EADS supports the data needs of the Office of Research and Development's Wastewater Treatability Coordination Committee in the development of treatability manuals, the data storage and analysis of wastewater toxics data for the Wastewater Research Division/Municipal Environmental Research Laboratory, and the evaluation of existing fine particle data pertinent to the inhalable particulate sampling program.

User documentation on the EADS was issued in late 1979 and consisted of an EADS System Overview Manual and a User Guide for each waste stream data system. Training seminars on the use of the EADS have been conducted at Research Triangle Park, in Cincinnati, and at two locations in California. In only a few months, the EADS waste stream data bases have grown dramatically as a result of this training. This growth is expected to continue as new sampling results are included in 1980.

CTA Interim Studies

The CTA project aims at determining the environmental, social, and economic impacts of coal use in the United States to the year 2030. The project, which began in 1978, is at midpoint. Based on three different levels of coal use with associated economic and social characteristics, investigators are comparing the potentials of conventional and emerging coal technologies for various applications—industrial, electric utility, residential and commercial, and synthetic fuels. These technological studies are integrated for impact analysis by a simple and flexible computer program that provides detailed estimates of resource, environmental, and economic factors using various coal technologies.

Results from 1979 include completed studies of hazardous material impacts from coal use, air quality impacts of projected power plants, a comparison of six coal technologies for industrial energy production, the problem of atmospheric accumulation of carbon dioxide, water availability and allocation, and reports of two forums of interested parties and energy experts who identified issues for further study.

CTA studies underway or projected include solid waste from coal technologies, coal for export, residential and commercial systems, utility systems, synthetic fuels and chemica from coal, the "acid rain" problems, and studies of the social and political systems that will constrain or facilitate coal use nationally and regionally.

In the final segment of the CTA, several regional and one national forum of interested parties will examine the technologic and publication options the study has revealed. The final report, due in 1982, will convey the findings of the investigatc and the reactions of the forums.

Environmental Assessment of Wood Combustion

In response to the rapid increase in the use of wood and wood residues for both industrial boiler fuel and residential space heating, IERL-RTP has initiated several projects to evalua the potential environmental impacts of this growing energy source. Current national use of wood for energy is approximate 1.6×10^9 GJ (1.5 quads) per year, with 75 percent of this consumption occurring as direct combustion of wood processi residues in industrial boilers, primarily in the forest products industry. The Department of Energy's Wood Combustion Com mercialization program seeks to double the current rate to 3.2×10^9 GJ (3 quads) per year by 1985. Rising costs of conventional fossil fuels are already making wood fuels competitive for some applications in forested areas.

To determine the impact of residential wood combustion sources on ambient air quality, both source testing and ambie air sampling projects are underway. Emissions testing has been conducted on a prefabricated fireplace and two "airtigh stoves for two species of wood and for two fuel moisture levels. A significant portion of the particulate matter was fou to consist of condensable organic material. Analysis of this organic material resulted in identification of over 75 organic compounds, which included high-molecular-weight organic acids, high-molecular-weight fused ring aromatics, aldehydes furans, phenols, and naphthalenes. As many as 22 individual polycyclic organic compounds were identified. To relate the formation and emission of these compounds to ambient impacts, another study involves sampling ambient air in a small northeastern community where wood burning represen the primary mode of residential space heating. Analysis of the samples should provide information on the chemical fate of many of the organics emitted from wood burning.

IERL-RTP is also actively engaged in continuing assessment of industrial wood and wood residue boilers. Sampling and analysis of stack effluents for six small- to medium-sized industrial or commercial wood-fueled boilers has been accomplished. Emissions of hazardous organics, such as polycyclic organic materials, have been measured in addition to criteria pollutants.

The objectives of the wood combustion program are as follows:

- Characterize the types and quantities of emissions from both industrial and residential wood combustion sources.
- Determine the impacts on air quality of these wood combustion sources, relative to more conventional combustion processes.
- Learn how these emissions can be minimized through modification of combustion parameters (for example, combustor design, fuel properties, and operating variables).

Uncertainty in Data and Decision Making

Generally, the classification of a waste stream from an industrial source as acceptable or unacceptable is made from measurements of pollutant concentrations at the discharge point. Because these measurements are subject to error, the classification procedure should involve statistical considerations, such as the calculation of misclassification probabilities. The possibility of error has been recognized (and some theory developed) in past IERL-RTP studies.

