INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY–RTP

ANNUAL REPORT
1976

OFFICE OF ENERGY, MINERALS, AND INDUSTRY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY (RESEARCH TRIANGLE PARK)

ANNUAL REPORT
1976

Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Established on December 2, 1970,
by Reorganization Plan No. 3 of 1970,
the Environmental Protection Agency
is the Federal Government's lead agency
for pollution control and abatement.
EPA is concerned with the environment
as a single interrelated system
and is directing a coordinated research,
monitoring, standard-setting, and
enforcement effort to restore and
protect the quality of the environment.

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FOREWORD

This annual report presents the highlights of the programs and accomplishments of EPA's Industrial Environmental Research Laboratory--Research Triangle Park, between January 1 and December 31, 1976. Its approach is an intentional attempt to provide both the non-technical overview desired by the layman and sufficient technical details for the professional.

Although this is only our second year with the new name, abbreviated to IERL-RTP, the public recognizes us readily as a group that has existed as an organizational entity since 1965. The three-letter abbreviation RTP, following our name, is significant only because of the existence of a sister laboratory in Cincinnati, Ohio, following a parallel, but not duplicative, course.

Our former identity, Control Systems Laboratory, disappeared on July 1, 1975, following the implementation of a major reorganization of the program and management structures of EPA's Office of Research and Development. Among the benefits resulting from this reorganization were the delegation to us of greater resource management and program implementation responsibility, and a clarification and focussing of our mission as part of the newly created Office of Energy, Minerals, and Industry.

Basically, IERL-RTP manages programs to develop and demonstrate cost effective technologies to prevent, control, or abate pollution from operations with multimedia environmental impacts associated with the extraction, processing, conversion, and utilization of energy and mineral resources, as well as with industrial processing and manufacturing. The Laboratory also supports the identification and evaluation of environmental control alternatives of those operations as well as the assessment of associated environmental impacts. Our program, consisting of inhouse activities, contracts, grants, and interagency agreements, contributes significantly to the protection of National health and welfare through the research and development of timely and cost-effective pollution control technologies.

Although EPA is primarily a regulatory agency, the vital supportive role of research and development activities within the overall EPA mission must not be overlooked. Adequate pollution control technology, for example, must be available before effective standards for the protection of public health and welfare can be set and successfully enforced; the development of ever more efficient and economical environmental control technology benefits not only

the affected industry, but ultimately everyone. This is particularly true considering the present energy situation; in the long run, the protection of our environment and the conservation of our natural resources are integral parts of meeting our energy requirements in a viable manner.

This report reflects EPA's concrete support of, and dedication to, the practical realization of our Nation's energy goals, as well as those of a purely environmental nature.

January 1, 1977

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

TABLE OF CONTENTS

TABLE OF CONTENTS (con.)

TABLE OF CONTENTS (con.)

TABLE OF CONTENTS (con.)

TABLE OF CONTENTS (con.)

ILLUSTRATIONS

Illustrations (con.)

Illustrations (con.)

INTRODUCTION

Since 1967 the Federal Government, in cooperation with industry, has made a determined effort to develop technology to control environmental pollution produced by both stationary and mobile sources.

An organization--now the Industrial Environmental Research Laboratory, Research Triangle Park (IERL-RTP), North Carolina--was designated to carry out the major part of the Government's share of the effort relating particularly to stationary sources of air pollutants. Since the June 30, 1975, reorganization of EPA's Office of Research and Development (ORD), however, IERL-RTP's pollution control efforts have been more encompassing. Since that date, and with the cooperation and assistance of EPA sister laboratories previously charged with appropriate pollution control responsibilities, IERL-RTP has effectively accomplished a major redirection of effort to provide a multimedia approach to pollution control problems. The new multimedia program concerns itself with air, water, solid waste, thermal discharge, pesticides, and energy-conserving aspects of environmental pollution.

Congressional direction for this effort is provided principally by the Air Quality Acts of 1967 and 1970, and the Federal Water Pollution Control Acts and its Amendments.

The latter cites two national policies specifically applicable to IERL-RTP: the prohibition of "discharge of toxic pollutants in toxic amounts," and a major research and demonstration effort to "develop technology necessary to eliminate the discharge of pollutants into the navigable waters, waters of the contiguous zone, and the oceans." Section 105 of the Act authorizes "research and demonstration projects for prevention of pollution of any waters by industry including, but not limited to, the prevention, reduction, and elimination of the discharge of pollutants."

Among the purposes cited in Section 101 of the Air Quality Acts are: "to protect and enhance the quality of the nation's air resources so as to promote the public health and welfare and the productive capacity of its population; (and) to initiate and accelerate a national research and development program to achieve the prevention and control of air pollution. . . ."

Two other sections of the Air Quality Acts are also significant, indicating Congressional support of specific activities of IERL-RTP: Section 103

(Research, Investigation, Training, and Other Activities) and Section 104 (Research Relating to Fuels and Vehicles).

In Section 103, EPA's Administrator is authorized to establish a national research and development program for the prevention and control of air pollution and, as part of that program, to conduct and promote the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, and control of air pollution. Section 104 specifically emphasizes research into and development of new and improved methods, with industry-wide application, of preventing and controlling air pollution resulting from fuels combustion.

Figure 1 shows energy requirements* that relate the problem of air pollution to the single largest source of air pollution--fuel combustion. The main cause of air pollution is combustion, accounting for over 80 percent of the mass of recognized air pollutants, with both mobile and stationary sources contributing substantially. If metallurgical processes and oil refining are added to combustion, the total will be about 90 percent of the total mass.

In line with the U.S. energy policy to increase the nation's self-sufficiency in energy resources, a closer look has been taken at our coal reserves which are relatively abundant in contrast to our limited oil and gas reserves. Only about 7 percent of our coal resources, however, are usable under the New Source Performance Standards. Figure 2 shows the need to develop techniques to permit the use of eastern and western coals.

ENVIRONMENTAL POLLUTION CONTROL

The development and demonstration of environmental pollution control technology is one of EPA's largest tasks. Approximately $45 million was devoted to this effort in FY 76 (including the transition quarter). These funds supported both IERL-RTP's on-going studies to demonstrate control methods for sulfur and nitrogen oxides, particulates, and other pollutants, and its expanded programs addressing the environmental aspects of accelerated energy resource development in the U.S.

IERL-RTP's goal in stationary source air pollution control development is fourfold:

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*Although EPA policy is to use metric units, this report contains certain nonmetric units for the convenience of the reader. Use the factors in Appendix B to convert to metric equivalents.

U.S. RESERVES--

COAL (CURRENTLY RECOVERABLE):	3.6	x 10^{18} Btu
COAL (USGS TOTAL ESTIMATED):	77	x 10^{18} Btu
URANIUM (LIGHT WATER REACTOR):	0.84	x 10^{18} Btu
URANIUM (BREEDER REACTOR):	18.5	x 10^{18} Btu

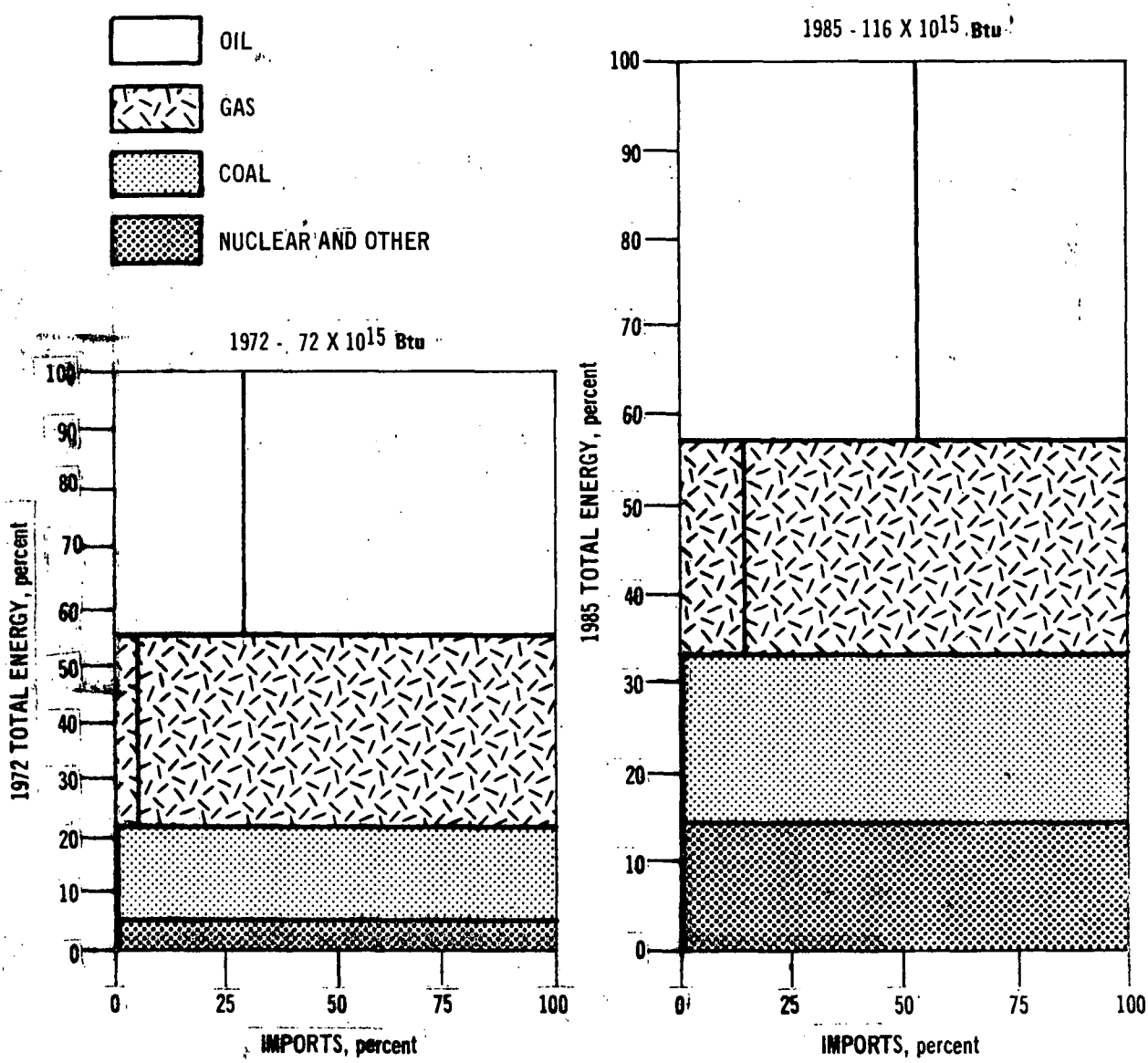


Figure 1. Total U.S. energy requirement.

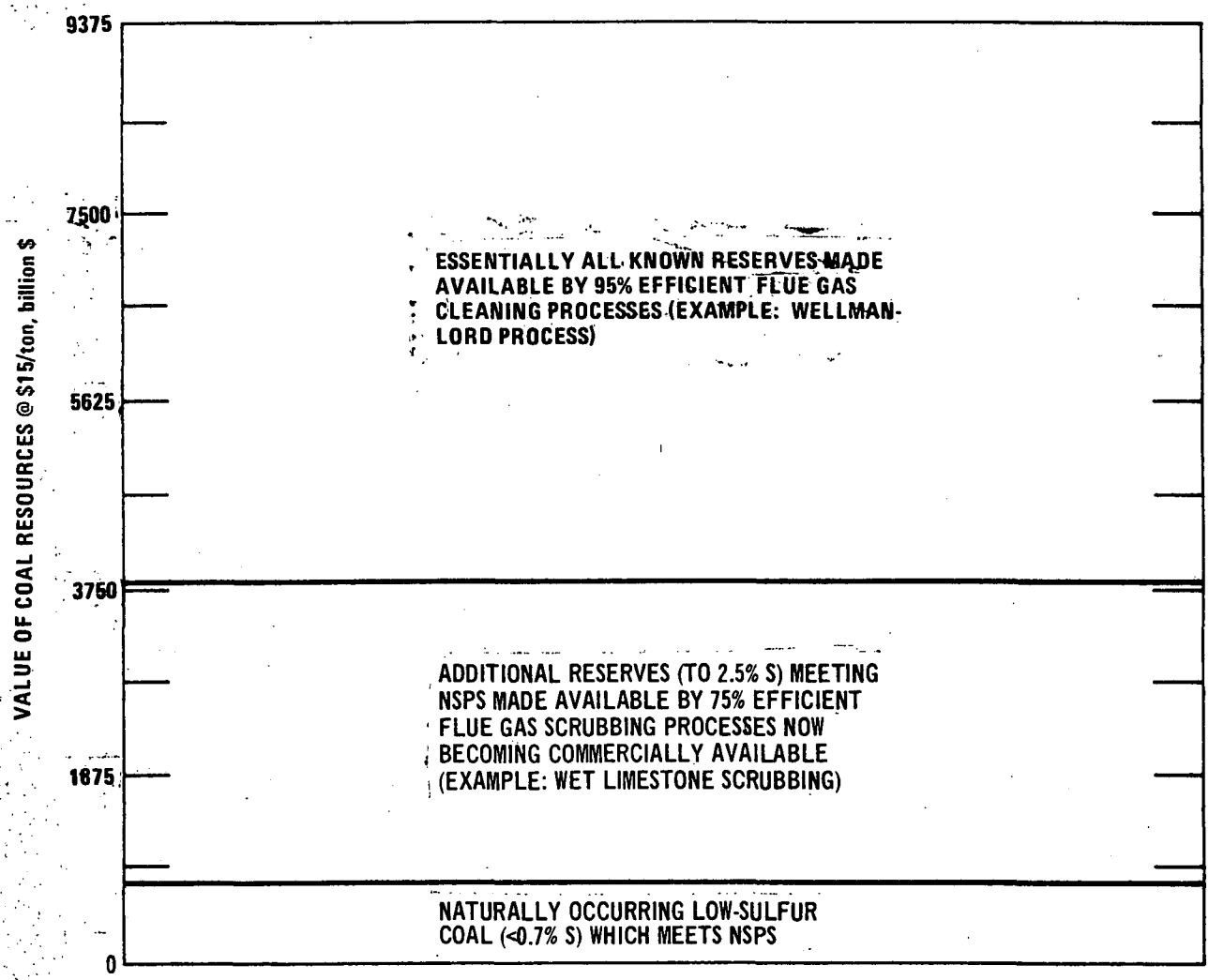


Figure 2. Value of Eastern and Central coals meeting new source performance standards as a function of efficiency of flue gas cleaning processes.

- To describe at least one method for controlling each major source of pollution.
- To provide a technical base for the Agency's enforcement activities.
- To establish technical and economic data to support New Source Performance Standards (NSPS).
- To provide information required to make environmentally sound decisions on energy development policy.

Sulfur Oxides (SO_x)

The Agency has directed much of its research and development effort in the sulfur dioxide (SO_2) control area toward demonstrating flue gas desulfurization (FGD) technology, in which SO_2 is removed from the gas stream emitted after a fuel is burned. The emphasis on FGD has been dictated by its economic feasibility and by its availability for near-term application as compared to other SO_2 control options. EPA has funded, either totally or partially, a number of major projects over the past several years. Included in these projects are the following large-scale, electric utility oriented projects:

- Pilot work (at Research Triangle Park, N.C.) and prototype systems (at TVA's Shawnee Steam Plant) for development, demonstration, and optimization of lime and limestone scrubbing technology.
- Magnesium oxide scrubbing demonstrations at Boston Edison Company and Potomac Electric Power Company.
- Sodium sulfite/bisulfite scrubbing (Wellman-Lord Process) at Northern Indiana Public Service Company.
- Aqueous carbonate process demonstration at Niagara Mohawk.
- Double-alkali process demonstration at Louisville Gas and Electric Company.

Control techniques suited to smaller industrial and commercial combustion sources are being examined in full-scale test programs at a General Motors double-alkali installation, at a U.S. Air Force installation using the Bahco lime scrubbing process, and at a St. Joe Minerals Company installation using the citrate process. Supporting and supplementing these major demonstrations are numerous other projects, such as full-scale testing on commercially installed systems, engineering studies, and smaller-scale hardware studies.

The commercial economics of FGD technology, including by-product marketing and disposal options, and the evaluation of new processes and of process improvements, are subjects of continuing engineering efforts. A major effort

underway in technology transfer will promote use of the best and most reliable techniques and equipment for future FGD installations.

The Agency is also studying a number of other approaches for reducing sulfur oxide (SO_x) emissions. One such approach is to "clean" a fuel--to remove sulfur and other contaminants--before the fuel is burned. This pretreatment method is especially suited to sources smaller than electric utilities; e.g., industrial boilers and fuel-burning equipment. EPA is studying (through research, development, and environmental assessment) several techniques for removing pollutants from fuels. One technique, coal cleaning, involves physically and/or chemically cleaning moderate-sulfur-content coal so that it can be burned in conformance with clean air standards. EPA's objectives in this area are: to develop commercially available processes for removing inorganic sulfur and ash from medium-sulfur coal, while producing reuseable wastes, or wastes which will not degrade the environment when discarded; to define the environmental problems associated with existing fuel cleaning technologies; and to derive means of minimizing problems which could hinder application of fuel cleaning technologies. In the clean fuels area, EPA is also studying the use of clean synthetic fuels (fuels produced from high- and low-Btu gasified coal and liquefied coal). Now underway is a program on residual oil processing and utilization aimed at defining better means of removing sulfur and other pollutants, toward an end product of a clean synthetic fuel. The major objectives of clean synthetic fuel studies are to determine the potential environmental impacts of processing these fuels, and to develop means of minimizing the adverse environmental effects of synthetic fuel technologies.

Another approach to reducing SO_x emissions is to modify the combustion process. The Agency's efforts in combustion modification have involved primarily the Fluidized-Bed Combustion (FBC) Process. These efforts have contributed to the National Fluidized-Bed Combustion Program, an interagency program coordinated by the Energy Research and Development Agency (ERDA). EPA's contributions to the interagency program consist of environmental assessments of FBC systems, optimizing control of SO_2, NO_x, fine particulates, and other pollutants in the FBC process, and continued testing of its small (0.63 megawatt) FBC mini-pilot-plant. The Agency also conducts independent research, from an environmental perspective, to determine the implications of alternative designs and of alternative uses of fluidized-bed combustors.

Nitrogen Oxides (NO_x)

Combustion modification is the primary existing control technique for preventing or minimizing NO_x emissions from fossil-fuel burning in utility and large industrial boilers; in small industrial, commercial, and residential systems; in industrial process furnaces and afterburners; in stationary engines; and in advanced processes.

Several combustion modification techniques have been developed or are under study. EPA-supported and -directed efforts have shown that staged combustion (often combined with low excess air) is an effective method of controlling NO_x emissions originating from the thermal fixation of nitrogen emissions in combustion air and from the conversion of nitrogen atoms chemically bound in fuel (heavy oils and coal). Flue gas recirculation has been shown to be a most effective technique for controlling NO_x emissions originating from thermal fixation of atmospheric nitrogen during the combustion of clean fuels (natural gas and distillate oils). Additional EPA research and development efforts seek to modify combustion by redesigning burner/combustor systems, to investigate novel approaches to combustion modification (such as catalytic combustion, advanced power cycles, and alternative fuels), and to provide, through basic research, an understanding of the physical and chemical factors influencing the formation and degradation of pollutants.

Flue gas treatment (FGT) is another technique under investigation for its potential as a highly efficient means of controlling NO_x emissions from stationary sources. In the U.S. flue gas treatment developmental effort, EPA will draw on the knowledge gained in Japan's now-active development of FGT.

Particulates

Control technology for large particulates has been fairly well established. EPA's efforts now are mainly concerned with development of techniques for the control of fine particulates (defined as that fraction of the particulate emission smaller than 3 microns). These small particles remain suspended in the atmosphere and are easily respirable and absorbable by the body. Fine particulates may contain toxic trace metals and sulfates, both of which have considerable impact on health. One current program seeks to better define the physical and chemical character of fine particulates. The Agency's present efforts center on developing adequate detection and measurement methods and on development and field testing of control methods. Additionally, EPA is working to improve and demonstrate existing collection capability for fine

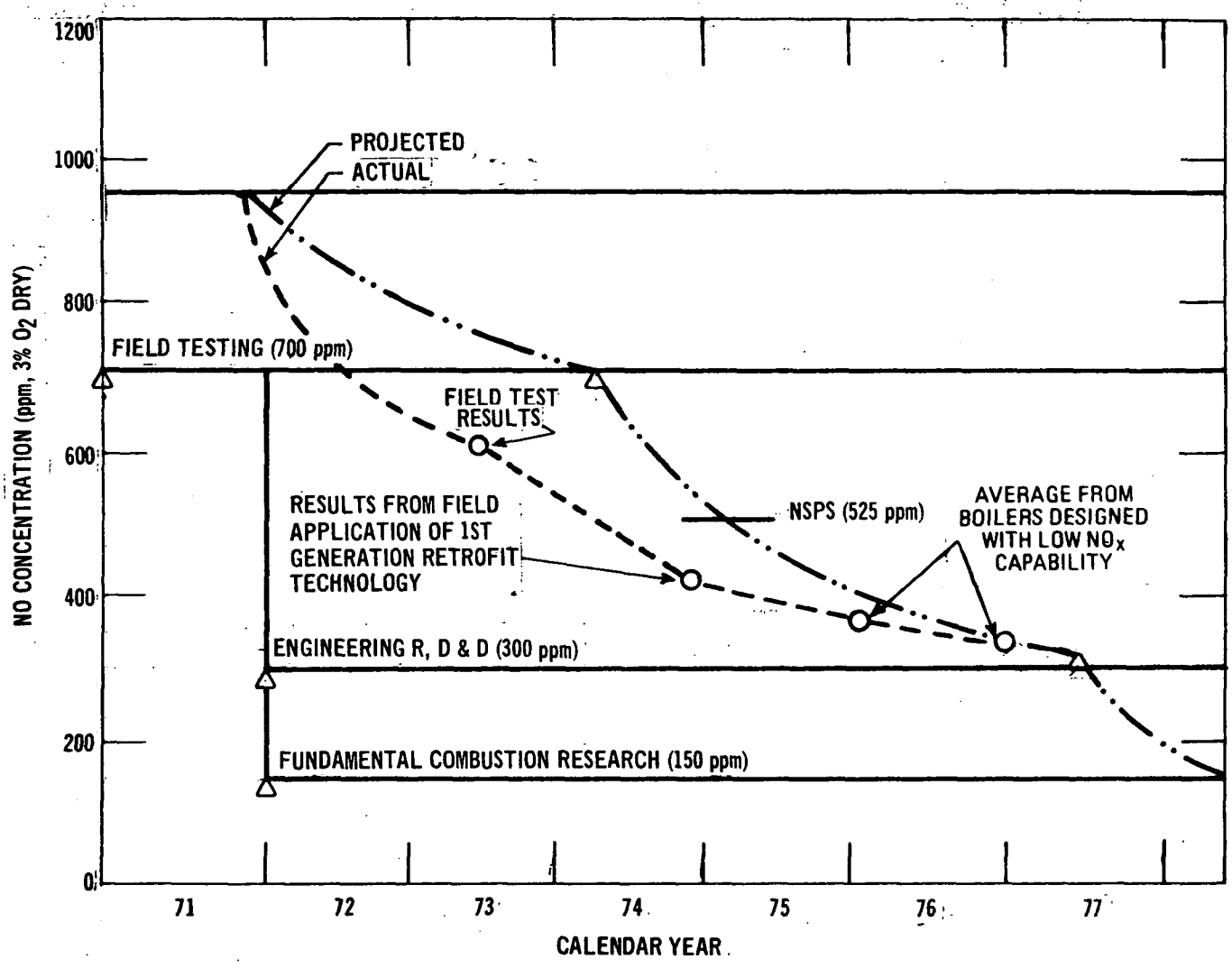


Figure 3. Control of NO_x emissions from coal-fired utility boilers.

particulate control and to identify and ultimately to demonstrate novel techniques which will offer both economic and performance advantages over current methods.

Other Pollutants

"Other" pollutants are both those pollutants for which no ambient air quality standards have been established and those three pollutants (asbestos, mercury, and beryllium) for which National Emissions Standards for Hazardous Air Pollutants (NESHAPs) now exist. Control technology research efforts are underway for a number of these pollutants, including trace metals, polycyclic organic matter (POM), and miscellaneous hydrocarbons, fluorides, and odors.

To assess the emission levels of these pollutants, several tasks are being funded for the field testing of coal-fired utility and industrial boilers, and for limited source characterization of gas- and oil-fired units. A field testing program is underway for residential and commercial heating units.

Source assessment is also underway for certain chemical processing industries. The objective of this program is to assess the environmental impact of sources of toxic and potentially hazardous emissions from organic materials, inorganic materials, combustion and open source categories, and to determine the need for control technology development for given source types. Sources under assessment include petroleum refining, petrochemicals, nitrogen fertilizer operations, phosphate fertilizer operations, pesticides manufacturing, and textile operations.

EPA has completed development at the pilot-plant level for ethylene dichloride plants and odor control for the rendering industry. An extensive testing program is underway to evaluate shipboard incineration of organic chemical wastes as a disposal technique. Nearly complete is the first phase of a test program designed to resolve the uncertainties in cost estimates for gasoline station hydrocarbon control systems.

Control technology for ferrous metallurgical industries is under continuing development. EPA has completed projects directed toward the control of emissions from cokemaking, blast furnace tapping, and charging of basic oxygen furnaces. Work is underway to develop full control of emissions from the sintering of iron ore. Extensive efforts are underway to assess, and ultimately to bring under control, fugitive emissions from all significant sources in the production of ferrous metallurgical products. The recent combining into a multimedia program of the previously separated ferrous metallurgical

air and water research and development programs is expected to result in optimum control of all discharges from these industries.

PROGRAM METHODOLOGY

Over the past ten years, the Federal Government has gained perspective and experience concerning its most effective involvement in pollution control activities. The following considerations support a Federally coordinated environmental pollution control research and development effort:

- In order to achieve cost-effective environmental pollution control to protect health and welfare, regulations should be based on a solid information foundation. This may include such detailed knowledge about the pollutants as health and welfare effects, sources and amounts, ambient concentrations, available control technology, and opportunities for research, development, and demonstration (RD&D) of new control technology.
- Few economic incentives exist for private industry to develop new technology to control environmental pollution, because the people benefitting from the control are not the ones directly paying for it. Traditional forces of the market place tend to preclude industrial expenditures unrelated to profits.
- Legal regulatory pressure, coupled with RD&D programs funded jointly by Government and industry, appears to provide an effective mechanism to ensure the availability of the necessary advanced environmental pollution control technology. Users will not generally apply control technology unless required to do so by law. Conversely, it would appear impractical to shut down large segments of industry if technically and economically feasible control devices are not available. Thus joint industry/Government technology development is desirable so that a common understanding of the availability of technology is shared by industry and Government.

IERL-RTP PROGRAM AREAS

Programs being pursued by IERL-RTP's Divisions and Branches have been realigned to reflect the multimedia and energy-related innovations resulting from EPA's recent Office of Research and Development reorganization.

The newly aligned functions fall into three natural categories: utilities and industrial power, energy assessment and control, and industrial processes.

A fourth function, related but not identified with any other single current program, is supportive of all IERL-RTP components. This fourth function falls in the category of special studies, relating to program operations.

Utility and Industrial Power

IERL-RTP's Utilities and Industrial Power program was formulated to ensure that adequate controls are available to prevent and abate pollution from utility and industrial power sources. To achieve this objective, the program involves multimedia research, development, demonstration, and environmental assessment. Major elements of this program include: flue gas desulfurization technology, waste and water utilization and control, flue gas treatment for NO_x removal, thermal pollution control, and particulate control technology.

FLUE GAS DESULFURIZATION TECHNOLOGY

Flue gas desulfurization (FGD) technology is the only near-term technological approach to utilizing plentiful high-sulfur coal supplies without excessive deleterious SO_x emissions. FGD technology development and assessment, therefore, are afforded a high priority. Studies indicate that FGD will be competitive in cost with advanced control methods (e.g., chemical coal cleaning, fluidized-bed combustion); therefore, FGD may play an important role in controlling emissions even in the post-1980's.

FGD technology has progressed rapidly over the past 4 years. Several commercial FGD installations are achieving high SO_x removal efficiency with good reliability. EPA believes that lime and limestone FGD processes can now be considered demonstrated technology, capable of being confidently applied to full-scale utility boilers. However, more work remains to be done in the FGD technology area, including: the development of cost-effective environmentally acceptable disposal technology for the large quantities of sludge produced from lime and limestone systems; the development and demonstration of improved lime and limestone process variations which will minimize cost and energy usage and improve sludge properties; and the development and demonstration of economically viable regenerable FGD systems producing sulfur and sulfuric acid instead of sludge.

For the last 8 years, IERL-RTP has been conducting a comprehensive FGD development and technology transfer program, which has been instrumental in accelerating the commercial viability of FGD technology. This program has aimed at demonstrating reliable and cost-effective FGD processes, yielding both nonregenerable (throwaway) products and regenerable (or saleable) sulfur products.

IERL-RTP's major program in the nonregenerable area is the lime/limestone prototype test program operating in cooperation with the Tennessee Valley Authority at the latter's Shawnee Steam Plant. This program has been instrumental in identifying reliable, cost-effective process variations for both lime and limestone scrubbing systems. Work continues on developing improved process variations offering cost and operational advantages over present commercial processes. Also in the nonregenerable FGD area, IERL-RTP has initiated a comprehensive program aimed at identifying environmental problems associated with scrubber sludge disposal, along with development and evaluation of appropriate control practices. In order to provide a nonregenerable alternative to lime/limestone systems, IERL-RTP is now undertaking the demonstration of the double-alkali scrubbing process on a full-scale coal-fired boiler; this process offers the promise of significant reliability and cost advantages.

In the regenerable FGD area, IERL-RTP has pursued an aggressive RD&D program aimed at identifying cost-effective processes with wide applicability producing saleable sulfur products. EPA is working with the Department of the Interior in developing sodium citrate scrubbing, a promising regenerable system. Other regenerable processes which have proven to be promising at pilot- or prototype-scale are being evaluated on full-scale coal-fired utility boilers as part of the IERL-RTP FGD demonstration program: Wellman-Lord (producing sulfur), magnesium oxide (producing sulfuric acid), and the aqueous carbonate process (producing sulfur).

WASTE AND WATER POLLUTION CONTROL

A comprehensive research and development program is being conducted by IERL-RTP to evaluate, develop, demonstrate, and recommend environmentally acceptable, cost-effective techniques for disposal and utilization of wastes from flue gas cleaning systems, with emphasis on FGD sludge. Efforts are also being conducted to evaluate and demonstrate systems for maximizing power plant water recycle/reuse. This program is a continuation and expansion of modest efforts initiated in the late 1960's in support of limestone scrubbing projects.

Projects under the program include laboratory and pilot field studies of disposal techniques for untreated and chemically treated FGD sludges (e.g., lined and unlined ponding and landfill, coal mine disposal, and ocean disposal); bench- and pilot-scale testing of FGD sludge utilization schemes (e.g., sludge conversion to sulfur with regeneration of calcium carbonate);

and pilot/prototype testing of water treatment schemes for maximizing overall power plant water recycle/reuse. Engineering cost studies of each process/technique being developed are also being conducted under this program. In addition, several related projects are being conducted at TVA under IERL-RTP sponsorship (e.g., fly ash characterization, disposal, and utilization studies; FGD sludge solids characterization studies; bench/pilot studies of FGD sludge use in fertilizers; FGD gypsum marketing studies; and studies of coal pile drainage, ash pond effluents, and other power plant water discharges).

Results from the program are being published in annual summary reports, the first of which was issued in late 1976.

FLUE GAS TREATMENT FOR NO_x CONTROL

Another important part of IERL-RTP's environmental program relating to coal combustion is the NO_x flue gas treatment (FGT) program. The FGT program has two main elements: strategy and technology assessment, and experimental projects.

The strategy and technology assessment element is designed to produce: a detailed state-of-the-art technology assessment; an assessment of the extent to which FGT could be used in an optimized control strategy for stationary sources; and information concerning the economic, energy, and environmental aspects of commercial application of FGT technology. The experimental projects element is designed to provide for the development and demonstration of FGT technology for removal of NO_x with both high and low SO_x concentrations and for simultaneous removal of both NO_x and SO_x.

THERMAL POLLUTION CONTROL

Power plants reject enormous amounts of heat energy which is no longer able to perform useful work in the power production cycle. Current projections indicate that waste heat rejection from central power stations in the year 2000 will nearly equal the total U.S. energy consumption in 1970. Under the provisions of the Federal Water Pollution Control Act Amendments of 1972, EPA is required to regulate thermal effluents. IERL-RTP's research and development program in the thermal control area supports the Agency's statutory requirements and falls primarily into two broad areas: combustion source cooling technology, and waste heat utilization. Programs underway in the former area include analysis of first generation cooling system performance and economics, assessment of advanced heat rejection techniques, and development of control technology for treatment and reuse/recycle of cooling system

effluent streams. Waste heat utilization studies presently underway involve primarily agricultural applications. Aquaculture uses may merit future consideration.

PARTICULATE CONTROL TECHNOLOGY

IERL-RTP's program for particulate control is designed to establish engineering design techniques and performance models, and to improve the collectability and economics of control devices for particulate matter.

Attainment of the present Primary Standard for particulates in some cases will be difficult and expensive with existing technology; attainment of the Secondary Standard (or a more stringent Primary Standard) appears impossible without improved technology. There are two basic causes for this: particulate control technology has limited control capability, in many cases even for coarse particulate; and technical and economic factors often prevent control technology from being feasible in specific industrial applications.

IERL-RTP is placing increased emphasis on the control of fine particulates which persist in the atmosphere, comprise a variety of known toxic substances, and are major contributors to atmospheric haze and visibility problems. The objective is the development and demonstration of control technologies capable of effectively removing large fractions of the under-3-micron size particles from effluents. The technical approach is to identify capabilities of existing equipment (electrostatic precipitators [ESPs], filters, scrubbers, and proprietary devices), to determine deficiencies in present design and operating procedures, and to pursue remedies for the deficiencies through research and development. New concepts will be applied as discovered, and successful advancements in removal technology will be demonstrated. Results will be applicable to improvements in high-temperature/high-pressure particulate removal devices.

Actual source tests have shown that both ESPs and baghouses should be capable of controlling fine particulate from a limited number of sources emitting fly ash. It is quite possible that the applicability of ESPs to fine particulate control over a broad range of sources can be extended by developing dust conditioning techniques and by modifying the design of charging sections and collecting electrodes. During 1976, a completed mathematical model for the design of ESPs was greatly improved; this will allow cost-effective design for specific particulate control technology applications. Also completed was the demonstration on actual sources at a pilot scale (10,000-

30,000 CFM) of a charged droplet scrubber, a high throughput fabric filter, and a flux force/condensation scrubber. In addition, a major program thrust was initiated to find solutions to the particulate emission problems associated with the burning of, or switching to, low-sulfur coal by a number of eastern utilities.

Energy Assessment and Control

IERL-RTP's activities relating to energy assessment and control are focused on two primary objectives: utility and industrial power; and energy control technology (fuel processing). Within these objectives are several energy technology areas:

- Nitrogen oxides/combustion-pollutant control.
- Fluidized-bed combustion.
- Coal cleaning.
- Synthetic fuels.
- Advanced oil processing.
- Other support (advanced, low-emission, energy conserving systems and strategies).

The major activities of these multimedia programs--environmental assessment and control technology development--can best be described in terms of the components and relationships shown in Figures 4 and 5. An environmental assessment is a continuing iterative study aimed at: (1) determining the comprehensive multimedia environmental loadings achievable and costs, from the application of the existing and best future definable sets of control/disposal options, to a particular set of sources, processes, or industries; and (2) comparing the nature of these loadings with existing standards, estimated multimedia environmental goals, and bioassay specifications as a basis for prioritization of problems/control needs and for judgement of environmental effectiveness. EPA has been given responsibilities for environmental assessment and control technology development in the energy area to ensure an independent and timely environmental consideration of this national priority.

NITROGEN OXIDES CONTROL

IERL-RTP activities relating to NO_x and other combustion pollutant control include the following subobjectives:

- NO_x Environmental Assessment/Applications Testing--Determination of the environmental emissions of NO_x and other combustion-related pollutants from stationary combustion sources. Evaluation of the environmental effectiveness

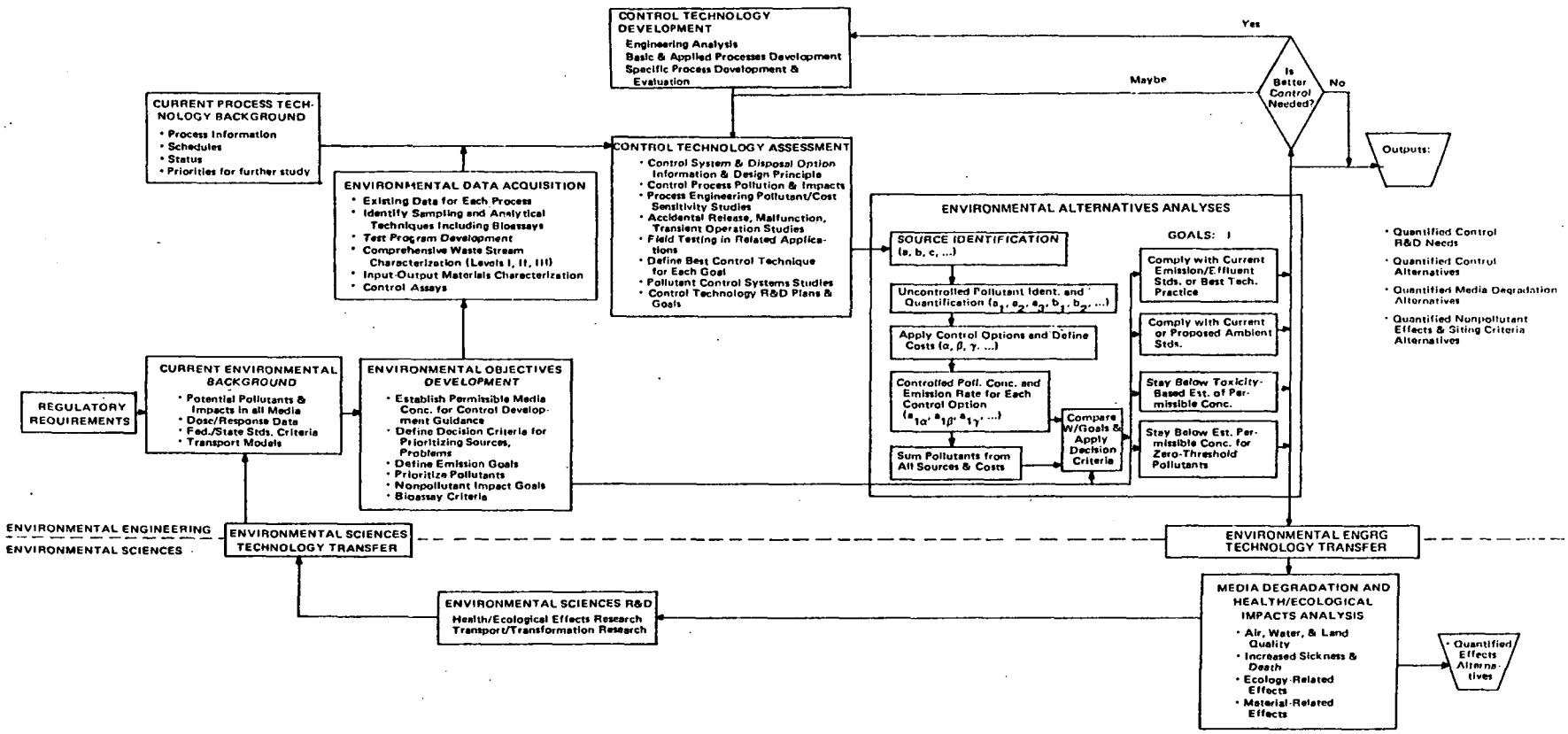


Figure 4. Environmental assessment diagram.

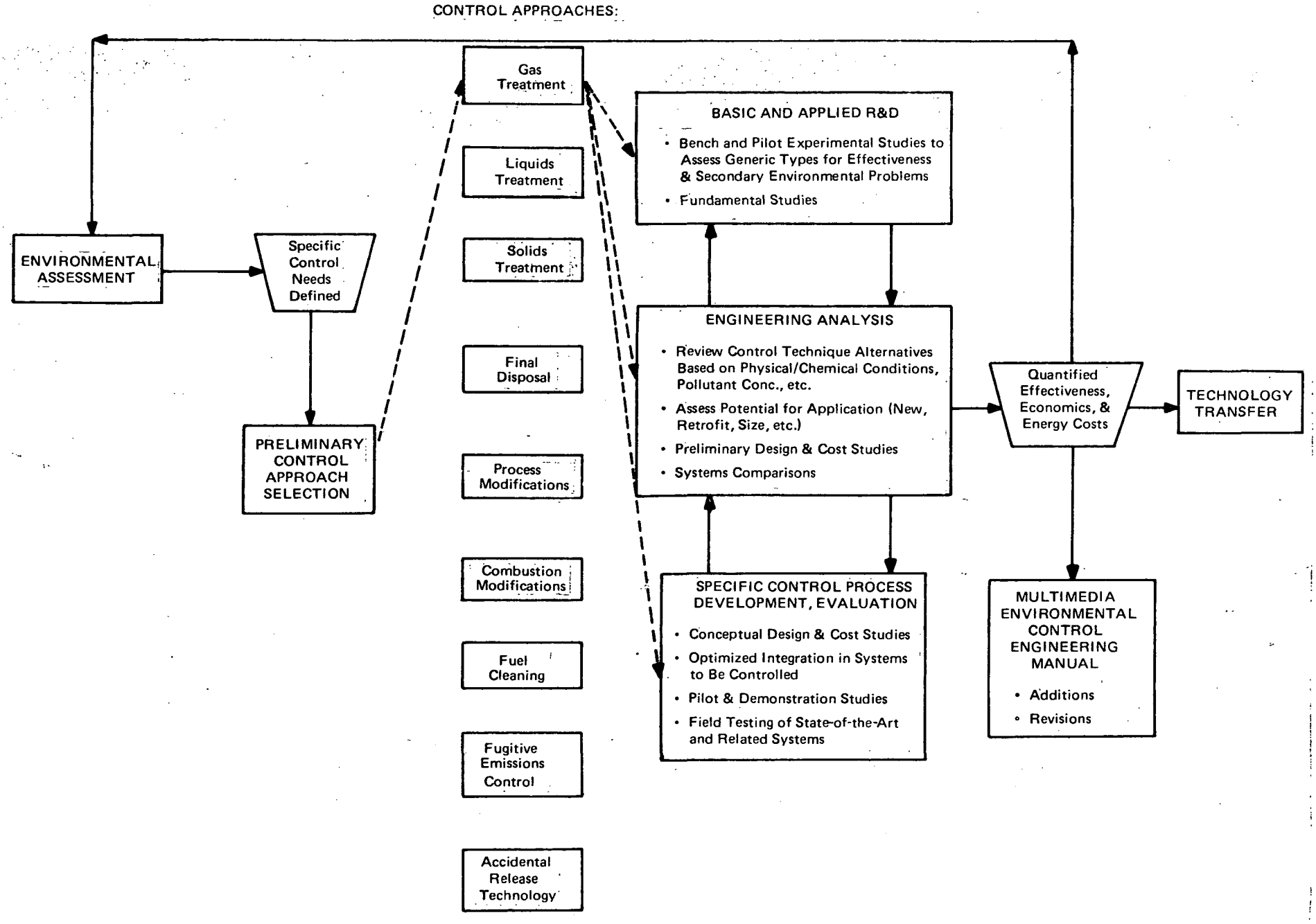


Figure 5. Control technology development diagram.

(compared to the uncontrolled state) of combustion control modifications including alternative operating conditions, retrofit control, maximum stationary source technology (MSST) for existing units--extensive retrofit, and MSST for new units--and optimized design or alternate processes. Significant accomplishments included:

- Identification and characterization of stationary NO_x source categories. A final report, "Inventory of Combustion-Related Emissions from Stationary Sources," is under preparation.
- Collection of field test data and establishment of state-of-the-art combustion control for domestic and commercial heating systems.
- Development of control technology goals based on best projections of control technology research and development.
- Initiation of a major NO_x environmental assessment contract for activities in this area as well as systems analysis and program support. A report, "Preliminary Environmental Assessment of Stationary Source NO_x Combustion Control Technologies," is being prepared. It will contain important information on stationary combustion equipment categories, fuel consumption data, and multimedia emissions inventories.
- A final report, "Field Testing: Application of Combustion Modifications to Control Pollutant Emissions from Industrial Boilers--Phase I," was published by KVB. It describes the results of a 2 year field study of industrial boilers. A supplemental report describes trace specie sampling results.
- Guideline manuals have been prepared for residential and commercial space heating equipment service technicians. Similar guidelines are being prepared for industrial boiler operators and manufacturers and are planned for utility boiler operators and manufacturers.
- A pamphlet, "Get the Most from Your Heating Dollar--Servicing Cuts Costs and Pollution," has been distributed to homeowners throughout the U.S. It is designed to transfer technology developed during field tests of residential equipment directly to the public.
- A contract for assessment of afterburner technology is under negotiation. The research and development, expected to be initiated by January 1977, will have as its primary objectives, environmental assessment and expanded application of these emission control systems to a wider range of industrial processes. A standards of practice manual will be developed.

° Develop Combustion Modification Technology for NO_x--Development and demonstration of practical combustion modification technology for controlling NO_x and related combustion generated pollutants from utility and large industrial, small industrial/commercial and residential system boilers, industrial process furnaces and afterburners, stationary engines, and advanced processes. Significant accomplishments include:

°° A two-volume final report, "Burner Design Criteria for Control of NO_x from Natural Gas Combustion," was published by the Institute of Gas Technology. The report documents in detail the NO_x control techniques for three burner types (kiln, ported baffle, and moveable-vane boiler burner). NO_x reductions of nearly 90 percent were obtained depending on burner type and burner operating conditions.

°° A final report, "Applicability of NO_x Combustion Modifications to Cyclone Boilers (Furnaces)," is being prepared by Monsanto Research Corporation. The report will document: background information on cyclone boilers, cyclone boiler population data, and the state-of-the-art of NO_x control for cyclone boilers.

°° Results of testing new tangentially coal-fired utility boilers designed with overfire air systems for staged combustion have shown that NO_x levels as low as 0.45 lb per million Btu can be achieved with no apparent adverse effects.

°° A large-scale coal combustion facility (EPA Contract 68-02-1488) is nearing completion. Full operation at up to 125×10^6 Btu/hr was achieved in late 1976. The research and development for scale-up of the optimum pulverized coal burner for utility and large industrial boilers is finally underway.

°° The residual oil burner concept for package boilers has been developed extensively and has achieved NO_x reductions of 65 to 70 percent for three fuel oils with fuel nitrogen ranging from 0.2 to 0.71 percent. The limit of NO_x control is imposed by the onset of unacceptable levels of carbon particulate formation. Both fuel properties and atomizer design appear to play a key role which will be investigated further in a follow-on procurement currently in negotiation.

°° The prototype residential furnace has been designed based on experimentally defined burner/firebox matching criteria. The prototype has been successfully tested in a cyclic mode for 500 hrs and has maintained

outstanding performance (i.e., 70 percent reduction in NO_x relative to current practice, no increase of CO, HC or smoke, and low excess air operation). A follow-on letter contract has been signed for field verification of production prototype units.

- A low-cost burner head (approximately $1.50) has been developed and tested which is applicable to 75 percent of U.S. oil-fuel furnaces for reduction of emissions and increased efficiency. The Office of Minority Business Enterprise is pursuing a commercialization program.
- The first phase of a study of stoker-coal-fired combustion systems has been completed. A final report on this phase, which emphasized residential and small commercial units, indicated that the primary emission problems were smoke, particulate, and POM and that these emissions were related to stoker operating parameters (e.g., ON/OFF cycles and overfire air) and coal composition (especially volatile matter). Significant quantities of organics having high carcinogenic potential were identified in the POM. The investigation will be extended, under a new contract, to larger size units (spreader stokers) and both conventional and processed coals. Emissions will be related to coal composition and combustion modifications. Comprehensive sampling and analyses (Levels 1 and 2) will be used to provide environmental assessment data.
- A survey investigation of industrial process furnaces and state-of-the-art control technologies has been completed for five industries: iron and steel, glass, aluminum, cement, and petroleum refining.
- A current procurement is expected to result in initiation in January 1977 of research and development aimed at the development of low-emission, energy-efficient combustion chamber designs for large stationary reciprocating engines (diesel and spark ignition). Demonstration of the performance of the improved designs on full-scale engines is planned to complete the program. Extension of the inhouse capabilities for high-pressure combustion studies will permit further guidance and support of the gas turbine and internal combustion engines (diesel) research.
- Pilot-scale studies being conducted on EPA's versatile experimental furnace by Aerotherm/Acurex are showing significant results. Recent tests with coal under fuel-rich first-stage stoichiometry (0.85) and "long" first-stage residence time (4 to 5 seconds) have yielded NO_x levels as low as 79 ppm (corrected to zero percent O_2). This corresponds to an NO_x reduction of 90 percent from normal baseline conditions.

- Catalytic combustion offers promise of clean fuel combustion with very low emission levels (i.e., 10 ppm) of NO_x, CO, HC, etc. The catalyst screening program has established one catalyst concept that appears to have superior performance to all others tested. Extensive evaluation of the concept is underway. In addition, other catalysts with higher temperature (i.e., > 2200°F) capability are being sought. Following final catalyst evaluations, systems concepts will be evaluated with special emphasis on fuel NO_x control.
- The ability of package boilers to fire methanol has been established by field tests. Methanol produced significantly lower NO_x emissions than either natural gas or heavy oil in a 24,000 pph watertube boiler and a 12,500 pph firetube boiler.
- A major new contract to consolidate the various fundamental combustion research (FCR) activities under a single contract is nearing award (contractor has been selected and negotiation is in progress). The contractor will perform a large FCR effort himself and will subcontract other efforts to several organizations. The thrust of the program is application of FCR to the solution of practical problems in controlling pollutants from stationary combustion sources.
- Fundamental fuel pyrolysis experiments have identified HCN and NH_3 as the major oxidizable nitrogen species evolved under inert conditions. Flat flame burner studies have examined the details of the conversion of these compounds to NO_x and N, under combustion conditions. These experiments have verified that fuel NO is minimized under fuel-rich conditions and that, with sufficient residence time, the oxidizable nitrogen species are reduced essentially to zero.
- Experiments on coal devolatilization at the Massachusetts Institute of Technology have established that over 90 percent of the nitrogen species can be driven off in the "volatiles" at high temperature. By minimizing the fuel nitrogen in the char and control of volatile fuel N conversion to NO_x in a rich primary zone, total NO_x from coal can be reduced drastically. This confirmation of postulates from burner data provides valuable insight for further optimization of burner/combustor design for pulverized coal combustion.
- Extension of the application of combustion modification to coal-fired utility boilers has been shown to have the potential to reduce NO_x emissions by up to 50 percent for this source category.