In 1979, IERL-RTP has been concerned with the development of the ideas and concepts involved, with a view toward obtaining the best possible classification criteria and determining their precise statistical characteristics. In the course of this work, it has been recognized that various uncertainties, in addition to pure measurement errors, may arise. For example, the process of sampling may be variable, a goal level of acceptable concentration may be only imprecisely known, and a transport model used—needed when concentration at ambient points away from the source are of interest—may be only approximate.

The presence of temporal (or daily) variation in the discharged concentrations has also been recognized and accounted for by defining a source as unacceptable (or "dirty") if its discharged pollutant concentration is expected to exceed the goal level on more than some specified small percentage of days in the year. The work has been directed mainly toward obtaining appropriate criteria for classifying a source as acceptable or unacceptable, in view of whatever variability and error exist.

The classification procedures developed in this effort have been designed from the most realistic basic statistical assumptions and transport models currently known. Attention has been focused on the sizes of the misclassification probabilities, which depend on the numbers and accuracies of the measurements made, and on the amount of temporal variability involved. Worksheets have been designed to summarize and draw conclusions from the data and to highlight points at which further or more accurate measurements may be needed. Finally, the developed procedures are being tested with data obtained in previous and current IERL-RTP projects.

Information Transfer

IERL-RTP conducts a sizable information transfer program as an integral part of its stationary source research and development mission. During 1979, the laboratory produced 223 technical reports, 12 periodic research updates, and a monthly abstracts series, sponsored 9 conferences/symposia, and exhibited at 2 of its conferences and 1 national scientific meeting.

This section of the report provides assistance in acquiring information (Figure 2), indicates the scope of the Laboratory's information transfer program (Table 4), and previews information transfer activities for 1980.

Technical Reports

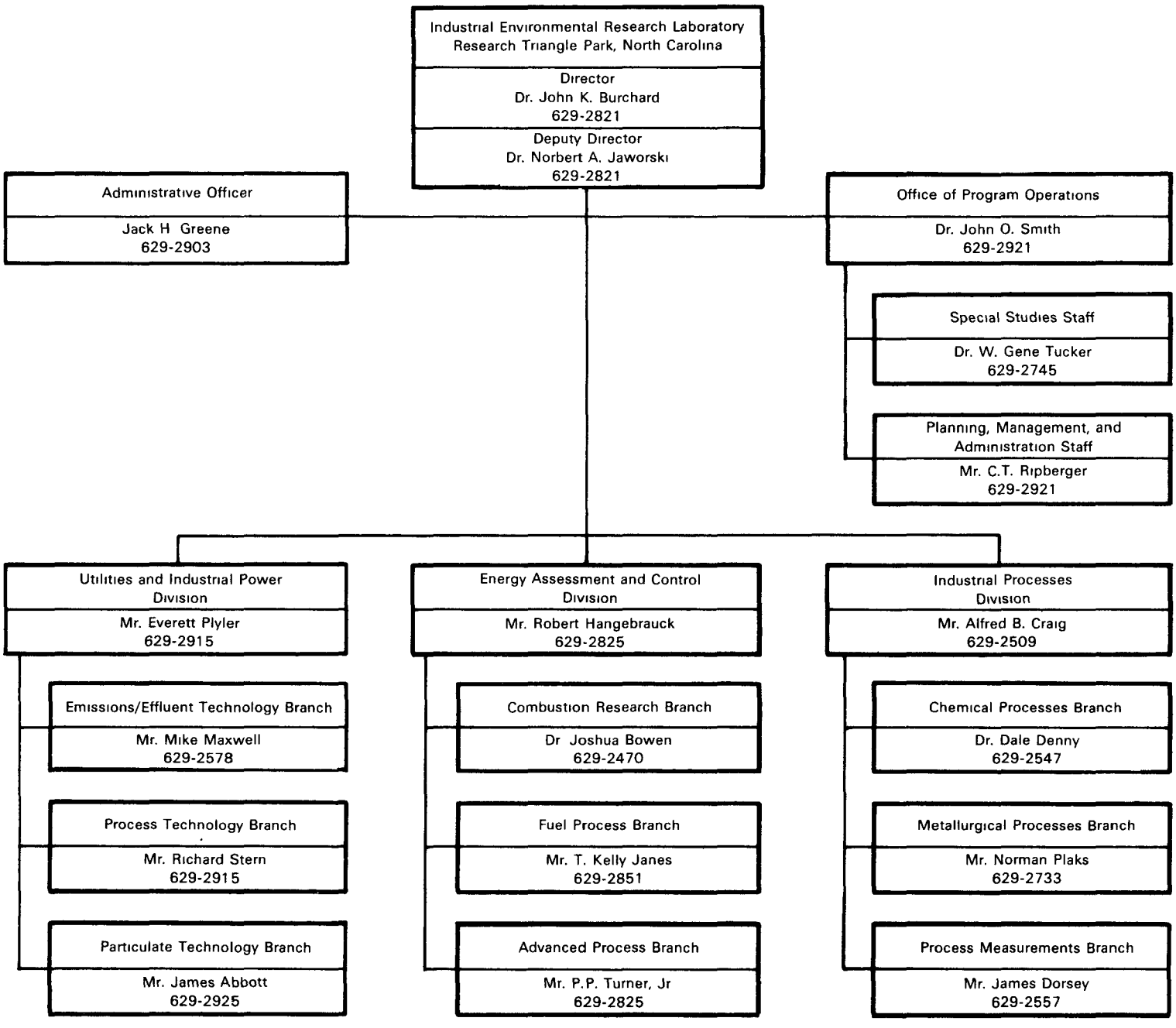
IERL-RTP produces numerous technical reports describing the results of its research projects. Table 5 indicates the level of technical report information transfer activity in 1979 for th program areas described in this report.

The monthly publication of *Report Abstracts: Industrial Environmental Research Laboratory-RTP* notifies the research community of new technical reports issued by the Laboratory To be placed on the mailing list for this report, write to Technical Information Coordinator (MD-64), Industrial Enviror mental Research Laboratory-RTP, U.S. EPA, Research Triangl Park, North Carolina 27711.

Periodic Research Updates

IERL-RTP produces several periodic reviews designed to keep its audiences abreast of current developments in variou areas of stationary source R&D. Table 6 lists periodic reviews produced in 1979 for the program areas described in this repo

IERL-RTP's 40-ft display at the June 1979 Air Pollution Control Association Annual Meeting in Cincinnati, Ohio.



Commercial Telephone No. (919) 541 + Extension

Figure 2.
IERL-RTP Organization Chart

Table 4.
Index of Research Programs and Contacts for IERL-RTP

Program	Contact	Federal Telepho Service (FTS) N
Boilers—utility/industrial:		
Byproduct marketing	Norm Kaplan	629-2556
Effects/assessment	Wade Ponder	629-3997
Fluidized bed combustion	Bruce Henschel	629-2825
NO_x control:		
By combustion modification	Josh Bowen	629-2470
By flue gas treatment	David Mobley	629-2915
Particulate control	James Abbott	629-2925
SO_2 control	Mike Maxwell	629-2578
Thermal effects control	Ted Brna	629-2683
Waste disposal	Julian Jones	629-2489
Water pollution	Julian Jones	629-2489
Coal:		
Cleaning	Jim Kilgroe	629-2851
Gasification	Bill Rhodes	629-2851
Liquefaction:		
Direct	Dale Denny	629-2825
Indirect	Bill Rhodes	629-2851
Combustion modifications	Josh Bowen	629-2470
Environmental assessment data system	Gary Johnson	629-2745
Ferrous metallurgy	Norm Plaks	629-2733
Fugitive emissions control	[b]	—
Furnaces—residential/commercial	Josh Bowen	629-2470
Gas turbines/IC engines	Josh Bowen	629-2470
Iron and steel foundries	Norm Plaks	629-2733
Lime/limestone scrubbing—power plants	Mike Maxwell	629-2578
Measurements for stationary sources:		
General	Jim Dorsey	629-2557
Organic analysis	Larry Johnson	629-2557
Inorganic analysis	Frank Briden	629-2557
Particulate samples	Bruce Harris	629-2557
Instrumentation	Bill Kuykendal	629-2557
Oil processing:		
Petrochemicals	Dale Denny	629-2825
Refineries	Dale Denny	629-2825
Residual oil	Sam Rakes	629-2825
Particle control:		
Control devices:		
Electrostatic precipitators	Les Sparks	629-2925
Fabric filters	Jim Abbott	629-2925
Scrubbers	Dennis Drehmel	629-2925
From specific sources	[b]	—