°° Initiation of minidemonstration test programs for use of low-sulfur western coal in intermediate sized boilers appears to show substantial potential for use of low-sulfur western coal as an SO_x control approach for small and intermediate sized coal-fired units which are not economically controlled by FGC.

FLUIDIZED-BED COMBUSTION

Subobjectives comprising IERL-RTP's fluidized-bed combustion (FBC) program are:

° FBC (Environmental Assessment)--Characterization of air, water, solid waste, and other environmental problems associated with atmospheric and pressurized FBC processes; development of environmental objectives; publication of a best-available technology manual; and provisions of an overall preliminary environmental assessment analysis. IERL-RTP's program to environmentally assess FBC has produced the following accomplishments:

°° Initiation of the FBC environmental assessment activity, including initiation of work by the FBC broad environmental assessment contractor (Battelle).

°° Initiation of comprehensive analysis of emissions from a variety of FBC units, including atmospheric units at ERDA's Morgantown Energy Research Center (MERC) and Battelle-Columbus Laboratories, and pressurized units at Exxon and at Combustion Systems Ltd./British Coal Utilization Research Association (CSL/BCURA).

°° Contacts with ERDA to lay the groundwork for conducting comprehensive analyses at ERDA facilities, including the 30 MW atmospheric boiler at Rivesville.

°° Initiation of efforts to establish environmental goals for FBC based on health and ecological effects, including initial efforts on the Multimedia Environmental Goals Chart.

°° Continued bench-scale investigation of air and solid emissions control from FBC units, including sorbent regeneration (Argonne, Exxon, Westinghouse).

°° Provision of substantial environmental support to ERDA's FBC program.

°° Identification of potential FBC environmental problems requiring control research and development.

° FBC (Control Technology Development)--Development of laboratory- and bench-scale multimedia control technology for SO_x, NO_x, total particulates,

hydrocarbons, CO, and hazardous and other pollutants from FBC. Development of treatment and final disposal techniques for spent sorbent and ash. Demonstration of techniques at available pilot facilities. Significant accomplishments include:

- °° Completion of installation of a Ducon granular bed filter for high-temperature/high-pressure particulate control on the Miniplant.
- °° Continued laboratory- and bench-scale investigation of air and solid emissions control from FBC units, including sorbent regeneration (Argonne, Exxon, Westinghouse).
- °° Contacts with ERDA to initiate planning for testing EPA's mobile particulate control test devices on the 30 MW Rivesville boiler.
- °° Contacts with ERDA to lay the groundwork for establishing a large field cell near the Rivesville site to test the environmental impact of disposal of solid residue from the facility.
- °° Completion of shakedown of the integrated Miniplant combustor/regenerator systems, including a 100 hour continuous run with continuous circulation of sorbent between the combustor and the regenerator. Regeneration reduced fresh sorbent requirements to 15 to 25 percent of that which would have been necessary to achieve the same degree of SO_2 removal without regeneration.

COAL CLEANING

IERL-RTP subobjectives relating to coal cleaning are:

° Physical/Chemical Coal Cleaning (Environmental Assessment)--Complete characterization of the environmental problems from existing coal cleaning plants and coal handling methods; definition of environmental goals for coal cleaning plants as a function of time; assessment of control technology in relation to these goals; publication of a manual of recommended practice for near-term goals; and modeling of the applicability of coal cleaning on a national and regional basis. Significant accomplishments this program has produced include:

- °° Major environmental assessment contract for coal cleaning signed with Battelle and project work initiated.
- °° Protocol between GPU and EPA signed for the cooperative evaluation of the coal cleaning plant at Homer City/Penelec.
- °° Report, "Atmospheric Potential from Fossil Fuel Resource Extraction, On-Site Processing and Transportation," issued.

°° Computerized data base for the characteristics of some 450 different U.S. coals established.

°° Washability studies/trace contaminants in coal and residues continuing. Coal preparation wastes leachability studies initiated.

° Physical/Chemical Coal Cleaning (Control Technology Development)

°° Cleaning and Handling Facilities--Development and demonstration, where needed, of the best available technology for multimedia pollution control from coal cleaning plants, coal storage, and coal transportation systems in coordination with the standards-setting timetables.

- Work underway to identify preliminary control/control development needs.

°° New Coal Cleaning Technology--Development and demonstration of advanced technologies for cleaning coal of sulfur, nitrogen, ash, and potentially hazardous trace pollutants. Promotion of the commercialization of promising processes. Significant accomplishments this program has produced include:

- Revised report, "Sulfur Reduction Potential of U.S. Coals," issued.
- Bench-scale demonstration completed of the effectiveness of pyrite leaching as a means of removing pyritic sulfur from a variety of coals, including those not amenable to physical desulfurization.
- Identification made of specific U.S. coals amenable to desulfurization by pyrite leaching in report, "Applicability of the Meyers Process for Chemical Desulfurization of Coal; Survey of 35 Coals."
- Construction initiated of a facility to demonstrate pyrite leaching at the pilot-plant scale (TRW-Meyers Process).
- Independent review initiated of pilot-plant designs to identify alternative concepts and equipment and evaluate their technical merit.
- Economic and engineering design analyses made of commercial-scale chemical processes for extraction of pyritic sulfur from coal.
- Construction of Multistream Coal Cleaning Strategy (MCCS) demonstration plant progressing satisfactorily at Homer City. This plant will eventually control 1850 MW of capacity at a capital cost of $53 million.
- Encouraging desulfurization results achieved using Institute of Gas Technology's flash desulfurization concepts at bench-scale. However, extensive early testing will need to be done to determine carcinogenic and other hazardous potentials of the desulfurized product.
- Application and process improvement studies of Battelle's Hydrothermal Coal Process underway.

- EPA/USBM coal cleaning program expanded. Need identified for more sophisticated control/instrumentation techniques. Two-stage froth flotation demonstration agreements finalized. Design underway on a coal cleaning research facility.
- Six areas of research identified by basic fuel contaminant removal study. Two reports published: "Fuel Contaminants: Volume 1. Chemistry;" and "Fuel Contaminants: Volume 2. Removal Technology Evaluation."

SYNTHETIC FUELS

IERL-RTP's program on synthetic fuels includes the following subobjectives:

° Synthetic Fuels from Coal (Environmental Assessment)--Characterization of multimedia pollution and other environmental problems from processes for conversion of coal to synthetic fuels. Development of environmental goals, assessment of control technology in relation to these goals, publication of standards-of-practice manuals, and provision of an overall preliminary environmental assessment analysis. The synthetic fuels environmental assessment program has produced substantive results as follows:

°° Analysis completed of over 100 coal samples from eastern and midwestern coal sources (over 1,500 individual trace element analyses).

°° Identification made of potential pollutant releases by several conversion processes: Koppers-Totzek gasification, Synthane gasification, Lurgi gasification, CO_2 acceptor gasification, Bi-gas gasification, COED liquefaction, and SRC liquefaction. Final report issued entitled "Evaluation of Pollution Control in Fossil Fuel Conversion Processes."

°° Initial perspective provided to those with a need to know on the potential hazards associated with some synthetic fuel processes and the relative potential environmental attractiveness of other processes.

°° Background information obtained on needs, that indicates the desirability of focusing the program primarily on commercial and first generation processes needed for energy independence.

°° Completion of an analysis of high- versus low-temperature cleanup of gas streams with emphasis on application of combined cycles. (High-temperature cleanup was about 5 percent more efficient, but had other potential environmental problems.)

°° Completion of an analysis of problems and opportunities in retrofitting industrial processes to utilize low-Btu gas. (Industrial processes, representing a significant portion of energy use in industry, can be adapted to low-Btu gas use.)

°° Examination of commercial-scale gasification plants in five foreign countries, and contracts for operational data and pollutant-emission measurement on Lurgi units in several countries.

°° Sponsorship of a 1974 symposium that produced a comprehensive report on the state-of-knowledge on environmental effects on fuel conversion processes.

°° Publication of a survey of potentially hazardous emissions from the extraction and processing of coal and oil.

°° Major contractors for environmental assessment of coal gasification (Radian) and liquefaction (Hittman/Versar) are active along with a support contractor (Cameron Engineers).

°° Research and development support for gasification New Source Pollution Standards (NSPS) development initiated.

°° Kosovo gasification plant (Lurgi) environmental data acquisition studies initiated.

°° Negotiations for information/testing of the Sasol gasification/liquefaction plant underway.

°° Research grant initiated with the Research Triangle Institute to identify pollutants and chemistry of pollutants associated with coal conversion.

° Synthetic Fuels from Coal (Control Technology Development)--Development, evaluation, and demonstration of environmentally sound control technology for multimedia pollution and other environmental problems from synthetic fuel processes in coordination with the goals defined in the environmental assessment studies. Significant accomplishments include:

°° Major contractor on board for products/by-products control technology (Catalytic).

°° Negotiations underway on two other major control technology contractors (Converter Output, and Preparation, Water, and Waste).

°° Raw and acid gas bench-scale cleaning facility underway with an operation and study research grant active at North Carolina State University and construction contract active with Aerotherm Corporation. Initial studies will be aimed at NSPS support for controls for commercial or near-commercial technology.

°° Water treatment bench-scale facility studies initiated through a research grant at the University of North Carolina.

°° Wrap-up work being completed on development and bench-scale demonstration of a highly effective desulfurization process for high-temperature fuel gas.

ADVANCED OIL PROCESSING

Advanced oil processing activities in which IERL-RTP is involved include the following subojectives:

° Advanced Oil Processing (Environmental)--Characterization of waste streams from oil processing methods and evaluation of the applicability of alternate advanced oil processing methods for utilization of petroleum residuals; evaluation of the application of available control technology; and publication of a manual of best-available technology in coordination with the standards-setting timetables. Significant accomplishments include:

°° Residual oil conversion/utilization identified as a national multimedia environmental problem with diverse potential consequences ranging from atmospheric sulfates to hazardous oil spills.

°° An inventory completed of potential pollutants in crude oils from specific locations (domestic and foreign).

°° Background report developed entitled "Residuum and Residual Fuel Oil Supply and Demand in the United States. . .1973-1985."

°° A major environmental assessment contractor on board to provide environmental tradeoffs on all existing and projected processing/utilization options for residual oil.

°° Contract negotiations initiated for comprehensive categorization and characterization of residual oils.

°° Report issued entitled "Environmental Problem Definition for Petroleum Refineries, Synthetic Natural Gas Plants, and Liquefied Natural Gas Plants."

° Advanced Oil Processing (CAFB Development)--Demonstration at small to moderate commercial-scale of the chemically active fluid bed (CAFB) process for converting heavy high-sulfur, high-metals content residual oils to clean, high-temperature gaseous fuel. Significant accomplishments include:

°° Success in the pilot-plant program with design work begun on demonstration of CAFB process on utility boiler as an environmentally sound fuel switching technique.

°° Progress report issued entitled "Development of the Chemically Active Fluid Bed Process, A Status Report and Discussion."

°° Continuous operation of the CAFB pilot plant at Esso Petroleum, Ltd., for periods as long as 412 hours and 212 hours between decaking or cleaning of the gas duct. Sulfur removal percentages of 85 percent and vanadium retention of 100 percent on the bed material based on residual oil inputs.

°° Pilot testing of coal feedstocks in the continuous CAFB pilot plant begun in support of the planned demonstration.

°° Design/construction of a 10 MW demonstration plant at Central Power and Light (CPL), San Benito, Texas, underway with Foster Wheeler Corporation as prime contractor.

°° Westinghouse control technology studies have shown that the trace metals sequestered by the bed material are bound tightly and will not leach out into the environment. The spent sorbent shows promise as a component of concrete. The spent bed material was found to contain very little, if any, organic compounds.

° Advanced Oil Processing (Control Technology Development)--Development and demonstration, where needed, of technologies for the removal of sulfur, nitrogen, and potentially hazardous trace materials from petroleum, petroleum derivatives, and other liquid fuels. Development and evaluation of the best-practical control technologies for commercial or near-commercial processes.

°° Determination of the fundamental characteristics of the reactions involved in simultaneous hydrodesulfurization and denitrification. Report issued entitled "Catalytic Desulfurization and Denitrogenation."

°° Identification of specific catalysts that tend to optimize demetallization of oils, and preliminary estimates of catalytic demetallization and desulfurization of specific Venezuelan, Soviet, and Iranian oils. Phase III report issued entitled "Demetallization of Heavy Residuals.

°° Work initiated to optimize denitrogenation of residual oils.

OTHER SUPPORT

IERL-RTP has done some work in support of other subobjectives, especially relating to advanced low-emission/energy-conserving systems and strategies. The following significant accomplishments have resulted:

°° Completion of the construction of an advanced domestic energy utilization system demonstration involving solar panels, heat pump, fuel cells, and catalytic burner. Identification of a need to explore impact of air quality degradation on solar energy cost effectiveness.

- Completion of a paper feasibility study which indicated a number of applicable approaches for increasing efficiency of small heating systems and also indicated potential for the Heat and Emission Loss Prevention System (HELPS) employing direct contact water heat exchanger to scrub fuel gas from residential/commercial furnaces and bring furnace efficiency from 80 to almost 97 percent while reducing pollution. Recommendations for follow-up were made to IERL-CIN.
- Definition of the potential for low environmental impact use of electrical energy as a substitute for clean fuels which can go a long way toward helping the United States meet the goals of Project Independence.
- Publication of a preliminary study on the extent to which clean and dirty fuels can be switched to aid in reduction of pollution.
- Publication of Phase I report on a comprehensive program to evaluate indoor air quality and its relationship to energy conservation.

Industrial Processes

The Industrial Processes program seeks to identify, develop, and demonstrate cost-effective technologies for the abatement of multimedia pollution associated with industrial processing and manufacturing. The program involves the identification, characterization, and quantification of pollutants from assigned industries; the experimental modification of process equipment, operations, raw materials, and products; and the application of control processes, devices, or systems.

CHEMICAL PROCESSES

The segments of the Chemical Process Industries which are assigned to IERL-RTP include petrochemical manufacture, petroleum refining, agricultural chemicals manufacture, textile manufacture, conventional combustion assessment, and incineration at sea. Work underway consists of comprehensive multimedia environmental assessment in all of these areas plus control technology development in some areas where the need for such has already been identified.

Details of the Chemical Processes projects appear later in this report.

METALLURGICAL PROCESSES

In the metallurgical field, IERL-RTP has been assigned responsibility for iron and steel. This includes integrated iron and steel production, ferroalloy production, and iron foundries. These efforts cover mining, beneficiation, pelletizing, cokemaking, sintering, iron and steel manufacture, ferroalloy production, surface preparation and finishing, fugitive emissions and surface

runoff, and abnormal operating conditions. Details of programs in these areas appear later in this report.

Process Measurements

The Process Measurements Branch (PMB) is responsible for all measurements programs in IERL-RTP. Major areas of activity are carried out through a coordinated contract/inhouse effort. Program areas include methods evaluation and development, review of test programs and proposals, evaluation of test results, on-site troubleshooting, and special field studies. Inhouse activities include coordination of measurement programs with IERL needs, review of the measurement aspects of all procurement plans and proposals, and specialized measurements to fill gap areas. Contract activities include methods development, measurement program reviews, and on-site troubleshooting. Six specific areas of expertise are developed through the contracting program: inorganic sampling and analysis, organic sampling and analysis, particulate sampling, fugitive emissions, high-temperature/high-pressure measurement, quality assurance.

The current major thrust of PMB's work is in support of IERL-RTP's environmental assessment program. The major objective is development of a conceptual approach to a coherent sampling and analytic program suitable for application to a wide variety of environmental assessment programs. Concurrently, work is conducted in the areas of quality assurance and control equipment evaluation as techniques, methodology, and instrumentation continue to be improved and expanded. The PMB is publishing a series of technical and procedural manuals oriented toward IERL-RTP project requirements.

Details of the PMB program are described later in this report.

Program Operations

A majority of this report is concerned with details of programs relating to the IERL-RTP line divisions. The fourth IERL-RTP organizational group, the Office of Program Operations, provides staff technical and program administration support to the Office of the Director, IERL-RTP, including essential functions encompassing program and project analysis, review, planning, and data analysis and interpretation.

SPECIAL STUDIES

Within the Office of Program Operations, the Special Studies Staff provides technical analysis and assessment support to the Office of the Director. This function includes broad technical assistance in program planning, guidance, and

review; recommendations to the Laboratory Director for program direction; technical assistance to Laboratory components in data analysis and interpretation; and technical evaluation of projects or programs as may be requested by the Laboratory Director or other Laboratory components. Other services provided by the Special Studies Staff include management of engineering services contracts and consultation on technical aspects of Laboratory computerized data processing applications.

During the past year, special studies conducted by the Staff have covered a wide range of activities. Statistical reviews were made of experimental test plans on data from numerous projects, including boiler corrosion during combustion modification tests, charged droplet scrubbing, fluidized-bed combustion, and Wellman-Lord/Allied scrubbing demonstration.

Technical analyses of several Laboratory programs were conducted or initiated during the year, including a new advanced flue gas desulfurization demonstration proposal. In addition to Laboratory projects, a number of unsolicited grant and contract proposals were reviewed and appropriate recommendations regarding them were made to the Laboratory Director. To support the development of cost-effective control technology by other Laboratory components, a program has been initiated to formulate standard cost-estimating procedures which may be utilized uniformly throughout the Laboratory. In order to provide IERL-RTP with an awareness of programs and activities in other laboratories, special studies include maintaining liaison with such laboratories involving health effects, ambient air quality studies, and standards development which may have significance upon control technology development. In this regard, special studies included the preparation of IERL-RTP's contribution to the criteria document for lead ambient air quality as part of an inter-laboratory Office of Research and Development (OR&D) task force.

During the past year, several major projects were either initiated or continued in support of particular Laboratory or OR&D objectives. These include the development of a computerized information system on fine particle emissions from stationary sources, the initiation of an integrated assessment of coal-based energy technologies, an environmental assessment of energy supply systems using fuel cells, and a compilation of industrial process profiles.

The computerized Fine Particle Emissions Information System (FPEIS) provides an extensive compilation of data on stationary source testing and evaluation of control technology. Numerous requests for information from the FPEIS were received following its development. Data which may be found in the FPEIS include particle size distributions; results of chemical and biological analysis of the particulate sample; process description of the source; design and operating parameters of applied control technology; and description of the measurement equipment and techniques employed during data collection. Continuing development and improvement of the FPEIS is planned.

The Integrated Assessment of Coal-based Energy Technologies will identify, describe, compare, and quantify where possible the range and magnitude of environmental, socio-economic, and energy impacts of the development and deployment of such energy technologies, supply systems, and end uses. From this total assessment, alternative policies will be recommended that will achieve the best balance of environmental quality, energy efficiency, economic costs, and social benefits, and strategies will be proposed for policy implementation.

The Environmental Assessment of Energy Supply Systems Using Fuel Cells examines the potential role of emerging fuel cell technology in the nation's future as a localized source of energy for multi-family residential heating and cooling. Consistent with current energy policy emphasis, the study focuses upon coal-derived fuels for use in fuel cell applications. Close cooperation with concurrent ERDA programs is maintained to ensure that maximum benefits may be obtained by both the ERDA and IERL-RTP programs.

The Industrial Process Profiles for Environmental Use (IPPEU), formerly called the Environmental Catalog of Industrial Processes (ECIP), presents in several volumes a detailed description of selected processes from 24 chemical and metallurgical process industries. Each profile identifies the process inputs, the end products, the quantity and type of waste streams to be expected, and the quantity and types of utilities (water, air, etc.) required by each process.

Similar special studies will be conducted in the future as needed to respond to the evolving mission and interests of IERL-RTP.

UTILITIES AND INDUSTRIAL POWER

IERL-RTP's work in the area of utilities and industrial power can be subdivided into three distinct functional groupings: process technology, emissions and effluent technology, and particle technology. The following subsections of this report discuss these groupings separately.

PROCESS TECHNOLOGY

Flue Gas Desulfurization--Regenerable Processes

MAGNESIUM OXIDE SCRUBBING (CHEMICO)

The Mag-Ox scrubbing process--developed by Chemical Construction Company (Chemico) and Basic Chemicals, and currently offered commercially by Chemico--is one of the more promising regenerable flue gas desulfurization approaches. The process is based on the reaction of magnesium oxide with sulfur dioxide to form magnesium sulfite, which is removed from the scrubber effluent by centrifugation. The magnesium sulfite is dried (to remove surface and bound moisture) before being calcined to regenerate magnesium oxide for recycle and sulfur dioxide for conversion to sulfuric acid or other saleable products.

The chief advantage of the process is its wide applicability to both existing and new power plants: it removes both sulfur dioxide and particles very efficiently without interfering with normal boiler operation. The process is also amenable to the centralized processing concept; i.e., spent sorbent can be regenerated at a central plant capable of servicing a number of power or industrial plants. The major disadvantage of the process is its relatively high regeneration energy requirements. Other disadvantages include those common to wet scrubbing processes; e.g., the apparent requirement for stack plume reheat.

In 1974, IERL-RTP and Boston Edison completed a $9 million cofunded demonstration program involving the design, construction, and operation of a 155 MW capacity scrubbing/regeneration system (see photo). Scrubbing, centrifuging, and drying operations were located at Boston Edison's oil-fired Mystic Station; a regeneration system was constructed at Essex Chemical's sulfuric acid plant in Providence, R.I. The system was started up in April 1972. Results obtained during 2 years of operation indicate that sulfur dioxide removal efficiencies in excess of 90 percent were obtained consistently, using both virgin and regenerated magnesium oxide. Additionally, more than

EPA/Boston Edison demonstrate Mag-Ox process.

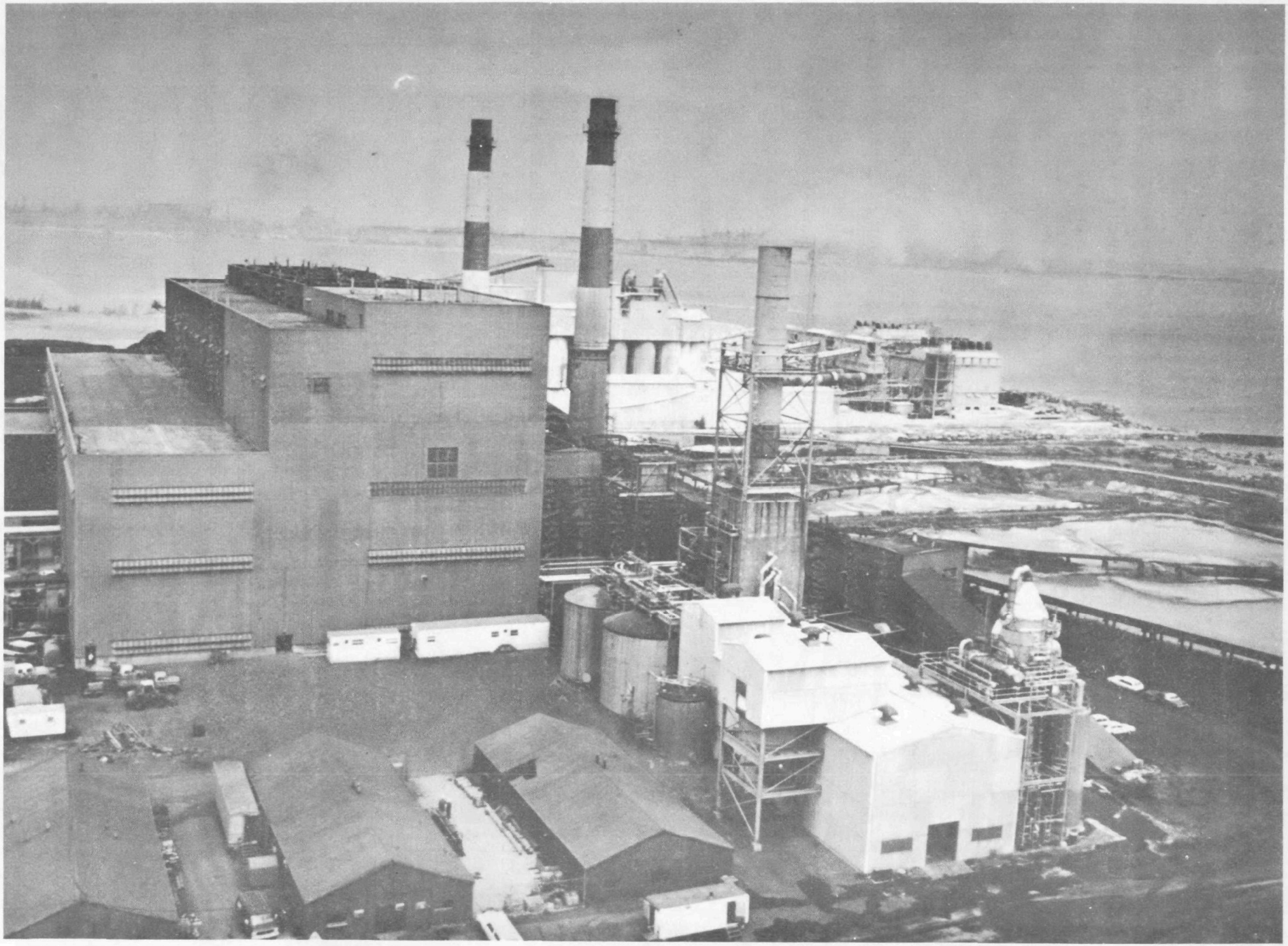
5,000 tons of commercially saleable sulfuric acid of high quality were produced from the sulfur recovered from the stack gas and sold conventionally. A number of problems were solved that were primarily equipment (rather than process) related. Consequently, continuous, long-term, reliable operation was not achieved. However, from mid-February until June 1974, the scrubbing system demonstrated an availability of about 90 percent. The final report on this work is available from NTIS.

Potomac Electric Power Company has installed a 100 MW Mag-Ox scrubbing system at its coal-fired Dickerson Station. Since completion of the EPA/Boston Edison program in June 1974, EPA provided the Providence Mag-Ox regeneration system for Potomac Electric's use in processing spent scrubber sorbent. Potomac Electric supplied data relative to overall system operation on coal-fired plants. Results indicate SO_2 removal efficiencies greater than 90 percent with few discernible differences between coal- and oil-fired boiler applications. Work on this program has been completed, and the final report is being prepared.

Two studies in support of Mag-Ox scrubbing are being conducted currently. Radian Corporation has evaluated the feasibility of producing elemental sulfur directly from magnesium sulfite. This would expand the applicability of current Mag-Ox processes. Another study is concerned with the mechanism of formation of tri- and hexa-hydrate forms of magnesium sulfite ($MgSO_3 \cdot 3H_2O$, $MgSO_3 \cdot 6H_2O$). The hexa-hydrate crystals separate and handle easily; the tri-hydrate crystals require less drying energy but are more difficult to separate and handle. The study has attempted to generate information on formation mechanisms and operating conditions that can be used to control the type of crystal formed. Final reports on the two studies will be available soon.

SODIUM SULFITE/BISULFITE SCRUBBING WITH THERMAL REGENERATION (WELLMAN-LORD/ALLIED CHEMICAL)

IERL-RTP and Northern Indiana Public Service Company (NIPSCO) jointly funded the design and construction of a flue gas cleaning demonstration system utilizing the Wellman-Lord (W-L) SO_2 recovery process. The Allied Chemical SO_2 reduction process will be used with the W-L process to convert the recovered SO_2 to elemental sulfur. The total $11 million cost for design, construction, and start-up was borne equally by IERL-RTP and NIPSCO. The operational costs for the system will be borne solely by NIPSCO, and a detailed test and evaluation program will be funded by IERL-RTP. The demonstration system has been retrofitted to the 115 MW, coal-fired Boiler No. 11 at the D.H. Mitchell Station in Gary, Indiana. (See photo.)



Wellman-Lord process to be demonstrated.

Phase I of the three-phase program, completed in December 1972, entailed the development of a process design, major equipment specifications, and a detailed cost estimate. Phase II, the final design and construction, was completed by Davy Powergas, Inc., (owner of the W-L process) in August 1976. Davy constructed both the W-L and Allied portions of the system. After the completion of start-up activities, the plant will be operated by Allied Chemical Corporation under contract with NIPSCO. During the demonstration year a comprehensive test and evaluation program will be carried out by TRW, Inc., under contract with IERL-RTP.

The W-L process utilizes a sodium sulfite/sodium bisulfite solution to absorb SO_2 from gas streams containing a wide range of inlet SO_2 concentrations. Spent absorbent, rich in bisulfite, is processed in a steam-heated evaporator/crystallizer, regenerating active sodium sulfite and a stream of SO_2 for further processing. The basic chemistry of the W-L process can be represented in simple form as:

Absorption--

$$SO_2 + Na_2SO_3 + H_2O \rightarrow 2NaHSO_3$$

Regeneration--

$$2NaHSO_3 \xrightarrow{\text{heat}} Na_2SO_3\downarrow + SO_2\uparrow + H_2O\uparrow$$

The process generates inactive sodium sulfate by three mechanisms: SO_3 absorption, disproportionation, and sulfite oxidation. In order to maintain adequate levels of active sodium sulfite and to avoid excessive steam demand, it is necessary to purge sodium sulfate from the absorber/evaporator loop. Since the purge results in the need to dispose of or market an additional system product as well as loss of useful sodium ions, much emphasis has been placed on purge minimization in development of the demonstration system.

The SO_2 product from the W-L process is suitable for recovery in three forms: liquid SO_2, sulfuric acid, and elemental sulfur. For purposes of the IERL-RTP/NIPSCO demonstration, the Allied Chemical SO_2 reduction process will be applied to generate elemental sulfur. The Allied process utilizes natural gas as a reductant in a proprietary catalytic reactor system. The process has been demonstrated on a large scale, treating a 12 percent SO_2 gas stream from a nickel ore roaster at Sudbury, Ontario.

IERL-RTP has high confidence for the success of this first coal-fired boiler demonstration system in meeting guarantees for pollution control,

product quality, and material and utility requirements. This confidence is based on the already appreciable quantity of successful operating experience to date for W-L systems on various applications including acid plants, Claus plants, and oil-fired boilers. About 25 systems are now in operation in the United States and Japan. The knowledge gained from operating these systems has resulted in a series of process improvements (reducing costs and purge requirements) which have been incorporated in the IERL-RTP/NIPSCO demonstration.

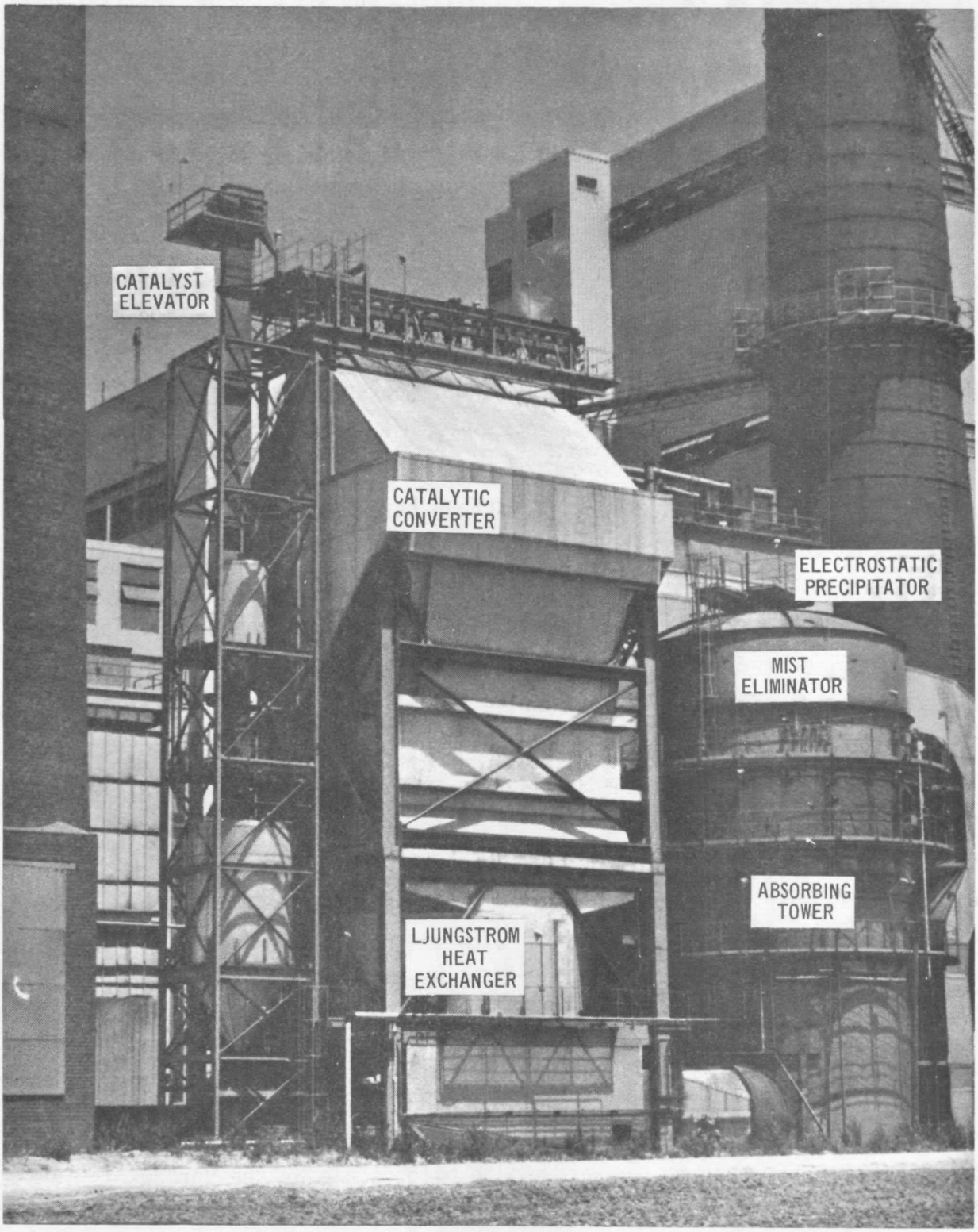
CATALYTIC OXIDATION (MONSANTO CAT-OX)

The catalytic oxidation (Cat-Ox) process is an adaptation of the contact sulfuric acid process. Monsanto Enviro-Chem Systems, Inc., has developed this adaptation through work on a pilot-scale unit, followed by a 15 MW prototype. IERL-RTP and Illinois Power Co., sharing the $8 million total funding requirement, have been attempting to demonstrate the process on a 103 MW coal-fired boiler at Illinois Power's Wood River Station (see photo). Detailed design, construction, and shakedown testing of the system took about 3 years; performance guarantee testing was carried out using gas-firing of the reheat burners in July 1973. The unit met all guarantees and was subsequently accepted. Because of the shortage of natural gas, however, the burners were modified to allow either oil- or gas-firing, as conditions permit. Design and start-up problems have precluded successful initial operation and initiation of the comprehensive 1 year test program.

A thorough technical and economic study has been made of the costs and benefits of continuing the demonstration at Wood River. Results of this study have led to the decision to end the project.

A major factor that entered into the decision to terminate the demonstration program was the conversion to low-sulfur coal at Wood River. Since only one of the generating units at Wood River has an FGD unit, the utility has chosen to comply with SO_2 regulations by burning low-sulfur coal. (They are physically constrained from burning a different coal in the Cat-Ox generating unit.) This step significantly reduced the benefits from a Cat-Ox demonstration, designed to produce sulfuric acid on the flue gas from a high-sulfur fuel. In addition, extensive and very costly refurbishments and modifications are required at Wood River. Acid coolers would have to be replaced as would a large fraction of the acid circulation piping and brickwork.

Thus, it has been mutually agreed by all parties that, despite the failure to demonstrate either feasibility or infeasibility at Wood River, further



EPA/Illinois Power demonstrate Cat-Ox process.

large expenditure of funds cannot be justified and that the demonstration project must be discontinued.

AQUEOUS CARBONATE PROCESS (ATOMICS INTERNATIONAL)

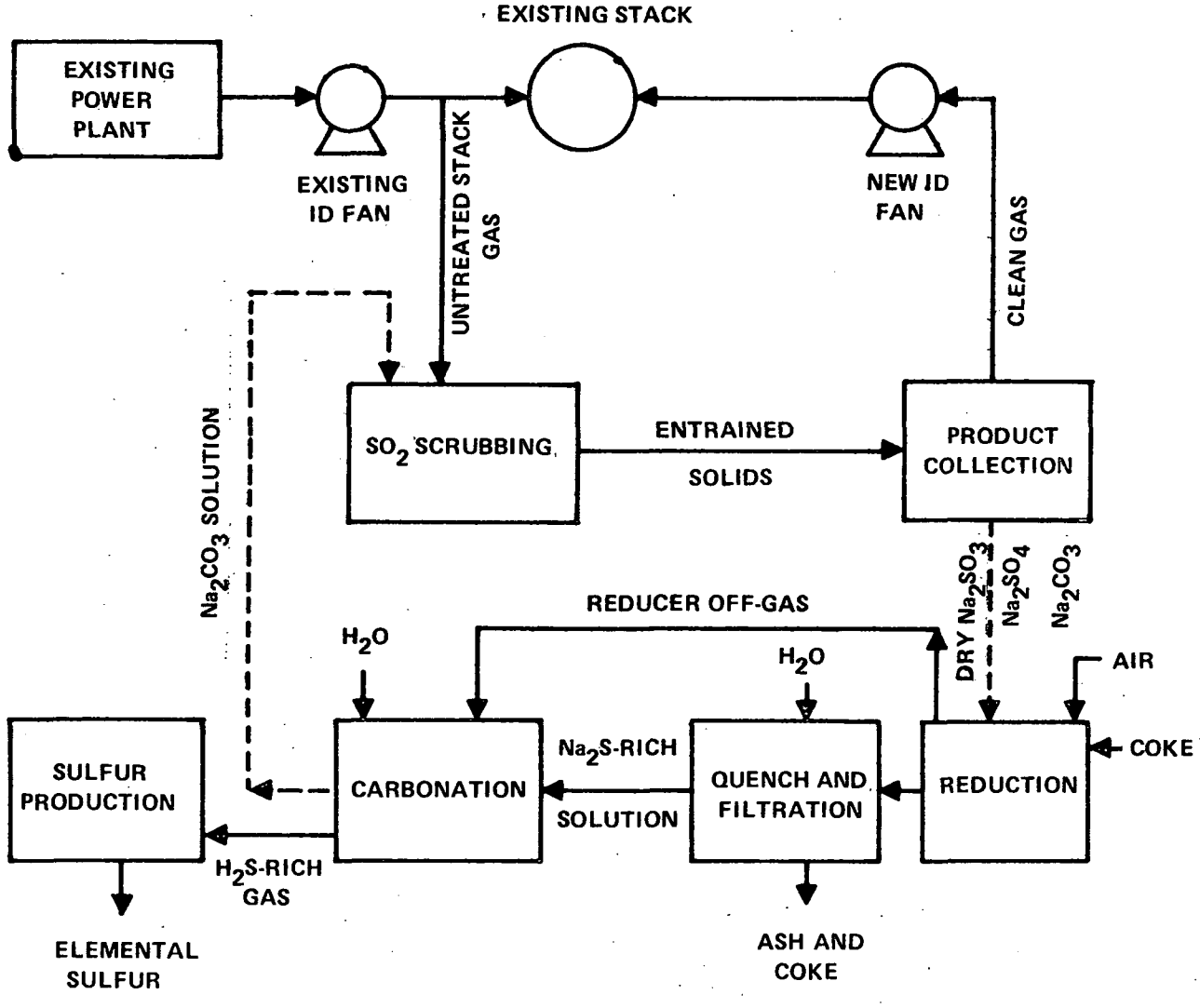
IERL-RTP and Empire State Electric Energy Research Corporation (ESEERCO), a research organization sponsored by New York's eight major power suppliers, have recently contracted to fund jointly the design and construction of a demonstration of Atomics International's sulfur-producing Aqueous Carbonate Process (ACP). In addition to its $8 million share of the expected $22 million in project cost, IERL-RTP will fund a detailed test and evaluation program. The demonstration is being retrofitted to Niagara Mohawk Power Company's 100 MW coal-fired Huntley Station in Tonawanda, New York.

The demonstration will be in four phases. Phase I, the design and cost estimate, is expected to be completed by mid-1977, and Phase II, construction, by mid-1979. Acceptance, Phase III, should be accomplished by the end of 1979, at which time a 1 year test and evaluation program, Phase IV, will be initiated.

In the Aqueous Carbonate Process (see following illustration), sodium carbonate is contacted with the flue gas in a spray dryer. A reaction with SO_2 takes place, forming sodium sulfite as a dry powder which is collected and regenerated as follows. The dry product is fed, along with carbon (in the form of either coal or coke), to a molten salt bath, which is maintained in the 900 to 1000° C range. The sulfite is reduced to sulfide; carbon is oxidized to carbon dioxide. The molten sodium sulfide is solidified, broken up, and dissolved in water, and the solution is filtered to remove ash. The clarified solution is then contacted with the carbon dioxide-rich off-gas from the reduction step to regenerate sodium carbonate and evolve hydrogen sulfide. The hydrogen sulfide is fed to a Claus plant where elemental sulfur is produced.

CITRATE PROCESS

IERL-RTP and the U.S. Bureau of Mines have entered into a cooperative agreement to pool funds and technical talents to demonstrate the Citrate process which has been developed through pilot scale by the Bureau of Mines. A concurrent development program, carried out by an industrial consortium headed by Pfizer Chemical Company, also led to a successful pilot operation of the process. Based on the success of these two pilot programs, IERL-RTP and the Bureau of Mines have initiated the demonstration of this technology on a 53 MW coal-fired boiler at St. Joe Minerals Corporation in Monaca, Pennsylvania



Aqueous carbonate process.

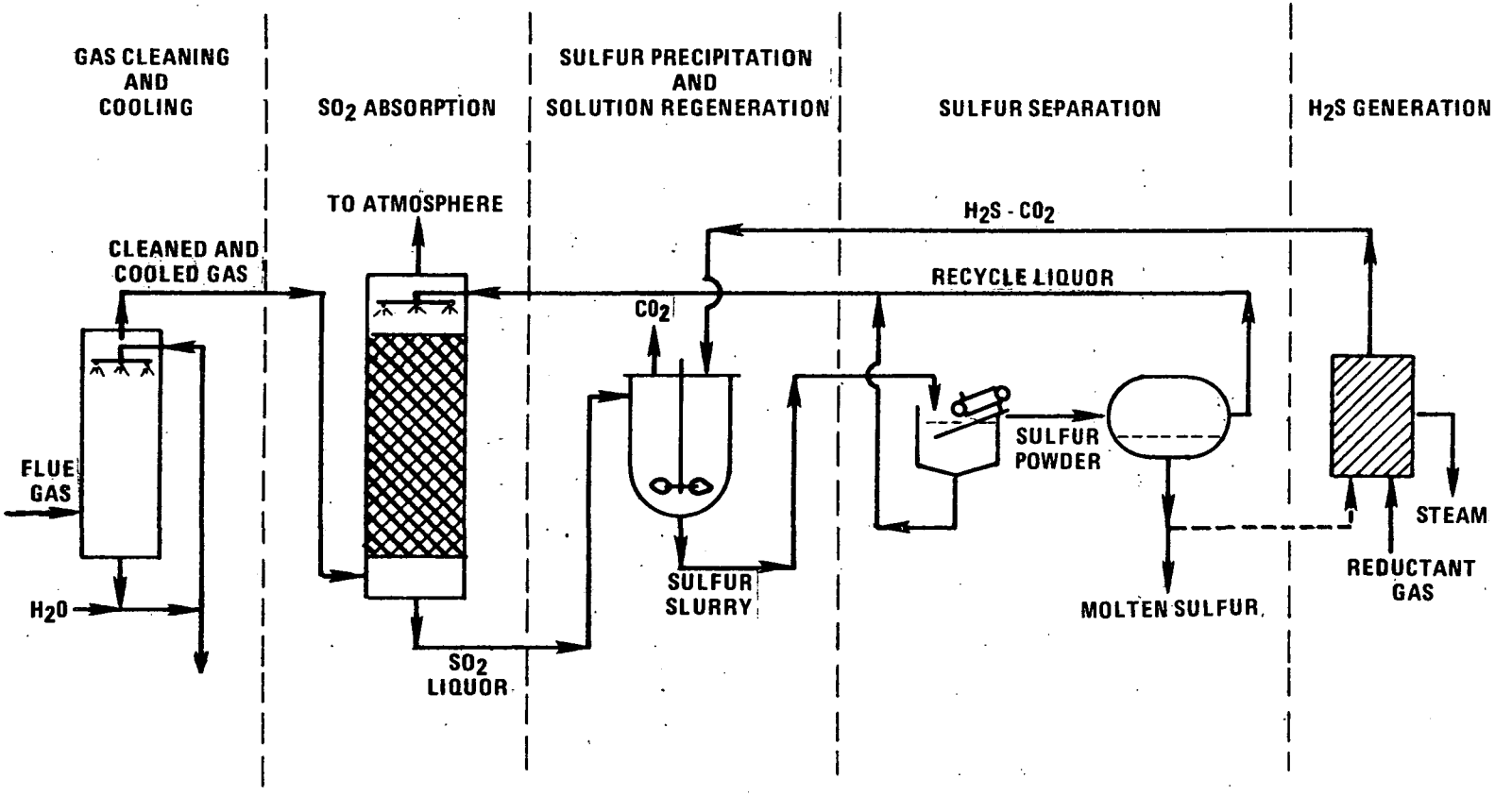
(coal to be at least 2.5 percent sulfur). The contract between USBM and St. Joe Minerals was signed in June 1976, and Phase I, initial design and cost estimation, was completed in November 1976.

As shown in the generalized flow sheet below, the Citrate process consists of five steps: gas cleaning and cooling, SO_2 absorption, sulfur precipitation and solution regeneration, sulfur separation, and H_2S generation. After gas cleaning and cooling (to remove particulate matter and to reduce flue gas temperature), an aqueous solution containing sodium sulfite, sodium bisulfite, sodium thiosulfate, and other sulfur compounds absorbs SO_2 from the flue gas stream. The solution is buffered with citric acid to maintain pH at an optimum level for high-efficiency scrubbing and high-SO_2 loading capacity. The SO_2-rich scrubber liquor is then fed to a series of reactors where gaseous H_2S is added. Although a number of reactions take place in these reactors, the net reaction is the combining of SO_2 and H_2S to form elemental sulfur, which precipitates and is then separated by flotation. The recovered sulfur is melted to separate out the residual scrubbing solution. A portion of the sulfur is sent to an H_2S generator where it is reacted with reducing gas; the remainder is sent to product storage for subsequent sale. The regenerated solution is returned to the scrubber, and the H_2S generator product is sparged into the regeneration reactors.

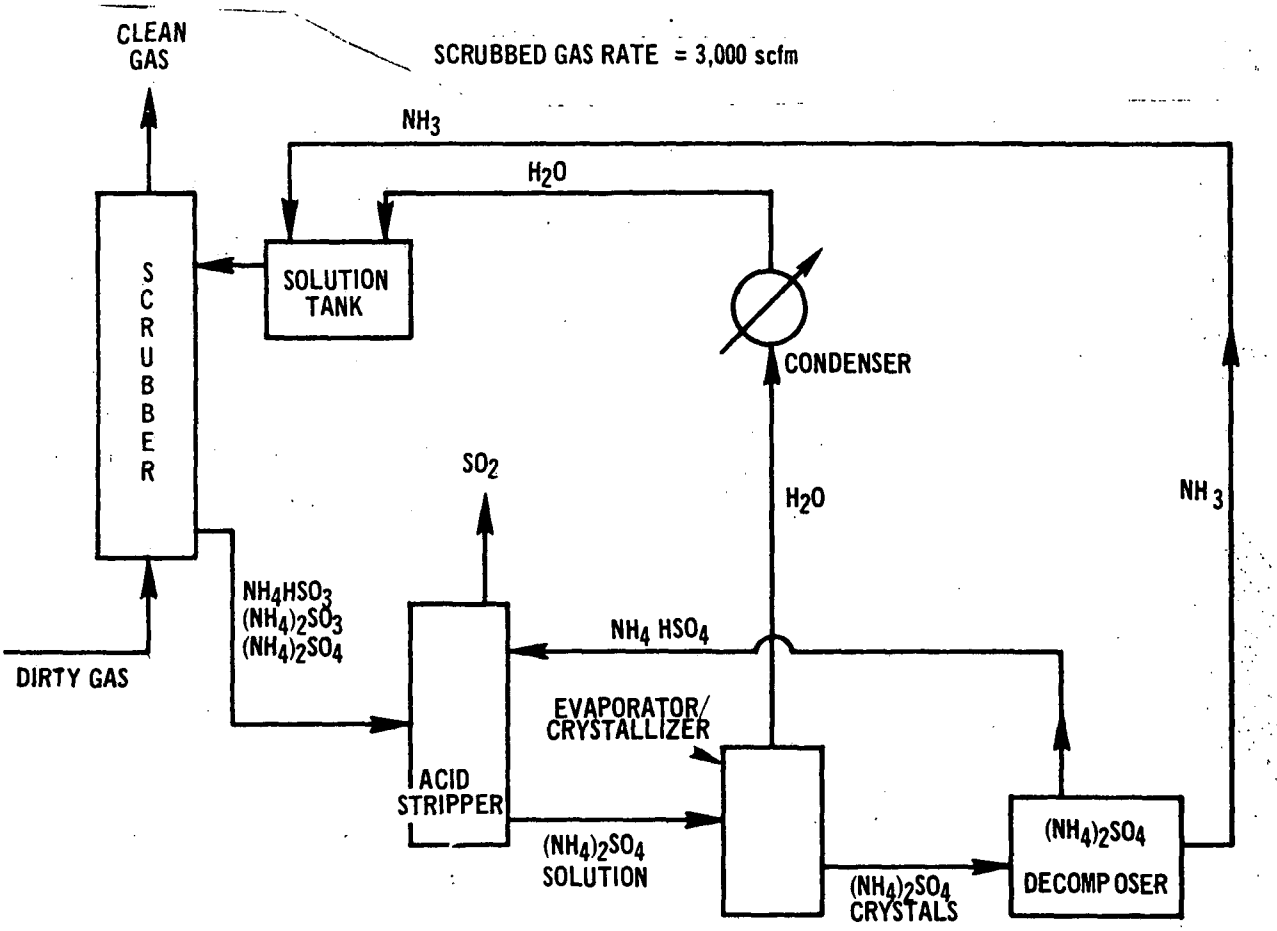
AMMONIA SCRUBBING WITH BISULFATE REGENERATION

Stack gases have been commercially desulfurized by contact with solutions of ammonium sulfite and bisulfite since the mid-1930's. The early processes recovered SO_2 in a pure form by acidifying the scrubbing liquor with sulfuric, nitric, or phosphoric acid. The resulting ammonium salt of the acid was further processed for use as a fertilizer. Because of the enormous tonnages of SO_2 involved in desulfurizing power plant stack gases, fertilizer markets are not expected to support wide-scale use of fertilizer-producing ammonia processes. Therefore, IERL-RTP, in a joint venture with TVA, undertook the development of a completely cyclic ammonia-scrubbing/bisulfate-regeneration process which has as its major product a concentrated stream of SO_2 which can then be used to produce sulfuric acid or elemental sulfur.