Table 4.
Index of Research Programs and Contacts for IERL-RTP—Concluded

Program	Contact	Federal Telephone Service (FTS) No.[a]
Pesticides manufacturing	Dave Sanchez	629-2547
Petrochemicals manufacturing	Dale Denny	629-2825
Petroleum refineries	Dale Denny	629-2825
Steelmaking	Norm Plaks	629-2733
Synthetic fuel production:		
Coal gasification (surface)	Bill Rhodes	629-2851
Coal liquefaction:		
Direct	Dale Denny	629-2825
Indirect	Bill Rhodes	629-2851
Textile manufacturing	Max Samfield	629-2547
Toxic chemical incineration:		
At sea	Dave Sanchez	629-2547
Specific sources	[b]	—

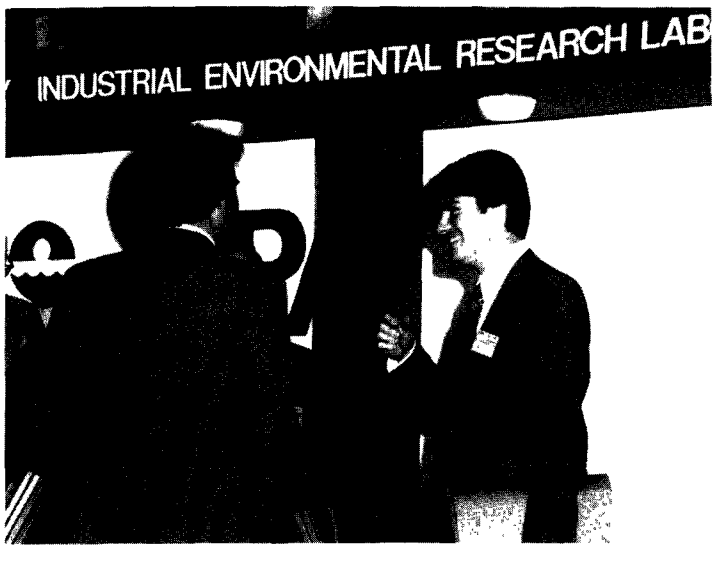
For those using commercial telephone lines, use the prefix code 541 plus the 4-digit number given (e.g., Norm Kaplan's commercial telephone number is 541-2556; commercial area code for all numbers listed is 919).

Call appropriate industry contact.

Note.—For further assistance on IERL-RTP programs, contact C. T. Ripberger at 629-2921.

Table 5.
Technical Report Information Transfer Activity

Subject	Number of reports produced in 1979
Ferrous metallurgical processes	15
Chemical processes	16
Coal cleaning	19
Coal conversion (synthetic fuels)	22
Residual and waste oils	4
Combustion modification	33
Advanced combustion processes	7
Flue gas desulfurization	29
Fine particulates	40
NO_x flue gas treatment	2
Power plant waste and water management	10
Process measurements	22
Special studies	4
Total technical reports produced in 1979	223



1979 Flue Gas Desulfurization Symposium attendees exchange information at the IERL-RTP exhibit booth.

Table 6.
Periodic Reviews of Stationary Source Research and Development

Subject	Title (issues produced in 1979)	Production schedule	Project officer[a] (mail code)
Ferrous metallurgical processes	*Ferrous Metallurgical Processes Review:* Vol. 1, No. 1	Intermittent	Norman Plaks (MD-62)
Coal cleaning	*Coal Cleaning Environmental Review:* Vol. 2, No. 1; Vol. 3, No. 1	Semiannual	James D. Kilgroe (MD-61)
Coal conversion	*Environmental Review of Synthetic Fuels:* Vol. 2, Nos. 1-4	Quarterly	William J. Rhodes (MD-61
Combustion modification	*CCEA Quarterly Report:* Vol. 1, Nos. 1-3	Quarterly	Wade H. Ponder (MD-62)
	NO_x Control Review: Vol. 4, Nos. 1-4	Quarterly	David G. Lachapelle (MD-6
Advanced combustion processes	*FBC Environmental Review:* none in 1979	Intermittent	D. Bruce Henschel (MD-61
Flue gas desulfurization	*FGD Quarterly Report:* Vol. 2, No. 4; Vol. 3, Nos. 1-3	Quarterly	John E. Williams (MD-61)
	Industrial Boiler FGD Survey: first quarter 1979	Quarterly	J. David Mobley (MD-61)
	Utility Boiler FGD Survey: Dec.-Jan. 1978-1979, Feb.-Mar. 1979, April-May 1979, June-July 1979, Aug.-Sept. 1979, Oct.-Nov. 1979	Bimonthly	Norman Kaplan (MD-61)
Fine particulates	*Particulate Control Highlights: Recent Developments in Japan,* Nov. 1979; *Research at High Temperature/Pressure,* Dec. 1979	Intermittent	Dennis C. Drehmel (MD-61
Process measurements	*Process Measurements Review:* Vol. 1, Nos. 3-4; Vol. 2, Nos. 1-2	Quarterly	James A. Dorsey (MD-62)
Special studies—coal technology assessment	*Future of Coal: Issues and Impacts:* Vol. 1, No. 2	Intermittent	Michael K. Bergman (MD-6