The process (shown below) removes SO_2 from stack gases by absorption in a solution of ammonium sulfite and bisulfite. Scrubber product liquor is acidified with ammonium bisulfate to evolve SO_2 and form ammonium sulfate. This ammonium sulfate solution is partially evaporated and the ammonium sulfate crystallizes. After separation, the ammonium sulfate crystals are thermally decomposed into



The Citrate process.



Ammonia scrubbing with bisulfite regeneration.

ammonium bisulfate and ammonia. The ammonium bisulfate is returned to the acidifier, and the ammonia is absorbed into a solution and returned to the scrubber. Sulfites that are oxidized into sulfates during the process must be purged from the system.

This ammonia scrubbing process was evaluated at a 3000 cfm pilot plant located at the Colbert Steam Station in northern Alabama. Initial efforts at the pilot unit site concentrated on the absorber, and have since included work on all of the subunits of the system except the decomposer. As evaluation of the process continued, it became apparent that the process had two major problems: (1) the formation of a persistent fume which could not be controlled or eliminated by reasonable control efforts, and (2) unfavorable economic projections due primarily to energy consumption by the decomposer. As a result of these problems, the development project was terminated during the summer of 1976.

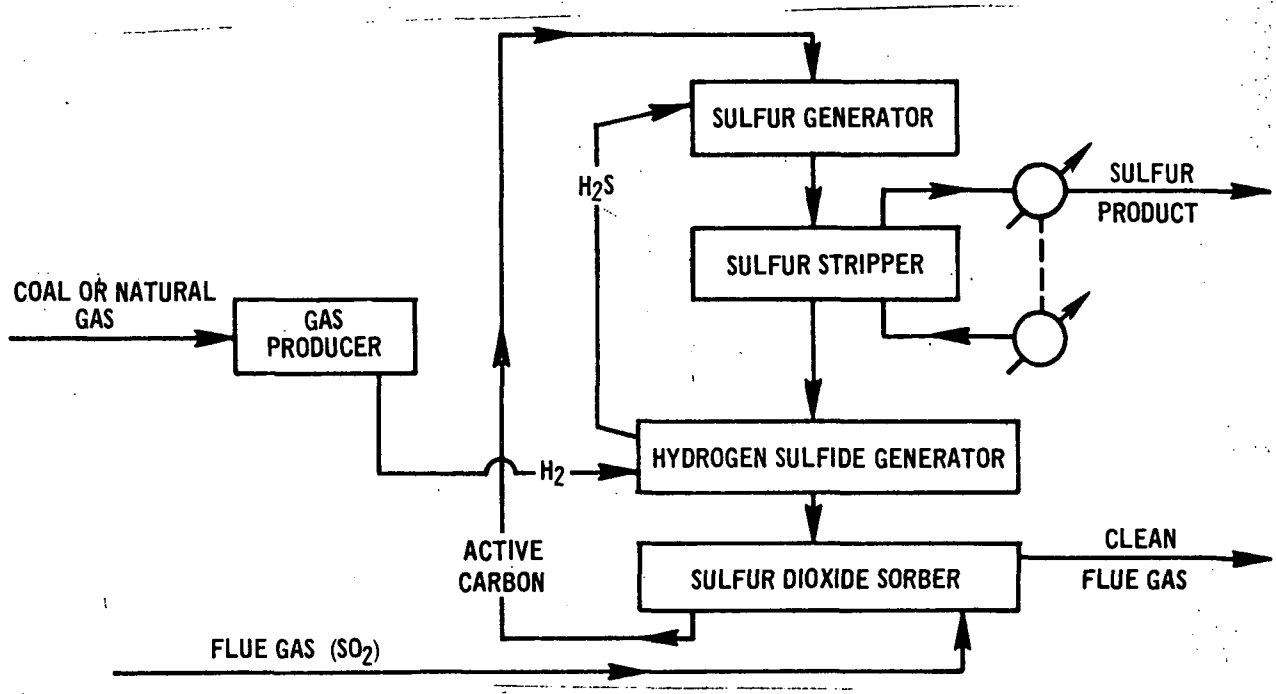
ACTIVATED CARBON (WESTVACO)

The use of multistage, dry fluidized-beds of recycling activated carbon appears attractive both for sorption of SO_x from flue gases and for converting the removed SO_x to elemental sulfur. Under an IERL-RTP contract, development of the activated-carbon-based flue gas desulfurization process was advanced to a stage where three major process units--sorber, sulfur generator, and carbon regenerator--were integrated for continuous and cyclic operation.

In the sorption stage, shown schematically below, combustion flue gas is contacted with the activated carbon, and the contained sulfur dioxide (in the presence of oxygen and moisture) is first catalytically converted into sulfur trioxide, and then to sulfuric acid, which is adsorbed by and contained in the pores of the activated carbon.

In the sulfur generator, sulfuric acid contained in the activated carbon is reacted with hydrogen sulfide to produce the elemental sulfur which remains on the carbon.

In the carbon regeneration stage, the sulfur-loaded activated carbon is reacted with a measured quantity of reducing gas which sweeps out the deposited sulfur. About 25 percent of deposited sulfur is recovered as a by-product; the remaining 75 percent is converted into hydrogen sulfide to decompose sulfuric acid in the sulfur generator unit. Activated carbon is continuously returned to the sorber.



Activated carbon process.

Integrated pilot plant operation, as a culminating point in the effort to determine overall technical feasibility of the process, is complete. Cyclic operation of the approximately 300 scfm capacity pilot plant has yielded encouraging results. Estimated process economics, based on these results, appear to compare favorably with those of other flue gas desulfurization processes. Westvaco, under contract to IERL-RTP, has prepared a detailed final report on this process. The report includes results of the test work and cost estimates for a hypothetical large-scale commercial application. There are no current plans to continue this project.

REDUCTANT GASES

As part of its program for developing and demonstrating SO_x control technology for fossil-fuel-fired steam-generating equipment, IERL-RTP is currently supporting (or evaluating for future support) the development of several flue gas desulfurization (FGD) processes which recover the SO_x as elemental sulfur. Elemental sulfur may be the most desirable form for recovery of SO_x because it is the minimum quantity of any FGD waste or by-product and because of its saleability, ease of transport, and suitability for long-term storage.

Production of sulfur from SO_x requires the use of a reductant for conversion of the SO_x to sulfur: to date, major emphasis has been on the use of natural gas for this purpose. In view of the current and continuing shortage of natural gas, it is imperative that other sources of reductant gas be utilized in the future. IERL-RTP has embarked on a program leading to the demonstration of processes and equipment for economical generation of reductant gases from more plentiful ultimate sources, such as coal, coke, residual oil, and petroleum coke.

As a first step, IERL-RTP retained Battelle-Columbus Laboratories to conduct process evaluation and cost estimates of gasification processes that are suited for application to FGD requirements, and to recommend avenues of continuing development and demonstration. The report is available from NTIS. An example of the use of an alternative reductant is the EPA demonstration of Atomics International's Aqueous Carbonate Process which uses either petroleum coke or coal.

NON-UTILITY COMBUSTION SOURCE CONTROL

Modeling studies have shown that the impact of non-utility combustion (NUC) source SO_2 emissions on ambient air concentrations is higher than anticipated from their fraction of the amount of SO_2 emitted. For example, in St.

Louis, area sources accounted for 15 percent of the SO_2 mass emissions, but contributed 40 percent of the ultimate ambient concentration.

The first step in IERL-RTP's approach to reducing NUC source sulfur dioxide emissions has been to compile and standardize a data base that characterizes fossil-fuel combustion NUC sources which are about 50 MW in capacity (about 500,000 pounds of steam per hour) or less, and which are categorized as industrial or commercial/institutional. The base, developed by Battelle-Columbus Laboratories, draws together all pertinent information and contains data on such factors as number, size range, boiler type, fuel usage, and emission. The end product of this effort is a set of recommendations of strategies and technologies for implementing an NUC source control program.

Battelle has also conducted for IERL-RTP a review of available package sorption processes that can be applied to the control of sulfur oxide emissions from the lower size range of the boiler population described above, as well as from residential sources. Initial activity is directed toward extending the characterization of NUC sources down to small combustion sources. Recommendations of strategies and technologies for implementing control programs for small sources are also to be included. Stress is on existing technology, but Battelle has also gathered information on emerging technology. Desirable characteristics of a package sorption device would include small size, simple installation, off-the-shelf availability (essentially shop fabricated), easy operation by nonspecialized personnel, low capital and operating costs, minimum waste products, useful or marketable by-products, and multipollutant control capability. All of this work was included in the final report, "SO_2 Reduction in Non-utility Combustion Sources," which is available from NTIS.

PEDCo-Environmental Specialists, Inc., under contract to IERL-RTP, is evaluating the relative impact of SO_x emitted from utility and non-utility combustion sources on ambient air quality. Existing air quality and emission data from selected regions will be gathered, analyzed, and extrapolated for more extensive use. These data will be correlated with actual field data from a major metropolitan area. The field data, gathered during the summer of 1975, are based on sampling ambient air resulting from tracer-doped emissions from utility and non-utility sources. The large number of non-utility combustion sources makes their consideration necessary in an overall SO_x control scheme.

In a separate task, PEDCo will survey non-utility combustion sources that are applying or considering the application of various strategies for control

of SO_x emissions. Meetings will be held with regulatory agencies and industrial representatives in the selected study areas to determine the various strategies/technologies in use and to conduct surveys of selected plants. The overall applicability of each control technology to each study area will be assessed and the results extrapolated to other areas.

MARKETING ABATEMENT SULFUR/SULFURIC ACID

By-products of flue gas desulfurization processes fall into two categories: throwaway and saleable. In the latter category are sulfur, sulfuric acid, and (to a much lesser extent) gypsum.

Under interagency agreement with IERL-RTP, TVA has studied the economics of marketing sulfuric acid that could theoretically be produced from its coal-fired plants. The study assumed that TVA would be the only utility producing abatement acid and that the existing production, distribution, and marketing patterns would be changed only slightly by the introduction of abatement acid. The objective was the creation of a model for estimating the net sales revenue to TVA. Of the total 18,109 MW of TVA's coal-fired capacity, it was assumed that 9,806 MW would be considered for sulfuric acid production. The study made no attempt to select a process or to estimate production costs: it was assumed that the acid would have a zero value at the point of production.

Results indicate that the net sales revenue of abatement acid would range from $6 to $9 per ton of 98 percent sulfuric acid, and might reduce the cost of operating a power plant sulfur oxide control system by 10 to 20 percent. The final report of this initial study is available from NTIS.

A second phase of the marketing study is also underway. In this phase, TVA is considering all potential abatement acid or elemental sulfur from power plants located in states that are served by the inland waterway system in the Eastern United States. These include states bordering the Mississippi River and its navigable tributaries, the Great Lakes, and the Eastern seaboard: they encompass Minnesota, Iowa, Nebraska, Kansas, Oklahoma, Texas, and all states east of these. Unlike the first phase, however, this is not a hypothetical model, but is based on the actual utility and sulfuric acid plant population of the region in question. Moreover, TVA's computer program is considering compliance with sulfur dioxide emissions standards and is to identify optimum production and distribution patterns based on freight costs and market demand. As in the first phase, the net sales revenue is to be estimated. A preliminary report of this work was prepared in March 1976. Based on the favorable results

obtained so far, this second phase was expanded to include abatement acid or elemental sulfur from power plants throughout the contiguous 48 states. The project was also expanded to include marketing of ammonium sulfate and calcium sulfate (gypsum) in addition to sulfur and sulfuric acid.

A final report covering the marketing of abatement sulfur, sulfuric acid, and calcium sulfate is planned for early 1977. A report on the use of sulfur, sulfuric acid, and ammonium sulfate in fertilizer production and marketing is planned for 1978.

ENGINEERING APPLICATIONS/INFORMATION TRANSFER

The Process Technology Branch of IERL-RTP has initiated a program to disseminate more effectively air pollution control technology data and information to meet the needs of the user community. In the past the Laboratory has attempted to meet its technology/information dissemination responsibility primarily through periodic symposiums, reports, and personal communications. These activities will be continued, but they will be augmented by a comprehensive Engineering Applications/Information Transfer (EA/IT) Program now being designed by IERL-RTP and contractor personnel to assure the efficient and effective dissemination of information on pollution control technology to all concerned sectors of the nation.

The expanded EA/IT program will assess the control technology information needs of industry, utilities, vendors, control/enforcement agencies, and others; compile information and data from past, current, and continuing government/industry development and demonstration efforts; use the data/information to design EA/IT programs and materials; and develop and implement effective mechanisms for dissemination of the programs and materials to the user community. Sample EA/IT materials which are being evaluated are (1) a Summary Report on the Wellman-Lord FGD process, (2) a Quarterly Report of Progress in FGD Research Development and Demonstration sponsored by EPA, and (3) a Lime Scrubbing FGD Data Book.

One specific facet of the comprehensive EA/IT program is the design, development, and implementation of a Flue Gas Cleaning Decision Model (FGC-DM). The FGC-DM will provide one-source availability of pertinent FGC data and information gathered from past and present FGC efforts within EPA, TVA, Electric Power Research Institute (EPRI), the utility industry, FGC vendors, and other foreign and domestic organizations. The objective of the FGC-DM is to assist potential users in choosing an FGC system for a specific location with specific

requirements/restrictions. Thus, the FGC-DM will make available a means of effective, informed FGC decision-making which should result in earlier operational dates, lower costs, and increased operability/availability.

NO_x Emission Control by Flue Gas Treatment

STRATEGY AND TECHNOLOGY ASSESSMENT

Catalysts for Controlling NO_x Emissions

In 1975, a research grant was awarded to the University of California at Los Angeles (UCLA) School of Engineering and Applied Sciences to further the development of promising catalysts. The study extended the catalyst screening work performed earlier by UCLA under an IERL-RTP contract with TRW, Inc. The objectives of the grant were to optimize the compositions of the vanadium and iron-chromium catalysts for selective reduction of NO_x with ammonia and to perform long-term durability studies of the optimum catalyst compositions in flue gas containing sulfur dioxide.

The results of the study indicate that a 15 percent loading of vanadium oxide on alumina support material and a 10 percent loading of iron oxide-chromium oxide on alumina support material with an iron/chromium ratio of 9:1 were the optimum catalyst formulations.

Parametric tests showed that both catalysts were selective in the presence of O_2 with strong enhancement of NO_x conversion rates due to the presence of O_2 under typical operating conditions. Neither CO_2 nor H_2O was found to affect the NO_x reduction in the concentration ranges applicable to power plant exhaust. Both catalysts were most active between 400° and 425° C and required excess NH_3 for maximum activity. Long-term durability tests of both catalysts in the presence of SO_x indicated no degradation in catalyst performance. Typical conversion levels for the vanadium and iron-chromium catalysts operating at 400° C in simulated flue gas were about 90 percent and 80 percent, respectively, at 20,000 hr^{-1} space velocity.

A final report is available on the UCLA grant work entitled "Parametric Studies of Catalysts for NO_x Control from Stationary Power Plants," EPA-600/7-76-026.

Ozone Oxidation of NO Study

A series of studies is planned to estimate the supply, demand, production economics, and energy consumption of key FGT process steps. Ozone is used as the oxidizing agent in nearly all of the wet processes for NO_x removal being developed in Japan. Under an IERL-RTP task order, the Research Triangle Institute (RTI) analyzed the conversion of NO to NO_2 by gas phase reaction with ozone.

The results of the study indicate that to a good approximation only a stoichiometric amount of ozone is required to achieve essentially complete conversion of NO to NO_2, which may be subsequently scrubbed from the gas stream.

The energy requirements and the capital and operating costs were examined for ozone generation with air and oxygen as feed to the ozone generator. Approximately 13 percent more energy is required for ozone generation from ozygen feed than air feed. The capital investment for ozone generation from oxygen is about three times as large as that required for air feed and operating costs are about twice as large.

For a 500 MW plant with air as feed to the ozone generator, the estimates for oxidizing 200 ppm of NO were: energy requirement, 1.1 X 10^8 kWh/yr or 3.1 percent of station capacity; capital investment, $17.60/kW; and operating costs, 2.0 mills/kWh. The 200 ppm concentration is representative of a coal-fired source with combustion modification techniques applied or an oil-fired source without supplementary NO_x controls applied. The estimates are for oxidation of NO only. The energy requirements and cost of flue gas treatment for control of NO_2 would be additive.

The final report on the RTI study, "Technology and Economics of Flue Gas NO_x Oxidation by Ozone," will be available for distribution in early 1977.

NO_x Control Strategy Assessment

IERL-RTP contracted with Radian Corporation to determine the potential effectiveness of applying NO_x controls to large stationary combustion sources. The Chicago Air Quality Control Region (AQCR) was selected for a modeling study of emissions from point, area, and mobile sources to determine the relative impact of each category on ambient NO_x concentrations.

The calibrated dispersion model predictions of annual average concentrations indicate that, while the major point sources account for nearly 40 percent of the total NO_x emissions in Chicago, they account for less than 10 percent of the ambient NO_2 levels. However, preliminary investigation of expected short-term concentrations of total NO_x shows that major point sources may account for as much as 80 percent of measured NO_x levels. Therefore, it appears that more stringent NO_x control for large point sources may be required to meet a potential short-term NO_2 standard, but that more stringent control of NO_x emissions from large point sources cannot be justified on the basis of the existing annual average of NO_2 standard.

As a result of these findings, the Chicago AQCR modeling study was expanded to determine more adequately the short-term ambient NO_2 levels, to project the annual and short-term NO_2 concentrations to 1985, and to assess the use of NO_x emission control by combustion modification and/or flue gas treatment to attain or maintain compliance with possible NO_2 ambient short-term and annual average standards.

In conjunction with the modeling study, Radian conducted a survey of state-of-the-art of control techniques for the abatement of NO_x emissions from stationary combustion sources. In addition, a survey was made of the nationwide sources of NO_x, the factors affecting transport and transformation of NO_x in the atmosphere, and the environmental effects of NO_x and its various transformations.

The results of these studies will be integrated into a comprehensive picture to assist in assessing research, development, and demonstration needs. It is anticipated that several reports will be published in 1977 as a result of Radian's work, which will continue in support of the overall FGT program.

Japanese NO_x Control

A series of reports has been planned to facilitate the transfer of information on Japanese flue gas treatment technology for control of NO_x and simultaneous control of SO_x and NO_x.

The reports are prepared, through an IERL-RTP contract with PEDCo-Environmental, by Dr. Jumpei Ando of Chuo University, Tokyo, Japan. The reports are "SO_2 Abatement for Stationary Sources in Japan," EPA-600/2-76-013a, and "NO_x Abatement for Stationary Sources in Japan," EPA-600/2-76-013b. The first set of reports was published in January 1976 and an updated version is anticipated to be released in January 1977.

Economic Assessments of NO_x FGT Processes

In a recently initiated project, the Tennessee Valley Authority (TVA), through an interagency agreement, will develop comparative economics of NO_x FGT emission control processes. The projects will involve performing technical assessments, preliminary economic evaluations, and detailed cost analyses of selected NO_x abatement processes.

In Phase I, TVA will select the promising NO_x control processes for preliminary economic evaluations. This will involve a general technical assessment of the feasibility of the process being developed and implemented in the U.S.

In Phase II, preliminary economic appraisals will be developed for four to eight of the most promising processes. In Phase III, detailed economic projections of four promising processes will be completed.

The project is scheduled for completion in mid-1978. The overall project will be cofunded by IERL-RTP and the Electric Power Research Institute.

EXPERIMENTAL PROJECTS

Catalytic Reduction of NO_x with Ammonia

In 1973, an IERL-RTP contract was awarded to Environics, Inc., to pursue the development and demonstration of selective catalytic reduction of NO_x emissions with ammonia over a platinum catalyst.

A utility pilot plant treating a slipstream from an operating electric utility boiler, equivalent to approximately 1.5 MW output, was designed, installed, and tested with gas firing and with oil firing. Laboratory pilot-plant testing was also conducted to supplement the utility pilot-plant testing.

Results of operating the utility pilot plant on gas firing, together with results of the laboratory pilot-plant testing, indicated that the catalytic reduction system provided 85 to 90 percent NO_x removal with no significant loss of performance. Results of operating the utility pilot plant on oil firing, together with results of laboratory pilot-plant oil-fired testing, indicated that this system could provide at least 65 percent NO_x removal.

A preliminary cost estimate indicates that a full-scale system would require a capital expenditure of less than $11 per kilowatt of plant capacity, with an operating expenditure of less than 0.2 mills per kilowatt-hour. These estimates were based on 1974 dollars and a gas-fired 480 MW plant.

A final report is available on the Environics work, entitled "Catalytic Reduction of Nitrogen Oxides with Ammonia: Utility Pilot Plant Operation," EPA-600/7-76-031.

Planned Pilot and Prototype Plants

The experimental program is slowly progressing toward full-scale demonstration of NO_x FGT technology by the early- to mid-1980's. The next phase of this program will be the demonstration of FGT processes at the pilot- and prototype-scale. IERL-RTP has outstanding a request for proposal for these pilot or prototype plants. It is contemplated that two contracts will result from this procurement process. One will be for removal of NO_x only with either high- or low-SO_x concentrations, and the other will be for simultaneous removal of NO_x and SO_2. The actual number and size of projects to be undertaken will depend on budgetary constraints and availability of cost-sharing funds from industry.

The pilot plants must treat a flue gas volume equivalent to 0.5 MW. The minimum acceptable NO_x removal efficiency is 90 percent for the NO_x-only plant and 90 percent for both SO_2 and NO_x for the simultaneous plant. Proposals must contain both a host site and a control process. The desired fuel for the host site is coal. Proposals must be submitted to EPA by January 17, 1977. It is anticipated contracts will be awarded by June 1977. The pilot- or prototype-plant projects will each consist of a 24 month program which will be conducted in four phases. Phase I includes the preparation of a detailed process design and an estimation of capital and operating costs for the pilot plant. Following erection and mechanical acceptance test of the pilot plant in Phase II, the contractor will perform system start-up and debugging, parametric testing, and optimization testing over a wide range of flue gas conditions during Phase III. Phase IV provides for duration testing and evaluation of the plant during 90 days of continuous operation.

It is currently anticipated that final reports will be published on the results of the pilot- or prototype-plant operations in early 1980. A project manual conveying the total concept of the proposed plant will be published in late 1977 or early 1978.

There is the possibility of an additional experimental project being initiated in 1977 with the Tennessee Valley Authority. The IERL-RTP experimental projects in the NO_x FGT area are predicated on substantial cost sharing funds from industry.

EMISSIONS/EFFLUENT TECHNOLOGY

Flue Gas Desulfurization--Nonregenerable Processes

LIME/LIMESTONE WET SCRUBBING

These processes involve the wet scrubbing of fossil-fuel boiler flue gas (from power plant or industrial/commercial sources) with limestone or lime slurries to remove sulfur oxide and particulate pollutants. Results of many studies, ranging in size from pilot- to full-scale, indicate that the processes are capable of high pollutant removal efficiencies with acceptable reliability.

IERL-RTP is supporting several lime/limestone research, development, and demonstration programs. A test program is being conducted, using two parallel multiple-configuration 10 MW prototype units at TVA's Shawnee power plant. This program is being supplemented by an IERL-RTP inhouse pilot plant, located at Research Triangle Park, N.C. A program involving carbide and commercial lime scrubbing tests and an evaluation of scrubber waste treatment disposal

options is discussed later, under Waste and Water Pollution Control. Under an interagency agreement with the U.S. Air Force, IERL-RTP is funding a comprehensive test program to characterize the Swedish Bahco lime scrubbing process installed at Rickenbacker Air Force Base, near Columbus, Ohio, to handle up to seven coal-fired heating boilers. The Bahco test program began early in 1976. A competitive procurement has also been initiated to select a contractor for a comprehensive stack gas reheat assessment study to determine the present status of reheat technology, what factors have influenced selection of type and degree of reheat applied, performance of existing equipment, and to make an assessment of the actual need for reheat under various combinations of factors such as weather, type of FGD system, and ground level air pollutant concentrations.

Lime/limestone wet scrubbing processes have the inherent advantages of low reactant costs, relative simplicity, and final products in the form of relatively inert disposable materials. These processes are widely applicable to both old and new power plants and to the smaller industrial applications. Process disadvantages include: requirements for plume reheat, potential reliability problems (e.g., scaling and erosion), and potential solids disposal problems in some urban locations. These problems are being investigated in the various IERL-RTP lime/limestone projects.

TVA's Shawnee Power Plant

Construction of the prototype facility at TVA's Shawnee power plant was completed in March 1972; testing started the next month. The facility, consisting of three different (but parallel) scrubber circuits, can handle about 90,000 cfm (30 MW equivalent) of the output of one of the ten coal-fired Shawnee boilers. The versatile facility is being used to evaluate the performance and reliability characteristics of lime/limestone wet scrubbing systems under a variety of operating conditions.

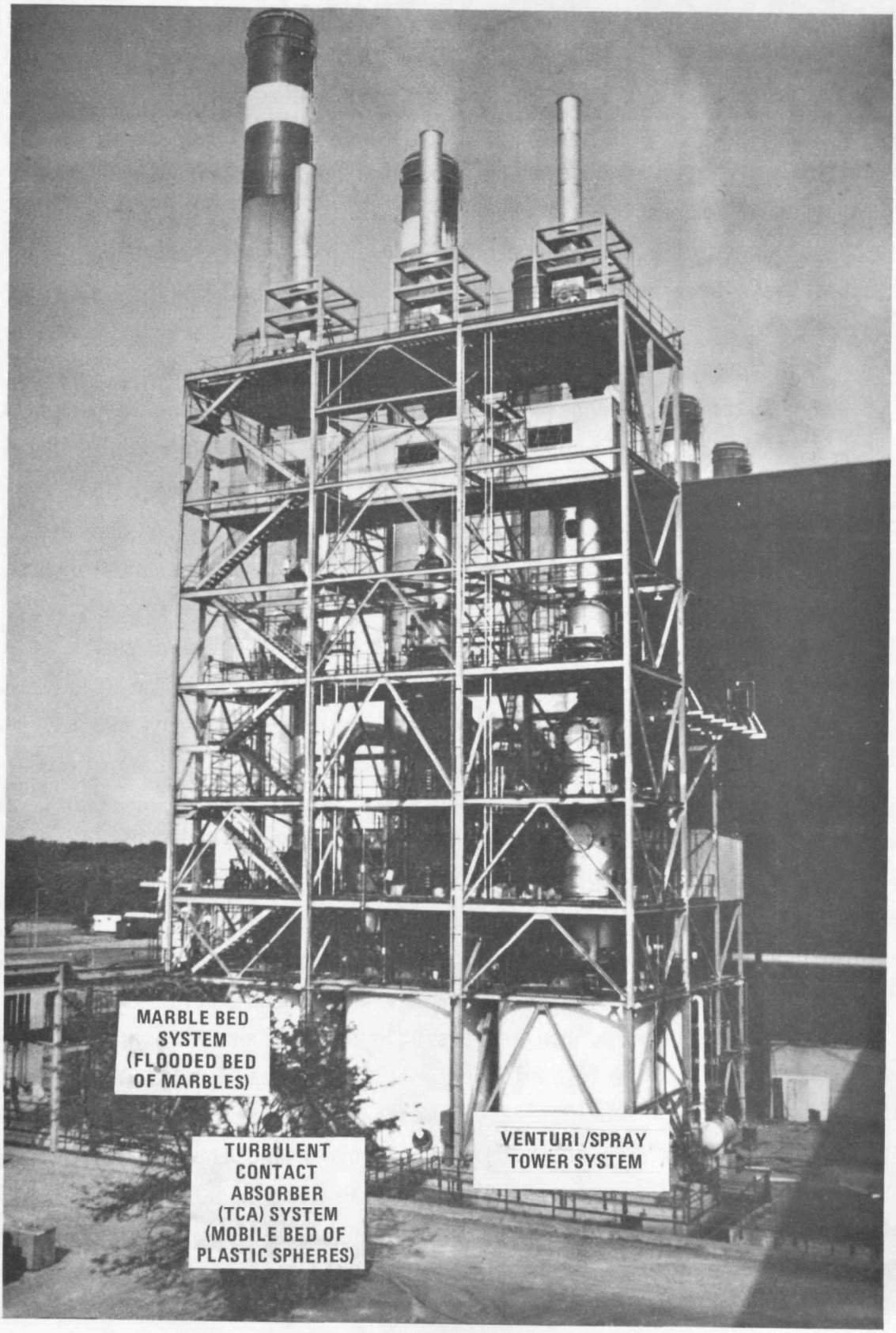
The original test program included short-term (less than a day) factorial tests, longer-term (2 to 3 week) reliability verification tests, and long-term (2 to 6 month) reliability demonstration tests--with both lime and limestone. This phase of the test program was completed in May 1974 and the results were reported periodically: two topical reports (published in August 1973 and January 1974), a December 1973 industry briefing, and a summary of testing through October 1974 (published in June 1975).

The original test program has been extended for at least 3 more years to provide additional information and to improve the reliability and process economics of the lime/limestone systems. The extended test program is also expected to produce: a design and economics computer program to assist users in studying and selecting a scrubber process for their particular application; field evaluation of alternate methods (including chemical fixation) for disposal of the sludge produced by the lime/limestone systems; and a larger-scale study of some of the advanced scrubbing concepts which have shown promise during tests at IERL-RTP's Research Triangle Park pilot plant.

The results of the continuing work at Shawnee are being reported periodically: two progress reports have been published (in September 1975 and in September 1976); and industry briefings were held in September 1975 and in October 1976.

Recent work at Shawnee has been very encouraging. The present mist elimination systems are operating reliably and with high efficiencies. Successful operation of the venturi/spray tower system was achieved at greater than design gas velocities using both lime and limestone. The TCA system was successfully operated using both limestone and lime at design gas rates and without a wash tray. Variable load operation of the venturi/spray tower scrubber with lime has also been demonstrated at Shawnee. For about 2 months, scrubber variables were adjusted to follow boiler operation over a range of 60 to 150 MW with 1,200 to 4,500 ppm variations in inlet SO_2 concentration. Both ranges are much more severe than expected in most commercial applications. Operation of the scrubber was entirely satisfactory throughout the period.

Alkali utilization studies at Shawnee have shown: (1) use of three stirred tanks in series to replace a single stirred reaction tank increased limestone utilization by 10 to 15 percent; (2) operation at low inlet pH (approximately 5.2 pH) can increase limestone utilization to over 90 percent or roughly equivalent to that normally obtained using lime, but with a corresponding loss in SO_2 removal efficiency (the loss in SO_2 removal efficiency can be compensated for by operating at higher L/G ratios, higher pressure drop, addition of MgO, or by using three stirred tanks in series); and most importantly, (3) a correlation was shown between the alkali utilization and reliable operation. At above 85 percent alkali utilization there is a marked reduction in the accumulation of soft mud-type solids, which was particularly apparent in the mist eliminator area where only very infrequent intermittent washing was required compared to continuous washing required at alkali utilizations below 85 percent.



Versatile lime/limestone wet scrubbing demonstration at Shawnee plant.

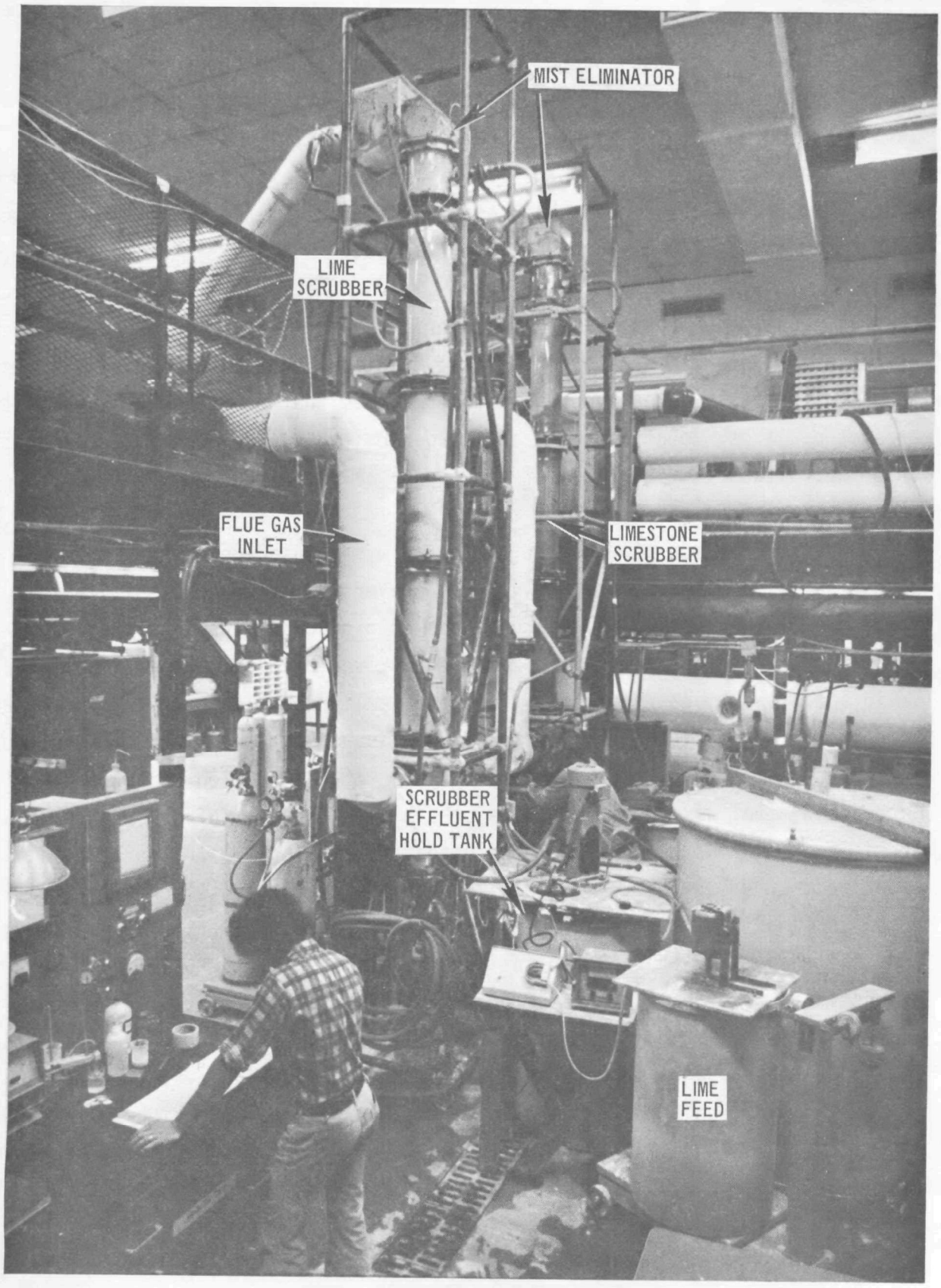
IERL-RTP's Pilot Plant

IERL-RTP's two model scrubbers (300 cfm each) have been operating at IERL-RTP since October 1972, providing direct experimental support to the larger prototype studies at TVA's Shawnee test facility. One lime- and one limestone-fed scrubber, designed for maximum test flexibility, are operated concurrently 24 hours a day. Each essential component of the complete closed-loop scrubbing system is included in the layout: a three-stage TCA scrubber, scrubber effluent hold tank, lime slaker, fans, thickeners, and rotary vacuum filters. Their compactness permits material balances to be performed on each component to determine the extent of all reactions occurring within it. Operating variables are investigated over ranges that cannot be achieved (or are not practical to attempt) in the larger units, such as operating without chloride, without fly ash, and at varying inlet oxygen and sulfur dioxide levels in the flue gas.

During 1976, the pilot-plant operation was focused upon the problem of sludge and oxidation, which involves the conversion of calcium sulfite to calcium sulfate (gypsum). The advantages of producing gypsum as the throwaway product of FGD scrubbers derive from the improved physical properties of the solid and its chemical inertness. The physical properties of gypsum associated with its large crystal structure led to faster settling, better filterability, and reduced sludge volume. Theoretically, a total reduction of about 47 percent in total waste production is possible as a result of the change in physical properties brought about by oxidation to gypsum. In addition, it is expected that the oxidized sludge will meet the requirements for direct disposal as landfill, thus avoiding the necessity of chemical fixation.

The results of the pilot-plant investigations over the past year have demonstrated that the conversion to gypsum can be made efficiently and completely at operating conditions that are realistic for full-scale application. Excellent results were achieved in both two-stage and single-stage scrubber designs, both of which were shown to be capable of obtaining high SO_2 removal efficiency and high limestone utilization concurrently with complete oxidation of the sludge. By accomplishing the oxidation in a single-stage scrubber, it was shown that the process will be applicable to systems now in operation without extensive modification.

The key to good oxidation was shown to lie in the efficient transfer of oxygen from the injected air. This transfer was maximized in shallow tanks by



IERL-RTP lime/limestone scrubber pilot plant.

the use of a jet aspirator/ejector for aerating the holding tank. Alternatively, it was shown that the required transfer efficiency can be obtained with an air sparged tower. The use of a tall tower which combines the functions of the holding tank and oxidizer should provide maximum overall efficiency with minimum operating power.

These tests have further shown that the high limestone utilizations (85 percent) required for eliminating demister fouling--which has been the principal restraint on reliable operation in the past--can be maintained while forcing oxidation to gypsum, without loss of SO_2 removal efficiency.

The pilot-plant studies of forced oxidation, which were conducted in preparation for large-scale testing in the Shawnee prototype scrubber, thus indicate that very significant improvements in the performance of limestone FGD systems can be expected, both from the operating and the environmental viewpoints.

Bahco Process

In 1971, Research-Cottrell, Inc., was licensed by A. B. Bahco of Sweden to test, refine, and offer the Bahco lime scrubber commercially in the United States. The process generally consists of a mechanical particulate removal system followed by a unique, two-step, vertical scrubbing tower for sulfur dioxide removal.

The Bahco system is currently offered in sizes up to about 40 MW, which makes it applicable to many industrial-sized boilers throughout the United States. Because most of the engineering on the Bahco scrubber is complete (it is offered in several standard sizes), installation costs make the system a reasonable alternative to low-sulfur fuels for industrial boiler applications.

There are about 20 Bahco scrubbers in operation in Sweden and Japan; however, the installation at Rickenbacker Air Force Base, Ohio, is the first in the United States, and the first on a coal-fired application anywhere. The Bahco scrubber at Rickenbacker AFB is designed to handle the flue gas from up to seven coal-fired heating boilers equivalent to about 3 MW each (or a maximum total of 21 MW). The IERL-RTP sponsored test program was begun early in 1976 and the preliminary results appear promising.

DOUBLE ALKALI

The double-alkali process, like the lime/limestone wet scrubbing processes, produces a throwaway product consisting of fly ash and calcium sulfite/sulfate. The process, in its various forms, was developed in an effort to

avoid the problems associated with the use of absorbent slurries in the lime/limestone processes.

Flue gases are scrubbed, using a soluble alkali (usually sodium-based) solution as the absorbent. The spent absorbent solution is treated with lime and/or limestone in a regeneration system to produce a regenerated soluble alkali for recycle to the scrubber system and a throwaway product for disposal.

Although less developed than lime/limestone wet scrubbing processes, double-alkali systems show potential for attaining high sulfur oxide removal efficiency and good reliability at relatively low cost.

Technology Development

The development of double-alkali technology by IERL-RTP has followed an orderly, progressive pattern. After initial inhouse engineering feasibility studies and laboratory experiments in 1971 and 1972, IERL-RTP contracted with Arthur D. Little, Inc., in May 1973 to conduct a laboratory- and pilot-plant study of various double-alkali modes of operation. In early 1975 the project was expanded to include a prototype test at the 20 MW facility installed at the Scholz plant of Gulf Power Company by Southern Company and constructed by Combustion Equipment Associates. The total funding for the expanded contract was $1,169,000. In late 1976, EPA contracted for a full-scale utility demonstration of the process.

Work in the laboratory and pilot plant included the study of "dilute" and "concentrated" systems, lime and limestone regeneration, sulfuric acid addition for sulfate removal and solids characterization. Prototype testing at the Scholz station lasted from February 1975 to July 1976, with the EPA-sponsored portion of testing beginning in May 1975. As a whole, the prototype system performed very well and indicated that a double-alkali system would be a viable flue gas desulfurization system for coal-burning utilities. During the entire program of approximately 17 months, the system showed availability to the boiler of 72 percent; however, during three specific operating periods of approximately 4 months each, the system showed availability of 90 percent. Sulfur dioxide removal was generally in the range of 90 to 99 percent.

A two-volume report on the entire laboratory, pilot-plant and prototype development study conducted by A. D. Little, Inc., for IERL-RTP will be issued in early 1977.

Three 20 MW prototype FGD systems at Gulf Power's Scholz plant.

General Motors Industrial Boiler Demonstration

General Motors and IERL-RTP participated in a cooperative program to demonstrate, test, characterize and evaluate GM's "dilute" mode double-alkali system for flue gas desulfurization of emissions from coal-fired industrial boilers. The program was conducted at GM's industrial boiler complex in Parma, Ohio. The system, consisting of four coal-fired boilers having a steaming capacity of 320,000 lbs per hour (equivalent to 32 MW electric generating capacity), was constructed and operated by GM. The construction cost amounted to approximately $3.5 million. Arthur D. Little, Inc., designed and conducted the test program to evaluate the system with funding from IERL-RTP. The program consisted of three 1 month intensive test periods and longer term nonintensive testing. The FGD system tested consisted of four valve tray scrubbers, each with three trays and a mesh demister. Each of the intensive tests evaluated a slightly different flow scheme. In the third and best scheme, the system achieved 90 percent SO_2 removal, with a lime stoichiometry of 1.3, and produced a semi-solid waste product containing 56 percent total solids. The testing took place during the period of August 1974 to May 1976, with an overall scrubber availability to the boilers of about 78 percent, excluding four long-term planned shutdowns for system modifications.

A report on the entire test program will be issued by IERL-RTP in late 1976 or early 1977.

Full-Scale Utility Demonstration

In September 1976, IERL-RTP contracted with Louisville Gas & Electric Company for a cost-shared, full-scale coal-fired utility demonstration of the double-alkali process at the 280 MW Cane Run #6 boiler. The entire project is estimated to cost in excess of $20 million with EPA's share being $4.5 million.

The demonstration project consists of four phases: (1) design and cost estimation; (2) engineering design, construction and mechanical testing; (3) start-up and performance testing; and (4) 1 year of operation and long-term testing. Proposals are currently being evaluated to establish a contract with an independent company to design and conduct the test program.

Phases 1 and 2 are presently being conducted concurrently. Construction is expected to be complete by the end of 1978, and testing will begin in early 1979. System performance guarantees have been established and are backed financially by the system designer/constructor, Combustion Equipment Associates. Guarantees are in force on SO_2 removal, sodium consumption, calcium consumption, energy consumption and system availability.

SURVEY OF FGD SYSTEMS

IERL-RTP has contracted with PEDCo-Environmental to survey flue gas desulfurization (FGD) systems which are operational, under construction, or planned in the United States and Japan. The survey is being conducted using plant visits and a comprehensive questionnaire. Through December 1975, 11 systems had been visited and detailed reports issued concerning their operation. This survey is to continue, with emphasis on those systems which have significance with respect to FGD in the United States. Both new installations and some previously visited ones have been included in site visits made during 1976. Reports on these site visits are being prepared.

In addition to detailed technical reports, giving results of the visits, PEDCo is providing bimonthly status reports indicating the number of each type of sulfur dioxide control system in operation, under construction, or planned in the United States, and the MW capacity controlled or to be controlled. As of November 1976, 120 such systems are planned to control over 46,000 MW of electrical generating capacity.

A survey of Japanese installations and of their operating experiences, problems, and solutions is being conducted, under subcontract, by Dr. Jumpei Ando of Chuo University in Tokyo.

Flue Gas Desulfurization--Waste and Water Pollution Control

IERL-RTP's flue gas cleaning (FGC) waste and water pollution control program is a continuation and expansion of modest efforts initiated by the Laboratory in the late 1960's. It is aimed at the development, demonstration, and recommendation of environmentally acceptable, cost-effective techniques for disposal/utilization of FGC wastes, and for maximizing power plant water recycle/reuse. The theme of each of the 12 IERL-RTP program projects, described below, is in one of three categories: FGC Waste Disposal Methods, FGC Waste Utilization, and Power Plant Water Reuse. (Four FGC Waste Disposal Methods projects--other than those described below--are being conducted by EPA's Municipal Environmental Research Laboratory in Cincinnati; results of the Cincinnati projects are being coordinated with those described below.)

FGC WASTE DISPOSAL METHODS

FGC Waste Characterization, Disposal Evaluation, and Transfer of FGC Waste Disposal Technology

Since late 1972, Aerospace Corporation, under contract with IERL-RTP, has been conducting a broad-based study to: (1) identify environmental problems

associated with FGC waste disposal; (2) assess current FGC waste disposal methods, including feasibility, performance, and costs; (3) make recommendations regarding alternate disposal approaches; and (4) assemble, assess, and report all FGC waste-related research and development activities in EPA, TVA, and private industry. This project is the key effort in IERL-RTP's program for waste and water pollution control.

Shawnee FGD Waste Disposal Field Evaluation

Under this program, initiated by IERL-RTP in 1974, the Chemfix, Dravo, and IUCS processes for chemical fixation of scrubber wastes are being evaluated in three separate impoundments. (See photo of one of the impoundments, below.) As an alternative approach, ash-free lime and limestone wastes have been further "dewatered" by the addition of dry fly ash and placed in two additional impoundments which have underdrainage systems for dewatering and stabilization. Untreated/unstabilized lime and limestone wastes are placed in two additional impoundments (for a total of seven). Leachate, runoff, and ground water samples (as well as core samples of the wastes and soil) are being collected and analyzed to evaluate environmental effects. The final impoundment will involve evaluation of oxidized sulfite waste (gypsum) disposal.

Louisville Gas and Electric Evaluation of FGD Waste Disposal Options

Louisville Gas and Electric Company, under contract with IERL-RTP, is currently conducting a program of carbide and commercial lime scrubbing tests and an extensive evaluation of scrubber waste treatment/disposal options. Laboratory studies of nonchemical and chemical (fixation) processes for stabilization of scrubber sludge are being conducted and samples will be mixed with fly ash alone or fly ash and one of several additives (e.g., lime). The field studies consist of small-scale impoundment tests and larger-scale (about 76 cubic meter) landfill tests in which leachate migration, runoff, and physical stability tests of unstabilized and stabilized waste material will be conducted.

Lime/Limestone Scrubbing Waste Characterization

This project, funded by IERL-RTP, involves the physical and chemical characterization of lime/limestone waste solids as a function of scrubber operating conditions. Under these studies, lime/limestone scrubbing waste materials from the Shawnee facility are being characterized and an attempt is being made to correlate the properties with the scrubber operating conditions. If feasible, a means of controlling waste characteristics to improve disposal or utilization economics will be recommended.

Test pond for disposal of Shawnee's chemically treated scrubber waste.

Dewatering Principles and Equipment Design Studies

This project is being conducted under an IERL-RTP grant by Auburn University. It consists of the following efforts to improve the performance of current FGC waste dewatering equipment: (1) an examination of current dewatering equipment design principles to determine their applicability to FGC wastes; (2) laboratory settling and other tests to determine the physical properties and behavior of FGC wastes as a basis for dewatering equipment design studies; (3) analytical design studies to develop dewatering equipment designs based on FGC waste physical properties and behavior (these efforts will continue and will be updated based on subsequent bench-scale testing); and (4) laboratory tests of dewatering equipment design concepts. This project offers the potential of cost savings through reduction in the size of dewatering equipment and the volume of the disposal site, as well as through reduction in the amount of chemical fixation additive (if used) required.

Characterization of Effluents from Coal-Fired Power Plants

This IERL-RTP sponsored project involves TVA efforts to: (1) characterize and quantify the chemical parameters of coal pile drainage; (2) assess and quantify the chemical and physical composition of ash pond effluent after adjustment of pH to meet effluent standards; (3) evaluate an ash pond monitoring program to determine the sampling and analyses necessary to obtain representative information; (4) assess, characterize, and quantify the effects of coal ash leachate on ground water quality; and (5) evaluate and quantify the chlorinated effluent in the discharge canal from once-through cooling systems.

Information from this project will be supplemented by the fly ash characterization efforts described below.

Ash Characterization and Disposal

This IERL-RTP project involves TVA efforts to: (1) summarize and evaluate existing data on the characteristics of coal ash and ash effluents from inhouse TVA studies and from studies made by other organizations (this effort is now complete); (2) perform chemical and physical analyses on coal, coal ashes, and ash effluents to obtain a complete characterization of these materials as a function of variation in boiler design and operation, as well as coal type; (3) evaluate various methods for disposal and utilization of fly ash; (4) summarize information on methods of ash sluice water treatment for reuse; (5) conduct conceptual design studies of dry and wet ash handling systems; and (6) recommend the most promising systems for ash handling and disposal/utilization.

Alternative Methods for Lime/Limestone Scrubbing Waste Disposal

This project is one of several tasks which make up the economic studies of major FGD processes being conducted by IERL-RTP. Several FGD waste disposal methods and FGD system design and operating premises have been selected for a detailed economic evaluation of FGD waste disposal; these include chemical fixation via the Chemfix, Dravo, and IUCS processes. The final report on this effort should be issued in the spring of 1977.

Alternative FGC Waste Disposal Sites

This IERL-RTP-sponsored project is being conducted to identify, assess, and demonstrate on a pilot scale, alternate FGC waste disposal methods (other than local ponding and landfilling). The demonstration is to be limited to coal mine and ocean disposal.

Although environmental effects and operational safety will be the major initial considerations, the assessment will also include a study of the economics of the alternate disposal methods, as well as a study of applicable Federal and state regulations. Recommendations and conceptual designs for the pilot demonstrations will be based on all of the initial efforts. A preliminary assessment has been completed; the final assessment effort will be completed by mid-1977.

FGC WASTE UTILIZATION

Lime/Limestone Scrubbing Waste Conversion Pilot Studies

In a cost-shared contract to conduct pilot studies of two key process steps in M. W. Kellogg Co.'s "Kel-S" process for conversion of lime/limestone scrubbing waste to elemental sulfur with recovery of the calcium in the waste as calcium carbonate, design data are being generated to allow scale-up to a large (prototype) test unit for a power plant.

Gypsum By-product Marketing

This project is one of several tasks which make up the FGD by-product marketing studies being conducted by TVA for IERL-RTP. A preliminary study conducted by TVA during early 1974 indicated the possibility that production and sale of abatement gypsum might offer a substantial economic advantage over FGD waste disposal. These new studies include a thorough economic evaluation of gypsum producing processes (e.g., Chiyoda, carbon absorption, $CaSO_3$ oxidation) and a detailed U.S. marketing study of abatement gypsum for wallboard.

Use of FGD Gypsum in Portland Cement Manufacture

This project, which is being negotiated by IERL-RTP with the S.C. Public Service Authority (with Santee Portland Cement Corporation and Babcock and

Wilcox as subcontractors), will consist of the following efforts: (1) preliminary surveys of U.S. industry to determine the quantity of FGD gypsum which could be used in Portland cement manufacture; (2) collection and identification of waste samples from several FGD systems; (3) laboratory tests to identify and solve problems associated with chemical and/or physical characteristics of FGD gypsum in Portland cement manufacture; and (4) design and estimation of costs of a pilot demonstration unit either at a power plant or a cement plant, depending on the results of the laboratory tests.

Fertilizer Production Using Lime/Limestone Scrubbing Wastes

One of several tasks being conducted by TVA under an interagency agreement with IERL-RTP involves the use of lime/limestone scrubbing wastes as a filler material and as a source of sulfur in fertilizer. This study is a continuation and expansion of previous bench-scale laboratory production tests and small field plot application tests with rye grass. In the proposed process, phospheric acid and ammonia are the phosphate and nitrogen sources. Most of the development work has centered around avoiding losses of sulfur and/or ammonia in the fertilizer reactor.

FGD Waste/Fly Ash Beneficiation Studies

This IERL-RTP-sponsored project will consist of the following efforts: (1) a conceptual design/cost study of a TRW-conceived, proprietary process (for which two related patents have been issued) for producing sulfur, alumina, and dicalcium silicate for FGD waste and fly ash (and/or clay), including the development of a preliminary process design (including material and energy balances) and an estimate of capital and operating costs to determine the economic viability of the process; (2) if the economics of the process appear favorable, a bench-scale laboratory investigation to determine probable ranges of operating conditions for each of the major processing steps (reduction, calcination, leaching, separation) and to determine (with actual FGD waste) probable yields and purity of products; (3) assuming the process still appears viable, possible pilot-scale testing of the process steps to obtain design data for large-scale equipment. Reports will be issued after each of the efforts described above.

The conceptual design/cost study was recently completed; TVA is assisting in a review of the final report. The bench-scale tests should be initiated in 1977.

POWER PLANT WATER REUSE

Alternatives for Power Plant Water Recycle/Reuse

This IERL-RTP sponsored study, with Radian Corporation, is designed to develop methods for minimizing water use and wastewater discharges from coal-fired steam-electric power plants. The study consists of six tasks: (1) selection and characterization of five specific power plants; (2) preparation of computer models to simulate makeup, process, and effluent water streams, as well as chemical equilibria of the processes for each plant selected; (3) verification of process computer models by comparing existing plant chemical and operating data with data predicted by the models; (4) formulation of several water recycle/reuse options to minimize plant water requirements and discharges for the specific plants selected for study; and evaluation of at least one option (via process simulation) for each plant; (5) preparation of capital and operating cost estimates for each viable water recycle/reuse option; and (6) detailed presentation of program results, including recommendations of the recycle/reuse options to be used at each of the plants studied. The first four tasks have been completed for three plants; the study should be completed by mid-1977. Future plans include pilot plant testing of one or more of the recycle/reuse options.

Treatment of Flue Gas Scrubber Waste Streams with Vapor Compression Cycle Evaporation

This IERL-RTP-sponsored pilot demonstration, using the Resources Conservation Company's brine concentrator, is being conducted at Gulf Power Company's Scholz power station. The brine concentrator is a 6,000 gal./day unit which is being tested for 90 days on a waste stream from a Chiyoda FGD system. A report on the demonstration will be issued in mid-1977.

Thermal Pollution Control

Thermal pollution control programs of IERL-RTP are divided into two broad areas: cooling technology, and waste heat utilization. Cooling technology programs include studies of cooling system economics, advanced heat rejection techniques, and development of control technology for the treatment and possible reuse/recycle of cooling effluent streams. Waste heat utilization programs currently involve agricultural applications, although promising residential/industrial and aquacultural uses of waste heat are also of interest. The transfer of technology is an objective of programs in both areas as exemplified by present support for a state-of-the-art manual in thermal pollution control technology and a 1977 conference on waste heat management and

utilization. The following sections describe significant programs under these two broad areas.

COOLING TECHNOLOGY

During the past year IERL-RTP supported several studies on cooling system performance and economics. The objectives of each included the definition of costs and other penalties for steam-generated electrical power and the examination of environmental factors, such as water consumption, drift, and fogging, which impact on the various types of cooling devices.

In one IERL-RTP-sponsored supported study, a computer program for optimizing the design of large, dry cooling systems was developed. Program variables included: heat exchanger design parameters (tube length, bundle width, number of tube rows and tube passes); type of condenser (spray or surface), type of turbine (conventional or modified for high back pressure); climatic factors; and cost factors (fuel, fixed charges, lost capacity, auxiliary power). The resultant program is being used to optimize the cost of power generation for various practical combinations of program variables.

Two important factors in power plant siting and cooling system selection are consumptive water use and vapor plume emissions. The use of evaporative, or wet, cooling towers may impact adversely on both of these factors. Hence, an IERL-RTP-supported project studied the feasibility of using combined wet/dry cooling towers for conserving water and abating vapor plume emissions. Since increasing the dry heat exchanger surface area reduces both water consumption and water content in tower plumes but increases capital and operating costs while converse trends are evident when evaporative heat exchangers are used, these studies entailed various wet/dry heat exchanger combinations for cooling towers situated at ten U.S. sites. Six of these studies were aimed at minimizing water use in the arid but coal-rich western region, while the remaining studies were directed toward vapor plume abatement at urban sites. A sensitivity analysis for Casper, Wyoming, a representative site having limited water but extensive coal and energy development, is also a program output.

In a 4 year project scheduled for completion in 1980, IERL-RTP is participating with the Town of Braintree, Massachusetts, in a dry cooling tower demonstration and performance study. Specific objectives of this project involving a combined cycle plant (60 MW gas turbine/25 MW steam turbine with a direct condenser) include the measurement of steam flow distribution

and temperatures for better definition of optimal design conditions, the assessment of meteorological effects from the plant and of meteorological factors on plant performance, the monitoring of noise and control, air quality considerations on or from the plant, and the economic effect of design and operational factors. Test instrumentation has been obtained and will be installed prior to the start-up of the plant which is now projected for late January 1977.

IERL-RTP is continuing control technology development for the treatment of wastewater streams inherent in evaporative cooling systems. With IERL-RTP support, the University of California has developed a system for renovating cooling tower blowdown for recycle or reuse which requires substantially less capital and operating costs compared to the best systems in current usage. This new system uses vertical tube (VT) evaporation with interface enhancement to attain a higher heat transfer performance. In a test facility using a 5,000 gpd VT evaporator-crystallizer in the downflow mode and using a low temperature (125°F) to simulate the use of waste heat from a conventional power plant cooling cycle, sodium sulfate was crystallized and cooling tower blowdown from the Mohave plant was reduced to a 30-fold concentrate, and system feasibility was demonstrated. The evaporator-crystallizer was also operated with a vapor compressor in the evaporation temperature range of 215 to 224°F in tests for concentrating saline agricultural drainage and industrial cooling tower blowdown. Comparison of results for the conventional and interface-enhanced modes of operation from these tests showed that in each case interface enhancement resulted in better heat transfer performance of the evaporator-crystallizer while its energy requirements were simultaneously reduced.

Since the biofouling of condenser tubes reduces heat transfer while conventional chlorination of cooling water to combat biofouling may have adverse impacts on biota, IERL-RTP is seeking viable alternatives to chlorination. The findings of an IERL-RTP-supported study concluded that more efficient methods of chlorine application are available than are currently being used; most alternative chemicals studied (bromine chloride, ozone, chlorine dioxide) may have reduced ecological effects but are more expensive; mechanical tube cleaning techniques may require complementary chemical treatment of cooling water and some mechanical techniques may not be retrofitted; controlled-release antifoulants coated on or embedded in heat transfer surfaces, while

promising, require considerable development; and radiation techniques are not expected to be cost-effective unless the use of nuclear waste is feasible.

IERL-RTP and TVA cooperation in thermal pollution control is evidenced by several programs. With IERL-RTP financial support TVA is assessing methods for cooling tower blowdown and wastewater treatment and developing cooling water intake structures which reduce harmful effects to fish. The water treatment methodology study involves evaluation of reverse osmosis and ultrafiltration systems supplied by vendors. These tests use effluents supplied from various fossil-fueled power plants, the wastewater consisting of ash pond discharge, cooling tower blowdown, boiler blowdown and SO_2 scrubber slurry waste streams. For different membranes, the data will be used to design and operate experimental treatment facilities with the aim of minimizing treatment costs. Results of tests in these facilities will be evaluated to determine the economic and technical feasibility of the prototype systems.

A review of cooling water intake structure technology has been completed by TVA. With continued IERL-RTP support, TVA is planning detailed testing of one or more screen devices in addition to continued evaluation of a fish removal pump.

WASTE HEAT UTILIZATION

The beneficial use of warmed condenser coolant can alleviate or reduce thermal pollution problems, lead to secondary profits, and promote energy conservation since waste heat will be constructively used. IERL-RTP continued its support of a Northern States Power Company/University of Minnesota demonstration of waste heat utilization in a greenhouse operation. During 1976 the first and second crops were planted and harvested, the second crop making use of waste heat from condenser cooling water after connection of the half acre greenhouse to the power plant cooling system in the late summer. Using waste heat for both soil warming and air heating, both vegetables (tomatoes, peppers, lettuce) and flowers (roses, snapdragons) were grown.

In another cooperative effort between IERL-RTP and TVA, soil warming experiments will be performed by TVA in a program aimed at extending the crop growing season. Different pipe sizes (2.5 and 5 cm diameter), materials (copper and polyethylene), and lateral spacings (90, 180, and 360 cm) were studied. Based on heat dissipation rate tests, the smaller polyethylene pipe with a spacing of 180 cm (with plant rows spaced 45 cm on each side of the heated pipe) was found to be the best economic arrangement. The monitoring of soil temperatures also indicated that the pipes should be placed as close to

the surface as possible while avoiding damage from tilling operations. This program is a continuing study with the objective of determining the feasibility of using waste heat for optimizing the recycling of nutrients from livestock wastes into protein for animal and/or human feed supplement.

PARTICULATE TECHNOLOGY

Fine particulates are a health hazard because, in contrast to coarse particles, they can bypass the body's respiratory filters and penetrate deep into the lungs. Fine particles released into the atmosphere remain airborne for extended periods of time, obstruct light, and cause limited visibility typical of air pollution haze and smog. They have been identified as transport vehicles for gaseous pollutants. The health hazards of fine particulates are intensified by the tendency of metallic materials from high-temperature processes, such as pyrometallurgical and combustion processes, to condense as chemically and catalytically active fine particulates. Many toxic and potentially hazardous compounds are also emitted as fine particulate. Particulate matter formed in the atmosphere from the reaction and condensation of reactions makes it difficult to relate atmospheric particulate pollution levels to specific sources. This has hampered the development of effective control strategies and the establishment of meaningful emission standards. The control of these secondary forms of particulate must be through control of their precursors, and primary particulate does play an important role in the formation cycle.

Many years will be required to develop a sound data base to quantify the health effects problem of fine particulates. Sufficient information does exist, however, to conclude that fine particles must be controlled if public health is to be protected.

EPA has established a goal of setting fine particulate standards. To develop these standards, research and development is necessary to provide a minimum data base. This data base and the necessary adequate control technology do not now exist.

It is currently IERL-RTP's responsibility to develop and demonstrate, on a pilot scale, control technology which is generally applicable to particulate and fine particulate matter emitted from all stationary sources. For the past 4 years, the Laboratory's Particulate Technology Branch (PATB) has been engaged in a program aimed at determining the limitations of conventional particulate control devices and defining a research and development program which will eventually produce the needed technology for the control of fine particulate matter.

IERL-RTP's Particulate Program

In order to pursue the goal of developing control technology for fine particulate emissions, the basic IERL-RTP program in this area has been divided into seven major areas:

- Measurement.
- Characterization and improvement of conventional control equipment and assessment of the collectability of dusts.
- New particulate control technology development.
- New idea evaluation and identification.
- Fine particulate control for combustion processes utilizing low-sulfur coal.
- High-temperature/high-pressure particulate control.
- Accelerated pilot demonstrations.

MEASUREMENT

The principal goals of this effort are to: (1) select, calibrate, and standardize measurement equipment and procedures to be used in support of the entire particulate control program; and (2) develop instruments capable of determining efficiencies of control equipment on particle size fractions on a real time basis.

CHARACTERIZATION AND IMPROVEMENT OF CONVENTIONAL CONTROL EQUIPMENT AND ASSESSMENT OF THE COLLECTABILITY OF DUSTS

It is the aim of this program area to: (1) ascertain, using the best available conventional equipment operating on real sources, the actual control capability in terms of size fractional efficiency; (2) develop a data base for decisions and judgments with respect to the capability of commercially available control equipment; (3) develop improvements in conventional control devices which will eliminate deficiencies in their potential for fine particle control; and (4) determine the ease or difficulty with which any given industrial dust pollutant may be collected. With the information collected in this program area, it should be possible to predict with reasonable accuracy the ease or difficulty of and the system required for control of almost any particulate problem.

NEW PARTICULATE CONTROL TECHNOLOGY DEVELOPMENT

The goals for this area are: (1) assess all potential collection mechanisms; (2) initiate exploratory projects to evaluate feasibility of concepts and/or mechanisms; and (3) develop pilot units for promising systems.

NEW IDEA EVALUATION AND IDENTIFICATION

The goals of this program area are: (1) evaluate novel devices; (2) generate a plan to solicit, stimulate, and identify new ideas and concepts for fine particulate control; and (3) pilot-scale demonstration of the most promising devices.

FINE PARTICLE CONTROL FOR COMBUSTION PROCESSES UTILIZING LOW-SULFUR COAL

This represents a new program area added in FY 76 to provide solutions to problems associated with the projected increase in the use of low-sulfur coal. Major increases in the combustion of low-sulfur coal are expected both as a result of increased power generation in the West and as a result of a switch from high- to low- sulfur coal in the East to meet SO_2 emission standards without using scrubbers. In general, combustion of low-sulfur coal produces a fly ash with high electrical resistivity. This fly ash is difficult to collect in electrostatic precipitators (ESPs) (the most common particulate control device for utility boilers). Thus, use of low-sulfur coal, especially in plants designed for high-sulfur coal, produces serious problems for achieving adequate particulate and fine particulate control.

The goals of this new program area are:

- determine the effects of flue gas and/or fly ash conditioning agents on electrostatic precipitator performance and on overall pollutant emissions.
- develop and demonstrate an improved electrostatic precipitator which is relatively insensitive to changes in fly ash physical and chemical properties.
- demonstrate the feasibility of using fabric filters to control particulate emissions from large utility boilers.
- determine the impact of coal cleaning on ash collectibility.
- demonstrate the use of environmentally acceptable conditioning agents to improve particulate control by electrostatic precipitators.

In FY 76 IERL-RTP sponsored two conferences (one on the West coast and one on the East coast) on the problems associated with combustion of low-sulfur coal. One field evaluation of conditioning agents was also completed.

HIGH-TEMPERATURE/HIGH-PRESSURE PARTICULATE CONTROL

This program area was added in FY 75 as a result of the particulate removal problems associated with advanced energy processes. Its goals are: (1) for the near term, develop fundamental information on the mechanics of

aerosols at high temperature and high pressure; (2) using this fundamental information, choose the most promising collection mechanisms, and mount a research and development effort aimed at exploiting these mechanisms; and (3) develop the devices necessary to ensure the environmental acceptability of the advanced energy systems.

Current Program Status

MEASUREMENT

Current devices used for measuring particle size on control equipment include impactors, optical counters, diffusion batteries, and condensation nuclei counters. These devices require lengthy manual techniques for operation, and their reliability is less than satisfactory. For instance, with current measurement technology, it is not always possible to discern the difference between a device collecting 90 percent of particles less than 0.5 microns in diameter and one collecting 95 percent or sometimes even 99 percent. In order to maintain the momentum of control technology development, this situation must be remedied.

The objective of this effort is to produce a device which will measure fractional efficiencies of control devices in real time with a high degree of precision and accuracy.

CHARACTERIZATION AND IMPROVEMENT OF CONVENTIONAL CONTROL EQUIPMENT

Electrostatic Precipitators

IERL-RTP has completed the total characterization of seven ESPs operating on a number of sources ranging from power plants to aluminum plants. Data from these tests clearly show that ESPs can collect particles of all sizes with high efficiency when dust resistivity is not a problem. Data and theoretical predictions indicate that high dust resistivity limits ESP performance.

IERL-RTP has completed work to determine the current conduction mechanisms in fly ash at high temperatures (>300°F). This work is being extended to low temperatures in an FY 75 funded program. One outcome of this work has been the recognition of sodium as a potential conditioning agent to reduce resistivity. IERL-RTP has evaluated and published reports on conditioning agents such as SO_3 and NH_3. Conditioning appears to be a possible solution to retrofit types of problems, but not for new installations.

Specially designed charging or precharging sections are a possible means of improving the collection of fine high resistivity particles. Fundamental studies and limited pilot-plant work on fine particle charging, funded in FY

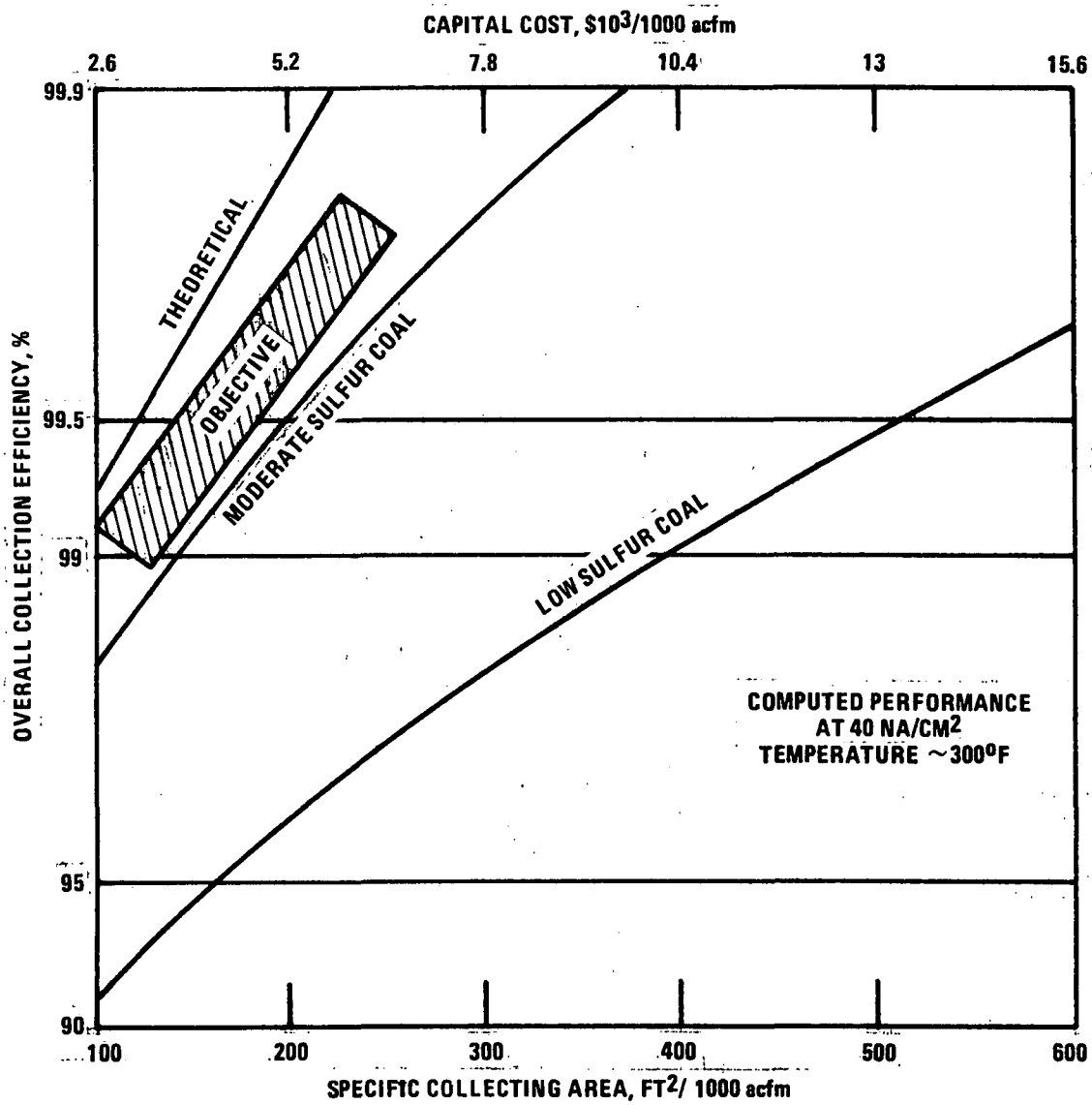
74, demonstrated that the precharging concept is technically feasible. Follow-on work is being conducted to reduce the concept to practice.

A mathematical model for the design of ESPs was completed in FY 75. This model is in two forms: a design and selection manual for the plant engineer, and a programmed computer version for the design engineer. The model predicts well the performance of ESPs down to particle diameters approaching 0.01 microns. Programs currently underway will improve the model by better defining losses due to poor gas distribution or rapping and reentrainment. These losses are currently handled in the model on an empirical basis.

Wet ESPs offer a solution to high resistivity and fine particle collection problems from some sources. IERL-RTP is completing a systems study of wet ESPs which was funded in FY 73. The results of this study indicate that wet ESPs have performance characteristics similar to dry ESPs without the latter's resistivity problems. However, cost and other factors limit the application of wet ESPs. Wet ESPs do not appear to be a solution to the problem of collecting high-resistivity fly ash.

The broad objective of the ESP improvement program is to develop an ESP of moderate size (specific collection area < 300 ft^2/1000 acfm at 300°F) for high- (>99 percent) efficiency collection of high-resistivity dusts. Such ESPs would have a minimum particle collection efficiency of 90 percent at 0.5 micron particle diameter. This objective is shown in the chart below. High-resistivity dusts are produced from several sources: the largest is combustion of low-sulfur coal.

As shown below, moderate to small sized ESPs can collect particles with high efficiency when the dust resistivity is not excessive. The figure also shows that very large cold-side ESPs are required for efficient collection of high-resistivity dusts. Hot-side ESPs are somewhat smaller, based on specific collection area (SCA) for acfm than cold-side ESPs for high-resistivity dusts. However, theoretically perfect (e.g., no reentrainment, no sneakage) hot-side performance does not approach the actual performance of the cold-side low-resistivity ESP. If the SCAs are converted to a common temperature, the hot-side ESP is seen to be much less attractive than the ESP that would result from successful completion of this effort. For example, a hot-side ESP with good gas flow distribution and moderate-to-low sneakage and reentrainment has an SCA of 450 ft^2/1000 acfm at 700°F or 690 ft^2/1000 cfm at 300°F. The object ESP would require an SCA of only 180 ft^2/1000 cfm at 300°F for the same efficiency.



Capital cost of ESP's vs. computed performance.

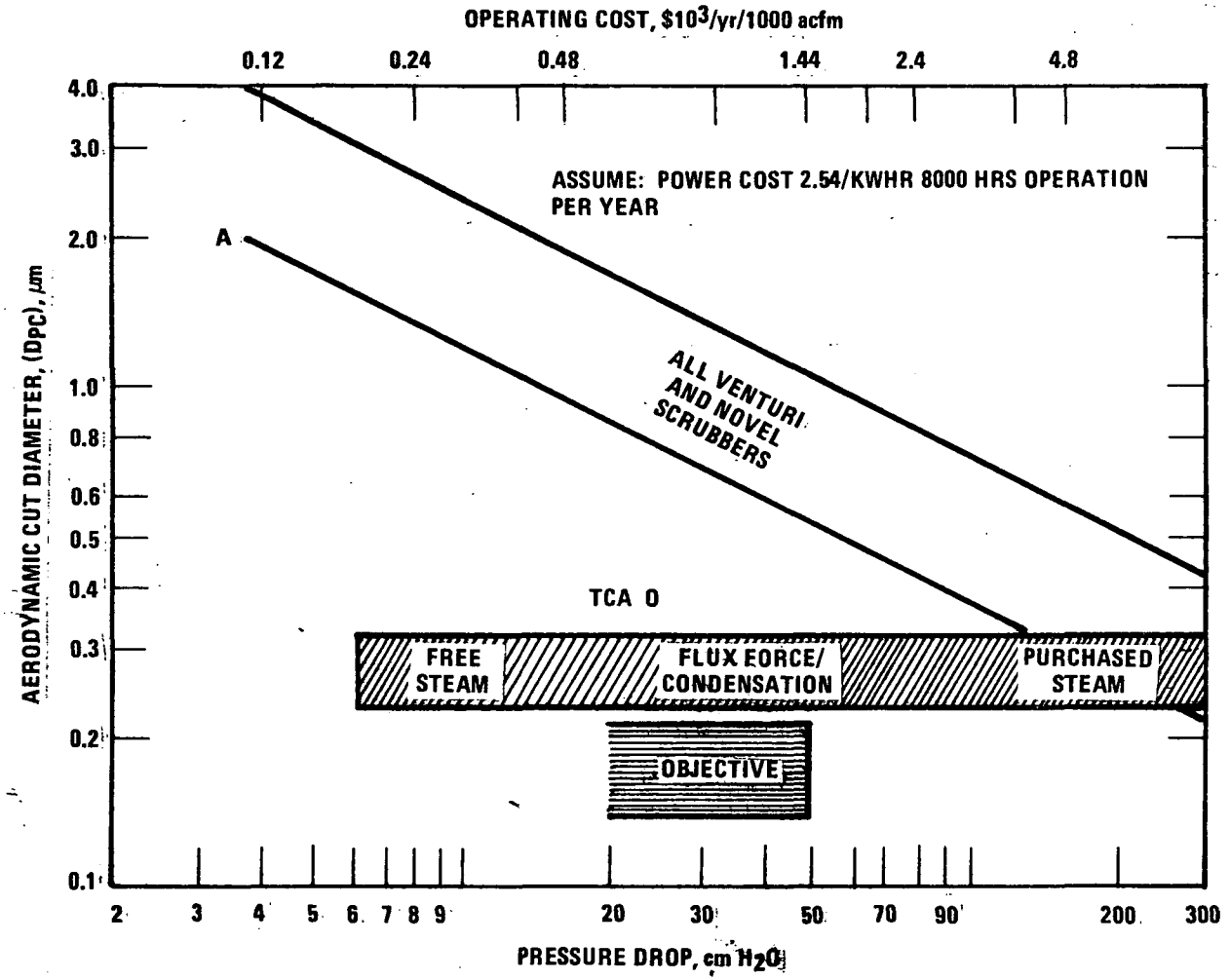
Scrubbers

The Industrial Environmental Research Laboratory, Research Triangle Park, has tested approximately ten scrubbers of conventional design on a variety of particulate sources. In general, the performance or efficiency of a scrubber drops off rather rapidly as the particle size decreases. Also efficiency is directly related to the energy consumed by the scrubber.

The broad objective of the fine particle scrubber program is to develop low pressure drop (30 to 50 cm H_2O) scrubber systems capable of collecting at least 90 percent by mass of particles smaller than 3 microns in diameter. This objective, for a dust with a typical fine particle distribution, is shown graphically below. Except for two TCA scrubbers, the performance of all conventional and novel scrubbers tested by IERL-RTP is represented by points along or above line A in the graph. The TCA scrubbers are represented by the circle labeled TCA.

The major thrust of IERL-RTP's scrubber program has been aimed at developing and demonstrating flux force/condensation (FF/C) scrubbers. In an FF/C scrubber, water vapor is condensed in the scrubber. When the water vapor condenses, additional forces and particle growth contribute to the particle collection process. When the water vapor or steam is "free," FF/C scrubbers are low energy users. However, when water vapor or steam has to be purchased, FF/C scrubbers require additional energy inputs for efficient particle collection. A rough idea of the energy consumption/performance relationship for FF/C scrubbers is shown in the graph. Note that when steam is free, FF/C scrubbers approach the program objective. How much steam is needed and how much is free are major unknowns at present. Since answers to both questions are likely to be source specific, pilot demonstrations on a variety of sources are necessary to provide required data. One pilot demonstration is complete and a second is underway.

With one possible exception, all the non-FF/C scrubber work confirms these data. The possible exception to the figure is the TCA or mobile bed scrubber. The figure below shows data from field tests of TCA scrubbers. Note that the TCA point is below the venturi and other scrubber lines by a significant amount. At present, there is no explanation for the observed performance of mobile bed scrubbers. In fact, one scrubber vendor claims that mobile bed scrubbers (single-stage or multi-stage) are less efficient than venturi scrubbers. On-going programs will provide the explanation for the



Scrubber operating cost vs. aerodynamic cut diameter.

observed performance and design equations and theoretical models for mobile bed scrubbers. The research program also includes an investigation of the effects of slurry scrubbing on mobile bed scrubber performance.

The overall efficiency of a scrubber system is determined by the efficiency of both the scrubber and the entrainment separator. Recent field data indicate that in some cases inefficient entrainment separator operation is a major cause of poor fine particle collection by scrubbers. IERL-RTP has completed a systems study of entrainment separators. On-going development work will be used to develop and demonstrate high-efficiency and trouble-free entrainment separators in conjunction with SO_x scrubbing research and development.

Fabric Filters

The performance of baghouses has been completely characterized on several sources, including two utility boilers, an industrial boiler, and an electric arc furnace. The data obtained from these tests show that baghouses are excellent fine particle collectors and that their performance is not very sensitive to particle size in the processes tested. A major advantage of fabric filters is that they do not require increases in size or energy usage for efficient collection of fine particles.

The current purpose in maintaining a research and development program in fabric filtration is to promote increased capabilities and extend the range of applicability in control of fine particulates. Of the three conventional devices which can collect fine particles, fabric filters have been in industrial service longest, but the least information is known about their operation from a theoretical standpoint. Although the filter is a simple device in operation, there are complex problems in describing it mathematically. The types of analyses used for scrubbers and electrostatic precipitators (ESPs) have not been effective when applied to filters. Perhaps because the filter already has a reputation for efficiency, EPA spending on filtration research over the last few years has been at a lower level than for ESPs and scrubbers. However, a major effort is now underway to produce design equations and mathematical models for filtration processes. Publication of a comprehensive model is expected in 1977.

Filtration work performed under IERL-RTP's Particulate Technology Branch (PATB) has been aimed at acquiring information for a two-fold use: incorporation into mathematical models, and; addition to the empirical knowledge used by designers and operators for everyday operation. This work has included studies of fiber property effects and fabric-type effects; evaluation of new fabrics;

development of mathematical descriptions for specific parts of the filtration process; characterization of fabric filters in the field; investigation of electrostatic effects; support of a pilot, and now, a demonstration program to apply fabric filtration to industrial boilers at a several-fold increase over normal filtration velocity; studies of cleaning and energy consumption in bag filters; and a pilot program for control of municipal incinerators.

Industry can handle most of the filtration problems for sources which are already controlled by fabric filters. Help is needed for sources which present new problems and which are of priority interest to EPA. To design for new sources, a better understanding of the filtration process must be acquired. The objectives of immediate work in filtration then become:

- Understanding the filtration process.
- Applying it to priority sources.
- Achieving cost/energy effectiveness.
- Developing and testing new filter materials which can extend the applicability of baghouses to a broad spectrum of sources.

In addition to a comprehensive contract research and development program in fabric filtration, IERL-RTP also maintains a hands-on inhouse program. Its objectives are to identify superior fabric filter materials and operating conditions by conducting screening studies on inhouse equipment, and to derive basic information about the filtration process. It has provided information on the performance of many types of filter fabrics. Much experience has been gained with cotton and Dacron filter materials and this baseline data can be used to evaluate the properties of novel filter fabrics (such as spunbondeds and expanded PTFE laminates) when tested on inhouse equipment.

Laboratory work to complement and support grants, contracts, and other inhouse tasks will continue. Tests such as studies of fabric type, cleaning variables, effects of humidity, electrostatics, and process variations will be conducted as needed. In addition, with two different baghouse systems in operation, mechanical-shake cleaning can be compared with pulse-jet cleaning to determine which cleaning mode can be optimized for the lowest particle penetration. To complement the baseline data for overall efficiency for various bags, instruments are being utilized to determine the collection efficiency for various size ranges.

A new versatile fabric (baghouse) test chamber was ordered in FY 75. This device will be capable of testing bags at both high (1500°F) and normal

temperatures in environments which will simulate real process conditions. The chamber is scheduled for operation early in 1977.

ASSESSMENT OF THE COLLECTABILITY OF DUSTS

A fleet of mobile conventional collectors which can be easily transported from source to source and tested has been constructed and will be used in support of this program.

The fleet includes a mobile fabric filter, a mobile scrubber, and a mobile ESP unit. These mobile units are highly versatile and will be used to investigate the applicability of these control methods to the control of fine particulate emitted from a wide range of industrial sources. The relative capabilities and limitations of these control devices will be evaluated and documented. This information, supplemented by data from other IERL-RTP particulate programs, will permit selection by equipment users of collection systems that are technically and economically optimum for specific applications.

NEW PARTICULATE CONTROL TECHNOLOGY DEVELOPMENT

This program area has become known as "New Concepts." As the requirement to collect finer and finer particulate has developed, the cost of conventional control (ESPs, fabric filters, scrubbers) has risen. Since many important collection mechanisms become far less effective on particles <1 micron in diameter, conventional devices (except for fabric filters) have become larger or require more energy and thus are more expensive. The objective of new concepts research and development is to develop new mechanisms or new combinations of well-studied mechanisms in order to achieve cost-effective control of fine particulate not easily controlled by conventional devices. New concepts include any new technology which has not been reduced to practice and may or may not have been previously studied.

Mechanisms utilized by scrubbers and fabric filters are impaction, interception, and diffusion; and by ESPs, are field and diffusion charging. This combination of mechanisms gives rise to a minimum in efficiency at the 0.2 to 0.5 micron range for conventional devices. Under optimum conditions, this minimum may be greater than 90 percent for scrubbers and ESPs and greater than 99 percent for fabric filters. However, under conditions such as high temperature, high ash resistivity, sticky particulate, and corrosive or explosive flue gases, new concepts specific to a problem will have an advantage.

Most work to date has been directed toward combining electrostatic removal mechanisms with scrubbing or filtration mechanisms. The first area to

be developed was charged droplet scrubbing with a feasibility study at the Massachusetts Institute of Technology and a pilot demonstration at TRW, Inc. on a Kaiser coke oven. Electrostatics and filtration are being studied at both Battelle-Northwest (BNW) and Carnegie-Mellon University Research Center; the former with bed filters; the latter with baghouses. At least two new concepts--a ceramic membrane filter and a magnetic metallic fiber bed--may be applied to cleanup of high-temperature gases (1000 to 2000°F). Other new concepts being studied include foam scrubbing and pleated cartridge filters of a novel material.

Most new concept work is in an intermediate stage of development so that demonstration data is limited. The TRW charged droplet scrubber has been demonstrated and was capable of better than 94 percent removal of 0.6 micron particulate. IERL-RTP has evaluated nearly 40 new concepts to date; of these, nine have been selected for funding support.

NEW IDEA EVALUATION AND IDENTIFICATION

This program area has become known as "Novel Devices." It includes, in addition to novel device evaluation and testing, a program aimed at soliciting, stimulating, and identifying new ideas for fine particulate control.

As a part of this latter objective, IERL-RTP's Particulate Technology Branch has planned and sponsored six symposiums and one seminar aimed at fine particle control. PATB also has funded (FY 75) a literature search aimed at identifying new technology in foreign countries (Japan, Australia, Russia, and Canada).

Devices or systems based on new collection principles or on radical redesign of conventional collectors are sometimes offered by private developers. Under this program area, all such novel devices will be reviewed and, if promising for fine particle collection, will be evaluated for performance and related cost. It is intended that those showing promise of high-efficiency fine particle collection at reasonable cost, if necessary, be further developed or demonstrated.

More than 40 novel particulate devices have been identified. About half of these are of sufficient interest to justify evaluation by IERL-RTP. So far, the following devices have been tested:

- Braxton--Sonic Agglomerator
- Lone Star Steel--Steam Hydro Scrubber
- R. P. Industries--Dynactor Scrubber

- Aronetics--Two-Phase Wet Scrubber
- Purity Corporation--Pentapure Impinger
- Entoleter--Centrifield Scrubber
- Johns-Manville--CHEAF Filter
- Rexnord--Granular Bed Filter
- Air Pollution Systems--Electrostatic Scrubber
- Air Pollution Systems--Electrotube Scrubber
- Century Industrial Products--RFP 100 Wet Scrubber

Of the devices tested, the Lone Star Steel scrubber gave the highest efficiency on fine particulate, but it is also a high energy user. It can use waste energy, when available. The Aronetics scrubber is similar to the Lone Star unit, but (in one test) did not appear to be as efficient. In a field test, the CHEAF filter had an overall mass efficiency of 95 percent but maintained the efficiency down to about 0.3 microns. Laboratory tests have confirmed that this phenomenon is real. The APS electrostatic scrubber was equal in fractional collection efficiency to a venturi scrubber using 1-1/2 to 2-1/2 times as much power. The APS electrotube, which is similar to a wet wall ESP, gave some very high efficiencies on fine particulates--as high as 98.9 percent on 0.5 micron particles. This performance is similar to that which can be achieved in small wet ESPs with the same ratio of plate area to volumetric flow rate. The Century Industrial Products scrubber performed slightly better than a venturi scrubber with the same pressure drop on the effluent from a lightweight aggregate drying kiln. None of the other devices tested had acceptable fine particulate collection efficiencies.

The following devices are now being considered for testing:

- United McGill--NAFCO ESP
- Combustion Power--Dry Scrubber
- Dart Industries--Hydro-Precipitrol Wet ESP
- Ceilcote Company--Ionizing Wet Scrubber
- Du Pont--Du Pont Scrubber

A University of Washington charged droplet scrubber has been fabricated as a portable unit and is being installed on a steel plant electric arc furnace for evaluation. If this unit shows promise, it will be evaluated on other sources.

Parallel to the field testing effort, a small inhouse facility for testing novel devices is being operated. A small foam scrubber has been constructed and operated to complement contract work on this new concept.

HIGH-TEMPERATURE/HIGH-PRESSURE PARTICULATE CONTROL

This program area was added in FY 75 as a result of the critical particulate and fine particulate collection problems associated with advanced energy processes. The broad objective of the high-temperature/high-pressure program is to develop the particulate collection devices which are needed to ensure the environmental acceptability of advanced energy processes. However, because the requirements of such energy processes are as yet unknown, IERL-RTP has established a near-term (18 to 24 month) objective of developing the fundamental information on the mechanics of aerosols at high temperatures and pressures necessary to determine the path of high-temperature/high-pressure particulate collection research and development.

The state-of-the-art of high-temperature/high-pressure particulate collection is very unclear. There is no clear specification of the degree of particulate collection needed by advanced energy processes. Also, there are no reliable data for the performance of the particulate collection devices proposed by various companies; e.g., granular bed filters and high-pressure-drop cyclones. There are few data, correlations, or verified theories that can be used to predict the performance of particulate collection devices at elevated temperatures and pressures.

Most, if not all, developers of advanced energy processes are assuming that either cyclones or granular bed filters will provide the degree of particulate collection required by their processes. However, there is no real justification for such an assumption.

IERL-RTP, through FY 75 funded contracts, is conducting research to: determine the feasibility of high-temperature/high-pressure ESPs; determine the effects of high-temperature/high-pressure on basic particle collection mechanisms (literature search funded in FY 75, experimental study funded in FY 76); and determine the estimated particulate cleanup requirements of proposed energy processes. These tasks are not connected with specific energy processes. IERL-RTP, as part of the advanced energy processes program, is looking at granular bed filters (Exxon miniplant) and high-pressure-drop cyclones (Consolidation Coal) for use in particular energy processes.

IERL-RTP, as part of the Novel Particulate Device Program, is attempting to evaluate either or both the Rexnord and CPC granular bed filters. IERL-RTP, as part of the high-temperature/high-pressure control program, is supporting work on hot filtration and on dry scrubbing of fine particulate.

ENERGY ASSESSMENT AND CONTROL

IERL-RTP's work in the area of energy assessment and control can be subdivided into three distinct functional groupings: combustion research, fuel processes, and advanced processes. The following subsections of this report discuss these groupings separately.

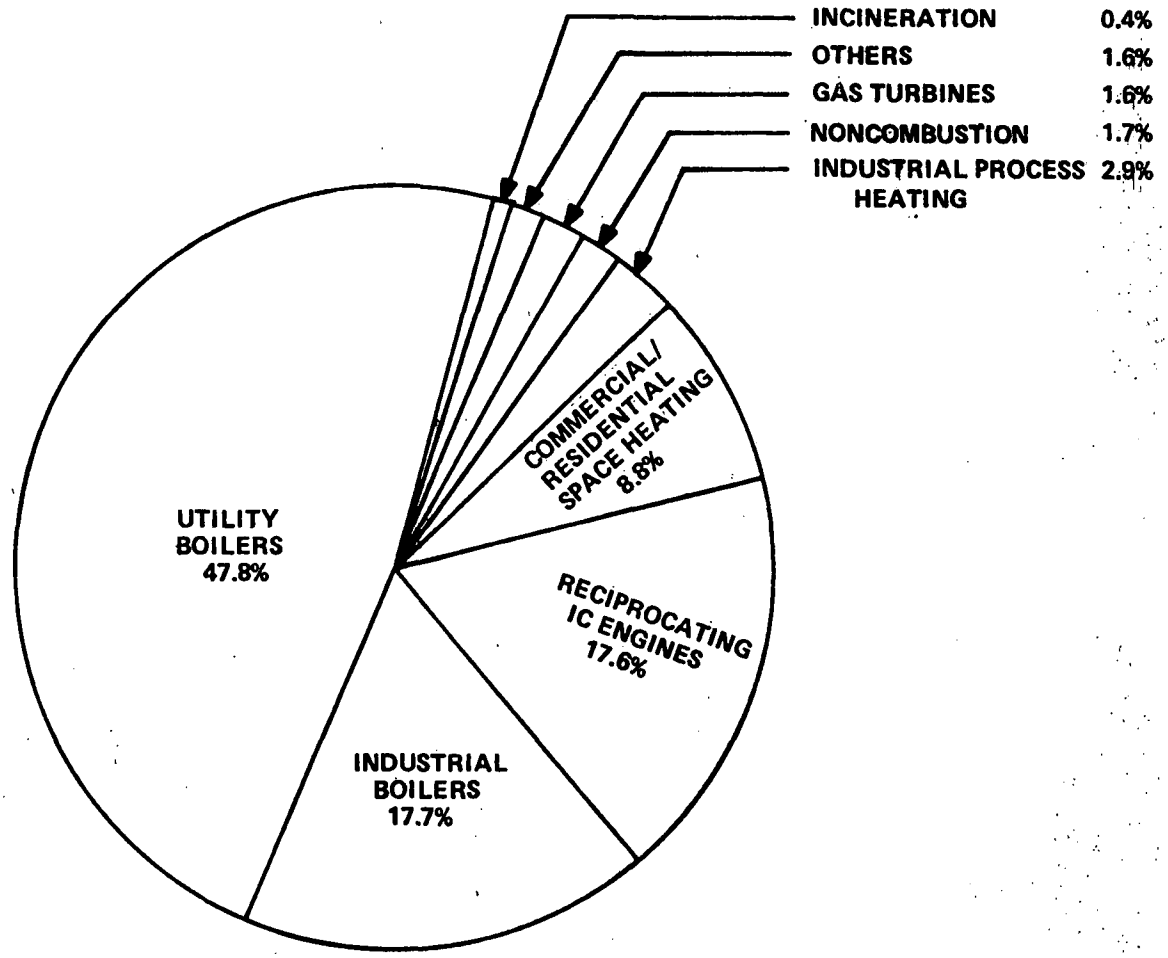
COMBUSTION RESEARCH

The Combustion Research Branch is directed toward the characterization, assessment, and control of the environmental impact of energy conversion technologies. Programs are underway to identify the multimedia pollution problems associated with combustion processes (i.e., related to residential, commercial, industrial, and utility boilers, industrial furnaces, and stationary gas turbine and reciprocating internal combustion (IC) engines) utilizing conventional fossil and alternate new fuels.

The major goals of these efforts are the development and demonstration of combustion modifications and control techniques or devices to prevent or minimize pollution problems for these processes in a cost-effective, energy-conserving, process-efficient, and environmentally acceptable manner. Although the major emphasis of the program is on investigation of technology for control of oxides of nitrogen (NO_x), efforts are also underway to reduce or eliminate other pollutants (such as hydrocarbons, carbon particulate, smoke, carbon monoxide, and various potentially hazardous species) while simultaneously maximizing system efficiency by optimizing system design and operating characteristics.

Combustion sources contribute about 98 percent of the total NO_x emissions from stationary sources. Some NO_x is formed in all fossil fuel combustion processes. Recent estimates of NO_x emissions from major source categories in 1974 are shown in the following figure. Control technology development studies to date indicate that combustion modification is the primary near-term method of controlling NO_x emissions from the combustion of fossil fuels.

Until recently, it appeared that existing or a low level of development of stationary source control technology would be adequate to achieve and maintain air quality in the 1980 to 2000 period. However, since 1973, the energy shortage and changes in the national NO_x abatement strategy have placed additional demands on the stationary source control technology.



SOURCE	ESTIMATED NO_X EMISSIONS TONS/year
UTILITY BOILERS	5,814,000
INDUSTRIAL BOILERS	2,153,000
RECIPROCATING IC ENGINES	2,140,000
COMMERCIAL/RESIDENTIAL HEATING	1,069,000
INDUSTRIAL PROCESS HEATING	350,000
NONCOMBUSTION	224,000
GAS TURBINES	190,000
INCINERATION	43,400
OTHER	192,000
TOTAL	12,175,400

Summary of 1974 stationary source NO_X emissions.

Current combustion research activities to address the above needs are divided into the following elements: field testing and environmental assessment, process research and development, fuels research and development, and fundamental studies. Field testing is directed toward the determination of the range of NO_x control possible in existing equipment, and environmental assessments identify the multimedia environmental impact of stationary combustion sources and NO_x control systems for attainment and maintenance of current and projected air quality standards. Process research and development encompasses the development and demonstration of optimum NO_x control technology for existing and new combustion systems. Fuels research and development studies are designed to develop generalized combustion control technology which is applicable to the control of NO_x and other pollutant emissions from the combustion of conventional fuels, waste fuels, and future fuels. Fundamental studies provide an understanding of the important phenomena in the formation and destruction of pollutants during combustion which may then be utilized in pilot-scale equipment and fuels control technology.

A further element of the program is the efficient dissemination of technical information from its research activities to control developers, equipment manufacturers and users, and the authorities involved in setting and enforcing standards. Two practices have been initiated to establish an efficient means of technology transfer: (1) symposiums and (2) bulletins.

The first symposium on Stationary Source Combustion took place in Atlanta in September 1975, and the next meeting is scheduled for New Orleans for August 29 through September 1, 1977. Sessions were held in the key program areas of the Combustion Research Branch. The Fundamental Research session highlighted results from ten analytical and experimental studies of pollutant formation and reduction and concluded with a panel discussion on "Combustion Chemistry and Modeling." Developments in external combustion control, burner modifications, combustion of alternate fuels and alternate combustion concepts were presented in the Fuels Research and Development session. The Process Research and Development session highlighted development of advanced NO_x control technology through minor hardware changes to existing equipment which will provide guidelines for low NO_x new unit design and for retrofit field implementation of NO_x controls. The final session, Field Testing and Survey, contained seven papers on uncontrolled emission characterization and on control

achieved by alteration of operating conditions. The proceedings of the Atlanta meeting have recently been published as an EPA report.