[a]To be placed on the mailing list for a given review, write to the appropriate project officer at Industrial Environmental Researc Laboratory-RTP, U.S. EPA, Research Triangle Park, North Carolina 27711.

Conferences and Symposia

To extend its outreach as far as possible, IERL-RTP sponsors a number of conferences and symposia each year. Attended by industry, Federal, State, and local government representatives, consultants, the academic community, public interest groups, and representatives of public and private foreign organizations, these meetings have a twofold purpose:

- To present up-to-the-minute findings on key issues
- To gather user-community feedback that can be factored into the R&D process

Table 7 gives an indication of the level of conference/symposiu information transfer activity in 1979 for the program areas described in this report.

IERL-RTP has several conferences/symposia in its calendar of planned events for 1980 and beyond. Table 8 lists meetin tentatively scheduled to take place during the next 18 month for the program areas described in this report.

Table 7.
Conference and Symposium Information Transfer Activity in 1979

Subject	Conference or symposium		
	Title	Location	Date
Ferrous metallurgical processes	Iron and Steel Pollution Abatement Technology	Chicago IL	Oct. 30-Nov. 1, 1979
Chemical processes	Assessment of Air Emissions From Petroleum Refineries	Austin TX	Nov. 4-6, 1979
Coal conversion	Environmental Aspects of Fuel Conversion—IV	Hollywood FL	Apr. 17-20, 1979
Combustion modification	Coal Combustion Technology for Emission Control	Pasadena CA	Feb. 5-7, 1979
	Stationary Source Combustion	San Francisco CA	Mar. 4-8, 1979
Flue gas desulfurization	Flue Gas Desulfurization	Las Vegas NV	Mar. 4-8, 1979
	Shawnee Industry Briefing	Raleigh NC	Dec. 5, 1979
Fine particulates	Transfer and Utilization of Particulate Control Technology	Denver CO	July 23-27, 1979
Process measurements	Advances in Particle Sampling and Measurement	Daytona Beach FL	Oct. 7-10, 1979

Table 8.
Proposed Conferences and Symposia for 1980-1981

Subject	Conference or symposium title, tentative location, and date	Conference coordinator[a] (mail code)
Combustion modification	Catalytic Combustion Workshop IV, Cincinnati OH, May 13-15, 1980	G. Blair Martin (MD-65)
	Catalytic Combustion Workshop V, location not selected, Sept. 1981	G. Blair Martin (MD-65)
	Combustion Symposium, Denver CO, Oct. 6-9, 1980	Robert E. Hall (MD-65)
Flue gas desulfurization	Flue Gas Desulfurization, Houston TX, Oct. 27-31, 1980	Michael A. Maxwell (MD-61)
Fine particulates	Transfer and Utilization of Particulate Control Technology, Orlando FL, Mar. 9-12, 1981	Dennis C. Drehmel (MD-61)
Process measurements	Environmental Assessment Measurements, Atlanta GA, Feb. 25-27, 1980	James A. Dorsey (MD-62)
	Fugitive Emissions Measurement, New Orleans LA, May 1980	D. Bruce Harris (MD-62)

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16. ABSTRACT

The Industrial Environmental Research Laboratory in Research Triangle Park, NC is responsible for the research, development and demonstration of control technologies for stationary source pollution and multi-media impact of energy and industrial processes. This research review presents the Laboratory's 1979 programs and accomplishments, including pollution control from ferrous metallurgical and chemical processes, fundamental and advanced combustion research, air, waste, and water pollution control systems, process measurement research, and supporting programs of the Laboratory.

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