The first issue of a bulletin, entitled "NO_X Control Review," was published in March 1976. Issued approximately quarterly, the Review presents the status of stationary source NO_x control technology and related topics. Each issue leads off with major recent developments or topics of general interest; the remainder is divided into the following topical categories: control research and development, control implementation, alternate processes, flue gas treatment, regulatory strategies, technical briefs, recent publications, and a calendar of upcoming meetings. Future issues will include a listing of applications of NO_x control technology to major utility and industrial stationary combustion sources.

Field Testing and Environmental Assessment

The field testing element includes studies designed to determine the potential for control of NO_x emissions from existing equipment. This work is generally performed by research and development organizations familiar with the specific combustion systems being studied, and with the financial and technical assistance of manufacturers, users, and trade associations. The field testing and survey studies are the initial efforts in the development of control technology and are designed to demonstrate the state of the art in control of NO_x and combustible emissions. In addition to developing trends and providing application guidelines for industry to minimize emissions with present technology, the work also suggests where research and development efforts should be concentrated by developing emission factors as a function of equipment type and size, and fuel consumed.

The environmental assessment component of the program element focuses on identification of the multimedia environmental impact of stationary combustion sources and NO_x controls and, for this impact, identifies the most cost-effective, environmentally sound NO_x control systems for attainment and maintenance of current and projected NO_2 air quality standards. This activity provides program guidelines for development of NO_x controls sufficient to assure compliance (to the year 2000) with air quality standards in critical air quality control regions.

UTILITY BOILER/POWER GENERATION EQUIPMENT FIELD TESTING

IERL-RTP's NO_x control program was initiated in 1970 when Exxon Research and Engineering Company began field testing utility boilers to define baseline

emissions and establish the effect of combustion modification techniques. It was found that NO_x emissions from gas- and oil-fired boilers could be reduced by 50 to 60 percent by using combustion modification techniques such as low excess air firing, staged combustion, flue gas recirculation, load reduction, air preheat reduction, change in burner tilt, and change in primary to secondary air ratio. Of these, the first two were found to be most applicable and cost-effective. Combustion modification with coal-fired boilers was less successful for NO_x reduction and more difficult because of operating problems. Since the Exxon systems study identified coal-fired utility boilers as the top ranking source of NO_x emissions from stationary sources, efforts were concentrated on these units. Further Exxon studies showed that reducing the excess air level and employing staged combustion, as with gas- and oil-fired boilers, resulted in significant NO_x reductions, averaging about 40 to 50 percent for the boilers tested. The degree of reduction, as well as baseline NO_x emission levels, varied with the design and size of coal-fired boilers tested and with coal type. No extreme differences in flue gas particulate loadings and in the carbon content of the fly ash were found during the boiler tests.

A subsequent extension to the Exxon field test program of utility power generation equipment includes trace specie emission measurements and testing of an additional six units including a carefully controlled investigation into the effects of NO_x controls on tube wastage in coal-fired boilers. Emission measurements will be made of sulfates, nitrates, HCN, HCl, POMs, and PCBs in addition to the original NO, NO_2, SO_2, SO_3, CO, CO_2, O_2, HC, particle loading, and particle size distribution. The additional test sites extend previous emission characterizations and control tests to a broader range of design types and operating conditions. Corrosion tests will be conducted on a 500 MW horizontally-opposed, dry-bottom coal-fired boiler with an initial 4 month baseline test to establish normal tube wastage rates followed by a 6 month run in which low NO_x conditions will be accomplished through low excess air firing and staged combustion via burners out of service. The tests will use a new ultrasonic tube thickness sensor (accurate to ± 0.0001 inch), corrosion coupon probes, and replaceable tube wall panels with before and after metallographic characterization.

A new program is being initiated to conduct long-term comprehensive emissions and corrosion tests on coal-fired utility boilers designed to meet the New Source Performance Standards for NO_x of 301 ng NO_2/J (0.7 lb $NO_2/10^6$ Btu)

heat input. Each test boiler will exceed 125 MW in capacity and burn high-sulfur bituminous coal. It is expected that these tests will fully quantify the effects of NO_x combustion modification on emissions, corrosion, boiler performance, and reliability for major coal-fired boiler design types.

Future work with utility boilers will continue to concentrate on coal-fired units, but will also consider firing of mixed fossil fuels (e.g., coal and oil, and gas and oil) simultaneously, coal-derived fuels (e.g., low-Btu gas and solvent refined coal), and waste fuels. Tests are also underway with other power generation equipment such as gas turbines and large internal combustion engines.

FIELD TESTING OF INDUSTRIAL BOILERS

In 1973, a major field test program with industrial boilers was initiated. KVB Engineering was awarded a contract to test approximately 50 gas-, oil-, and coal-fired boilers, ranging in size from 10,000 to 500,000 pounds of steam per hour during the first year. Measurements included efficiency and emissions of NO_x, SO_x, HC, CO, smoke, and particulate mass. The tests were short-term and concentrated on operating variables such as excess air, load, swirl adjustment, and primary, secondary, and tertiary air adjustment. During the second year, 18 boilers were tested in more detail with more extensive modifications, such as overfire air, flue gas recirculation, and variable air preheat temperature. Also, particle size distribution and (on approximately five oil- and coal-fired boilers) trace specie emissions were measured. The 2 year study provided the following data on uncontrolled baseline emissions: 164-922 ppm, 65-619 ppm and 50-375 ppm for coal, oil and gas firing, respectively. Corresponding baseline operation emission averages were 275 ppm, 120 ppm, 293 ppm, 269 ppm and 139 ppm for coal, #2 oil, #5 oil, #6 oil, and natural gas. Excess air, burners out-of-service and flue gas recirculation proved to be the most effective combustion modification techniques for reduction of NO_x emissions without sacrificing boiler efficiency. NO_x reductions up to 35 percent without increases in particulate emissions were experienced with low excess air firing. Flue gas recirculation reduced NO_x by 10 to 40 percent, but increased particulate by 5 percent and boiler efficiency was slightly reduced. The burners out-of-service technique reduced NO_x up to 54 percent without reduction in efficiency, but particulate emissions always increased. A final report was recently completed on the second phase of this project, and the study will culminate in the issuance of instructional guidelines for low-emission operation and design of industrial boilers.

FIELD TESTING OF INDUSTRIAL PROCESS EQUIPMENT

IERL-RTP has contracted with KVB to conduct a 1 year field test program for industrial process equipment, gas turbines, and internal combustion engines. Emphasis is on detailed emission characterization of a representative group of furnaces, kilns, ovens, and dryers, firing coal, oil, gas, waste fuel, and mixed fuels. Measurements will be made of NO, NO_2, SO_2, SO_3, O_2, CO, CO_2, HC, particle size and grain loading, opacity, and where relevant, trace metallics and trace organics (POM, PCB). KVB will also assess the degree of emission control achievable from modification of operating parameters such as unit load, excess air, and combustion air preheat. The gas turbine tests will assess the use of water injection as a means of NO_x control. A total of 25 units will be tested.

RESIDENTIAL/COMMERCIAL HEATING SYSTEMS TESTING

In an IERL-RTP-sponsored effort, Battelle has recently completed work on guidelines for residential and commercial oil burner adjustments. Intended for use by service managers for service training and by skilled service technicians in their oil burner service work, the adjustment guidelines are important because they ensure reliable automatic operation, provide for efficient fuel utilization and minimize air pollution. In addition, the guidelines also include appendixes with background material on pollutants of primary concern, field-type instruments and significance of measurements, fuel oil characteristics, and emission characteristics of residential and commercial oil burners and boilers.

A pamphlet produced inhouse entitled "Get the Most From Your Heating Oil Dollar - Servicing Cuts Cost and Pollution" is being distributed to homeowners throughout the U.S. It is designed to transfer emissions and fuel conservation technology developed during field tests of residential equipment directly to the public.

Inhouse studies closely related to the field testing are being conducted on emission characterization and design evaluation for commercial combustion systems. The objective of this work is to investigate, under controlled laboratory conditions, the emission performance of existing/prototype commercial combustion systems and components and to evaluate effects of new burner/combustor designs and modifications on emissions and energy efficiency performance. Two different equipment systems have been baselined; that is, the best conditions for minimum emissions with unaltered equipment have been established.

These systems include two major types of firetube packaged boilers: Scotch marine and firebox.

The Scotch marine firetube boiler has been utilized for the study of two fuel-oil/water emulsion devices: The Cottell Ultrasonic Emulsifier and the Total Emulsifier. The Cottell device provided significant reductions in smoke number and particulate emissions. The Total device provided significant reductions in particulate when firing distillate-oil/water emulsions, but smoke increased because the particle size distribution shifted to a smaller size. Neither emulsifier reduced NO_x emissions significantly when firing residual oil (which has a high-fuel nitrogen content); however, a significant NO_x reduction was observed when distillate oil was fired. On-going tests on the Elf Union (a French oil company) emulsion burner with a capability of 10 to 70 gph capacity have not resulted in data as yet. Some emulsion devices may have a small potential for energy conservation by permitting boiler operation at lower excess air levels, but this may require trading back the emission improvements.

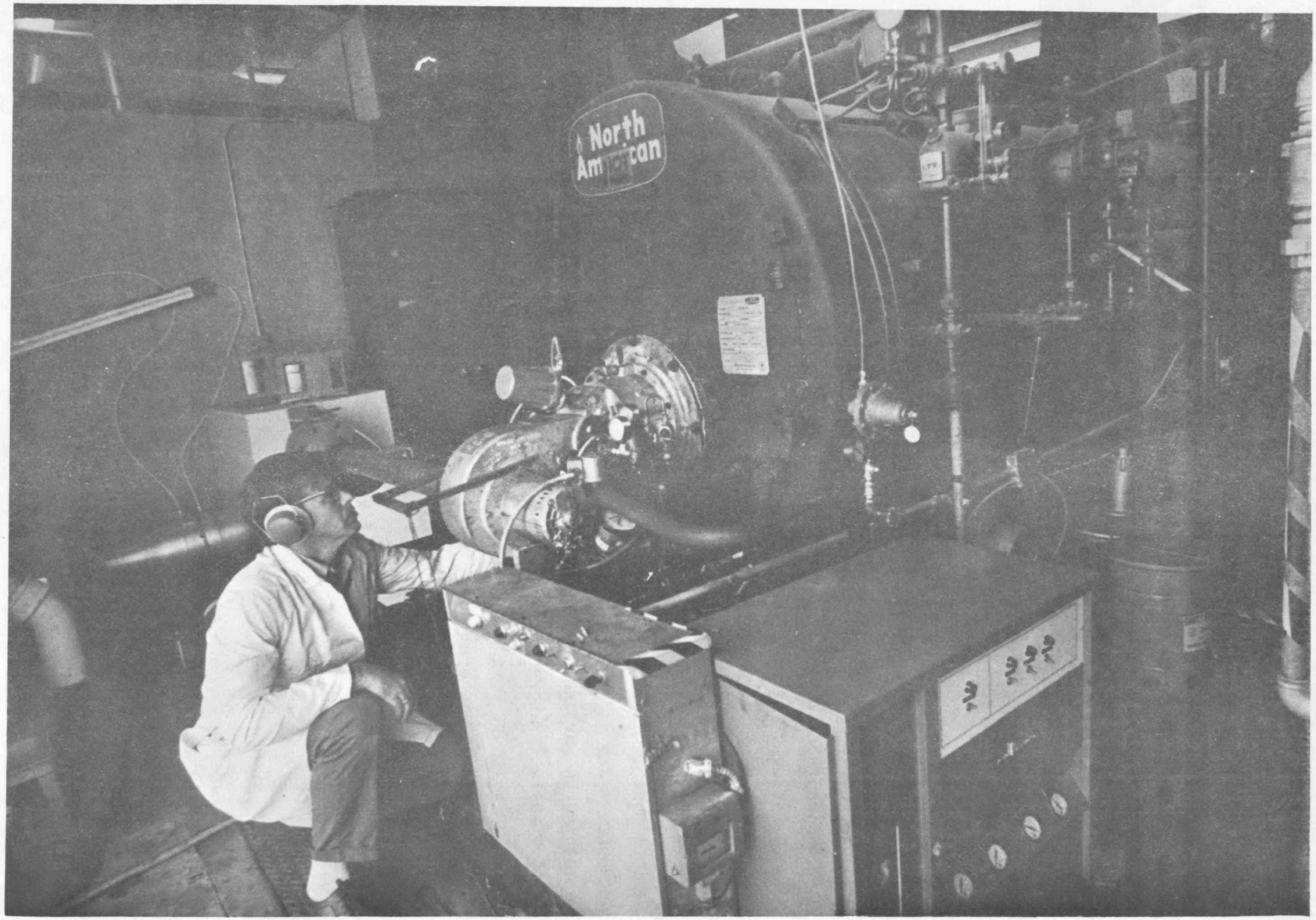
In addition to the basic emission characteristics, a number of design and equipment changes have been studied. A burner redesign program was successful in reducing CO, HC, and smoke emissions from the firebox/firetube package boiler without increasing NO_x emissions. A fuel injection equipment program has been carried out to determine emission characteristics from air, high-pressure, and sonic atomization of #6 residual oil.

A comprehensive sampling and analytical system for use on IERL-RTP inhouse equipment facilities is being developed by Aerotherm and A. D. Little. The system, consisting of a specialized source assessment stack sampler and a complete analytical chemistry lab, is presently in the design phase. Design completion is expected in late 1976 or early 1977.

ENVIRONMENTAL ASSESSMENT AND SYSTEMS ANALYSIS OF NO_x COMBUSTION MODIFICATION TECHNOLOGY

A major contract award has been made to the Aerotherm Division of Acurex Corporation for a multimedia environmental assessment and system analysis of NO_x combustion modification techniques. This effort is to determine the technical soundness and environmental acceptability of these control methods, and to ensure that any deficiencies or potential problems are identified and corrected in a timely fashion, before the technologies are adopted commercially.

The general technical approach in this project is based on the need to provide efficient and timely assessments of near-term control technologies



Scotch marine boiler (60 hp) for emission control equipment evaluation.

while maintaining a comprehensive treatment of likely control needs to the year 2000. Throughout the program, emphasis will be given to synthesis of existing and emerging technology on control systems, trace emission and pollutant transport transformation and impact. The major project effort will go toward the compilation and evaluation of data from past and on-going programs for the EPA and other agencies. Additionally, the environmental assessment activities will be coordinated with the IERL-RTP guidelines developed for the numerous on-going source and environmental assessments. The evaluation of potential air quality standards and NO_2 abatement strategies will be coordinated with the Office of Air Quality Planning and Standards (OAQPS) as well as the several task forces established to define mobile source emission control needs. The intent of this evaluation is to obtain an objective overview of the future needs for combustion modification NO_x controls.

The approach and level of effort allocated to project tasks is based on prioritization of sources, controls, pollutants, and Air Quality Control Regions (AQCRs). The basis of the prioritization is to focus the study on development needs for environmentally sound control systems. Throughout the program, emphasis will be given to those sources, controls and multimedia impacts most likely to be involved in control implementation in critical AQCRs up to the year 2000. Early use of the systems analysis models will aid in setting the program priorities. A screening approach will be used in the systems analysis whereby a simple model will be used to prioritize the options. More sophisticated models will be introduced for verification as process and emission data become available.

The effort will be time-phased on a descending priority basis with early emphasis on near-term sources and controls. Subsequent updates will be made to maintain a current assessment of the high-priority areas. This approach requires parallel initiation of all program elements with early emphasis on gathering results from previous efforts and later emphasis on synthesis or generation of new data.

Process Research and Development

IERL-RTP's process research and development work involves the application of optimum NO_x control technology to existing and new combustion systems. The results of these studies provide the basis for the demonstration of combustion control technology. During the past year, interest in projects in this area has continued to develop.

COMBUSTION MODIFICATION FOR UTILITY BOILERS

In a study being conducted by Combustion Engineering, Inc., a 400 MW tangential utility boiler equipped with factory-installed overfire air firing western bituminous "B" coal yielded NO_x emissions as low as 189 ng NO_2/J (0.44 lb $NO_2/10^6$ Btu), which is below the Standard of Performance for New Stationary Sources of 301 ng NO_2/J (0.7 lb $NO_2/10^6$ Btu). Baseline NO_x emissions for this unit, without the use of the overfire air system, ranged from 258 to 301 ng NO_2/J (0.6 to 0.7 lb $NO_2/10^6$ Btu) at normal excess air levels. Further tests evaluated the effect of total excess air, overfire air rates and tilts, burner tilt, wall slag and unit load. A 25 percent NO_x reduction from baseline was observed at normal, total excess air levels (26.2 percent) with the primary flame zone operated at 105 percent of stoichiometric. Slag buildup produced a negligible increase in NO_x under staged conditions. As with baseline conditions, NO_x increased with unit load. Carbon heat losses of 0.2 to 0.6 percent resulted during staging. This level corresponds to the losses experienced under normal firing when operating below 15 percent excess air. Similar tests are now being conducted on a unit firing western subbituminous "C" coal. A final report on these two tests should be complete by early 1977.

Under an interagency agreement with IERL-RTP, TVA has evaluated biased firing on a 125 MW wall-coal-fired utility boiler. The tests indicate that a 30 to 50 percent NO_x reduction could be obtained for wall-coal-fired units depending upon load and burner configuration. Biased firing increases the carbon losses in the particulate causing a reduction in the ash conductivity which could affect ESP performance. The increases, however, were not deemed significant. Boiler efficiency is reduced over the entire load range under biased firing conditions. Data from 1 month tests using specially designed corrosion probes indicate accelerated tube wastage rates on the side walls, but the statistical significance of these results is currently in question.

Aerospace Corporation, under IERL-RTP sponsorship, has compiled and correlated field test data collected by the Los Angeles Department of Water and Power for some of their gas- and oil-fired utility boilers. A report on the extension of this effort to include coal-fired utility boilers is now in preparation. In addition to correlating emission data with combustion modification techniques, Aerospace has performed a combustion stability analysis to determine how a boiler can be redesigned to allow more flexibility in the use of combustion modifications. Aerospace is also generating a stationary source emissions

inventory to the year 1975 and emissions projections to the year 1985. A final report has recently been completed.

Monsanto Research Corporation is currently preparing a report based on a study of utility and industrial coal-fired cyclone boilers. The objective of the study was to assess the need and the potential for controlling NO_x emissions from existing coal-fired cyclones. The final report will provide a population and geographic distribution with NO_x emission rates from several sources, as well as definition of available combustion modification techniques. Results will include projections of potential NO_x reduction through combustion process modifications and estimates of research and development costs to develop corresponding retrofit controls.

COMBUSTION MODIFICATION FOR INDUSTRIAL BOILERS

KVB Engineering, Inc., under contract to IERL-RTP, tested ten intermediate sized (10,000 to 300,000 pph), pulverized-coal- and stoker-fired boilers to determine the feasibility of substituting low-sulfur western subbituminous coal for high-sulfur eastern bituminous coal primarily as a means of reducing sulfur oxide emissions. The resulting impact on NO_x was also assessed. Major emphasis was placed on stoker units as pulverized coal units in this capacity range are less prevalent. Lower NO_x emissions were measured on both pulverized coal units and stokers as a result of the lower fuel nitrogen content of the coal and of the lower combustion temperatures due to the high moisture content of western coals. In general, the conversion of intermediate boilers to western coals was found to be a feasible alternative. Guidelines for conversion of a variety of design types to the use of western coals are in preparation.

A contract program was initiated in late 1976 to study potential emission control technology for stoker-coal-fired industrial boilers. The program will focus on the complete spectrum of emissions from the sources and will develop technology to improve the environmental acceptability of stoker boilers. This contract will expand the prior work on small stokers to larger-scale spreader stoker boilers and include a more comprehensive assessment of processed coals.

COMBUSTION MODIFICATION FOR RESIDENTIAL/COMMERCIAL HEATING SYSTEMS

Battelle, under contract to IERL-RTP, completed a technical assessment of increased utilization of stoker coal systems for residential and small commercial space heating applications. The assessment was based on (1) an experimental study evaluating emissions (including carcinogenic POM) from a 20 hp boiler firing a variety of coals and processed fuel, (2) a survey to identify

equipment and manufacturers, and (3) a survey to identify processes for the production of smokeless coals. The experimental research indicated that modifications in design and operation of small stoker boilers have potential for emissions reduction and, coupled with utilization of processed coals, could achieve improvements over existing equipment. However, the conclusion was made that current economic and environmental factors are unfavorable for increased utilization of coal in residential and small commercial applications.

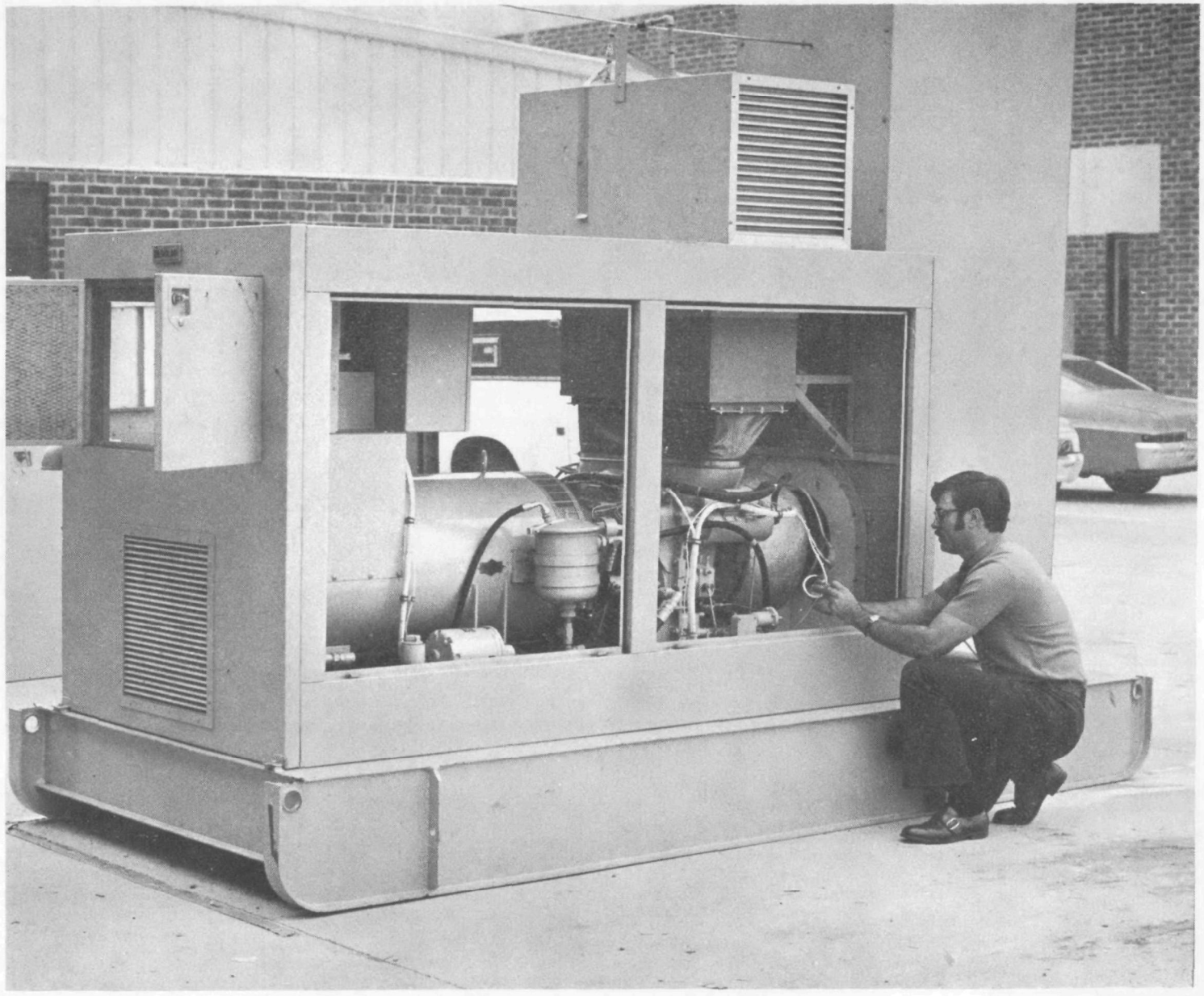
STATIONARY ENGINE COMBUSTOR TECHNOLOGY

A program recently initiated with Pratt and Whitney Aircraft is directed toward the development of low NO_x gas turbine combustor technology. The study will focus primarily on dry control techniques because of fuel economy and operational considerations and will specifically address utility size (25 MW and larger) gas turbine units. Since future gas turbines may be required to burn heavier fuel oils or low-Btu gas containing significant levels of ammonia, the contract will also address control of NO_x resulting from the conversion of fuel nitrogen.

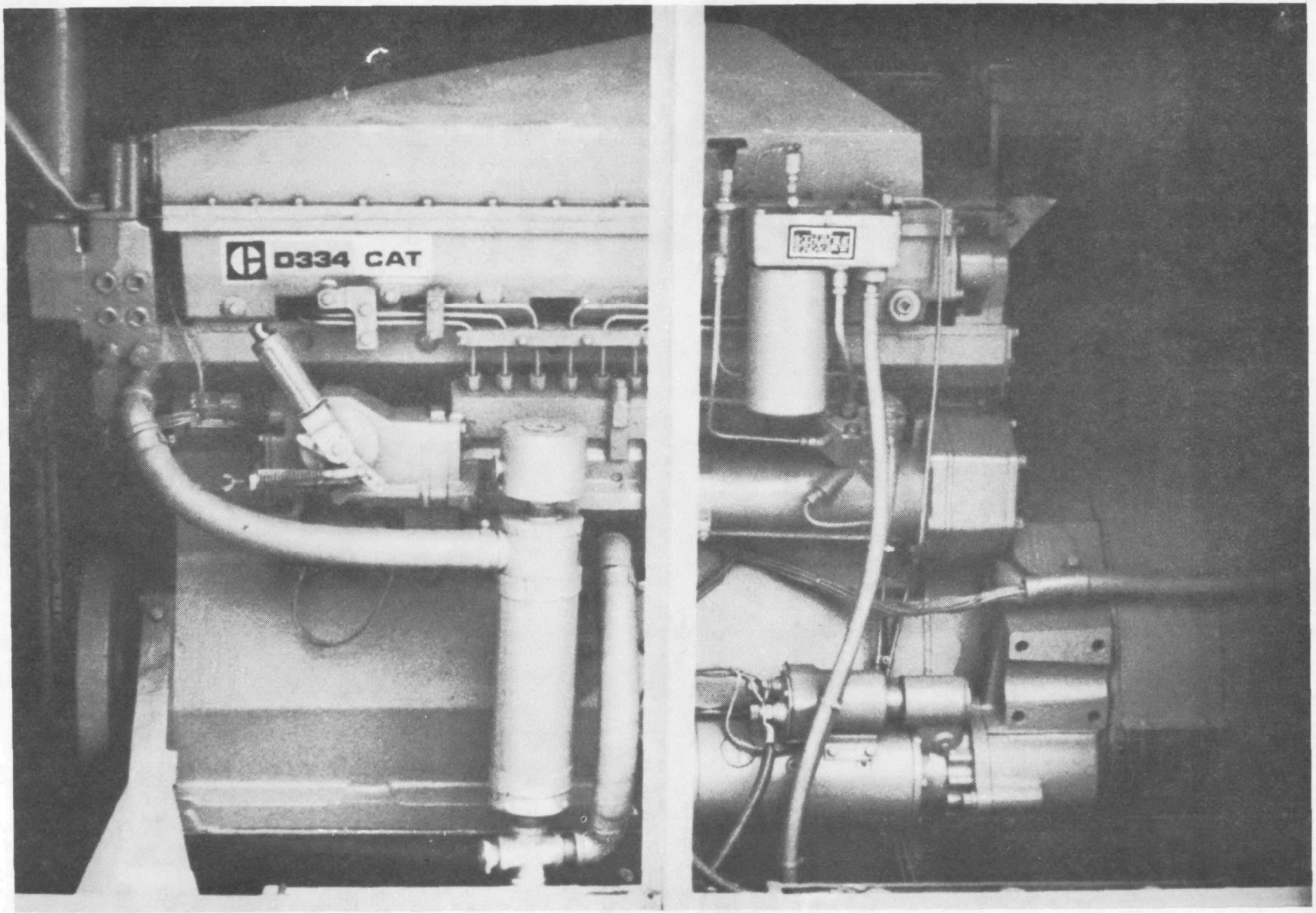
IERL-RTP has initiated an inhouse investigation of stationary engine emissions control. Two engines have been installed at IERL-RTP: a gas turbine and a precombustion chamber diesel. (See following illustrations.) Experimental work to date has concentrated on the gas turbine with initial indications that CO, HC, and fine particulate emissions are serious problems in the unit. Determination of the baseline emission characteristics resulted in the NO_2 fraction of total NO_x ranging from 45 percent at no load to a negligible amount at rated load. The water/oil emulsion proved beneficial as a NO_x reduction technique with a 33 percent reduction in NO and total NO_x with a 26 percent addition of water. The water fraction is limited by the characteristics of the emulsion to about 35 percent. At water injection rates sufficient to appreciably reduce NO_x levels, CO levels could increase by as much as 20 percent over the lowest emission rates.

Tests on the precombustion chamber diesel engine have recently begun. The NO_x levels appear to be reduced by use of an oil/water emulsion, but data are still being analyzed. A catalytic muffler was tested with the diesel in late 1976.

The CRB is selecting a contractor for a new program in low NO_x IC engine development. The purpose of the new program is to investigate internal combustion engine chamber design parameter effects on air pollutant emissions. The



225 KW gas turbine used for IERL-RTP in-house studies.



Precombustion chamber diesel (300 hp) for stationary engine controls development.

goal is the development of a design giving substantial reductions in NO_x emissions for large bore stationary IC engines while maintaining or improving current technology levels for CO, HC, and carbon particulate emissions and fuel efficiency. Both new design and retrofit to existing engines will be considered; designs will be developed for gas-fueled spark ignition and oil-fueled compression ignition 2- and 4-stroke engines.

INDUSTRIAL PROCESS EQUIPMENT AND AFTERBURNERS

The Institute of Gas Technology, under contract to IERL-RTP, has recently completed a survey of industrial process combustion. The objectives of the study were threefold: to identify the significant emission sources, to investigate the potential for effective emission controls, and to compile information on combustion equipment in use and future trends in process and equipment design. The iron and steel, cement, glass, aluminum and petroleum refining industries were identified as the major sources of combustion generated air pollution within the process combustion field. Recommendations were presented for NO_x control research and development programs for each of the significant processes within each industry.

A new program in 1976 will assess the pollution control and energy conservation potential of afterburner combustion systems. The primary objective of this study is to assess the environmental status of afterburner combustion systems and to develop guidelines for their application to minimize environmental problems. The program will completely analyze the problem of emissions from afterburner combustion systems and result in a standards-of-practice manual for applying these systems for emissions control without creating additional environmental problems.

FLUIDIZED-BED COMBUSTION SUPPORT

A contract has been awarded to Aerotherm for the design and construction of a fluidized-bed combustion (FBC) sampling and analytical test rig. This small pilot-scale equipment will be installed and operated in IERL-RTP's inhouse combustion research laboratory. This project is to provide for: comprehensive analyses of emissions from FBC, testing of alternative sampling and analytical procedures for FBC, and investigation of alternative add-on environmental control devices for FBC. Conceptual design has been completed, and installation and shakedown at IERL-RTP are scheduled for completion in mid-1977.

Fuels Research and Development

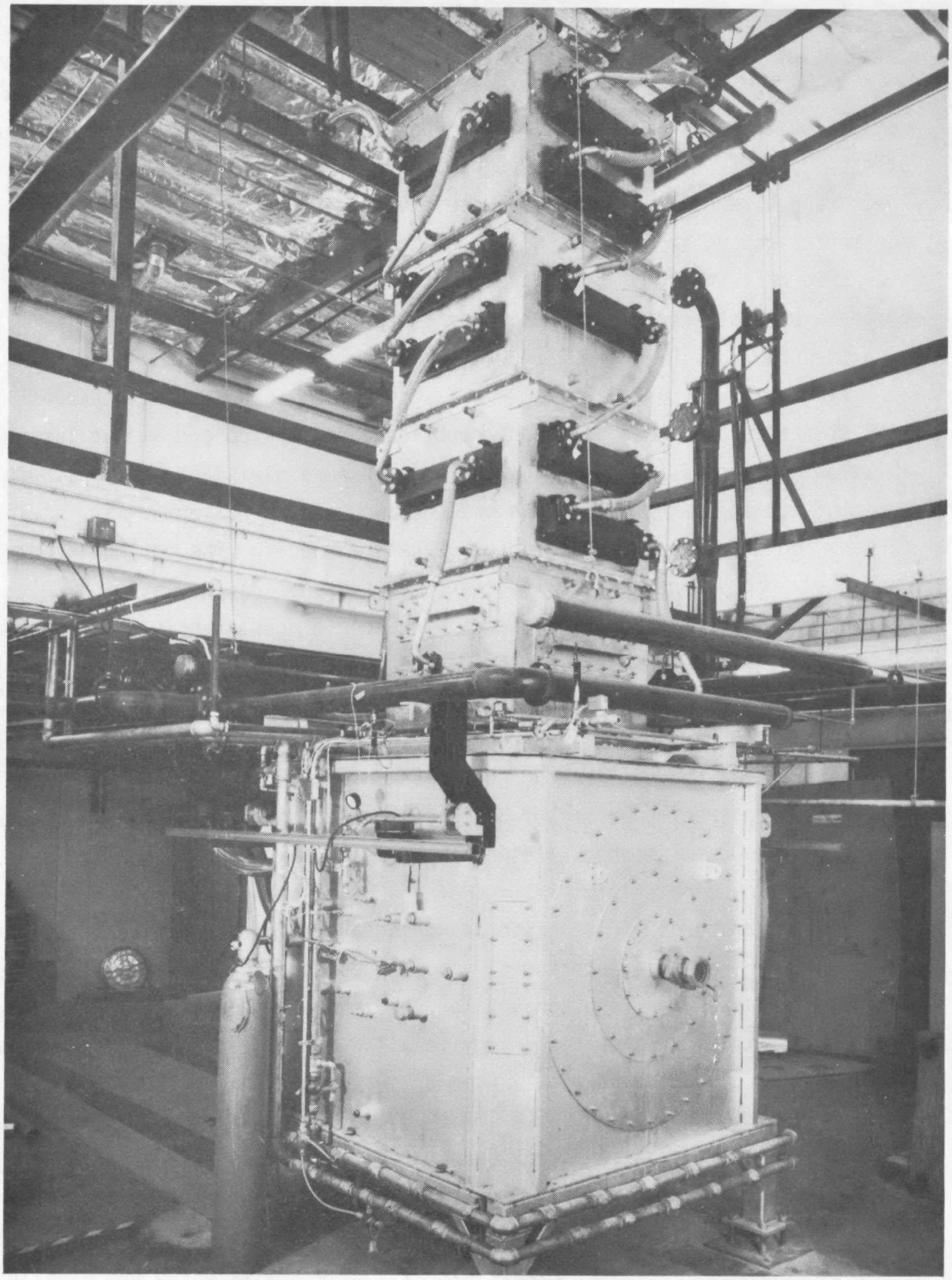
Fuels research and development studies are designed to develop generalized combustion control technology which is applicable to the control of NO_x and other pollutant emissions from the combustion of conventional fuels, waste fuels, and alternate new fuels. These studies are conducted on versatile experimental combustion systems with the specific purpose of developing combustion control technology for a specific fuel through single-burner design criteria or other combustion modification techniques.

IMPROVED BURNER/SYSTEM DESIGN

The Institute of Gas Technology has submitted a report on the investigation of the relationship between combustion aerodynamics and air pollutant emission characteristics of industrial gas burners firing natural gas. Three types of burners were studied: a scaled-down utility boiler burner, a kiln burner, and a baffle burner for steel reheat furnaces. The boiler burner showed NO_x reductions up to 91 percent with flue gas recirculation (FGR). For the boiler burner, use of a 30 degree ring nozzle consistently produced lower levels of NO_x emissions than the 60 degree gun nozzle. For the kiln burner, NO_x emission reductions as high as 68 percent were demonstrated. The preferred approach was to modify burner parameters to yield the flame shape and length that will produce minimum NO_x emissions. For the baffle burner, external flue gas recirculation of 30 percent resulted in as high as 90 percent reduction in NO_x emissions. Present emphasis in this study is on the assessment of the emission characteristics of low-Btu gases fired at ambient and elevated temperatures. Five gases are being investigated representative of the following industrial processes: Wellman Galusha-Air, Winkler-Air, Lurgi-Oxygen, Winkler-Oxygen, and Koppers Totzek-Oxygen. The overall objective of this program is to develop technology to allow optimum low-emission combustion systems to be designed and widely used by industry.

ADVANCED COMBUSTION MODIFICATION TECHNIQUES

Aerotherm Division of Acurex Corporation is conducting a 2 year IERL-RTP-funded pilot-scale furnace test program to develop advanced combustion control techniques for NO_x reduction. The test furnace (see following illustration), with a capacity of 3,165,000 KJ/hr (3,000,000 Btu/hr) is being operated in the wall-fired and tangential, corner-fired modes and is capable of firing coal, oil, gas, mixed fuels, waste fuels, and synthetic fuels from coal. The furnace



Multiburner experimental furnace (3 million Btu/hr).

was designed to give a temperature/time profile of the combustion gases representative of industrial and utility boilers providing for more direct translation of low NO_x firing configurations to full-scale equipment. The results of this program will guide demonstration tests on large-scale prototype units and provide suggestions for advanced equipment design. Preliminary baseline, uncontrolled tests showed very good correspondence with full-scale equipment with both the level of NO_x emission and the trend with excess air and preheat. Emphasis to date in the NO_x control development tests has been on optimizing procedures for staging by use of overfire air ports with the firing of pulverized coal in the wall-fired mode. Variables considered in the optimization tests include first-stage stoichiometry and mixing, first- and second-stage stoichiometry, overfire air preheat and injection pattern, total excess air and burner air preheat. Tests with a high-nitrogen Kentucky bituminous coal have shown NO_x reductions in excess of 75 percent when the primary flame zone is operated with 90 percent or less of stoichiometric air. At a total excess air level of 15 percent, NO_x emissions are in the range of 100 to 200 ppm (corrected to zero percent O_2) with staged combustion compared to a level of 850 ppm with normal, uncontrolled operation. These optimization tests are being extended to the firing of other coal types and to operation in the tangential firing mode.

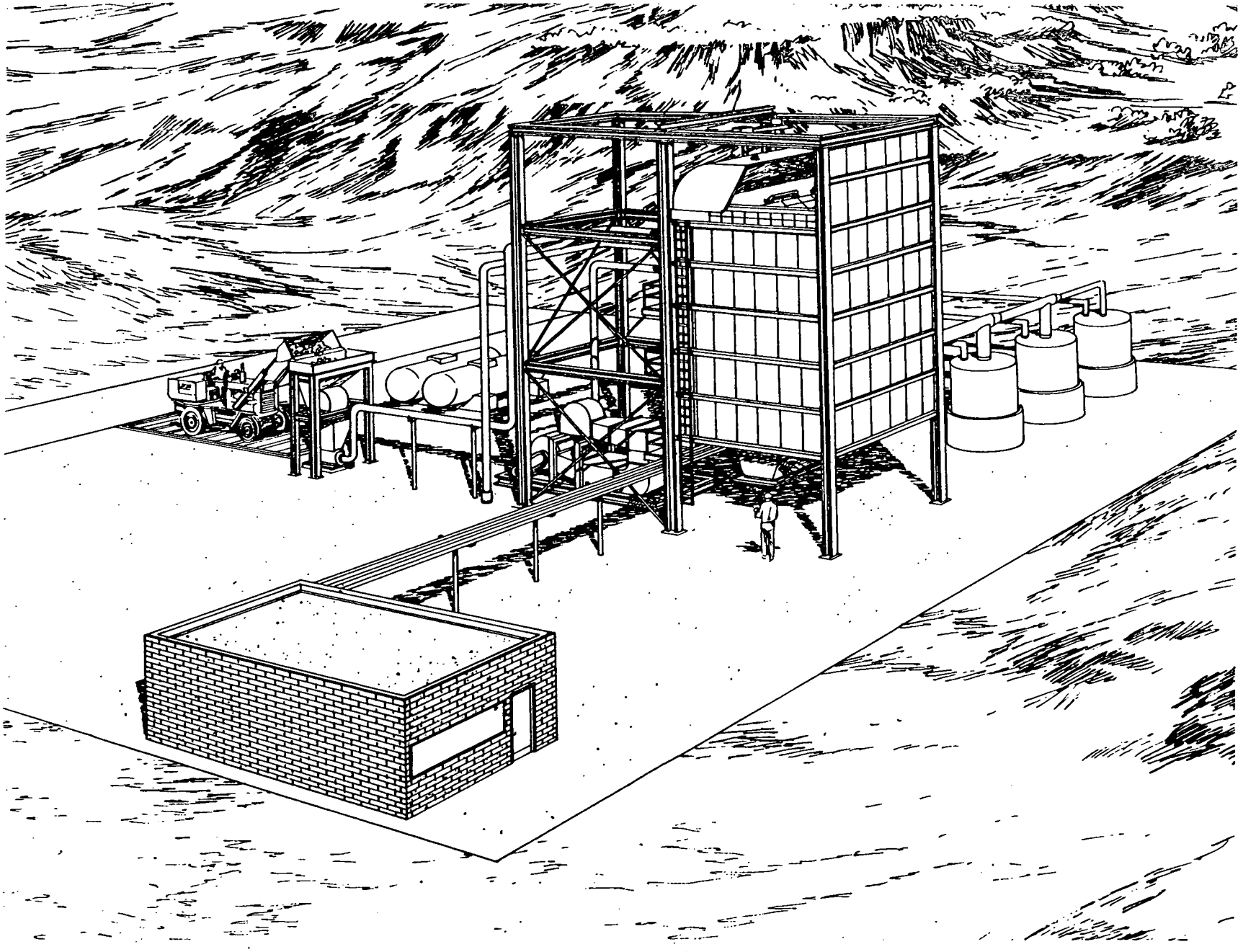
Rocketdyne Division of Rockwell International under IERL-RTP contract has recently completed a two-part study which resulted in the development of an advanced design residential warm air oil furnace which offers a 65 percent reduction in NO_x emissions and up to 10 percent increase in fuel efficiency. The initial effort involved the development of an optimal oil burner head through evaluation of the effects on NO_x formation of combustion air, swirl angle, nozzle spray angle, axial injector placement, flue gas recirculation, and combustion gas recirculation as a function of oil flowrate and overall excess air. The optimized burner was a nonretention gunburner with an optimized choke-diameter and swirl vanes. Hydrocarbon and CO emissions remained at commercial burner baseline levels while NO_x emissions were 1 g NO/kg fuel compared to 2 to 3 g NO/kg fuel at baseline. The second part of the program was directed toward development of an optimized burner/firebox combination. The final design utilized the optimized burner firing into the side of a vertical, cylindrical, fin-cooled firebox. At 10 percent excess air, NO_x emissions of 0.6 g NO/kg fuel were measured and increases in system efficiency of

up to 10 percent have been experienced. The system has recently completed a 500 hour laboratory performance test and will be ready for field testing in the near future. In addition to system development, the program has evaluated techniques for mass production of the optimized head. A final report is anticipated early in 1977. A new contract has recently been signed with Rocketdyne to extend the previous study to the investigation of feasible manufacturing processes for the new oil furnace designs. This contract calls for the manufacture of six units for use in field tests during the 1977 to 1978 heating season.

A contract has recently been awarded to Honeywell for an experimental study to investigate the characteristics of fuel oil atomization with a thermal aerosol oil burner using #1 and #2 fuel oils with emphasis on combustion efficiency, soot formation and design requirements. The effect of oil temperature and pressure, droplet size, inlet air temperature, air/fuel ratio and firing rate on flame luminosity, soot particle concentration and size distribution, NO_x emissions and flue gas temperature will be investigated. Additional measurements will be taken of CO, HC, smoke, O_2, CO_2, stack temperature and burner efficiency.

Ultrasystems, Inc. is under contract to IERL-RTP to define low NO_x burner design criteria for scale-up from an experimental 5 million Btu/hr optimized burner to practical size burners (125 million Btu/hr). The scaling criteria will assess the burner interactions occurring on full-scale boilers. The emphasis is on coal burners, although residual oil and combined coal/low-Btu gas are also to be studied. The burner test facility (see following illustration) was designed to allow evaluation of the performance of single burners of capacity up to 125 million Btu/hr and multiple burners totaling 60 million Btu/ hr in combustion chambers simulating commercial practice. The facility has been completed, and tests are scheduled for an early 1977 start date.

Ultrasystems is also conducting a study to generate low-emission burner concepts for residual oil combustion in packaged boilers. The study consists of an experimental phase (for the development of burner design concepts applicable to package boiler geometry) and an application phase (for testing a prototype burner in a field operating boiler). To date, a variety of burner configurations have been studied and an optimum has been identified which gives NO_x reductions in the range of 65 to 75 percent for three fuel oils with



Full-scale burner test facility (125 million Btu/hr).

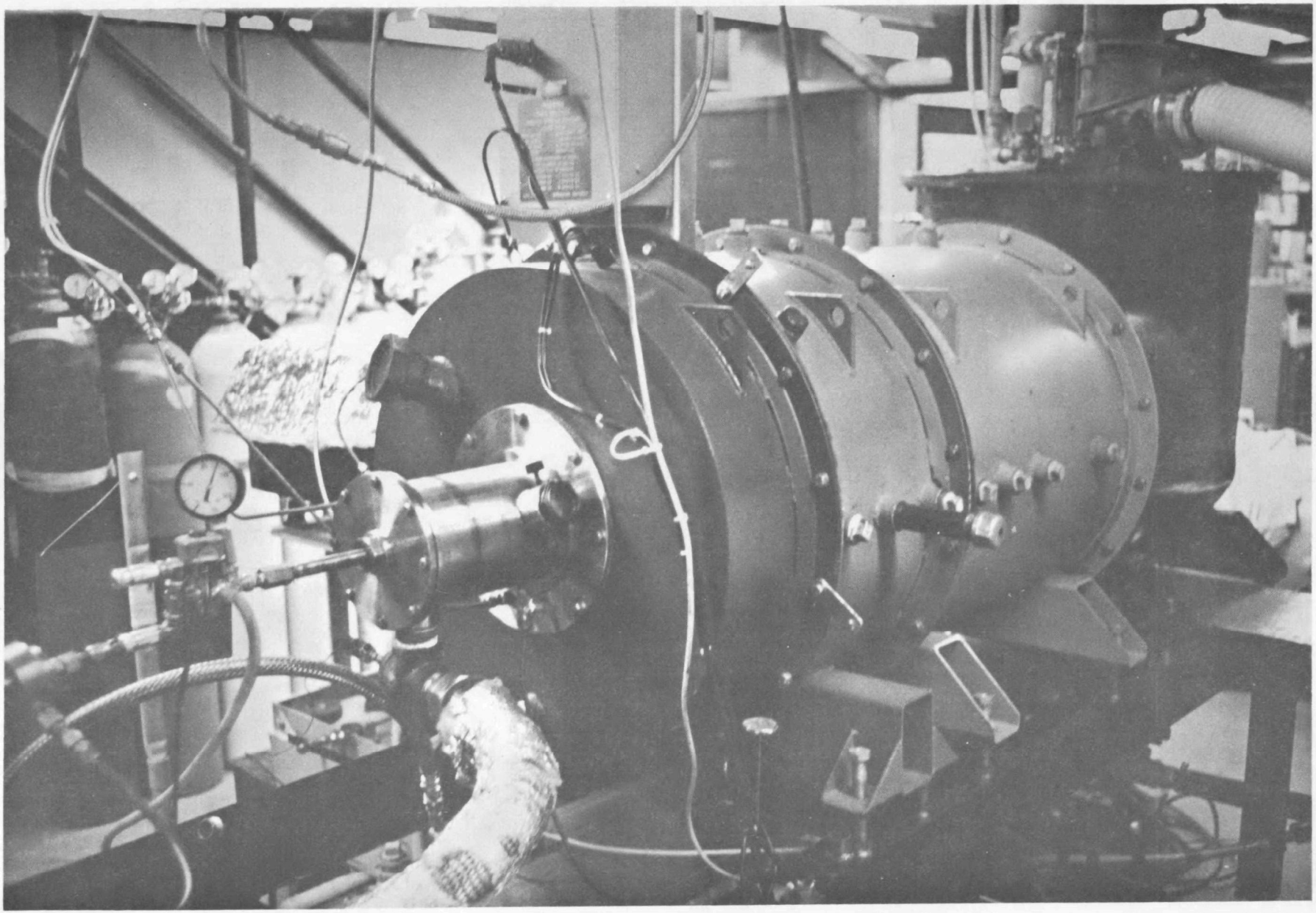
nitrogen content between 0.2 and 0.71 percent. The 0.2 percent nitrogen produced the lowest NO_x (120 ppm) while maintaining acceptable smoke levels. The results have also identified oil atomization conditions and fuel properties as important variables governing both NO_x and smoke levels. A contract is under negotiation to investigate these parameters as related to combustion air flow patterns.

CATALYTIC COMBUSTION

Aerotherm has recently been contracted by IERL-RTP to investigate the concept of catalytic combustion in which premixed clean fuels are reacted heterogeneously and at low temperature over catalytic monoliths. The overall objective of the program is to provide scale-up criteria to allow application to a wide range of stationary combustion equipment. The objective will be met by screening small-scale catalysts, performing small-scale system concept tests, and then scaling the results up to larger catalysts and systems. Results of the small-scale catalyst screening experiments have identified the graded-cell catalyst system as an acceptable concept for further testing. The graded-cell system uses a ceramic monolith with large cells at the combustion inlet, with subsequent monolith sections having progressively smaller cells. The catalyst used is platinum on an alumina washcoat. Tests with this system have shown good performance under lean conditions with both methane and propane fuels.

ALTERNATE FUELS

Past inhouse work has led to significant understanding of the formation and control of fuel NO produced from chemically bound nitrogen. The study has examined burner design, staged combustion, flue gas recirculation, and other techniques for control of both thermal and fuel NO from natural gas, propane, distillate and residual oils, and coal. The current thrust of this program is to define combustion and emission characteristics of alternate fuels, with emphasis now being placed on high-nitrogen coal-derived fuels. The program makes use of a versatile 300,000-Btu/hr experimental furnace with provision for precise control of combustion parameters such as fuel type and injection method, air rate and introduction method, air preheat, firebox residence time, and firebox and convective section heat removal rate (see following illustration). In addition, combustion modification techniques can be studied in a variety of applications. The initial class evaluated was alcohol fuels, which may be produced from coal gasification. They appear to have low emissions of NO and favorable combustion characteristics relative to conventional clean fossil



Experimental system for combustion modification and future fuel studies.

fuels. The next class of fuels to be studied will be low-Btu gas. A fuel gas generator has been designed and built by the Jet Propulsion Laboratory under an interagency agreement and will be delivered in 1977. The key process variables will be $CO/H_2/N_2$ ratios, fuel gas temperature, and NH_3 content.

Fundamental Combustion Research

IERL-RTP's fundamental research studies are providing an understanding of the important phenomena in the formation and destruction of pollutants during combustion. The basic knowledge is being translated to pilot-scale or field equipment studies to identify how the pollutant formation mechanisms can be controlled through combustion process modifications. The primary purpose of this program element is the application of fundamental research to practical NO_x control problems with emphasis on interpretation of test data, identification of further test programs, understanding and resolving operational problems, and suggestion of new research areas. A contractor will soon be selected to perform and subcontract a highly coordinated fundamental studies effort to consolidate the present programs. Program efforts will focus on application to field- and pilot-scale test results. Fundamental studies fall into two categories: combustion chemistry and combustion aerodynamics. Combustion chemistry is a complex process involving both fuel decomposition reactions and reactions of other flame species resulting in formation and destruction of pollutant species. The pollutant species of interest are NO_x, CO, HC, POM, carbon particulate, fuel ash, and SO_x. The emphasis in this program is on NO, although the formation and destruction of other oxides and reduced nitrogen species (e.g., HCN and NH_3) are also included.

COMBUSTION CHEMISTRY

The area of combustion chemistry can be further subdivided into two areas: pollutant formation related to combustion conditions, and pollutant formation related to fuel composition. These areas are reflected in the characterization of NO_x formed by fixation of atmospheric nitrogen at high temperature in the combustion process as thermal NO_x, and that formed from oxidation of nitrogen chemically bound in solid and liquid fossil fuels as fuel NO_x. For most fuels the total NO_x is the composite formed by both mechanisms.

A new experimental program has recently been awarded to United Technology Research Center for investigation of nitrate and sulfate formation and NO_x/SO_x interactions in flat flames in which various dopants will be used to promote formation of these species. Tests will be conducted to determine the extent

of in-situ probe interference on NO_x measurements in flames. A variety of measurement techniques will be used in this determination including microprobes, and optical and molecular beam mass spectroscopy. The data gained on inflame species concentrations will then be used to determine respective formation mechanisms through use of the PROF computer program described below.

A computer program has been developed at Aerotherm to analyze combustion and pollutant chemistry in premixed flat flames. The Premixed One-Dimensional Flame (PROF) code is a powerful tool being used to isolate governing kinetics by comparison to experimental data from past and on-going flat flame measurements. PROF has the capability of handling multicomponent diffusion, heat loss and wall effects characteristic of real flames. The systematic comparison of data and suggested kinetics is revealing the governing mechanisms of pollutant formation and destruction including those of inorganics and fuel nitrogen. Successful utilization of the PROF code will demonstrate the strong coordination between the experimental and analytical activities in fundamental studies.

Rockwell International's Rocketdyne Division is working, under an IERL-RTP contract, to establish the mechanism and chemistry of fuel nitrogen conversion to NO_x and other products. An experimental and analytical study has been carried out to investigate the chemical mechanisms involved in the conversion of fuel nitrogen to NO_x in combustion as a means of developing new approaches for minimizing fuel nitrogen conversion. The experimental work was composed of two portions: (1) pyrolysis reactions that the volatile fuel nitrogen compounds will undergo before approaching the flame front, and (2) combustion reactions of fuel nitrogen compounds and their reaction products. Pyrolysis experiments were conducted with model fuel nitrogen components, to measure the kinetics parameters that determine under what conditions typical fuel nitrogen structures will decompose and to identify the nitrogen-containing species that are formed. Common fuel nitrogen structures were represented by the model compounds pyridine, pyrole, quinilone, and benzonitrile. Fuel oils and coals were subsequently pyrolyzed under similar conditions, and the nitrogen containing inorganic products were measured and compared with those formed by the model compounds. Results indicate that HCN is a likely important intermediary compound in the formation of fuel NO_x from fuel-bound nitrogen in combustion. Burner studies of fuel NO_x reaction paths induced by the addition of HCN and NH_3 to premixed CH_4-O_2-Ar flames were also conducted to determine the kinetics of NO formation from these intermediaries. Results indicate that fuel NO

forms relatively slowly above the luminous zone in the same region where CO is oxidized to CO_2 or after. Results also indicate that NH_3 may yield HCN as an intermediary in the reaction to form NO. High NO yields were found with lean flames and low NO yields, with rich flames. A one-dimensional mathematical kinetic-diffusion model for the combustion of oil droplets and coal particles was developed to simulate the thermochemistry controlling the formation of fuel NO_x. The model is being used in a continuing effort to define the mechanisms and chemical paths leading to fuel NO_x. This contract has been extended to consider the pyrolysis of additional nitrogen containing fuels and pure compounds under oxidation conditions and further to explore the interactions of thermal and fuel NO_x formation mechanisms in flames.

The Massachusetts Institute of Technology, under IERL-RTP sponsorship, is investigating the formation of soot and polycyclic aromatic hydrocarbons (PCAH) in combustion systems. The objective of the study is the assessment of the production of particulate organic matter (soot and organic compounds) in well defined yet relevant combustion systems. Tests are being conducted on both laminar and turbulent atmospheric diffusion flames. Acetylene-oxygen laminar flat flame tests will be conducted at full equivalence ratios and burner exit velocities, and data will be taken on species concentrations, temperature profiles, and particle concentration and size distribution as a function of position in the flame. A water-cooled sampling probe will produce data on mass loadings of soot, number concentration, and size distribution of soot and concentrations of PCAH species in the turbulent diffusion flame. The apparatus is capable of burning either liquid or gaseous fuels with variation of equivalence ratios and full injection modes. Preliminary runs at an equivalence ratio of 1.0 showed a 4 order of magnitude increase in exhaust gas soot loading with a decrease in atomizing air pressure from 20 to 10 psig. This illustrates the extreme sensitivity of soot emissions and possibly PCAH emissions to changes in combustor firing practices in an effort to reduce NO_x.

Further studies by the Massachusetts Institute of Technology under IERL-RTP grant on the fate of coal nitrogen during pyrolysis and oxidation are now in progress. The overall objective of this study is the determination of the distribution of fuel nitrogen between char and volatiles and the fate of the char and volatiles under simulated combustion conditions. Tests are conducted on a controlled atmosphere isothermal furnace from which pyrolysis or oxidation products are withdrawn with a water-cooled probe. Long residence times are

simulated by allowing the coal particle to free fall through the furnace, and short residence times require a high preheated gas flowrate. A swelling bituminous coal and a nonswelling lignite of fuel nitrogen content 1.04 and 0.51 percent, respectively, have been selected. Preliminary data indicate that: (1) fuel nitrogen devolatilization is kinetically controlled, (2) significant amounts of nitrogen (about 70 percent at 1750°K) may remain in the char after devolatilization, (3) NO formation decreases with increasing fuel/air equivalence ratios, and (4) as much as 40 percent of the nitrogen may remain in the char at fuel/air equivalence ratios greater than 1.5. From these findings, current data indicate that nitrogen in the char may contribute significantly to NO_x emissions at temperatures below 1750°K but less at higher temperatures.

Under an IERL-RTP grant, the University of Arizona is conducting an experimental program to study the potential impact of fuel desulfurization on the formation of NO_x emissions. Laboratory flat flame experiments showed that the presence of sulfur may inhibit the formation of thermal NO_x. Data were inconclusive in establishing a relationship between fuel sulfur and fuel nitrogen conversion to NO_x. Further tests are presently being run on a larger furnace with swirling flames. These tests utilize dopants for both nitrogen and sulfur compounds in oil flames.

COMBUSTION AERODYNAMICS

Although combustion chemistry is responsible for the formation and destruction of pollutants, the actual conditions that exist in the flame zone are a strong function of the physical processes of combustion. Most practical combustors operate with diffusion flames where the fuel and air are introduced separately and mixing depends on the manner of introduction.

The flame zone is not of homogeneous composition; therefore, it is necessary to understand the role of combustion aerodynamics in pollutant formation.

United Technology Research Center (UTRC) is under contract to IERL-RTP to investigate the interaction of aerodynamics and combustion chemistry (in an idealized single-burner combustor) as a function of fuel type and various inlet parameters. During this study, detailed mapping of the local chemical composition, temperature, velocity, and turbulence profiles is being accomplished. Initial studies, using in-situ probes, investigated air preheat, stoichiometry and flame swirl. Further testing utilizing a laser-doppler-velocimeter (LDV) has recently been completed on gas- and liquid-fuel flames. The LDV allows for the determination of turbulent flame structure without

probe interference, and it measures turbulence level as well as mean velocity. Tests using the LDV on gas and liquid flames investigated the effect of swirl, fuel/air velocities and pressure level on the flow and NO_x formation. Results showed that large-scale turbulence was dominating both combustion and pollutant formation. These results indicate a need to identify the interaction of turbulence reaction kinetics within the flow field. Optical methods were utilized to measure the liquid spray characteristics from the injection of propane, iso-octane, and distillate oil. The results yielded good data on spray pattern, velocity profiles and droplet particle spacing. Reports on the UTRC experimental studies are due out soon. The UTRC experimental program is part of a coordinated experimental/analytical program to produce tools with which to evaluate practical test results. The analytical portion of the UTRC program is investigating the use of flow field computations to describe recirculating combustion flow. In addition, UTRC has been working to improve a computer code for rigorous solution of the Navier-Stokes flow equations. The major effort has been on improving the turbulence model and comparing model predictions with cold-flow and hot-flow furnace data. To date, simple chemical kinetics have been used. The strong influences of boundary conditions in general and of radial inlet profiles in particular on predictions have been demonstrated. It appears that advances in numerical differencing techniques will be needed before a generally applicable method can be used to develop a simplified treatment of combustion chemistry and aerodynamics.

APPLICATION FOR COMBUSTION CONTROL

A contractor is being selected to plan and execute a 3 year effort to integrate the results of prior and on-going fundamental studies and initiate new studies of combustion and combustion-generated air pollution. The new program, scheduled for an early 1977 start-up, will consolidate the diverse fundamental studies projects into one large highly coordinated program whose efforts will be focused on application to field- and pilot-scale test results. The control program has progressed to the stage where preferred approaches to NO_x control have been well defined. Consequently, the fundamental studies program is being structured to focus on needs in data interpretation, generation of new research and development directions, and operational problems.

FUEL PROCESSES

The programs being conducted under the supervision and direction of the Fuel Process Branch are a part of the Energy Assessment and Control Division's

5 year study of multimedia-environmental-assessment/control-technology-development for fossil-fuel-based technologies. These programs encompass two major areas: physical and chemical coal cleaning, and synthetic fuels from coal. Contracts supported within these two major areas have the following purposes:

- to conduct a multimedia (air, water, and land quality) environmental assessment of specific coal cleaning and synthetic fuels from coal processes;
- to develop control technology for these processes; and
- to develop physical and chemical coal cleaning techniques.

The multimedia environmental assessment contracts are studies designed to identify and quantify pollutants that would be discharged to the environment, and to determine the level of pollutant control achievable, through the use of best available control technology and technology likely to be developed in the near future, for specific coal cleaning and synthetic fuels from coal processes. (See following diagram.) The achievable pollutant control levels will then be compared with existing standards, estimated multimedia environmental goals (desirable levels to be defined by EPA), and bioassay specifications (toxicity to biota) to define control technology priorities.

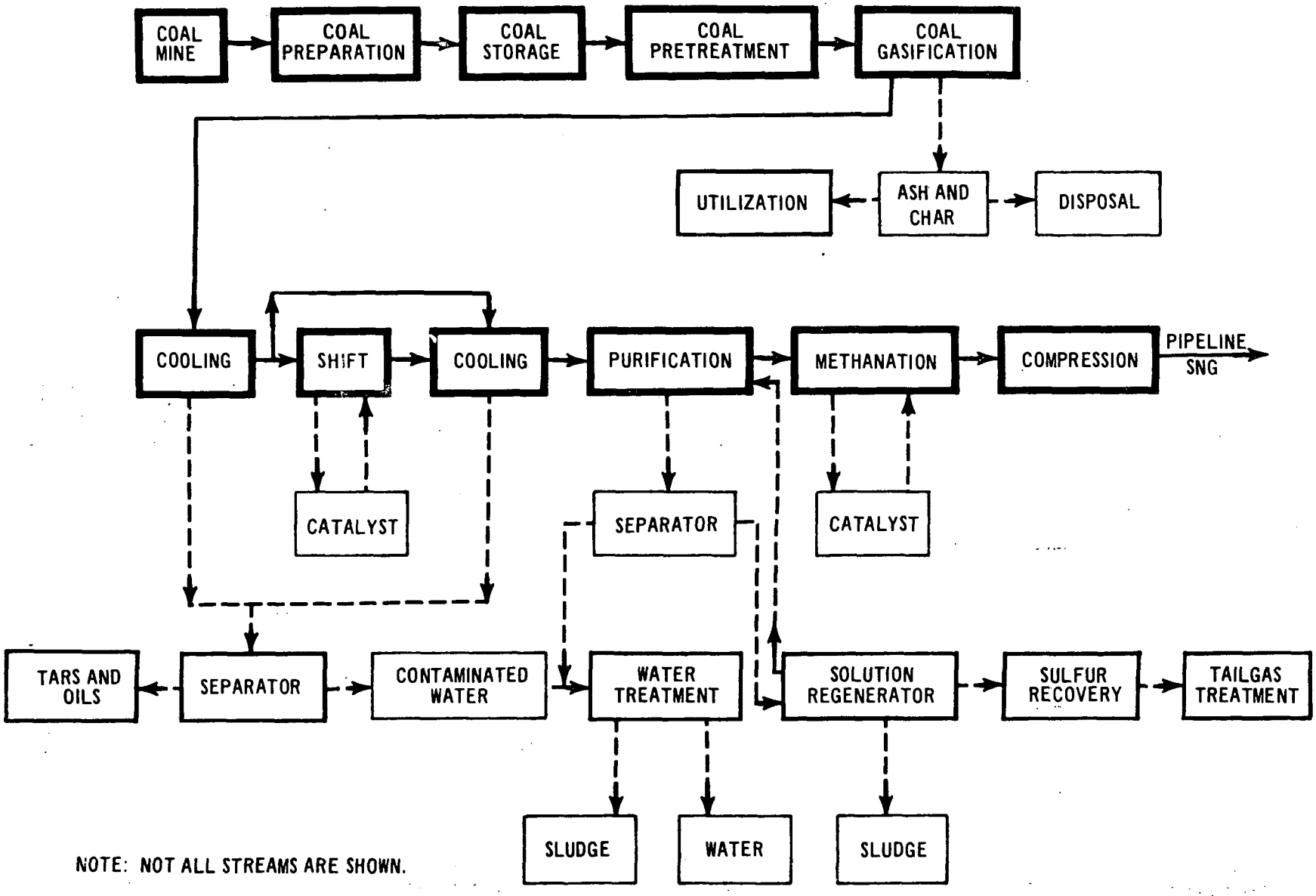
The control technology development contracts are aimed at applicability of existing control technology, modification of existing technology, and development of technology after specific control needs have been defined. This technology development is being accomplished through basic and applied research and development engineering analysis, and specific control process development and evaluation.

Fossil Fuels--Coal

COAL CONTAMINANT CHARACTERIZATION

The use of coal depends on several factors. Environmentally, the effects of its use on the total environment (air, water, solid effluents, land use) are major factors. As a first step in determining these effects, the coal constituents must be clearly and accurately defined. A multifaceted effort toward this goal is currently underway at IERL-RTP.

The Illinois State Geological Survey was awarded a 3 year grant extension (EPA Grant 2804403) to provide continued support for an investigation concerning the nature, distribution and origin of mineral in coal. The program period is April 1976 to April 1979.



Hypothetical simplified gasification flow diagram.

The major areas of interest which will be investigated are:

- The mode of occurrence and distribution of trace elements and minerals in coal.
- The mineralogy and genesis of iron and zinc sulfide minerals in coal seams.
- The washability of minerals and their constituent chemical elements by conventional washing techniques.

The results of this work will provide the EPA with mineral distribution maps primarily for the Illinois Basin and will generate information on the washability of specific minerals and related elements which can be used in coal utilization strategies.

A number of whole coals and wash residues have been analyzed to date. Analytical data are currently being interpreted and significant results will be submitted in quarterly reports.

The Illinois State Geological Survey was awarded a 36 month, 138 man-month contract (EPA Contract NO. 68-02-2130) to analyze a number of coals, coal by-products, and coal wastes for potential pollutants, to identify the controlling factors by which they are bound or released, and to determine their toxicity and possible mechanisms for control. The contract period is November 1975 to November 1978.

The overall technical objectives of the program are:

- To characterize the chemical, physical, and mineral properties of coals, coal by-products, and coal wastes.
- To investigate the effects of pyrolysis on the distribution of trace elements between the volatile components and the residue.
- To provide data on the solubilities and toxicities of potential pollutants contained in solid coal wastes.

Results of this work can be used to estimate the mineral solubilities for coal wastes over a wide range of disposal environment conditions.

A number of U.S. coals will be analyzed for major, minor, and trace elements. Several of the coal samples will be demineralized with acid and analyzed again to determine the amount of all organically combined elements. From a pyrolysis of this mineral-matter-free coal and other experiments, a material balance will evolve which can be used to predict a pattern of behavior for minor and trace elements in a coal utilization system. In addition, the

pyrolysis experiments will be used to relate the coal microstructure, surface area, rank, and petrographic constituents to volatile emissions.

Solid wastes from a number of coal utilization processes will also be analyzed for potentially hazardous materials. Standard fish toxicity tests will be used to determine the biological toxicity of the water soluble constituents obtained from the solid wastes. Leachates will also be contacted with clay or clay mixtures under both aerobic and anaerobic conditions to determine their effectiveness in the attenuation of hazardous pollutants.

All phases of this program have been initiated to date. An analysis for three coals, both whole and demineralized samples, has been completed. The first of three annual reports is to be completed by January 1, 1977.

The Illinois State Geological Survey was awarded an 18 month contract (EPA Contract No. 68-02-1472) to analyze some 170 U.S. coals and develop an extensive survey of the concentration and distribution of the trace and minor elements present. The contract period was June 27, 1974 to December 26, 1975.

The overall technical objectives of this contract were to perform an extensive survey of over 40 trace and minor elements, to determine their nature of association in the coal matrix, and to assess the vertical and areal distribution of these elements in a given coal seam.

This program provides the EPA with a complete and accurate survey of the concentration and distribution of potentially hazardous trace elements in coals from the major producing areas in the United States. It also furnishes some of the basic information necessary to judge the environmental soundness of various coal utilization systems.

All laboratory work has been completed. Much of the data has been compiled and the final report will be issued in mid-1977.

COAL CLEANING

The coal cleaning program includes both physical and chemical approaches to the cleaning of coal. This program includes the multimedia environmental assessment of specific processes presently used or being developed, and the development and demonstration of new processes for the removal of sulfur and other contaminants from coal.

The contract technology development portion of the coal cleaning program will include characterizing coal with respect to polluting constituents, defining the technical and economic suitability of cleaning processes to these coals, and then developing advanced cleaning processes from bench-scale through pilot-scale to make them commercially available.

Environmental Assessment

A 3 year contract (EPA Contract No. 68-02-2163) was awarded to Battelle-Columbus to perform a comprehensive assessment of environmental pollution which results from coal transportation, coal storage, coal cleaning (physical and chemical), and waste disposal. The contract period is July 1976 to July 1979.

The overall technical objectives for this contract are:

- To assess the environmental discharges from coal cleaning and related operations by conducting actual plant tests for all major processes in use, and by a detailed study of the processes under development.
- To develop a strategy for the evaluation of those processes which utilize clean coal and could influence the overall environmental impact of coal cleaning.
- To generate preliminary conceptual designs for coal cleaning processes that are environmentally more sound than existing systems.
- To provide a revised technology overview which will include a detailed update of all coal cleaning technology.

An environmental assessment effort will be the major emphasis of this program and will involve the compilation of detailed process descriptions obtained from literature, unpublished process data, and actual plant visits. Extensive inplant testing will be conducted to establish emission levels of these pollutants and better define the process descriptions. Computer models for each process and other information will be used to provide a comparison of costs and performance.

Technology Development

PHYSICAL/MECHANICAL COAL CLEANING--The Environmental Protection Agency and the United States Bureau of Mines have had a series of interagency agreements to cooperatively assess the economic and environmental impact that coal cleaning technology can have on the coal utilization industry. Several contracts have been awarded to accomplish the following overall technical objectives for the program:

- Determine the sulfur (and ash) reduction potential of U.S. coals.
- Develop and demonstrate the two-stage flotation technique for separating pyrite from fine size coal.
- Determine the reaction mechanisms and potential environmental problems for the Bureau of Mines Coal-Pyrite Flotation Process.

- Evaluate the use of magnetic separation in coal preparation.
- Assess the impact that physical coal cleaning will have on sulfur oxide emissions from stationary combustion sources.
- Appraise control techniques for the treatment of water effluents from coal processing plants.
- Develop a computerized model which will predict the performance for a given coal preparation plant configuration.
- Design a 10 to 25 tph coal preparation pilot plant.

Much of this work has been completed, and each study is listed below.

(1) Washability Evaluation of U.S. Coals (Bureau of Mines, on-going project since February 1965)

(2) Adsorption-Desorption Reactions in the Desulfurization of Coal by a Pyrite Flotation Technique (University of Utah, August 1974)--This work will be continued during the next year along with the study of residual reagents left in the water and their potential effect on subsequent coal flotation in an operating preparation plant.

(3) Pyrite Flotation Circuit Lancashire No. 25 Plant No. 25 (Heyl and Patterson, Inc., November 1974) (demonstration of the two-stage flotation technique)

(4) Engineering/Economic Analyses of Coal Preparation with SO_2 Cleanup Processes for Keeping Higher-Sulfur Coals in the Energy Market (Hoffman-Muntmer Corp., June 1975)

(5) Control of Black Water in Coal Preparation Plant Recycle and Discharge (Pennsylvania State University, June 1975)

(6) Surface Phenomena in the Dewatering of Coal (Syracuse University, June 1975)

(7) Computer Simulation of Coal Preparation Plants (University of Pittsburgh, December 1975)

(8) Magnetite Recovery in Coal Washing by High Gradient Magnetic Separation (Massachusetts Institute of Technology, March 1976)

(9) High Gradient Magnetic Separation for Removal of Inorganic Sulfur from Coal (General Electric Co., March 1976)

(10) Recovery of Fine Size Waste Coal (University of Alabama, March 1976)

(11) Professional Services for Design and Engineering Data for the Coal

Preparation Process Facility, Equipment, and Structural Support (Birtley Engineering Corp., April 1976)

(12) Architect-Engineering Services (William-Trebilcock-Whitehead, July 1976)

(13) Homer City Coal Cleaning Plant Demonstration, Pennsylvania Electric Co.--This cooperative agreement (between the EPA, the Pennsylvania Electric Co. [a subsidiary of General Public Utilities Corp.], and the New York State Electric and Gas Corp.) outlines a program to test and evaluate the use of physical coal cleaning to meet sulfur dioxide (SO_2) and other possible air pollution emission regulations. The test and evaluation programs will focus on the advanced technology coal preparation plant being built at the Homer City Generating Complex. The program, as initially outlined, will have a 4 year term which will begin in mid-1977.

The overall technical objectives for the Homer City program are to:

- Demonstrate the effectiveness of the multiproduct coal cleaning operation for meeting Federal and state SO_2 emission regulations.
- Develop the performance and cost information needed by others for the optimum use of physical coal cleaning as a pollution control strategy.
- Test alternative coal preparation techniques.
- Assess the environmental factors associated with coal cleaning including those affecting air and water quality and solid waste disposal.

The first step in accomplishing the program objectives is to finish the construction of the coal preparation plant and bring it into full production. This will be accomplished in two stages. Initially the facility to produce moderate-sulfur coal for the two existing boilers will be made operational. In conjunction with this, a second section of the facility will be constructed and brought on line to produce low-sulfur coal for the new boiler (estimated completion date is October 1977).

The coal preparation facility is currently under construction, and the statistical analysis review of sampling procedures in nearly complete.

Actual inplant testing will begin with a baseline study to determine existing pollutant levels and power plant performance. Upon completion of the coal cleaning facility, an initial operating period will be allowed to insure the reliability of test results. Accumulated test data will be used to characterize the performance of the coal preparation and power plants under a

variety of conditions. Operating and maintenance data will also be collected to evaluate the equipment and operating costs for all areas of the generating complex.

CHEMICAL COAL CLEANING--The objective of this program area is to develop and demonstrate advanced chemical coal cleaning techniques that would increase the availability of lower-sulfur coals that upon combustion would meet various state and Federal regulations. Chemical coal cleaning techniques would provide an alternative control option to smaller combustion sources that, because of cost on physical restrictions, may not be able to use other alternative control techniques. Technologies now under development and evaluation include:

- Meyers Process--TRW
- Flash Desulfurization--Institute of Gas Technology
- Hydrothermally Treated Coal--Battelle
- Microwave Desulfurization--General Electric.

MEYERS PROCESS--TRW Systems and Energy Group was awarded a 17 month contract (EPA Contract No. 68-02-1880) to design and construct a Reactor Test Unit (RTU) to demonstrate the Meyers Process, the chemical removal of pyritic sulfur from coal. Support work for this program is currently being conducted by TRW under EPA Contract No. 68-02-2121. The program period for the construction of the RTU is September 1975 to January 1977.

Overall technical objectives for this contract are:

- To design and construct a Reactor Test Unit (at TRW's Capistrano Test Site) which will be capable of continuous operation at the nominal rate of 250 to 750 lbs of coal per hour,
- To demonstrate the operability and economic feasibility of the Meyers Process for chemical removal of pyritic sulfur from coal, and
- To provide the design data base needed for the commercialization of this process.

A final design and a construction cost estimate was prepared by a subcontractor, the Ehrhart Division of Procon. After EPA approval of the design, a detailed design package suitable for fixed-price construction bidding was prepared by Ehrhart. All process equipment and major materials will be procured by Ehrhart and delivered to TRW's Capistrano Test Site by the various vendors. TRW will provide design and procurement interface and technical direction during this activity. Test planning data will be obtained at the bench-scale level for the two coals which are selected for plant operation.

TRW has improved the site, at its own expense, for the Reactor Test Unit. A construction subcontractor was selected through competitive bidding. The RTU will be constructed, with construction monitoring to be provided by TRW.

Construction of the RTU was initiated in October 1976. The subcontractor estimated completion of the plant by mid-March 1977. This estimate assumes no delays in the construction due to weather. All equipment, materials, and manpower to maintain the project are on the job site.

Concurrent with the RTU construction contract, TRW Systems and Energy Group was awarded a contract (EPA Contract NO. 68-02-2121) to define bench-scale operating parameters and to provide engineering analysis and evaluation for the Meyers Process pilot plant. The program period for the laboratory work is November 1975 to July 1977.

Overall technical objectives for this program are to:

- Support the RTU program.
- Investigate the potential of using chemical desulfurization, the Meyers Process, to adequately reduce the sulfur content in several grades of coal which will be used in the pilot program.
- Identify and evaluate possible sulfur recovery schemes.
- Develop acceptable storage methods for the sulfur products which will be produced.
- Determine the environmental discharges and control technology applicability to eliminate adverse effects.

FLASH DESULFURIZATION--The Institute of Gas Technology (IGT) was awarded an EPA contract (No. 68-02-2126) to develop a process for the treatment of coal to produce an environmentally acceptable solid fossil-fuel product.

The objective of the present program, a continuation of two previous EPA contracts, is to determine the operating conditions for the key steps in the IGT process to desulfurize coal by thermal and chemical means on both a bench- and pilot-scale unit. In the initial contract, lime was used to remove the sulfur from coal in a fluidized-bed reactor which subjected the feed to almost instantaneous heatups. Pyritic sulfur was removed to low levels; however, the quantity of organic sulfur removal was not greater than the coal devolatilization rate. Studies indicated that rapid heatup tended to inhibit organic sulfur removal by fixing it into the coal lattice. Consequently, the second contract was directed toward a program where the equipment would give controlled heatup rates.

A thermobalance, using small samples and relatively high gas flow, was used to establish the parameters for pretreatment of various coals in the redesigned batch reactor. The results of the program indicated promise for the process and led to the present contract for further study.

On the laboratory scale, a number of coals will be investigated to determine their susceptibility to desulfurization by chemical and thermal treatment.

The most satisfactory mode for the process will be determined on the small bench-scale and will be extended further to a 10 inch diameter pilot-scale reactor to define the scale-up parameters. The entire processing scheme will be integrated and the overall conceptual design of a Process Development Unit (PDU) will be prepared for a 10 ton/day facility. A technical and economic evaluation of the process will be performed.

The approach which will be used to accomplish the program objectives is defined in six phases: Coal Selection and Characterization; Laboratory Experimentation; Reactivity and Kinetic Studies; Product and By-Product Characterization; Process Development Unit (PDU) Design; and Technical and Economic Evaluation.

Phase I is completed. Coals selected were: Western Kentucky No. 9, Illinois No. 6, Pittsburgh seam West Virginia, and Pittsburgh seam Pennsylvania. Specifications for pretreatment include: operating temperature--750°F; minimum residence time--30 minutes; oxygen feed--1 scf O_2/lb dry feed; and fluidization velocity--1 ft/sec, measured at operating conditions.

Phase II is completed. With pretreatment, sulfur removal with subsequent hydrotreating is more effective to prevent agglomeration and decreases hydrogen treatment requirements.

Phases III and IV have been initiated. Thermobalance testing is complete. Batch reactor testing is continuing, as are exploratory tests on the pilot unit. The pretreatment of the 10 inch unit has been defined and exploratory tests on the unit have begun. Operations are on schedule and operability proven in two sizes of equipment. In analyzing the thermobalance tests, the benefit of lime is minimal and the treated material recovered is consistently greater in the no-lime tests than in the tests using the lime-pretreated coal mixture.

HYDROTHERMALLY TREATED COAL--Battelle-Columbus Laboratories was awarded a contract (EPA Contract No. 68-02-2187) to assess the economic and environmental impact that can be expected from coal desulfurization by the Hydro-

thermal Coal Process (HCP). The contract period is October 1976 through November 1978.

The overall technical objectives for this program are:

- To improve the economic viability of the HCP by reducing the cost of two segments of the process (leachant regeneration and solid/liquid separation), and
- To evaluate the use of hydrothermally treated coals in conventional boilers and furnaces.

The first phase of this program will investigate the use of iron oxide and zinc oxide to regenerate spent leachant and facilitate recycle. The metallic oxides are efficient in removing sulfide from spent leachates, but do not remove oxidized sulfur ions or trace elements. Oxidized sulfur ions inhibit the desulfurization process and trace elements (if accumulated) could contaminate the coal product. A series of recycle experiments will be conducted to determine how many times the regenerated liquor can be recycled and the possible need for removal of a side-stream to prevent product contamination. Additional tests will also be made to determine the most effective method to prohibit sulfide oxidation or to reduce the oxidized forms during the regeneration step.

A second aspect of the economic evaluation will be to investigate the relationship between particle size and water requirements in the solid/liquid separation segment of the process. Larger size coals may reduce the amount of entrained water leaving the process and thus reduce the cost for makeup water. Vacuum filtration, centrifugal filtration, and oil agglomeration will also be explored as possible methods to reduce water contaminant.

Finally, the results of these various studies will be integrated into the overall Hydrothermal Coal Process and an economic analysis will be conducted to define optimum operating parameters.

In the second phase, selected hydrothermally treated coals will be evaluated in stoker, pulverized coal, and coal-slurry combustion units. Both raw and conventionally cleaned coals will be made for sulfur and trace elements to evaluate the HCP as a control technology for sulfur emissions and to assess the overall environmental impact it will have.

The work plan for this project has been revised and submitted for approval. The experimental program was started in November 1976. Combustion studies have been postponed until additional funding is made available.

MICROWAVE DESULFURIZATION--The General Electric Company was awarded a contract (EPA Contract No. 68-02-2172) to study the basic mechanism of microwave treatment of coal as established by that Company in order to better define the technical and economic merits of the system as an environmental control system. This study will involve a comprehensive experimental program for investigation of process parameters in order to identify the technical advantages and disadvantages of the process. The program period for this effort is August 1976 through November 1977.

SYNTHETIC FUELS

IERL-RTP is very much involved in the emerging industry of coal conversion or synthetic fuels. There is a great need for on-going environmental research and development in this area. The synthetic fuel industry will consist of very large and complex plants and will involve great discharge quantities, large consumptions of water, air, and fuel, and massive effects on extraction of resources in relatively small areas. It thus presents a number of perplexing questions concerning the environmental impact of commercial technology still in its early stages.

Types, compositions, and quantities of discharge streams have not yet been completely identified; therefore, attendant pollutants that might result in significant health effects or other environmental effects are still unknown. Full control needs still await a reasonable technology and pollution determination. The degree of control of discharges from existing control techniques has not been quantified. IERL-RTP's programs for environmental assessment and control technology development are currently addressing these problems.

Cameron Engineers, Inc. has been awarded a 1 year contract to provide systems analysis and program support to the IERL-RTP Synthetic Fuels program, primarily in the areas of coal preparation, coal liquefaction, coal gasification, and shale oil processing. The contract is designed to provide EPA with a viewpoint independent from that of other EPA contractors working in the environmental assessment, environmental control technology development, and process technology development areas. Technical information is being provided through background functions (such as literature surveys and reviews of technical reports), coordination functions, communication functions, and program planning support.

Environmental Assessment

Water Purification Associates was awarded a contract (EPA Contract No.

68-03-2207) to recommend measures which will minimize water pollution and consumption by coal conversion plants and to determine the general environmental impact on water that can be expected from the commercialization of synthetic fuel projects in the western coal and oil shale bearing regions. The program period is June 1975 to October 1978.

The overall technical objectives for the program are to:

- Assess the general water use and pollution control alternatives for specific coal gasification and liquefaction processes.
- Determine, from an analysis of 40 to 50 commercial-scale synthetic fuel plants anticipated for the western U.S., the environmental impacts that can be expected from water-related site and process characteristics.
- Ascertain the level and mix of synthetic fuel industry that could be supported by 1990, based on a projection of locally available fresh and saline surface and groundwaters.

HIGH-BTU GASIFICATION--Individual reports and a summary report have been prepared on all synthetic fuels technology reviewed to date. Also available are reports on possible or probable trace elements from gasification processes and specific listings of probable pollutants from processes such as the Hygas process. Two more trace element reports are in preparation. Individual reports have included the high-Btu processes: Lurgi, Synthane, Bi-Gas, Hygas, and CO_2 Acceptor.

Extensive work will begin soon on an in-depth assessment of specific coal processes for environmental impacts associated with high-Btu conversion processes. This will include a complete environmental assessment of emissions and effects. An inhouse gas cleaning test rig is planned, and new data acquisition capability is being developed.

LOW-BTU GASIFICATION--Considerable effort is being exerted toward a comprehensive environmental assessment of the low-Btu gasification process.

Radian has been awarded a contract (EPA Contract No. 68-02-2147) to perform an environmental assessment of low- (and intermediate-) Btu gasification and its utilization. Contract period is March 1976 to March 1979.

The overall technical objectives of this contract are to:

- Perform a comprehensive multimedia environmental assessment of coal conversion processes which produce, and end-use options which consume, low- and/or intermediate-Btu gases.

° Define the control techniques which will have to be applied to guarantee the environmental acceptability of this technology.

A goal of this study is the development of a predictive model which can be used to predict impacts and specify control needs for a given facility based on feedstock properties, process configurations, operating conditions, and regulatory constraints.

The environmental assessment will involve a detailed process engineering analysis of all feasible options for producing low-Btu gas from coal, and methods of utilizing the resulting product gases. A unit operations or modular type analysis will be used in this assessment to facilitate comparisons of alternative process configurations.

Factors such as site characteristics and availability, the necessity for the development of new analytical methods, and alternative approaches will be considered in order to determine the most cost-effective approaches to be used in obtaining the required basic process data. Tests are planned at existing commercial plants and pilot plants in the U.S. and abroad.

Eleven technical directives (TDs) have been issued relative to this contract which serve to further define and guide the program effort. These include:

TD-1 - Work Plan and Support
TD-2 - Preparation for Data Acquisition
TD-3 - Initial Control Technology Assessment Reports
TD-4 - Initiation of Test Programs Development
TD-5 - Initiation of Technology Overviews
TD-6 - Initiate Preliminary Impact Assessments
TD-7 - Program Support Data Base
TD-8 - Data Base Analysis and Process Engineering
TD-9 - General Support Activities
TD-10 - Continued Development of a Test Manual

The United Technologies Research Center was awarded a contract (EPA Contract No. 68-02-2199) to perform a fuel gas environmental impact study. The contract period is from September 1976 to October 1977.

The objective of the study is to evaluate the technical, economic, and environmental intrusion characteristics of integrated coal gasification/sulfur removal/combined-cycle power systems utilizing additional gasifier types that were not studied in the previous contract. The approach to meeting the objective includes the following areas of study.

- Advanced gasification systems--A comparison of advanced technology gasifiers: one having integral cleanup of sulfur compounds; the other requiring external cleanup.
- Gasifier effluent models--Gasifier performance for different operating conditions and an evaluation of a two-stage entrained flow type (BCR) gasifier for both air- and oxygen-blown operations.
- Comparison of BCR type gasifier--An integrated coal gasification-advanced cycle power generating system.
- Cleanup system identification--Low- and high-temperature cleanup systems.
- Define new integrated systems--Combination of the gasifier/cleanup systems and an integrated combined cycle power system.
- Revision of previous systems studied under the contract.
- Environmental definition.

Results of the previous contract showed the potential for low-cost, environmentally acceptable electric power from integrated power systems consisting of coal gasifiers, low- and high-temperature sulfur cleanup processes, and combined cycle generating systems.

Under the present contract, the initial integration work has begun. Preliminary air- and oxygen-blown BCR data have been compared.

The Research Triangle Institute (RTI) has been awarded a research grant (R804979) to study potential pollutant production from synthetic fuels operations. The 5 year program is intended to perform both experimental and analytical studies. The program will include documentation of the specific chemical species present in various effluents from synthetic fuels processes along with a semiquantitative determination of their concentrations in the various process streams. The pollutants will be ranked in the order of their potential environmental hazard considering such factors as concentration, treatment, disposition, dispersion, and dilution of the effluent stream, and ultimate pathways to human exposure.

In addition, a catalog of kinetic data pertaining to the rates of formation of the pollutants of significance will be generated. This catalog will be useful in suggesting optimum reactor conditions to minimize the overall expense of emission or effluent control. As part of EPA's overall clean fuels program, the operating conditions which apparently minimize pollutant formation can then be subjected to experimental confirmation on a pilot-scale continuous gasifier.

During the first year, attention will be concentrated on coal gasification. A laboratory-scale gasification reactor of sufficient flexibility to simulate the time/temperature history of feed material proceeding through commercial processes will be designed, constructed, and placed in operation. (See following illustration.) Instrumentation will be provided to monitor and control temperature and pressure during gasification as well as the composition of feed gases to the gasifier. In addition, a sampling train will be designed and applied to the acquisition of char, tars and oils, water, and gases from the reactor. Prior to operation of the experimental reactor, analytical techniques will be developed and calibrated for the determination of synthetic fuels pollutants utilizing samples from actual gasification operations. Methods and techniques of determining kinetic parameters will be demonstrated, and analytical requirements for the successful completion of kinetic experiments will be developed.

Efforts during the following years are projected to involve application of the methods and techniques to the screening of many coals and to the investigation of other synthetic fuels technologies.

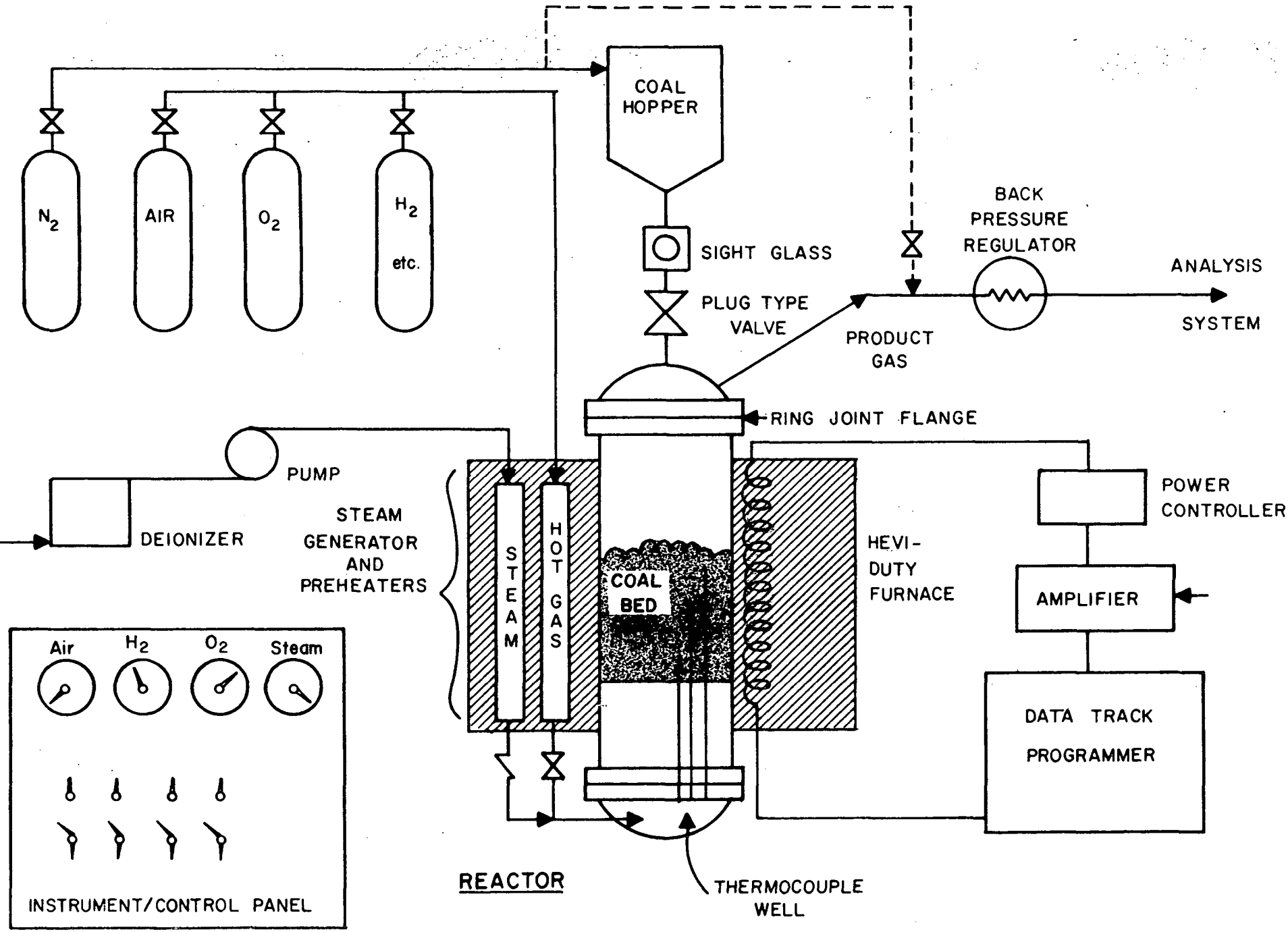
This program began on November 1, 1976.

Control Technology Development

In addition to control technology development work being done under contracts discussed as part of the environmental assessment program, several other control technology development contracts are underway and are discussed below.

North Carolina State University, supported by design capabilities provided by Aerotherm and the Institute of Gas Technology (EPA Contract 68-02-2187), has been awarded a three year grant (R804811) to provide and operate a facility for studying primarily the environmental factors in raw and acid gas cleanup associated with gasification. Tasks included under this grant are:

- Raw and acid gas cleanup facility.
  Bench-scale at NCSU for generic type acid gas cleanup system.
- Design of system (Aerotherm with subcontract to IGT for gasifier).
  Gasifier: double-walled, fluidized-bed, 100 psig.
  Synthetic gas mixtures: bottled.
  Gas cleanup: modular approach, methanol first.
  Data acquisition: sophisticated.
- Fabrication.



Concept of RTI reactor facility and sampling manifold.

° Operations.

Shakedown: Aerotherm.

Test Program: NCSU.

The contract schedule provides for the design package to be available early in November and finalized in December, with installation during the summer of 1977.

Work under an IERL-RTP 5 year grant (R804917) is being initiated by The University of North Carolina at Chapel Hill to assess biological and chemical treatment of wastewaters from fuel conversion, to determine environmental impact and health effects of treated waters, and to conduct bench-scale studies for developing design criteria. The system is for generic water treatment approaches. The research will include:

° Literature review.

° Modeling of organic compounds biodegradibility.

° Biological treatability in activated sludge system.

° Alternative physical/chemical treatments.

° Animal toxicology studies.

° Treatability of composite waste streams.

° Design criteria for continuous treatment.

Battelle-Columbus Laboratories was awarded a contract (EPA Contract 68-02-2112), initially for a 12 month period, to conduct a literature survey and evaluate past, present, and future control techniques for the removal of potential pollutant contaminants directly from solid and liquid fuels prior to combustion.

The results from this work will provide the EPA with a summary of control techniques which can be used in environmental control strategies for general fuel utilization processes.

Those techniques which show the most promise will be evaluated from a thermodynamic and kinetic viewpoint. Feasible methods will be ranked with respect to their potential removal efficiency for specific contaminants. In conjunction with this phase, laboratory tests may be required to fill data gaps and to remove ambiguities found in the literature survey.

All phases of this program are nearly complete, and efforts have resulted in two EPA reports:

° EPA-600/2-76-177a, "Fuel Contaminants: Volume 1. Chemistry," July 1976.

° EPA-600/2-76-177b, "Fuel Contaminants: Volume 2. Removal Technology Evaluation," September 1976.

Laboratory support studies are continuing for several removal techniques. Results from these preliminary studies are presently being written into a report. A continuing program in these and other selected areas is anticipated.

Catalytic, Inc., has been awarded a contract (EPA No. 68-02-2167) to develop control technology for the products and by-products of fuel conversion/fuel utilization systems based on coal. The contract period is September 1976 to September 1979. The overall technical objectives of this contract are to:

- Establish general processing schemes which will produce acceptable fuels and marketable by-products from coal.
- Assess the potential emission problems which could be incurred in each module of the above processes.
- Develop control technology for the recovery or destruction of these pollutants. This will include: utilization of existing processes; evaluation of developing processes; the identification of the need for, and the development of, new technologies.

Results from this work will enable the EPA to determine the overall control technology that is required to restrict pollutants to the desired levels during the conversion of coal to marketable products and by-products.

The approach which will be used to accomplish the program objectives is defined in six phases, summarized as follows:

Phase I. Project overview and compilation of published process information and control technology to provide initial estimates of potential pollution problems.

Phase II. Identification of pollutant problems, control needs, and new data requirements for processes to produce specific marketable products.

Phase III. Assessment, from information in Phase II, of existing and developmental stage technology and, if necessary, consideration for the development of new technologies.

Phase IV. Development of the control technology requirements identified in Phase III on bench scale and testing of those showing promise on a pilot-plant scale.

Phase V. Preliminary design and economic evaluation for those processes newly developed.

Phase VI. General support studies.

Phases I and II have been initiated. It is estimated that Phase I should be completed by February 1977. Three technical directives (TDs) have been issued:

TD-1: Work Plan and Support

TD-2: Support for Standards Development

TD-3: Overview Report

Fossil Fuels--Oil

OIL COMPOSITION

As with other fuels, the first important step is determining the oil's composition, especially regarding potential pollutants. A literature survey has collected and analyzed available data on domestic and imported crude oils. These data are supplying the initial basis for an inventory of potential pollutants whose fate must be followed in further oil processing and utilization.

OIL TREATMENT/PROCESSING

An area closely related to physical and chemical coal cleaning for which the Fuel Process Branch is funding research is liquid fuels cleaning. This includes demetalization, desulfurization, denitrogenation, and removal of trace metals and halogens. Studies presently being conducted by Hydrocarbon Research, Inc., and the Massachusetts Institute of Technology are aimed at determining reaction mechanisms and kinetics, developing catalysts, and evaluating processes for contaminant removal from liquid fuels.

Under EPA Contract 68-02-0293, Hydrocarbon Research, Inc., undertook a project to develop a low-cost scavenger catalyst to remove contaminant metals from petroleum resids prior to desulfurization with commercial hydrodesulfurization (HDS) catalysts. The contract is scheduled for completion in July 1977.

The work was divided into five phases. The objectives of each phase are defined as follows:

Phase I. Develop a low-cost demetallization catalyst for the removal of contaminant metals from heavy residual oils.

Phase II. Optimize the promoter metal level on the catalyst and explore commercial capabilities to produce this catalyst.

Phase III. Optimize the demetallization and desulfurization steps in producing low-sulfur fuel oils in order to obtain more accurate cost figures.

Phase IV. Join in a cooperative effort with the U.S.S.R. to gain knowledge of the technical status of the demetallization of residual oils in each country.

Phase V. Evaluate the denitrogenation catalyst on coal liquids and shale oil.

All work in Phases I, II, and III has been completed and final reports issued. All experimental work on Phase IV has been completed and a final report will be issued in 1977. Phase V work is proceeding and completion is scheduled for July 1977.

Under grant (EPA Grant No. R-800897), the Department of Chemical Engineering of the Massachusetts Institute of Technology is continuing studies on catalytic desulfurization and denitrogenation. The time period for this grant is August 1975 to July 1978.

Under a previous grant, the Massachusetts Institute of Technology completed an initial study in July 1975 on catalytic desulfurization and denitrogenation. The purpose of that study was to determine the implications of thermodynamics for hydrodenitrogenation (HDN) and to determine the effect of thermodynamics in pyridine HDN.

The objective of the present grant is to obtain a clear understanding of the ways in which HDS and HDN reactions interact with each other in the presence of representative hydrocarbon feedstocks, on industrial catalysts, and under practical hydroprocessing conditions. It is hoped that this study will define optimized conditions for nitrogen removal from liquid fuels derived from coal and oil shale.

Procedures for sulfiding the catalyst were designed to produce a standard state of catalytic activity in the reactor at the beginning of each run. Experimental investigations of quinoline HDN under industrial reaction conditions were continued and further studies will investigate the ramifications of the test results.

ADVANCED PROCESSES

Fluidized-Bed Combustion Processes

A vital element of the National Program on Fluidized-Bed Combustion (FBC) of coal for space-heating, steam-generation, and power-generation applications is the EPA program on the environmental characterization and control of this process. The goal of the EPA's FBC program is to obtain all necessary environmental data over the full range of operating variables for all variations of the FBC process.

The EPA program consists of tasks on environmental assessment, comprehensive analysis of emissions, and control technology development.

FLUIDIZED-BED COMBUSTION OF COAL

Environmental Assessment

The aim of environmental assessment is to set emission goals based on health and ecological effects of emitted pollutants and to design research, development, and demonstration programs to develop the necessary information to implement these goals. Comprehensive analyses of emissions from operating units provide data on pollutants and their emission rates in order to identify any potential problem.

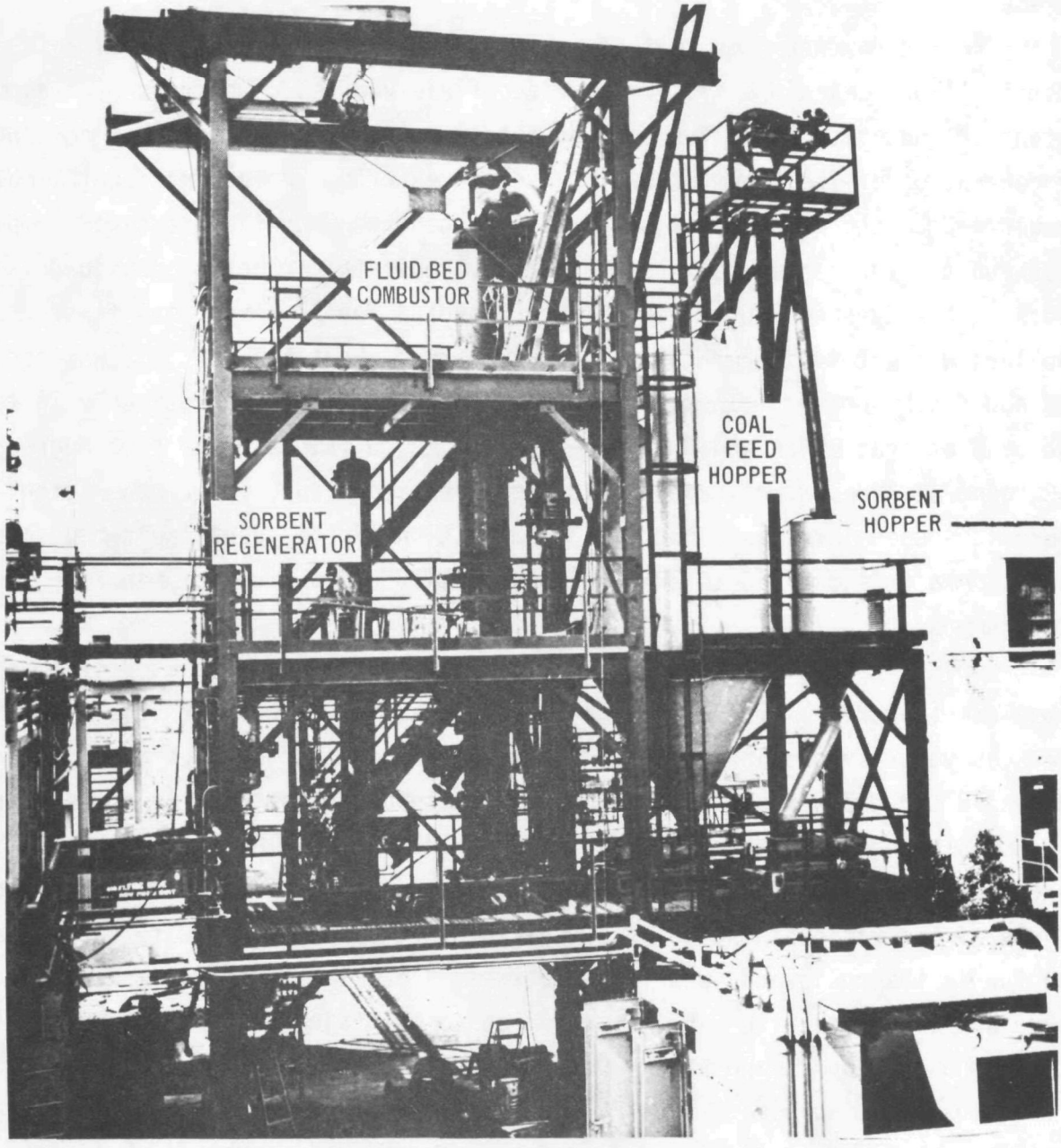
The major accomplishments related to environmental assessment during the past year included a preliminary environmental assessment program completed by GCA Corp. and the initiation of a major contract with Battelle-Columbus Laboratories (BCL) for a broad environmental assessment. The preliminary assessment by GCA indicated there were insufficient experimental data upon which to base any conclusions concerning potential environmental problems for FBC. BCL has made several preliminary planning studies to define needed research areas for improving the data base. BCL has also initiated the development of a multimedia environmental goals chart which is a concept for comparing emissions goals for specific pollutants based on health/ecological effects. Comprehensive analysis (CA) on a BCL 6 inch ID atmospheric pressure unit was completed and plans were made for analysis of other units. Mitre Corp. has completed a sampling and analysis manual for FBC units.

The Multimedia Environmental Goals Chart (MMEGC) is a concept developed by IERL-RTP which, when completed, will provide a unified presentation, for the emerging energy technologies, of environmental goals in all media.

Control Technology Development

Control technology development efforts include engineering analysis, basic and applied research and development, and specific control process development. In the area of control technology development, the major accomplishments include process studies on the Exxon miniplant and the Argonne National Laboratory (ANL) combustor/regenerator; studies on waste disposal, sorbent technology, and add-on controls; and applications studies by Exxon, TVA, and Dow Chemical Co.

Exxon is conducting a program in their bench-scale fluidized-bed combustion/regeneration equipment and miniplant facilities. The latter includes a 31.75 cm (12.5 inch) diameter pressurized combustor and a 20.32 cm (8 inch) diameter pressurized regenerator. The 0.63 MW fluidized-bed combustion miniplant (see following illustration) has been successfully operated for a sustained run



630 KW Exxon miniplant for pressurized (10 atm) fluidized-bed combustion of coal.

with continuous regeneration of the sorbent that is used to control sulfur emissions from the combustor. The sustained run was maintained at steady conditions for 100 hours. Previous operation of the miniplant had involved the coal combustor only, and did not include sorbent regeneration. The 100 hour run completed shakedown of the integrated combustion/sorbent regeneration miniplant system.

The run demonstrated that it is technically feasible to control sulfur dioxide (SO_2) emissions from pressurized fluidized-bed combustors with a substantial reduction in sulfur sorbent feed requirements, by means of continuous regeneration of the spent sorbent. Such a reduction in sorbent requirements would reduce the quantity of solid residue generated by fluidized-bed combustion units, and hence would reduce the environmental impact of residue disposal. The EPA New Source Performance Standard for SO_2 from coal-fired boilers was met by the miniplant combustor throughout the run. It was necessary to add fresh sorbent (limestone) to the combustor at a feed rate only 15 to 25 percent of that which would have been required to maintain the same degree of SO_2 control had sorbent regeneration not been employed. The regeneration technique used involves reductive decomposition of the spent, sulfated sorbent at temperatures of 1850 to 2050°F (1010 to 1120°C) in a vessel separate from the combustor.

During the 100 hour run, the combustor pressure was held at 7.5 atmospheres absolute (760 kPa). The combustor bed temperature was held at 1650°F (899°C), the gas velocity passing up through the bed was 4.8 ft/sec (1.5 m/sec), and the expanded bed depth was 11 feet (3.4 m). Pittsburgh seam coal (2 percent sulfur) was burned at a constant feed rate of 173 pounds (78 kg) per hour, with an excess air level of 25 percent. The limestone sorbent feed rate (expressed in terms of the ratio of the moles of calcium in the sorbent feed to the moles of sulfur in the coal feed) was varied between a calcium-to-sulfur mole ratio of zero and 1.3, averaging 0.55, as required to maintain constant bed levels in the combustor and regenerator. The regenerator was operated at a pressure of 7.6 atmospheres absolute (770 kPa), a bed temperature of 1850°F (1010°C), a gas velocity of 2 ft/sec (0.61 m/sec) and an expanded bed depth of 7.5 feet (2.3 m). Sorbent was transferred from the combustor to the regenerator and back at a rate of 100 pounds (45 kg) per hour.

Operation during the 100 hour period was smooth and stable, with no interruptions. Operating variables remained steady at the levels indicated above,

with the exception of the variation of the sorbent feed rate. Some agglomeration of bed material did take place on the regenerator distributor plate early in the run, but the agglomerate did not worsen as the run progressed, or interfere with stable operation of the systems.

Emissions of SO_2 from the combustor varied between 0.14 and 1.2 lb $SO_2/10^6$ Btu heat input (0.06 and 0.51 g/10^6J), with an average emission level of 0.63 lb/10^6 Btu (0.27 g/10^6J), compared to the EPA New Source Performance Standard for coal-fired boilers of 1.2 lb $SO_2/10^6$ Btu (0.51 g/10^6J). For the 2 percent sulfur coal burned, this average emission level corresponds to over 80 percent SO_2 removal by the limestone sorbent. As indicated previously, this degree of control was obtained with an average calcium-to-sulfur mole ratio of 0.55. By comparison, previous miniplant tests, in which limestone was added to the combustor without operation of the regenerator, indicated that limestone would have to be added on a "once-through" basis at a calcium-to-sulfur mole ratio of 2.5 to 4.0 in order to achieve the same average emission level without regeneration.

The average concentration of SO_2 in the off-gas from the regenerator was 0.5 percent during the run. It is desirable for this SO_2 level--which is the result of the reductive decomposition of the sulfated sorbent in the regenerator--to be as high as possible, to facilitate recovery of sulfur values in future commercial combustion/regeneration systems.

ANL, in a project confunded with ERDA, is conducting laboratory- and bench-scale work which includes testing on their 15.24 cm (6 inch) diameter pressurized combustor and 11.43 cm (4-1/2 inch) diameter pressurized regenerator.

Past studies have shown that the NO_x emission from FBC is generally lower than that from conventional coal-fired boiler systems. ANL's study revealed that an increase in operating pressure significantly reduces the NO_x emission in FBC. An increase in excess air increases the NO_x emission. The operating temperature and the presence of sulfur sorbent have little or no effect. Miniplant operation has confirmed that at 15 percent excess air and 10 atm, the NO_x emissions equivalent to 0.2 lbs NO_2/million Btu can be achieved (0.09 µg/J). This emission rate is significantly less than the current EPA standard of 0.7 lbs NO_x/million Btu (0.3 µg/J).

Particulate emissions from FBC of coal have been a major concern from both environmental and engineering standpoints. Past studies have confirmed that

the particulate emissions are affected by many factors, such as the characteristics of feed coal and sorbent, FBC geometry, heat transfer surfaces, operating conditions, and the design of cyclones. It is recognized that further development of particulate control technology is imperative (e.g., high-efficiency cyclones, electrostatic precipitators, and granular bed filters). Supporting this finding are recent measurements from Exxon miniplant operation which indicate that the particulate loading in the flue gas leaving the final cyclone was no less than 0.3 grams per standard cubic meter (0.13 grains scf). In some cases the particulate loading was as high as 2.8 grams per standard cubic meter (1.26 grains/scf). These particulate emissions are unsatisfactory when compared to the current EPA emission standards of 0.09 grams per standard cubic meter (0.04 grains/scf). These emissions are also excessive for a stream being fed to a turbine as is contemplated for pressurized FBC.

As FBC processes develop, particulate emission is one area which must be carefully monitored to ensure that proper control techniques are applied as necessary to eliminate significant environmental impact.

Extensive investigations on FBC solid waste have been started only recently and is an area of major environmental concern. These studies are in support of the control technology development objective of the EPA program.

Spent sorbent and coal ash are constantly withdrawn from the fluidized bed and can be immediately discarded (once-through), or the sorbent may be separated from the ash and reused after a regeneration process. Even with regeneration, the sorbent material eventually becomes less reactive and a portion must be discarded. The solid waste residue must be discarded in an environmentally acceptable manner to avoid problems from leaching, dusting, runoff, air pollution, and water pollution.

Applicability of FBC to large power plant boilers has been confirmed. EPA has participated in a study cofunded with ERDA and FEA on FBC applicability to industrial boilers. A good potential exists for FBC technology in the chemicals, paper, petroleum refining/petrochemicals and food industries. An EPA study is underway with TVA comparing the costs of atmospheric and pressurized FBC with conventional boilers/scrubbers.

Work was initiated by the Massachusetts Institute of Technology (MIT) in October 1976 under a research grant with the following objectives:

- Develop a mechanistic mathematical model for the prediction of NO emission from coal-burning fluidized beds both at atmospheric and at elevated pressures.

- Provide physical chemical input parameters for the model on the NO formation/destruction processes by carrying out a detailed experimental investigation using a 30 x 30 cm pilot-plant-size fluidized combustor, a 10 cm diameter bench-scale combustor capable of operating at pressures up to 10 atm, and a 7.5 cm diameter, externally heated bed for the batch type experimental study of the chemical kinetics.
- Provide information leading to the development of new control technology from the experimental study on the 30 x 30 cm atmospheric pressure fluidized combustor and by using the mechanistic model of the combustion/NO-emission processes.

ADVANCED OIL PROCESSING: FLUIDIZED-BED GASIFICATION/DESULFURIZATION OF RESIDUAL FUEL OIL

Environmental Assessment

The environmental impacts of the Chemically Active Fluid-Bed (CAFB) process and lime/limestone slurry flue-gas scrubbing have been compared. The basis of comparison is a 200 MW oil-fired power plant (retrofit). The CAFB process appears to be superior environmentally to limestone and lime slurry scrubbers. Sulfur removal capabilities for the processes are comparable, but the CAFB process provides a considerable reduction in nitrogen oxide emissions and consumes an order of magnitude less process water than do slurry scrubbing processes. Similar nitrogen oxide control could be achieved by the addition of special combustion equipment on the boiler. Auxiliary power requirements are comparable at 3 to 4 percent of plant capacity. The limestone usage is nearly identical for the processes-- about 1 mole of calcium per mole of sulfur removed from the fuel--but the CAFB process could potentially reduce this consumption to half that level by optimum utilization of regenerative operation with sulfur recovery. The CAFB process also produces a dry product with potential market value rather than a sludge which is difficult to handle and requires large land areas for disposal ponds. CAFB also permits the utilization of high-metals vacuum bottoms as a fuel. Priority problems currently are (1) reduction of stack particulate emissions, (2) reduction of SO_2 emissions during abnormal operating conditions, and (3) environmentally acceptable disposal of spent stone.

Control Technology Development

The CAFB process for gasifying and desulfurizing heavy fuel oil has been demonstrated in a 0.75 MW continuous pilot unit at Esso Research Centre, Abingdon, England (Esso England). The CAFB process injects heavy fuel oil

into a shallow (about 2 feet deep) fluidized bed of lime/limestone particles to partially oxidize, gasify, and desulfurize the oil. The continuous pilot unit is used to fire a commercial boiler rated at 10 million Btu/hour; it demonstrated a service factor of 95 percent during the latest run of approximately 400 hours' duration. In addition to 90 percent sulfur removal at a calcium-to-sulfur feed ratio of 1.5 to 1, the CAFB has shown complete vanadium removal, 75 percent removal of nickel, and 36 percent removal of sodium. A reduction in the NO_x emissions from 263 ppm (when the boiler was oil-fired) to 160 ppm (when fired on the CAFB product) has been demonstrated. Economic studies continue to show that the CAFB has the potential for becoming a viable commercial process. The effluent from the limestone regenerator is 5 to 10 percent SO_2 which can be reduced to sulfur, using existing technology.

A nominal unit is being considered at San Benito, Texas.

CAFB Demonstration

The nominal rating of the combined CAFB boiler and turbine system of the demonstration plant is approximately 10 MWe, when high-sulfur #6 residual oil is fed to the CAFB unit. The sulfur recovery scheme is one of several which could be used. However, the method for recovery of sulfur is beyond the scope of the EPA development plan. The CAFB gasifier section and regenerator are in the same vessel, separated only by a refractory wall and connected via fluidized solids transfer ducts.

The gasifier section provides for 13.8 m^2 fluidized-bed area and 1.8 m^2 for the regenerator fluidized-bed area. The internal configuration of the vessel is designed to provide a circulating flow of material through the bed area. A central division wall is placed in the gasifier portion to help accomplish this. The design superficial velocities are 1.4 m/s for the gasifier and 1.5 m/s for the regenerator.

The basic design fuel for the demonstration is a 2.67 percent sulfur #6 residual oil. The design also provides for consideration of other normally solid fuels, including coal.

The total estimated construction cost for the demonstration unit at San Benito, Texas, is:

Construction (including erection)	$ 991,900
FWEC/CPL Contract (including equipment)	1,634,250
Engineering, O/H (CPL)	86,900
TOTAL	$2,713,050

Advanced Low-Emission/Energy-Conserving Systems Strategies

EPA-VAN

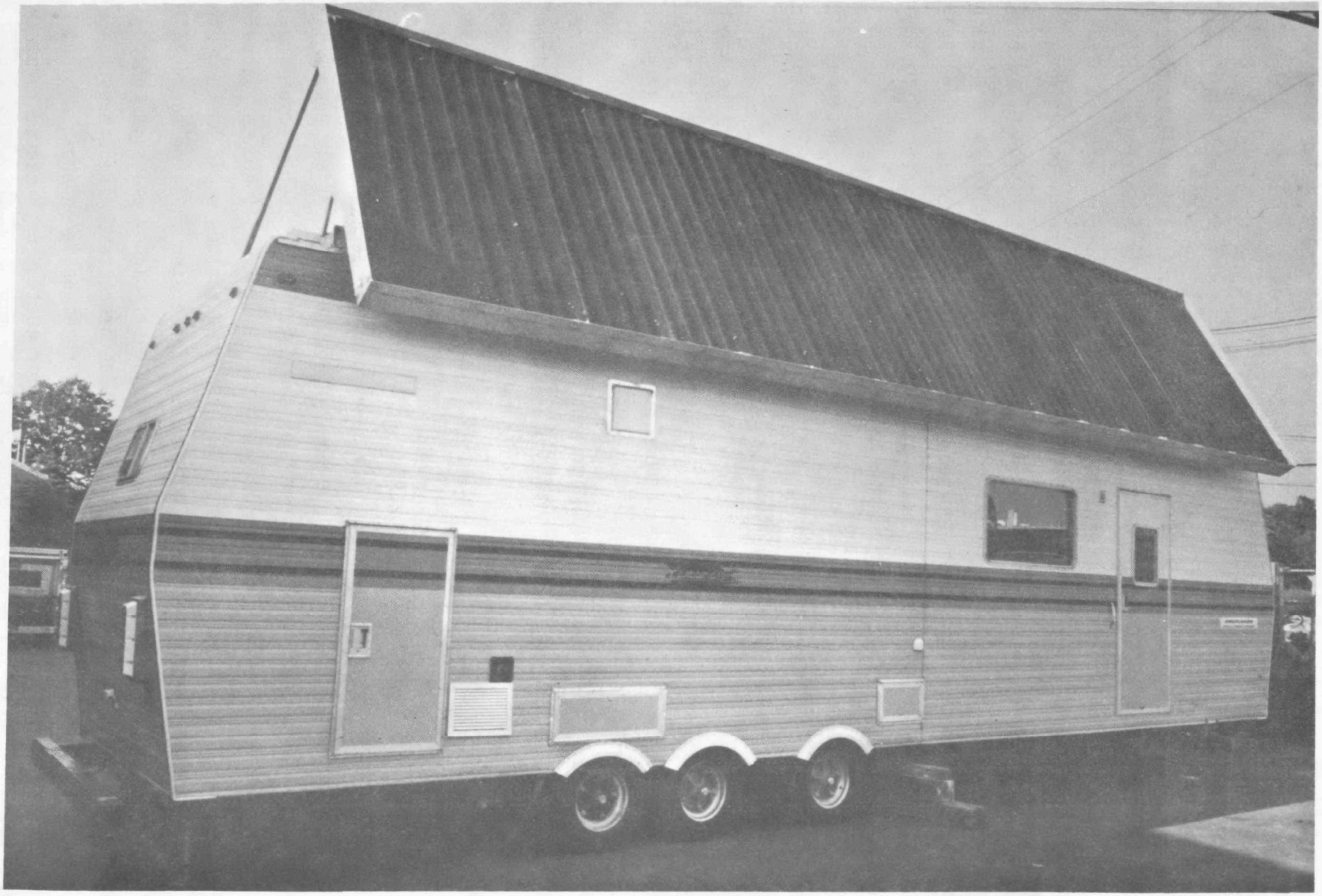
The Laboratory's EPA-Van, a mobile research unit, is part of IERL-RTP's program to control air pollution from homes, apartments, and small commercial buildings. The pollution control technique used here is an energy supply system containing environmentally clean and energy-saving components. The EPA-Van's integrated system includes fuel cells, solar energy collectors, a specially designed heat pump, and catalytic burners. This equipment is non-polluting and is designed to optimize the energy-conserving features of each of the components. The system provides all the energy needed for space heating, cooling, and ventilating; cooking; lighting; food refrigeration; water heating; and appliances.

Engelhard Industries Division, under contract to IERL-RTP, designed and built the Van. It was delivered to IERL-RTP early in 1976. The testing program for the Van was scheduled to begin before the end of 1976.

Although the total impact of the EPA-Van power system will not be known quantitatively until testing is completed, the environmental impact is felt to be substantial because of the reduced fuel consumption resulting from use of the coupled solar-energy/heat-pump system and the inherently nonpolluting nature of fuel cells and catalytic burners. The unknowns at this point are the environmental and economic impacts of the industrial equipment required to produce, store, and transport the consumable fuel, and the economic impact of the presently expensive fuel cells and catalytic combustors. The EPA-Van is shown in the photo below.

ELECTRICAL ENERGY AND WASTE HEAT

An IERL-RTP study (by Radian) has been completed to assess the degree to which electricity from coal might be employed in the residential, commercial, and industrial sectors as a supplement or substitute for clean premium fuels such as natural gas, distillate oil, synthetic natural gas (SNG), or liquefied coal. The electricity thus employed in these area sources would be completely nonpolluting at the point of use, but would be generated in large central power stations, burning coal and employing high-efficiency emission control technology or low-polluting advanced combustion processes. The energy usage efficiency and total environmental impacts (with emphasis on urban ambient air) were evaluated for alternative methods for meeting user needs, together with projections of changeover costs and rates. The oil and gas shortage and



EPA-Van.

the threat of a new embargo provide clear incentives for further examination of the degree to which substitution of electricity (from coal-fired power plants) for oil and gas usage in stationary end-use sectors can be implemented. Electrical substitution does offer the potential for significant future reductions in the amount of natural gas and distillate fuel oil consumed in the residential, commercial, and industrial sectors. The report on this study was published in the first quarter of 1976.

FUEL DISTRIBUTION PATTERN FLEXIBILITY

Battelle, funded by IERL-RTP, has completed a study designed to quantify the amount of clean fuels (natural gas, distillate fuel oil, low-sulfur residential oil, and low-sulfur coal) which should be available through the year 2000 for switching to small sources from larger users as a means of area source air pollution control. The report on this study was published early in 1976.

Under the study, an evaluation was made of factors affecting the ability to switch fuels between users (e.g., equipment-related factors, business factors, fuel supply network factors), and the quantities of fuel affected by each factor.

INDOOR AIR QUALITY

This project has been designed as an 18 month program of research, field observation and analysis to produce new data on the occurrence, behavior and significance of air pollution in nonwork places/indoor environments. The project's broad objective is that of optimizing the energy conservation/air quality/health relationships in indoor spaces through the identification of causal relations and identification of feasible points of intervention. Pollution sources, magnitudes of pollutants, and control techniques will be identified and the importance of energy conservation measures will be assessed. The first phase of the project includes the review and assessment of published research and of on-going research efforts. The second phase includes a program of indoor and outdoor air monitoring and determination of estimates of indoor and outdoor air quality through mathematical models.

BASIC STUDIES/FBC POLLUTANT FORMATION MECHANISMS

No fully satisfactory explanation exists for the lower NO emissions obtained at elevated pressures compared to those at atmospheric pressure in FBC processes. These basic studies aim at developing: a mechanistic model for predicting NO emissions, physical/chemical input parameters for the model, and information leading to new control technology. The model will be tested over a wide range of operating variables.

Experimental work will be carried out on pilot-plant and pressurized bench-scale combustors. The studies should (1) advance present understanding of the mechanisms of formation and destruction of NO in FBC processes, and (2) yield information on potentials for NO emission reduction.

INDUSTRIAL PROCESSES

IERL-RTP's work in the area of industrial processes can be subdivided into two distinct functional groupings: chemical processes and metallurgical processes. Because process measurements is applicable to the entire IERL-RTP program it is treated as a separate major program. The following subsections of this report discuss the first two groups separately.

CHEMICAL PROCESSES

IERL-RTP's Chemical Processes activities are presently grouped into six categories:

- Combustion sources
- Petrochemicals
- Refineries
- Agricultural chemicals
- Textiles
- Incineration at sea.

Additionally, IERL-RTP continues to be involved in review and other responsibilities for previously assigned functions during transition to other IERL locations.

Source Assessment

In order to define control technology development needs for sources in the six categories, information relating the characteristics of emissions to their probable impact on receptors must be assessed. Presently, much of the information required is nonexistent, or data reliability is uncertain.

A contractual effort was initiated in June 1974 to utilize the systems approach to acquiring the source assessment data needed for decision-making, regarding control technology development needs relating to air pollution aspects of specific sources.

Efforts to establish the order of performing detailed source characterizations have been completed. The sources were organized into the six categories previously discussed. A model was then developed to estimate the relative environmental impact of each source within each category. Factors included in the model were the pollutant type, the mass emissions, the atmospheric reactivity or stability of the emissions, number of the source type, the growth pattern for the industry, the location of the plants, population densities

at the source locations, the relationship between source emissions and ambient levels of the same type of pollutant at the location of the plant, and toxicity of the emitted pollutants. Data from a wide variety of sources were used as input to the model to calculate a relative environmental impact number. By this means, a priority listing based on relative potential for adverse environmental impact was developed for the sources in each of the six categories. (While IERL-RTP's Source Assessment Program was initially structured to address only the air pollution aspects of industrial sources, a change in orientation was brought about by the 1975 reorganization of ORD. Efforts are currently in progress to structure the program to address pollution of all media.)

The original program, which addressed only air pollution, did result in prioritization listings for sources based on the potential for adverse environmental impact from air pollutants. From these listings of source priorities for each category, sources were selected for which initial prototype Source Assessment Documents (SADs) are now being developed. These SADs will consider the aforementioned factors in detail and present all information necessary to allow decisions to be made by IERL-RTP personnel as to control development needs for the source types under consideration.

The SADs now under preparation or completed are:

Combustion Sources

- Pulverized Bituminous Coal-Firing Dry-Bottom Utility Boilers
- Industrial External Combustion Using Pulverized Bituminous Coal in Dry-Bottom Boilers, Furnaces, etc.
- Coal-Fired Residential Furnaces

Petrochemicals

- Acrylonitrile
- Solvent Evaporation--Surface Coating
- Chlorinated Hydrocarbons
- Phthalic Anhydride Production
- Carbon Black
- Acetone and Phenol from Cumene

Agricultural Chemicals

- Fertilizer Mixing Plants
- Ammonium Nitrate
- Synthetic Ammonia Production

Agricultural Chemicals (con.)

Phosphate Fertilizer Industry

Urea Manufacture

Chlorinated Phenolic Pesticides

Toxaphene Manufacture

Textiles

Cotton and Synthetic Textile Finishing Plants

Effluents from each source will be identified and characterized in terms of individual pollutant emission rates (i.e., source strength), potential for adverse health effects, and environmental stability of pollutants. Ambient pollutant levels will be estimated for typical sources by means of accepted dispersion equations. The source distribution will be presented and related to affected population. Studies of the availability and performance of viable control technology will be presented.

In addition to the assessment program described above, two new major assessment programs have been initiated: for conventional combustion systems and for petroleum refineries. Both are described below in their appropriate sections, along with control technology progams which are underway to the same source category.

Combustion Sources

CONVENTIONAL COMBUSTION SYSTEMS--EMISSIONS ASSESSMENT

Assessment and definition of the problem of emissions from combustion sources is a major concern to IERL-RTP. In addition to the Source Assessment Documents (SADs) being prepared for combustion sources by Monsanto Research Corp. (MRC), other approaches to assessment of conventional combustion sources have been employed. Operation of conventional combustion systems (i.e., those which currently use common fossil fuels such as coal, oil, natural gas, and agricultural, forestry, or other wastes for electrical power generation or space heating) causes continuous and intermittent vapor/liquid/solid discharges to the air, water, and land from a number of associated processes including: fly ash/bottom ash/bottom ash sluicing, water treatment, flash tank, scrubber sludge, stack, fuel storage, mud-drum blowdown, and fireside cleaning. Previous and on-going data collection programs are directed toward emission assessment related to these discharges.

Environmental and emission assessments of conventional systems were prepared for IERL-RTP by GCA Corp. and published in March 1976. (This was independent of the MRC program discussed earlier.) The overall objective of this project was to prepare a preliminary emission assessment of conventional stationary combustion sources (those currently in use and based on common fossil fuels--coal, oil, natural gas--or solid wastes such as those derived from agricultural, forestry, or municipal refuse).

The GCA report gives results of an emissions assessment of the air, water, and solid waste pollutants produced by conventional stationary combustion systems. It gives results in four principal categories: utilities (electric generation), industrial (steam generation, space heating, and stationary engines), commercial/institutional (space heating and stationary engines), and residential (space heating). For each principal combustion system category, it defines: process types and operating efficiencies, fuel consumption, pollutant sources and characteristics, major research and development trends, fuel consumption trends, and areas where emission data are incomplete or unreliable. It also gives the pollutant emissions from applicable unit operations for each of 56 source classifications, using a uniform combustion source classification system, and identifies major gaps in available data regarding the population and capacity of combustion systems, application of control measures, fuel composition, and other parameters which significantly influence pollutant characteristics and emission rates.

A supplementary report issued in August 1976 identifies and discusses major recent on-going and proposed programs in the area of pollutant emissions from combustion sources. The information covers the period from December 1975 to June 1976 and was obtained through a review of the literature and contact with governmental and industrial representatives.

Other work on emission assessment of conventional combustion systems was initiated by TRW in September 1976. This study will assess air and water pollutants, including those generated from solid waste disposal, from 54 combustion categories, including (1) residential, commercial/institutional and industrial sources from combustion of coal, oil, gas, wood, and lignite, and (2) electricity generation sources.

This program will (1) define criteria for determining adequacy of existing emissions assessment data, including a quantitative basis for decision-making relating to items such as error analysis, data reliability, pollutant

levels, pollutants considered, and techniques for criteria application, (2) identify those categories or portions of categories that have been adequately assessed on these criteria, (3) identify those categories that will require additional investigation, (4) develop a program to complete the emissions assessment, and (5) complete the emissions assessment. The assessment will include mass balances for each category and will include the following air pollutants: trace elements, CO, SO_x, NO_x, SO_4, POM, PCB, hydrocarbons, and particulate by size fraction. Characteristics of each category for water pollutants such as pH, alkalinity, hardness, and conductivity will be included.

ELECTRIC POWER GENERATION

Earlier discussion has described assessment of the many types of combustion sources. The following discussion relates to programs which involve combustion only from the standpoint of electric power generation.

Increasing attention is being directed toward obtaining information on the contribution of power plants to the atmospheric loading of toxic trace elements and toward development of better means to control their emission. Previous studies have succeeded in providing some knowledge of the distribution of trace elements in the flue gas, and the distribution of these elements in various fractions contained in the fly ash particles. Results of earlier work are considered inconclusive and fates of trace elements are still not known primarily because of the lack of adequate sample collection techniques. Less information is available on vapor-phase trace elements than is known for the particulate phase. In view of the potential hazards of toxic trace elements that may be released from fossil-fuel combustion and the need to improve vapor and fine particulate control technology, TVA has initiated a research program to quantify and characterize such combustion products from its coal-fired power plants. The objectives of this program are to gather, analyze, and interpret data on combustion products from coal-fired utility boilers in order to gain a better understanding and provide a basis for the improvement of control technology for fine particulates and vapor-phase trace elements. This is being achieved by chemically and physically characterizing vapor-phase trace elements and fine particulates in the flue gas and by relating formation of these compounds and their characteristics to boiler operations and control device performance.

INDUSTRIAL BOILERS

Field testing of trace element and organic emissions from industrial boilers was performed by KVB, Inc., and a report was issued in December 1976. Sampling of four coal-fired industrial boilers was conducted to determine emissions of 19 trace and minor elements and polycyclic organic matter (POM). Emissions of the trace and minor elements were related to total quantities of each element present in the fuel by examining the degree of mass balance and element partitioning based on fuel input and element output in furnace deposits, fly ash, and flue gas vapor. The tendency of finer particulates to be enriched in volatile elements was established by chemical analysis of cascade impactor fractions. Total measured output of elements classified as high in volatility tended to be less than the fuel input. This was attributed to possible low collection efficiency of sampling equipment for vapor-phase elements. These same elements were found to be more highly concentrated in the fly ash as opposed to furnace deposits and to have higher concentrations in the smaller particle sizes. Elements classed as medium or low volatility tended to be more uniformly distributed with respect to both location in the boiler and particle size. Total mass outputs for these elements frequently exceeded coal inputs indicating possible sample contamination by boiler or sampling system construction materials. The presence of four specific POM compounds was indicated in the coal, ashes, and stack gases but results were highly variable.

Petrochemicals

Petrochemical processing includes all industrial processes that use petroleum as a feedstock. Because of the size and importance of the oil and petrofuel industries, oil refineries are discussed separately later. Considered here are special multimedia pollution problems from nonfuel uses of petrochemicals.

ETHYLENE DICHLORIDE (EDC) PROCESSES

Hydrocarbon emissions are the major pollution problems associated with the manufacture of EDC: the ethylene oxyhydrochlorination absorber vent is the main source of these hydrocarbon emissions. Current processes employ air as the oxygen source and vent the resultant inert gases, along with about 0.03 tons of hydrocarbon per ton of EDC produced, to the atmosphere. EDC production is now about 5 billion pounds per year.

At the start of this project there was no practical way to eliminate the oxyhydrochlorination vent from existing processes; the gases are too dilute for incineration, and the addition of natural gas to make the gases combustible is an extravagance. Furthermore, incineration would form hydrochloric acid which would have to be controlled by scrubbing.

The objective of a project conducted by Allied Chemical Corp. was to demonstrate that emissions can be reduced by at least 90 percent from the levels encountered with typical existing processes. The modified process employs recycling of reactor exit gas, oxygen feed, and whatever additional processing steps are determined to be necessary to control build-up of by-products in the recycle stream. The modified process was intended to be economically competitive with present day processes. The process performance was evaluated on a pilot scale so that a preliminary study of technical and economic feasibility could be carried out.

The pilot work is now complete and the findings were presented to industry. Industry has completed similar or equivalent work. Further proposals were not received and work on this process has been discontinued.

VINYL CHLORIDE (VC)

An activity carried out during 1975 was a sampling of the interiors of seven different models of new U.S. automobiles in order to measure VC concentrations and detect the presence of other hazardous organic vapors: all cars had less than 1.2 ppm VC in the air, and no other problem vapors were detected. The final report of this sampling, carried out by Monsanto Research, was issued in May 1976.

POLYCHLORINATED BIPHENYLS (PCBs)

This effort makes use of the special expertise and equipment available at Envirogenics Systems Company to extend the application of a metal/metal couple reduction process to the treatment of the EPA "toxic/hazardous" material, PCB. The process system is a reductive chlorination process employing an iron powder doped with copper catalysts dispersed within a sand matrix. By stripping chlorine from compounds the process has the potential to produce less toxic and more readily biodegradable compounds. The work included laboratory-scale and bench-scale optimization (6 inch diameter, 1 to 3 gallons per minute). In laboratory tests the process was capable of reducing concentrations of PCBs in wastewater down below 1 part per billion. Studies have shown that with the reductive degradation process, 84 percent of the total

chlorine going in with the PCBs is converted to inorganic chloride. Fate of the remaining chlorine is unknown, and it is possible that some remains in hard-to-characterize, potentially toxic forms.

A cooperative program with EPA's Gulf Breeze Laboratory is in progress to define the toxicity of the residual, organically bound chlorine compounds to marine organisms. Other efforts are currently in progress to close the material balance for the technology and to identify and quantify all reaction products. The process is intended to be applicable to the treatment of PCBs in: (1) PCB manufacturing effluent; (2) PCB user effluent (e.g., electric transformer and condenser manufacture); and (3) treatment of accidental discharges and leachates from areas where PCB-containing equipment has been dumped, is being stored, or is being operated. The process also has the potential for application to drinking water supplies.

In addition to the above PCB work, the reduction process will be screened for its effectiveness in treating various light-end chlorocarbons often found industrially with PCBs; e.g., ethylene di- and tri-chlorides, carbon tetrachloride, and chloroform. The feasibility project is scheduled for completion in March 1978.

A demonstration grant on this process is in progress, with operational testing to start in April 1977. General Electric Co. and EPA have entered into a cost-sharing agreement to conduct full-scale tests at GE's capacitor manufacturing plant in New York State.

Environmental acceptability of wastewaters treated by this process will be evaluated by the Gulf Breeze Effluent Biotesting Program (EPA-Gulf Breeze/Bionomics). Acute and chronic toxicity tests involving fresh water and marine biota are underway, as well as bioaccumulation studies.

CHLOROLYSIS

A promising new technology is being developed by Repro Chemical Corp. and Hoechst-Uhde, Frankfurt, Germany, which involves use of high-temperature/high-pressure chlorination of chemical manufacturing waste. Assessment of such parameters as the magnitude of potentially available U.S. organic wastes suitable for chlorolysis feedstock and markets for chlorolysis conversion products (carbon tetrachloride, carbonyl chloride, and anhydrous hydrochloric acid) will determine the most practical chlorolysis process. Repro has surveyed the availability in the U.S. of pesticide wastes suitable for chlorolysis conversion.

Tests have shown that vinyl chloride, chlorinated solvents, vinylidene chloride, and other residues are readily chlorolyzed to carbon tetrachloride and hydrogen chloride; however, these residues must be relatively free of sulfur to avoid reactor corrosion. Investigations now underway by Hoechst-Uhde, with a subcontract to Repro Chemical, will include engineering design and economic feasibility of a regional integrated chlorocarbon disposal facility, based on previous EPA-supported bench-scale studies of chlorolysis of defoliants. The design capacity will be 25,000 metric tons per year of chlorocarbon wastes. This design should be ready during the first half of 1977.

Refineries

SOURCE ASSESSMENT--AIR POLLUTION

Petroleum refineries consist of a complex of physical and chemical transformation operations. While most of the individual point sources of emissions within the refinery have been identified, fugitive sources may be the principal emitters of hydrocarbons. In order to identify those refinery operations requiring air, solid, or water effluent control, IERL-RTP is now carrying out a detailed assessment of the environmental effluents associated with oil refining. The study will quantify the potential for emissions in each step of the physical and chemical transformation of petroleum. Particular emphasis will be placed on "fugitive" emissions. Operations which are expected to utilize heavier feedstocks will also be emphasized. Plants selected for sampling will be typical in terms of present control technology utilized. The field sampling program will quantify emissions. This data will be of adequate quality to support a guideline document for determining the environmental impact of existing and new petroleum refineries.

From this assessment and guideline document, the major control program emphasis of future years will be defined. On-going investigations are described in the remainder of this section.

TECHNOLOGY ALTERNATIVES: REFINERY SO_x CONTROL

Petroleum refineries are a major industrial emitter of sulfur oxides (SO_x). In 1969 the estimated SO_x emissions from 262 refineries (charging 12 million barrels of crude petroleum per calendar day) were 2.2 million tons. Moreover, the petroleum refining industry growth rate is projected to be 3 to 4 percent annually. As refineries process more higher-sulfur crudes, the need to control SO_x emissions from petroleum refineries continues to grow. IERL-RTP is, therefore, vigorously seeking methods for suppressing SO_x emissions from petroleum refining operations.

Four approaches to SO_x control currently exist for petroleum refineries: desulfurization of flue gases, desulfurization of in-process feedstocks, desulfurization of the whole crude feedstock, and combinations of the above.

The technology required for each approach has been developed to different levels. Since pollution control technology has developed rapidly, an up-to-date analysis of techniques applicable to petroleum refineries, the associated economic impact on petroleum products, and areas of inadequate technology need to be reviewed. IERL-RTP, with the assistance of the American Petroleum Institute, conducted a program to quantify the impact of the alternative approaches, based on up-to-date technology and economics.

This program, performed by Arthur D. Little, Inc., assessed the impact on the U.S. petroleum refining industry of a possible EPA regulation limiting the level of gaseous refinery sulfur oxide (SO_x) emissions. Computer models representing specific refineries in six geographical regions of the U.S. were developed as the basis for determining the impact on the existing refining industry. New refinery construction during the period under analysis (1975-1985) was also considered by development of computer models representing new refineries. Control of refinery SO_x emissions from both existing and new refineries was defined for the purposes of this study by maximum sulfur levels of refinery fuel and of fluid catalytic cracking unit feedstock and by increased sulfur recovery in the Claus plant. The computer models thus constrained were utilized to assess investment and energy requirements to meet the possible regulation and the incremental cost to manufacture all refinery products as a result of the regulation. Parametric studies evaluated the impact of variations in the types of imported crude oils available for future domestic refining and the projected sulfur level of residual fuel oil manufactured in the U.S. Reports on this project were issued in 1976.

AUTOMOBILE FILLING STATION CONTROL

This study, being conducted by Scott Environmental Technology, Inc., was initiated late in 1975 in response to a request from EPA's Office of Air Quality Planning and Standards. It is aimed at determining the variables affecting the working capacity of the charcoal beds used to control gasoline vapors in service stations. Any decrease in charcoal bed working capacity will

be identified. The first phase of this project has been completed and a report is expected in early 1977. An extension of this work will evaluate the economics and the range of data.

Agricultural Chemicals

Pollution problems arising from the production of agricultural chemicals involve both air and water pollutants. They are associated with the production of fertilizers and pesticides.

FERTILIZERS

Studies of effluent cleanup from fertilizer production were assumed by IERL-RTP during 1975. Many of these programs were originated by EPA's Athens (Ga.) Laboratory. One project is currently in progress with Farmers Chemical Assoc., Inc. and is jointly funded by them.

The objectives of this project were to: evaluate all conventional and several experimental methods for inorganic nitrogen removal from water, determine the optimum process(es), and demonstrate at full scale on wastewater from a balanced-N fertilizer production complex (i.e., one containing ammonia, urea, nitric acid, and ammonium nitrate units). In the demonstration model, high ammonia concentrations were reduced by air stripping. Oxidation of residual ammonia to nitrate was accomplished by bacteria in the trickling filter. Denitrification of nitrates was accomplished by anaerobic lagoons using methanol or another waste stream as a carbon source. The feasibility of waste stream segregation, recycle of concentrated streams, and internal use of dilute streams was also to be established. Advanced physico-chemical processes (such as ion exchange, reverse osmosis, electrodialysis, and mixed-salt precipitation) were evaluated. Ion exchange (IX) proved to be the only feasible method. Double loop, continuous IX beds were designed and installed by Chem-Seps in 1972. Total water reuse was achieved for 1 month (July 1974). Ammonia and nitrate were recovered and recycled as product. Economic data analysis and evaluation of the system are still underway. The complete air/water impact of the system is still to be determined.

A related project is being conducted by the Institute for Technology of Nuclear and Other Mineral Raw Materials, Belgrade, Yugoslavia, at the FMK, Novi Sad Plant site. Directed toward evaluating air and water pollution potential and abatement in granular fertilizer plants, this project will:

° Characterize air and water waste effluents generated in a typical N-P-K granular fertilizer plant operating in the non-recycle water mode. Both the quantity and composition of major sources will be correlated with plant production rate, product mix, and raw material variations. Primary pollutants of interest are (1) air--particulates, hydrogen fluoride, fluoride, ammonia, and ammonium salt fines (e.g., ammonium chloride and sulphate), and (2) water--ammonia, fluoride, and phosphate.

° Construct and verify first-generation air transport and dispersion model(s) specifically for application to granular fertilizer plant emissions--gases (fumes) and particulates. All models tested will be calibrated with local meteorological and pollutant concentration profile data. The basic model development in this task is to create a generalized plant operating-downwind dispersion model for granulation plants.

° The quantification and characterization of Task I will be repeated following installation of more advanced dust emission control equipment. Using the Rotoclone, performance will be established under a variety of operating conditions; e.g., products and production rates, and its economics delineated.

° Models developed will be reverified by comparison of calculated and measured downwind pollutant profiles at the lower emission rates expected after Rotoclone installation.

° Models in combination with plant waste source data will be used to conduct cost-benefit ratio calculations for various treatment options should additional control be needed. Based upon these evaluations, the plant waste source inventory data, and the technology literature, a plan of recommended, cost-effective abatement or operating techniques for minimizing pollutant discharges from each source will be presented to the plant management as the final task output.

A study to develop treatment of ammonia plant process condensate effluent is being conducted by Gulf South Research Institute for IERL-RTP. To date program activities have been concentrated on plant sampling and test programs, as well as economic evaluations of process schemes to reduce ammonia in the plant process condensate. These schemes include atmospheric-pressure steam-stripping for process condensate; reinjection of steam-stripped process condensate into

primary reformers; adsorption of ammonia on vanadium pentoxide (a catalyst), to produce aqueous ammonia (28 percent) and/or anhydrous ammonia by-product upon regeneration of the catalyst; and addition of phosphates and potassium magnesium sulfate to the process condensate stream to produce a marketable by-product of magnesium ammonium phosphate fertilizer.

Atmospheric steam-stripping, a process that utilizes live steam as the driving force to strip out the ammonia in the condensate effluent via a packed column, has been shown to have the following advantages:

- Least expensive of all processes to operate.
- Simplest process scheme requiring least supervision.
- Small amount of process land area needed.

Further work will be concentrated on this process.

PESTICIDES

In a project jointly funded with Velsicol Chemical, IERL-RTP is currently developing, demonstrating, and evaluating two processes for nonbrine chlorocarbon pesticide wastewater. Demonstration tests involve heptachlor and endrin wastewater effluent from Velsicol's Memphis, Tennessee, plant. Processes of choice are resin adsorption removal and catalytic reduction (dechlorination).

In experiments begun in December 1976, Rohm and Haas XAD-4 resins were used to remove heavy-end chlorocarbons from the wastewater. It is estimated that solvent (isopropyl alcohol) regeneration of the resin will permit a closed loop system with reuse of resin and solvent.

Metal reduction focuses on the use of copper-catalyzed iron powder to dechlorinate/dehydrochlorinate the light and heavy components alike. This reduces waste toxicity as well as increasing the biodegradability of the waste. Although either process alone should treat effluent to acceptable levels, tandem tests, with the resin and catalytic reduction steps in series, will also be investigated. The test runs and final report are scheduled for completion by early 1978.

Extension of catalytic reduction technology to other pesticide manufacturing waste applications is being studied at the laboratory-scale by Envirogenics. Catalytic reduction technology, including not only iron/copper, but also other metal couples, has potential for treating other toxic substances such as Kepone, aldrin, dieldrin mirex, endrin, toxaphene lindane, heptachlor, DDT

and its metabolites, 2,4-D and 2,4,5-T. Screening studies will be done to establish its feasibility to detoxify and chemically degrade atrazine, toxaphene, Kepone, mirex, and other chlorinated hydrocarbons.

Bench-scale tests will be conducted for some of these chemicals in order to optimize the system, establish operating experience, and obtain data for scale-up. Finally, a comprehensive economic analysis will be done to compare cost of reduction technology to other alternatives such as carbon sorption. This work is scheduled for completion in March 1978.

Another pesticide problem under investigation is treatment of DDT manufacturing waste effluents. Envirogenics Systems Company is developing a solvent extraction process to remove DDT from waste that is currently being landfilled. The only domestic manufacturer is Montrose Chemical. A demonstration grant was awarded to Montrose Chemical, enabling their DDT plant at El Monte, California, to be used by Envirogenics to apply the technology to a DDT waste stream. DDT wastewater streams characteristically are of large volume and have high salt content, high suspended solids content, high viscosity, and undesirable levels of DDT. Heptane and monochlorobenzene have been tested as solvents for extraction of DDT and homologs. Since monochlorobenzene is a reactant chemical for making DDT, the organic phase from extraction can be fed into the head-end of the DDT plant. For this reason, monochlorobenzene is the preferred solvent. A final report on the project is expected in early 1977.

A third major pesticide program, being studied by Hoechst-Uhde, is the conversion of chlorocarbon and pesticide wastes by complete or partial chlorolysis. The technical feasibility of the process has been demonstrated; the major question now is one of economic feasibility. The current work has been described under Petrochemicals, above.

In other activities, an extensive overview document on pesticides was completed by the Midwest Research Institute. This document serves as input to the MRC source assessment program and as an internal management decision tool.

Textiles

Textile manufacturing processes generate voluminous wastewaters which are environmental polluters if not treated. If wastewaters can be reused, there is considerable potential for lower manufacturing costs. A number of projects,

either totally or partially funded by IERL-RTP, are now underway which have pollution reduction from textile processes or wastes as one of their goals or their major goal.

ATMI STUDY

EPA is aiding ATMI (American Textile Manufacturers Institute) in a 30-month court-ordered study to evaluate the treatment efficiency of technological processes, defined by EPA as BATEA (Best Available Technology Economically Available) for the textile industry and to evaluate the economic achievability and impact on the industry resulting from the application of these technologies. The work is being performed by technical and economic consultants under the joint direction of ATMI and EPA. The actual investigations will be carried out through the use of two mobile pilot treatment units. Approximately 24 plants will be investigated. These 24 plants will be selected from among plants already achieving the Effluent Guidelines Division's Best Practical Control Technology Currently Available (BPCTCA) level. The treatment processes will include physical/chemical treatment (chemical coagulation, multimedia filtration, granular carbon adsorption, powdered activated carbon, dissolved air flotation, and ozonation). The economic study is being conducted by a mutually agreed upon consultant. He will evaluate the data collected in the pilot treatment study, and project the economic impact of the 1983 guidelines on the textile industry as a whole.

In connection with the ATMI study, an investigation is being started to determine toxicity of textile effluents from secondary treatment plants. The ability of the six treatment technologies to reduce toxicity will be tested. The toxicity of waste streams will be established, using biotesting screening techniques. It is anticipated that this project will involve cooperation between several EPA organizations: IERL-RTP, Effluent Guidelines Division, and two or three "water" laboratories.

OTHER PROJECTS

Holliston Mills, Inc., in Kingsport, Tennessee, has been investigating, on a pilot scale, the treatment of cotton textile waste by enzymes and a high-rate trickling filter. A report is expected in mid-1977.

In a novel approach based on a process modification, Auburn University is evaluating the impact of the use of solvent-based sizing techniques on textile plant effluent parameters. The project includes economic and technical evaluations. The project is nearly complete and a report is expected in mid-1977.

In another project, over the next several years, Auburn plans to: (1) analyze and characterize potentially useful solvent warp sizing polymers, (2) determine the physical/chemical effects of solvent substitution on fibers, (3) evaluate their effect on actual weaving performance, (4) evaluate the economic impact and potential of solvent technology in warp sizing, (5) evaluate the energy implications of solvent process substitution, (6) evaluate the effect of solvent slashing and desizing on process water discharge quality and quantity, and (7) evaluate the effect of solvent substitution on air pollution and ambient air quality. An additional project with Auburn is being funded to investigate the use of aqueous solutions of sizing agents that can be recovered by thermal precipitation. This project is directed toward eliminating the air pollution problem encountered with use of other solvents.

Owens-Corning Fiberglas in Toledo is demonstrating, first in pilot-scale and then in full-scale plants, the complete recirculation and reuse of a complex industrial wastewater from a fiberglass textile manufacturing plant. The reclaimed wastewater will be used for nonprocess uses such as washdown, chain scrubbing, and cooling. Accomplishing this objective of total reuse requires: (1) establishing water quality criteria for inplant water uses, (2) additional local water conditioning and recycle facilities for cooling, scrubbing, and chain washing, and (3) improved wastewater treatment so that remaining wastewater may be reused for nonprocess uses. The pilot phase of this study is complete and a report will be published in mid-1977. Owens-Corning, based on this work, will build a full-scale plant, the design of which is partially funded by EPA.

LaFrance Industries in LaFrance, South Carolina, is assessing the technical feasibility of producing a reusable effluent from textile wastewaters by applying hyperfiltration. The objective of this project is to demonstrate pilot-plant reverse osmosis, possibly in connection with ultra-filtration, for treatment of dye house wastewaters followed by reuse of the water, with attendant energy savings. Cellulose acetate and dynamic membrane systems are being evaluated for the separation of dissolved solids and color concentrates. Engineering and economic analyses are being performed for all aspects of the project, including water reuse in standard dyeing processes.

J. P. Stevens & Co. in Greensboro, North Carolina, is evaluating treatment sequences for cleaning textile wastes including biological treatment, multimedia filtration, and activated carbon/ion exchange. A key feature of the research

is the demonstration of reuse of the completely treated water in dyeing tests. The biological and multimedia filtration units are full scale; the activated carbon/ion exchange units are pilot scale; and the reuse investigations are on laboratory scale. The project is nearly complete and a report is expected in mid-1977.

Beaunit Fibers Corporation is biologically treating nylon 6,6 wastewaters using oxygen enriched off-gases (40 percent available oxygen) from the nylon manufacturing process. The oxygen aerated activated sludge system is monitored to determine raw waste characteristics, process kinetics, and economic data. This unique system demonstrates treatment of nylon wastewater and utilization of by-products to achieve pollution abatement. The project is nearly complete and a report is expected in mid-1977.

Bennett College, in Greensboro, North Carolina, is evaluating the ion exchange process for treating textile dyeing wastewater. This pilot-scale demonstration assesses dye reuse and makes cost projections for a full-scale plant. The project is nearing completion and a report is expected in mid-1977.

ENVIRONMENTAL ASSESSMENT--AIR POLLUTION SOURCES

An effort is being made to characterize the air pollution aspects of the American textile industry, including emissions from surface finishing operations such as dyeing and sizing. Monsanto has completed major portions of the preliminary source assessment document. Also in conjunction with this, Monsanto has completed a document "Preliminary Overview and Prioritization of Sources of Air Pollution in Textiles Manufacturing." This document presents impact factors for all major unit operations in textile manufacturing and provides the basis for making choices for further source characterization by source sampling and analysis.

Incineration at Sea

The major goal of the Incineration at Sea program is to establish minimum requirements and operating criteria to ensure that this waste disposal method is conducted in an environmentally acceptable manner. Monitoring, sampling, and analysis plans were developed for shipboard incineration of organochloride wastes. Considered were: (1) a description of incinerator ships, their incineration operation, and interface requirements necessary for obtaining samples; (2) design of sampling probe and mount, and the sampling procedure; (3) approach for on-line monitoring of combustion gases; (4) acquisition of combustion products; (5) testing work areas to ensure safety during tests; and (6) general analytical plan for all

the samples taken during waste destruction tests and of the wastes to be destroyed.

Two at-sea incinerations were observed by an EPA contractor. One "burn" was monitored by the French Government: its results were reviewed with EPA and served as additional input to our data gathering program. During 1977, EPA expects to conduct full scale monitoring on two different incinerator ships, results of which will be used to develop Federal regulations for the control of incineration at sea.

Miscellaneous Projects

FLARE SYSTEMS

Flaring, while a relatively cheap method for disposing of certain industrial waste gases, may create significant quantities of air pollutants. In a study completed in mid-1975, the number of flares operating in the petroleum, chemical, and metallurgical industries was estimated along with the amount of material flared. Design parameters for flare systems were reviewed to provide the background to establish the base on which additional work can be built in order to make flaring an economical and environmentally sound method of waste gas control. The report, issued in early 1976, includes an evaluation of present engineering technology and of existing flare systems, assessment of present practices and problems, determination of major sources, and development of research recommendations including potential applications. It summarizes emissions data, and gives emission factors for hydrocarbon waste streams, based on limited available data. It recommends the selection of applicable flare systems and components for flaring given waste streams and discusses potential problems which may affect design and component selection. Cost guidelines based on discussions with flare vendors and users are given.

VEGETATIVE STABILIZATION OF MINERAL WASTE HEAPS

This project, conducted at the Research Triangle Institute, consisted of an evaluation of the use of vegetation as a method for controlling fugitive dust emissions from man-made mineral waste heaps. Mineral waste piles exist primarily because of mining and milling operations. They are found in every state. In dry windy climates, such as those of the Great Plains and Rocky Mountains of the United States, they constitute a significant source of fugitive dust emissions. While on a national scale fugitive dust emissions from mineral waste piles are not the dominant source of fugitive dust emissions (dirt roads, agricultural activities, and construction sites emit more fugitive dust), they often dominate the air quality in their immediate vicinity. In

addition, the toxic character of a specific mineral waste, such as asbestos, can make control imperative even though the mass emissions alone are not exceptionally high.

Much revegetation research has been carried out in recent years and the bulk of the study reviewed this work in a pseudo case history format from which general guidelines and recommended methodologies for carrying out the revegetation of mineral waste piles were deduced.

The report on this project was issued in April 1976.

The study concluded that:

- Vegetative cover has been very successful in stabilizing many mineral wastes and is preferred, when practical.
- Revegetation of mineral wastes is sufficiently complex that no sure-fire procedure can be specified as to optimum procedures for any given waste in a specific area.
- Virtually any mineral waste pile can be stabilized with vegetation, given enough time and resources; the problem is knowing when it is economically reasonable to proceed with a vegetative control method.
- Little quantitative data exist by which to measure the magnitude of the fugitive dust emitted by mineral waste piles or to assess the improvement in air quality resulting from vegetative stabilization.

EQUILIBRIUM PARTIAL PRESSURE IN ALKALINE SCRUBBERS

A report on an inhouse study on equilibrium partial pressure of sulfur dioxide in alkaline scrubbing processes was released in December 1976. The study, performed on NaOH/KOH systems and citrate systems, produced data which invalidated Johnstone's equations and which provided the basis for a better understanding of the thermodynamic limitations of scrubbing efficiencies.

ODOR ABATEMENT FOR RENDERING INDUSTRY

The problem addressed by IERL-RTP in the rendering industry was control of odors. In a program jointly funded with the Fats and Protein Research Foundation, the Illinois Institute of Technical Research Institute, (IITRI) designed and evaluated wet scrubber systems for effective removal of rendering odors from plant ventilating air and process air. Scrubber performance was measured by both odor panel and gas chromatographic analysis. Experiments in a three-stage packed-bed laboratory-scale scrubber at the rendering plant evaluated solutions of sodium hydroxide and the strong oxidants sodium hypochlorite, hydrogen peroxide, and potassium permanganate. Since removal of 90 percent per stage was obtained with fresh alkaline sodium hypochlorite solution, this reagent was selected for subsequent longer-term tests. A 2 week test of a

plant-scale horizontal spray scrubber, operating on plant ventilating air, showed odor removal of 83 percent. The outlet odor units averaged 64; the inlet ranged from 165 to 2500 odor units. A three-stage packed-bed scrubber was evaluated to replace an existing incinerator being used to treat a process air stream that contained from 5000 to 50,000 odor units. A week-long test with the scrubber gave a lower-than-expected average odor reduction of 85 percent. Data were obtained on chemicals consumption and effect of flow variables on odor removal, and used to update computer models that can be used to design scrubbers for odor removal.

This project has been completed and an EPA report was issued in January 1976.

GUIDELINES FOR ENVIRONMENTAL ASSESSMENT OF ENERGY SYSTEMS

To standardize preparation of environmental assessment documents in the general field of energy systems, GCA Corporation, under IERL-RTP contract, prepared a guideline document which was published in March 1976. The report: (1) defines environmental assessment (EA) programs and their role in energy system development; (2) indicates data requirements of an EA; (3) outlines exemplary methodologies for acquiring the necessary data; (4) serves as a technology transfer vehicle by providing background information on environmental monitoring and modeling, which can be used in EAs; (5) summarizes the extent, quality, applications, and location of existing information resources which can be used in the planning of EAs; and (6) summarizes existing or proposed standards and criteria for evaluating air-, water-, and land-based pollution. It includes: waste stream characterization and pollution identification; indirect pollution associated with energy system development; estimating the sphere of influence of an energy system; evaluation of environmental impact; methodology for conducting source tests; use of dispersion models; available data banks and information sources; and existing and proposed environmental regulations. Each topic is explored to the degree necessary to acquaint the user with current standards, sampling and analytical techniques, and environmental models. General discussions are supplemented where possible with specific examples in order to clarify some of the concepts presented.

METALLURGICAL PROCESSES

The major reorganization of EPA's Office of Research and Development resulted in the divestment of nonferrous metallurgical air pollution programs and the acquisition of ferrous metallurgical water and solid programs by IERL-RTP. The ferrous metallurgical industry consists of the iron and steel, ferroalloy, and iron and steel foundry segments.

Iron and Steel Industry

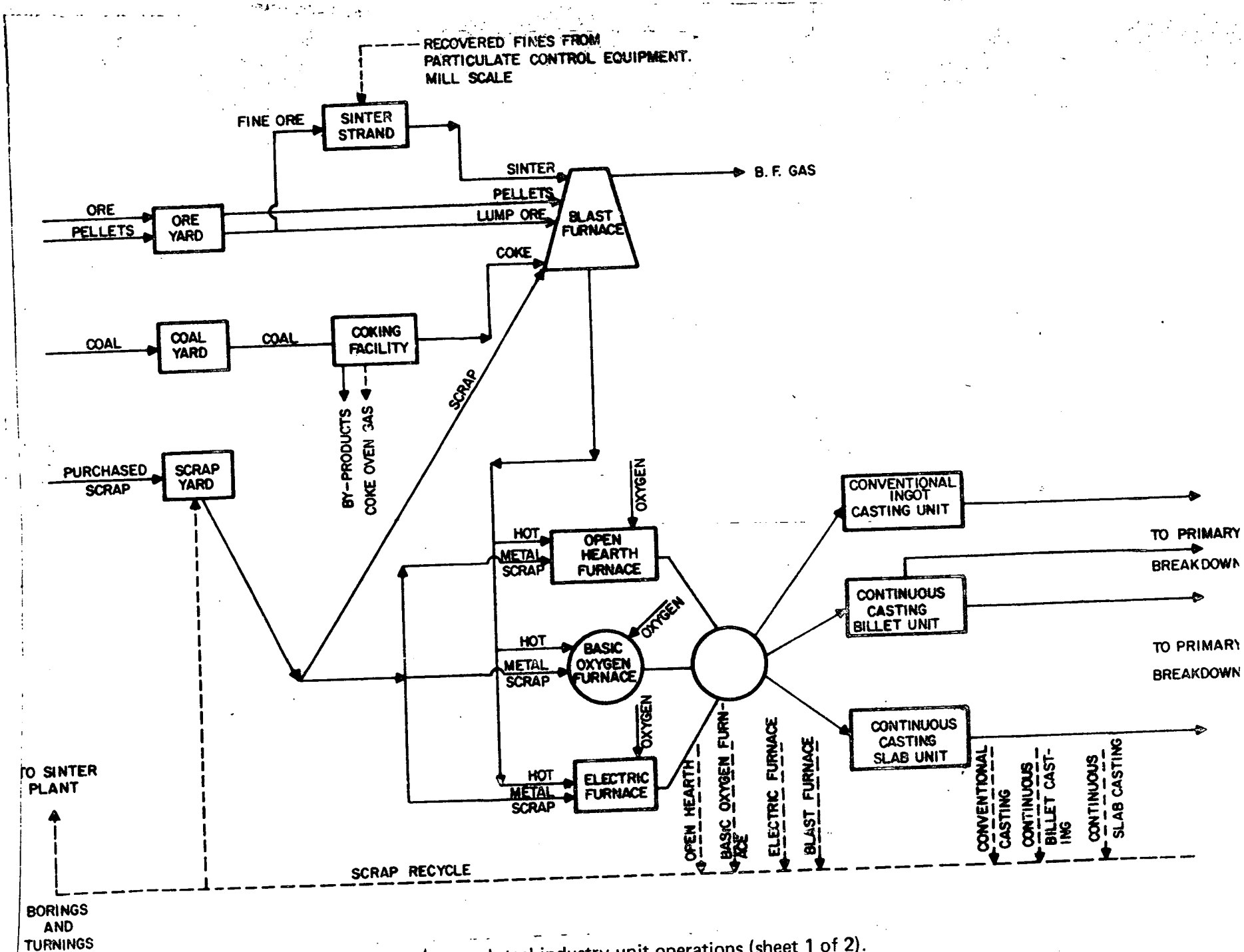
The iron and steel industry converts iron ore and scrap iron into useful iron and steel products (see following illustrations). At large integrated steel plants, iron-bearing material (lump iron ore, sinter, or pellets), limestone, and coke are charged to a blast furnace where the iron ore is reduced to molten metal which is periodically tapped. The iron from the blast furnace is saturated with dissolved carbon which must be removed to change the iron into steel. The iron from the blast furnace, usually molten, is generally mixed with cold scrap in a steelmaking furnace, where the carbon is reduced to the required level, impurities are removed, and alloying agents are added. In the basic oxygen steel process, the mixture is blown with oxygen to oxidize the carbon and other impurities. (Other, less important, steelmaking processes are the open-hearth and electric arc.) The steel from the furnace is poured into ingots that solidify. The ingots are then adjusted to proper and uniform temperature and physically squeezed into the desired shape in rolling mills. A newer variation of the process is to cast the steel from the steelmaking furnace continuously, thereby minimizing the rolling that is required.

The process sounds simple, but in reality it is rather complex. There are many ancillary processes and operations to contend with; e.g., sintering, coke production, scarfing, and galvanizing.

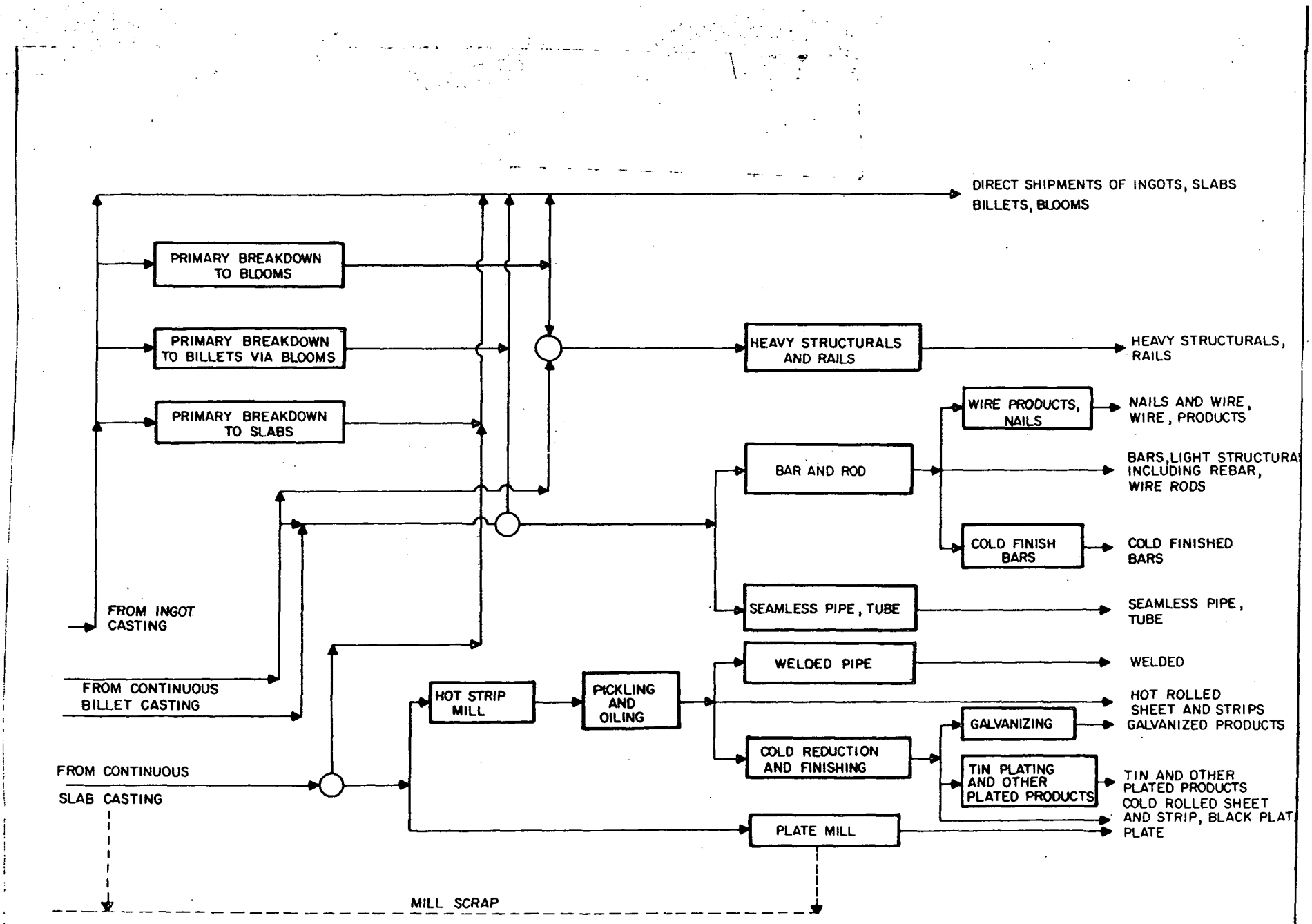
The iron and steel industry is not limited to large integrated plants; smaller plants are spread throughout the country. In these miniplants, scrap steel is melted in electric arc furnaces with little or no refining, then rolled and formed into simple shapes (e.g., concrete reinforcing rods) to meet local marketing needs. Other small iron and steel plants melt scrap in cupolas or electric resistance furnaces. The molten iron and steel at these foundries is cast into desired shapes.

Studies, started in 1968, have shown that effluents from the iron and steel industry are quite large and originate from a multiplicity of sources (see following illustrations).

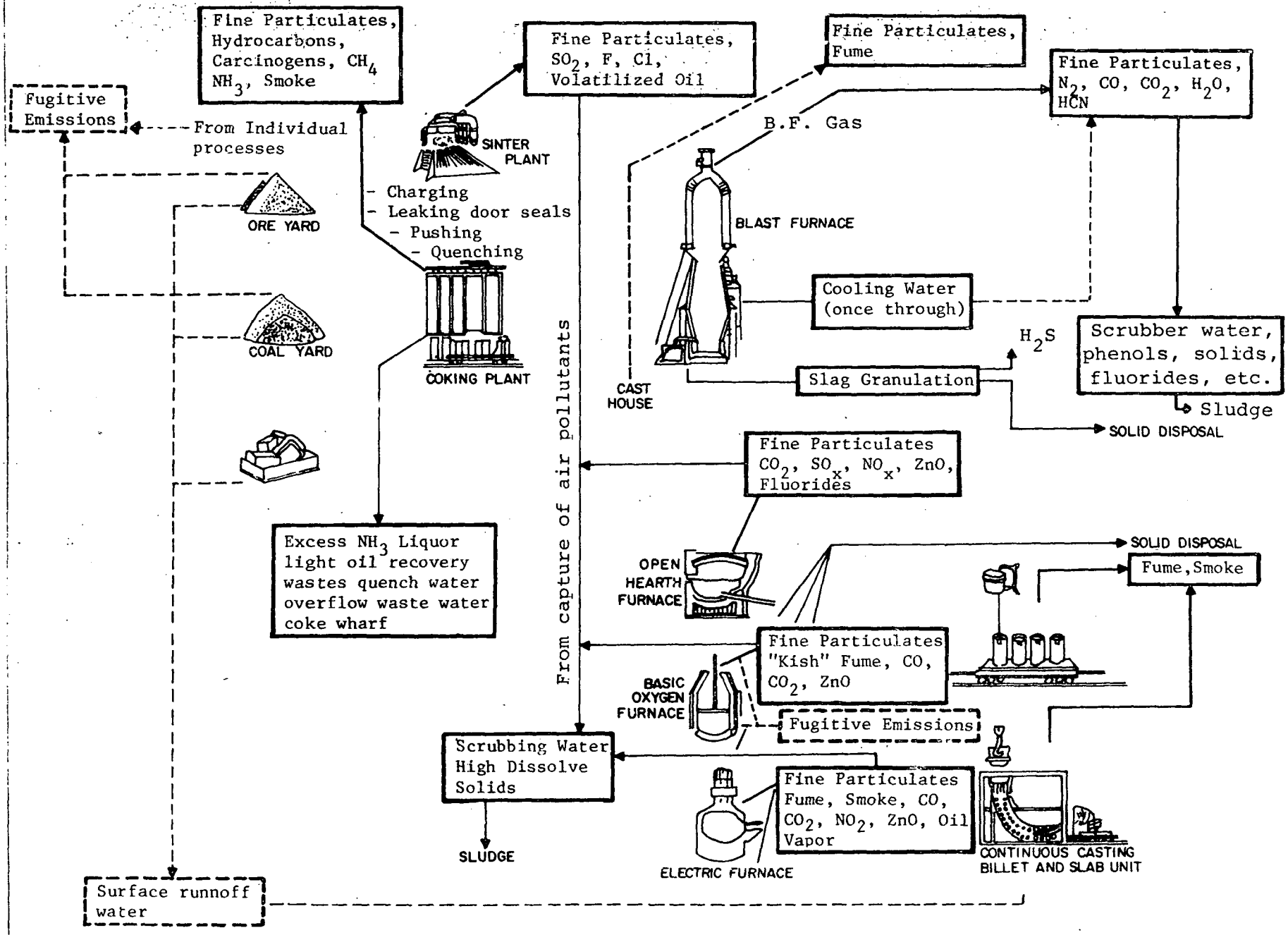
Since these studies clearly showed that coke production was the most serious pollution source in the industry, IERL-RTP directed its initial efforts toward controlling that source. With work underway on controlling emissions from coke production, IERL-RTP has now expanded its outlook--initiating projects in other areas of the industry, in addition to cokemaking.



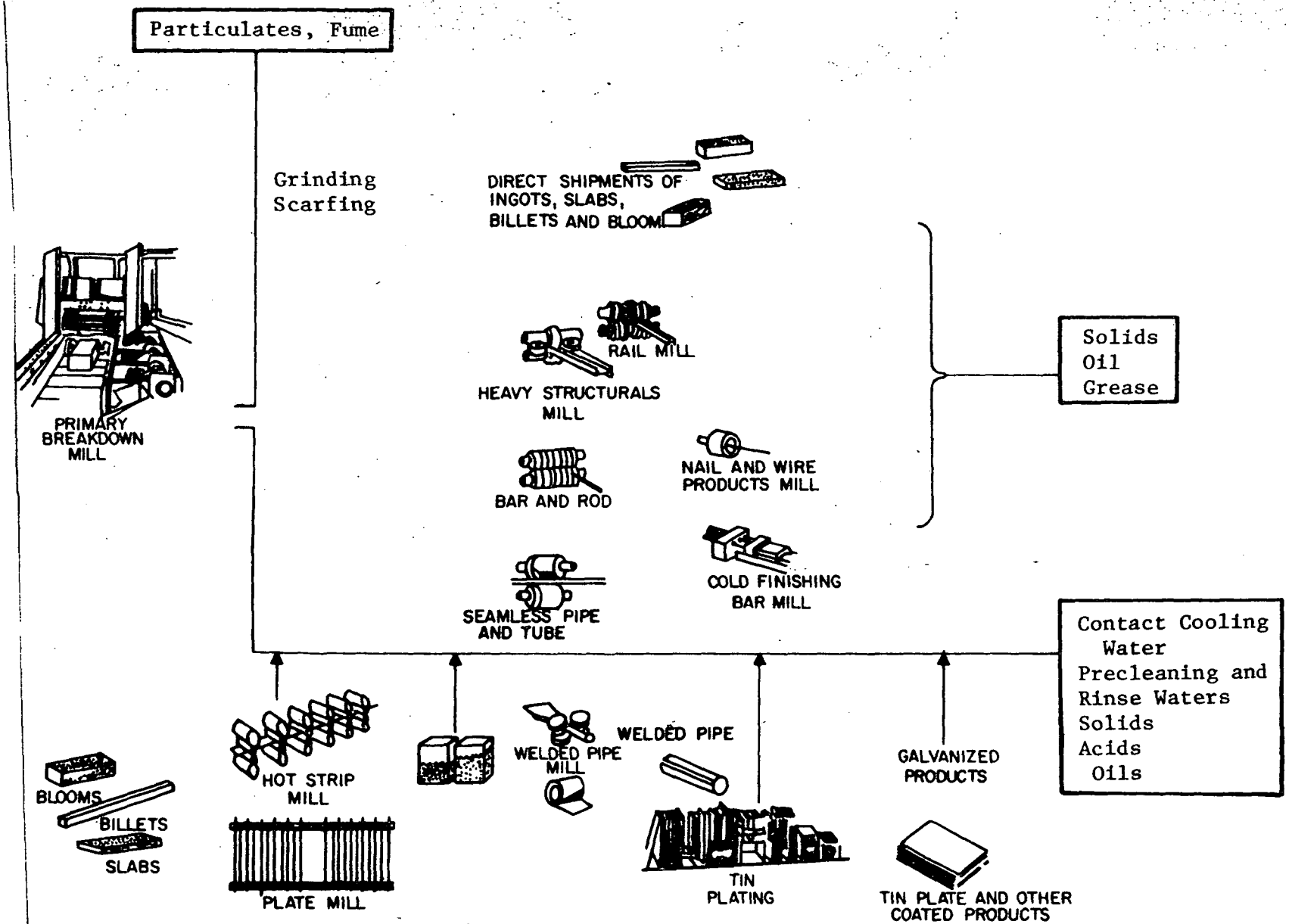
Iron and steel industry unit operations (sheet 1 of 2).



Iron and steel industry unit operations (sheet 2 of 2).



Discharges from iron and steel industry (sheet 1 of 2).



Discharges from iron and steel industry (sheet 2 of 2).

Since 1975, the Battelle-Columbus Laboratories have been involved in the characterization of emissions from metallurgical processes. This work has provided support to IERL-RTP in source testing and emission analysis from a variety of metallurgical processes.

A new contract being negotiated will provide environmental assessment and technology evaluation support on a continuing basis for basic iron and steel and ferroalloy processes.

The uses and fate of lubricants, oils, greases, and hydraulic fluids in the iron and steel industry are being examined by Pacific Environmental Services, Inc. All uses of these substances are being identified and the movements of them through the processes to the environment are being investigated. An examination will be made of possible methods of controlling discharges into the environment.

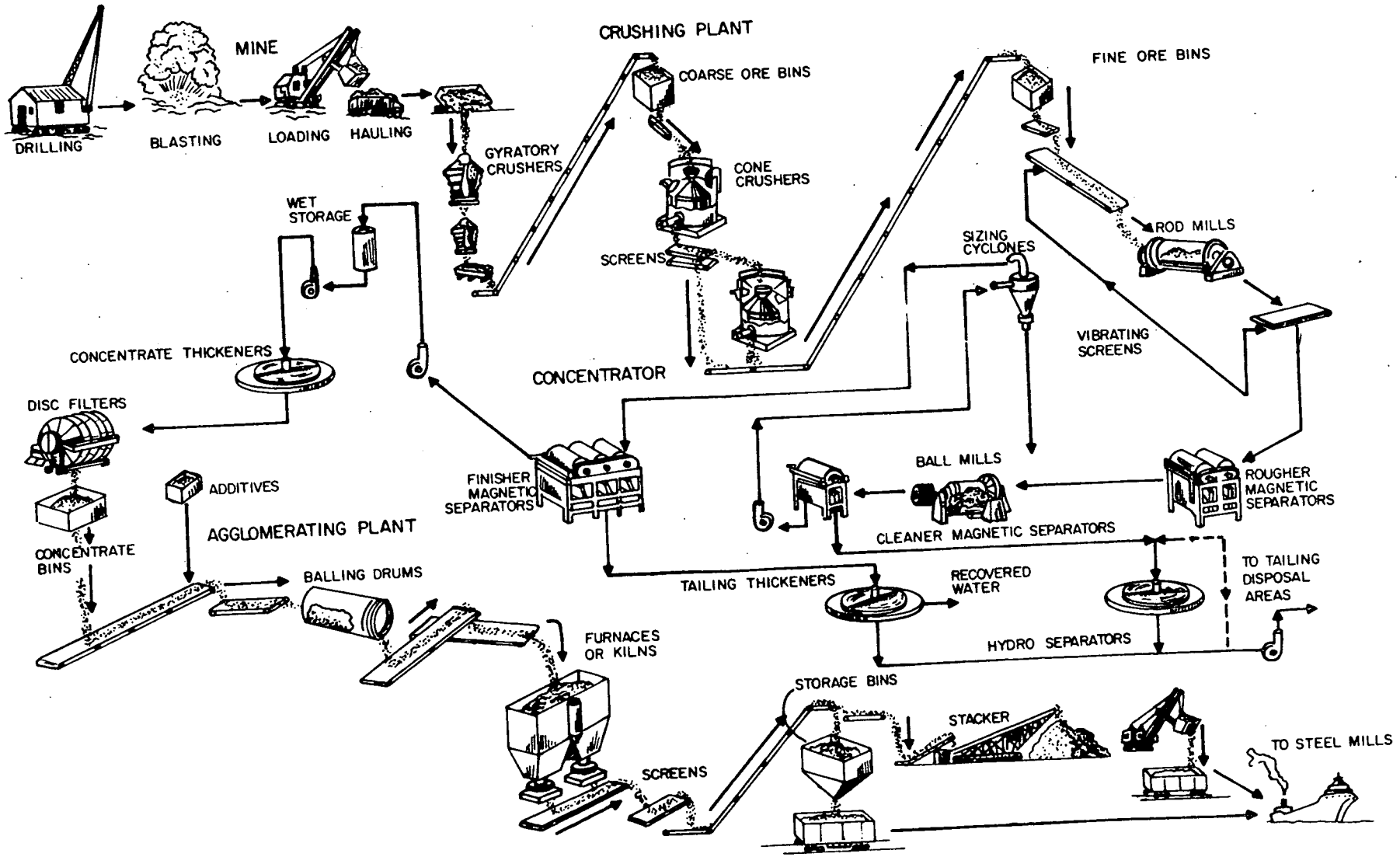
A contract to Hydrotechnic Corp. will examine the feasibility of demonstrating zero water discharge and minimum air pollution discharge at a single steel plant. Economic, technical, and time requirements will be determined.

Specialized environmental assessment and control programs have been initiated in the areas of mining, beneficiation, and pelletizing; cokemaking; sintering; ironmaking; steelmaking; ferroalloys; hot forming and cold finishing; surface preparation and finishing; fugitive emissions and runoffs; and abnormal operating conditions. An iron and steel cooperative program, developed under a U.S./USSR environmental agreement, has focused on making each participant aware of the other's technological advances in pollution control. The program has matured to the point that cooperative efforts will soon be starting.

MINING, BENEFICIATION, AND PELLETIZING

Domestic iron ore production is about 90 million tons per year, of which about 83 percent is from the Lake Superior region. Minnesota accounts for 65 percent of the total, Michigan, about 16 percent, and Wisconsin, 1 percent. The remaining production is from 17 other states. Production comes from over 50 mines, most of which are of the open-pit type. Open-pit mines produce approximately 90 percent of the U.S. iron ore. Principal iron ore minerals are the iron oxides, with the carbonates and sulfides being of secondary importance.

Most ores currently recovered are beneficiated to an iron ore concentrate, using methods that vary from simple to complex. Most of the concentrates are pelletized prior to shipment. A typical, though simplified, flow pattern for a taconite plant is shown below.



Mining, benefication, and pelletizing operation.

A 1-1/2 year contract was let in July 1975 to Midwest Research Institute as the first phase of a program which is intended to demonstrate techniques or systems for the control of emissions from the iron ore mining, beneficiation, and pelletizing industries. The purposes of this first phase are: (1) to identify the emission sources; (2) to quantify these emissions; (3) to prioritize these emissions based on their environmental impact; and (4) to make recommendations for future research, development, and/or demonstration projects to reduce emissions from those sources determined to be most critical.

The contract effort to date has been to accumulate data by literature search, by talking with industry and government personnel, and by plant visits. Major effort has been on source identification, finding source test data, making measurements where data is sparse, noting plant-to-plant similarities and differences, and discussing with plant personnel the control devices attempted on various process points and their reasons for selection of one device over others.

The effort for these sources may ultimately be expanded to include water pollution aspects of the program.

COKEMAKING

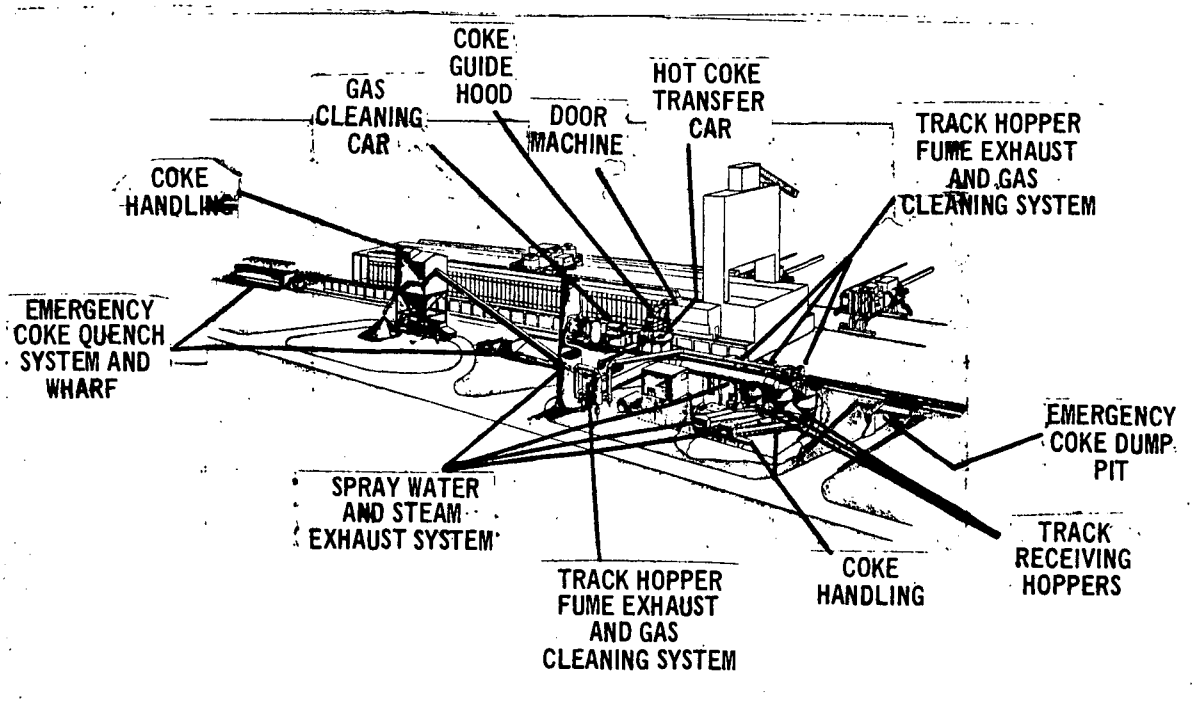
Control of emissions in cokemaking is a major IERL-RTP contribution to the iron and steel industry. It is the process which produces the most air pollution in the industry, itself one of the major air-polluting industries. Topside coke oven workers have been shown to have a substantially higher risk of lung cancer than the average worker, probably from carcinogenic materials associated with the particulate fraction.

Enclosed Coke Pushing and Quenching

IERL-RTP and the National Steel Corporation are funding a demonstration of the enclosed coke pushing and quenching system on National's new Weirton Steel Division Brown's Island coke plant. The conventional coke pushing and quenching system, used throughout the industry, involves pushing the incandescent coke from the sealed coking oven through a guide into an open, shallow-bed car for transport to a batch-type quenching station. Substantial emissions of smoke and particulate are discharged into the atmosphere throughout this operation. This situation is aggravated if the push contains incompletely carbonized coke. At the quench station, large quantities of water are poured into the bed of hot coke. The instantaneous formation of steam results in the discharge of large quantities of entrained particulates to the atmosphere.

In the EPA/National Steel system (shown below), the coke is completely enclosed from the moment it leaves the oven until after it is quenched. Emissions evolved during the push and transfer to the quench station are drawn off and removed by means of a high-energy scrubber on the gas-cleaning car. Emissions evolved from the hot coke in the underground track hoppers are also controlled by a high-energy scrubber. The relatively low-volume continuous steam plume generated during the continuous quenching operation is contained by hoods and controlled by a vapor suppressor in the stack.

Current information indicates that this system will apply to nearly all new coke batteries. This is particularly significant because at least half of the existing coke batteries are at least 20 years old. Based on an average life of 30 years, nearly half of the 250 existing batteries will have to be replaced in the next 10 years. Since continuous cokemaking processes may not be available until the end of that period, most new batteries will be conventional slot ovens with useful lives extending well into the next century. Demonstration of this system will provide proven emission control technology which can be integrated into the initial plant design.



EPA/National Steel coke pushing and quenching system.

It is estimated that the system being installed to serve the single 87-oven Brown's Island battery will cost $4 million over and above the cost of a standard pushing and quenching system. Expansion to serve a second battery will cost another $1.8 million (1972 dollars).

Start-up, originally targeted for December 1972, was delayed six months due to an explosion to the battery basement. Start-up actually occurred in May 1973.

Excessive wear in sludge pumps and in quenching units took some time to be resolved. Also, thermal effects on track hopper gates and roofs were difficult to obviate.

Extensive modifications to the track hopper gates and roofs, to the coke feeders and quench units, and to the hopper fume pollution control system are complete. Testing will be completed in the spring of 1977. Ambient air measurements were taken to develop data on background pollution levels prior to restart of battery.

The Phase 2 effort consists of long-term emission testing and a system evaluation program to establish the system's emission control potential; system operability, reliability, and maintainability, and the system's operating cost. This is accomplished by:

- Extensive tests across the various control devices to determine both the quantity of emissions generated and the efficiency of the control devices.
- Maintaining complete records of coke production, maintenance performed, malfunctions, and utility requirements.
- Continuously monitored ambient air concentrations of particulate at various locations around the coke plant.
- Extensive measurements of water quality to identify water pollutants in the effluents, as well as the potential air pollutants if the water were used to quench coke.

Phase 2 test and evaluation results will be contained in a final report, due to be published in mid-1977.

Smokeless Coke Pushing

IERL-RTP contracted with the Ford Motor Company to test and evaluate the pushing emission control system developed by Koppers Company and installed on the "A" battery of Ford's River Rouge plant, Dearborn, Michigan. Principal features of the system are a fume-collecting hood, a fume main, a venturi

scrubber, and a modified quench car with a synchronization system for coordinating the quench car's movement with that of the pusher (see diagram below).

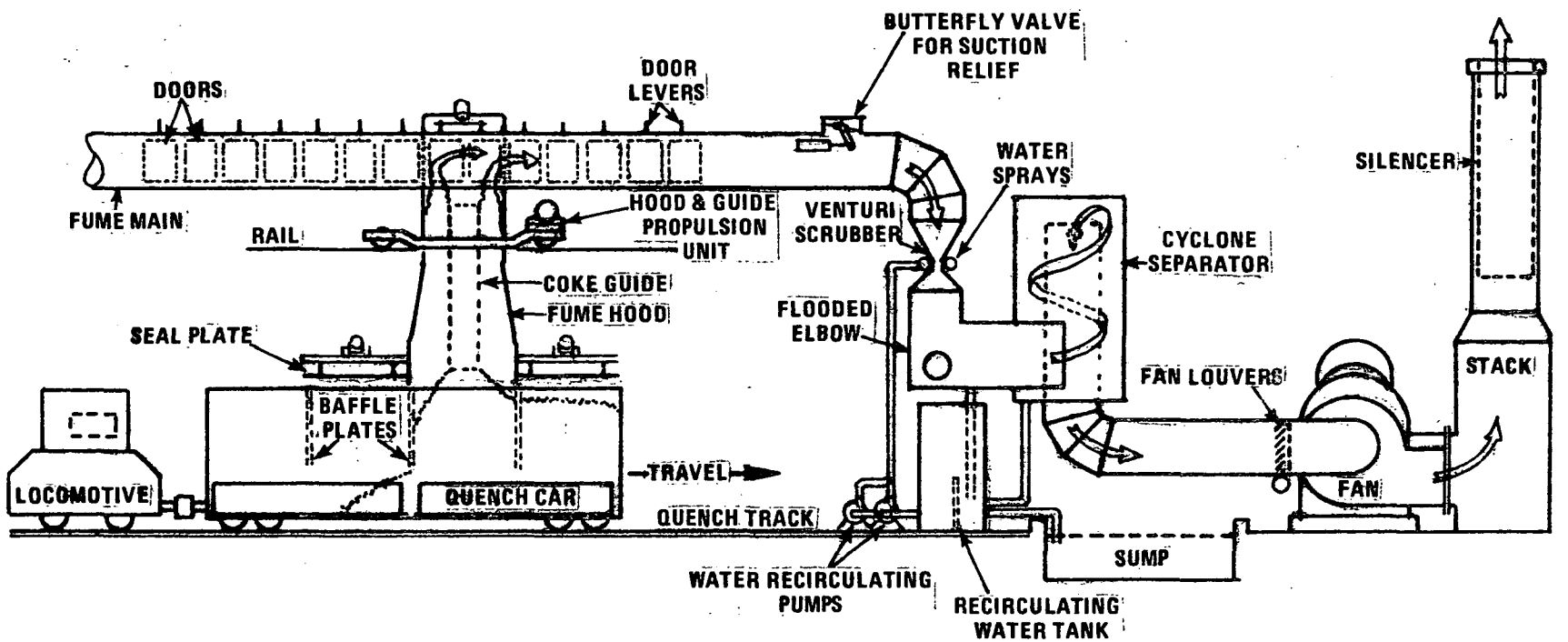
Since the control system apparently will fit most, if not all, existing coke batteries, demonstration of the Ford system will make available to the industry a relatively low-cost device capable of significantly reducing coke oven pushing emissions. The greatest application of this system will be on existing coke batteries which it will serve as an interim solution until these batteries can be replaced (average battery life is 30 years) and a more complete control system can be installed.

The test and evaluation portion of the study included examination of operating and maintenance records, long-term system observation, determination of system capture efficiency, and source testing for a number of pollutants both before and after the venturi scrubber of the captured effluent. Data on capital and operating costs were developed as well as data on utility and labor requirements, system reliability, and control effectiveness. The final report will be completed early in 1977. The design manual was published in September 1974.

Guidelines for Coke Oven Pollution Control Applicability

To encourage industry application of EPA-demonstrated coke oven air pollution control technology, there is a strong need for a set of guidelines showing specifically how the technology can be applied to each type of U.S. coke battery. Each of the demonstrated systems discussed above was designed specifically for the host coke battery; two of these--the EPA/AISI Smokeless Coke Charging and the Ford Smokeless Coke Pushing--were retrofits to existing batteries. The control technology demonstrations were designed and operated to co-exist with existing features and operating techniques of the host battery. Minor battery modifications were required in some cases. Although basic features must be adhered to in applying the technology, there are a number of design, construction, and operating options available that can be used to meet the requirements set by the battery features. Likewise, there are a number of battery specifications which must be met, if only by battery modification, to accommodate the control technology.

In addition to EPA-demonstrated projects, the sequential charging technique called "staged charging," first disclosed in 1961 by M. R. Meades and G. E. C. Randall of the United Kingdom, has recently been perfected by the private sector and applied to existing batteries. This technique involves



Koppers/Ford coke oven smoke emission abatement system.

some physical alterations to the charging components but is mainly dependent on the precise manual execution of specific procedures for good pollution control. On the other hand, the EPA/AISI Smokeless Coke Oven Charging System, also a sequential charging technique but of a different type, has the demonstrated potential advantage of a fully automated system in achieving repeatability of operation. A system which adapts the automated methods of the EPA/AISI system to the requirements of staged charging would be expected to perform, on a repeatable basis, better than either of the two basic approaches. Therefore, even though staged charging was not demonstrated by EPA, its apparent compatibility with one of the demonstrated EPA systems makes it a worthy candidate for an applications study.

Such a study would define both the salient features of demonstrated control technology and U.S. coke batteries and show how the control technology can be meshed with the batteries in the most technically feasible and economical way.

Accordingly, a 12 month project has been started (July 1976) to develop guidelines for application of demonstrated coke battery air pollution control technology to existing and new coke batteries. Specific control technologies to be examined include the EPA/AISI Smokeless Coke Oven Charging System, the Enclosed Coke Pushing and Quenching System, the Smokeless Coke Pushing System, and staged charging (industrial development). The guidelines will examine characteristics of the control system that are important in design, construction, and operation and relate these characteristics to application of the control systems to U.S. coke batteries based upon examination of their characteristics and requirements. The final report will be used by coke producers in planning the application of the control technology and by regulatory officials in specifying air pollution control strategies and enforcement actions.

Characterization of Coke Oven Door Emissions

Gases, particulates, and condensible organic materials being emitted from ineffective coke oven door seals are suspected of containing a number of toxic substances. Since these emissions have not been sufficiently quantified or analyzed, it is the purpose of this task to do so. The results of the study will be used to set future program priorities.

The sampling method being used was developed under contract with Battelle-Columbus Laboratories. During early trial runs, the system for capturing emissions worked well except that the hood and door temperatures rose sufficiently

high to cause excessive door leakage, making the test nonrepresentative. Detailed thermal analyses were performed on the coke oven door and sampling apparatus; modifications to the hood solved the temperature problem. Samples taken included coke and coal, gaseous, particulate, and condensible organic samples. Analyses performed included GC-MS, Spark Source MS, High Resolution MS, and toxicology studies. This study will be completed in January 1977.

Improved Coke Oven Door Seals

The leakage of gases and organic volatiles from coke oven end closures is a major pollution problem in the iron and steel industry. The problem can be partially solved by good operating practices and maintenance. However, completely solving the leakage problem will require significant advancement in the state-of-the-art of coke oven end closure. To this end, a program has been undertaken by IERL-RTP, cofunded on a 50-50 basis with the American Iron and Steel Institute (AISI). The first phase of the program, started in June 1975, was recently completed. The study by Battelle-Columbus Laboratories was designed to define the causes of the leakage, identify the operating conditions which must be tolerated by the sealing material, investigate other work being done in this area, and conceptualize improved methods to eliminate coke oven door leakage. Of the 45 sealing concepts produced by Phase I, two were selected (one an alternative) for further development and demonstration. The primary concept is of the metal-to-metal type; the alternative concept is of the compressible, elastomer type.

The Phase II contract was signed in August 1976. This phase will develop, fabricate, and test selected sealing concepts. This will be accomplished in eight tasks, including:

- Mathematical modeling and analysis of coke oven sealing systems.
- Physical modeling and laboratory experimentation.
- Field data collection.
- Analysis, evaluation, and recommendations.
- Full-scale unit design and component testing.
- Fabrication and installation.
- Planning and completion of field evaluation.
- Analysis and preparation of manuals and final report.

SINTERING

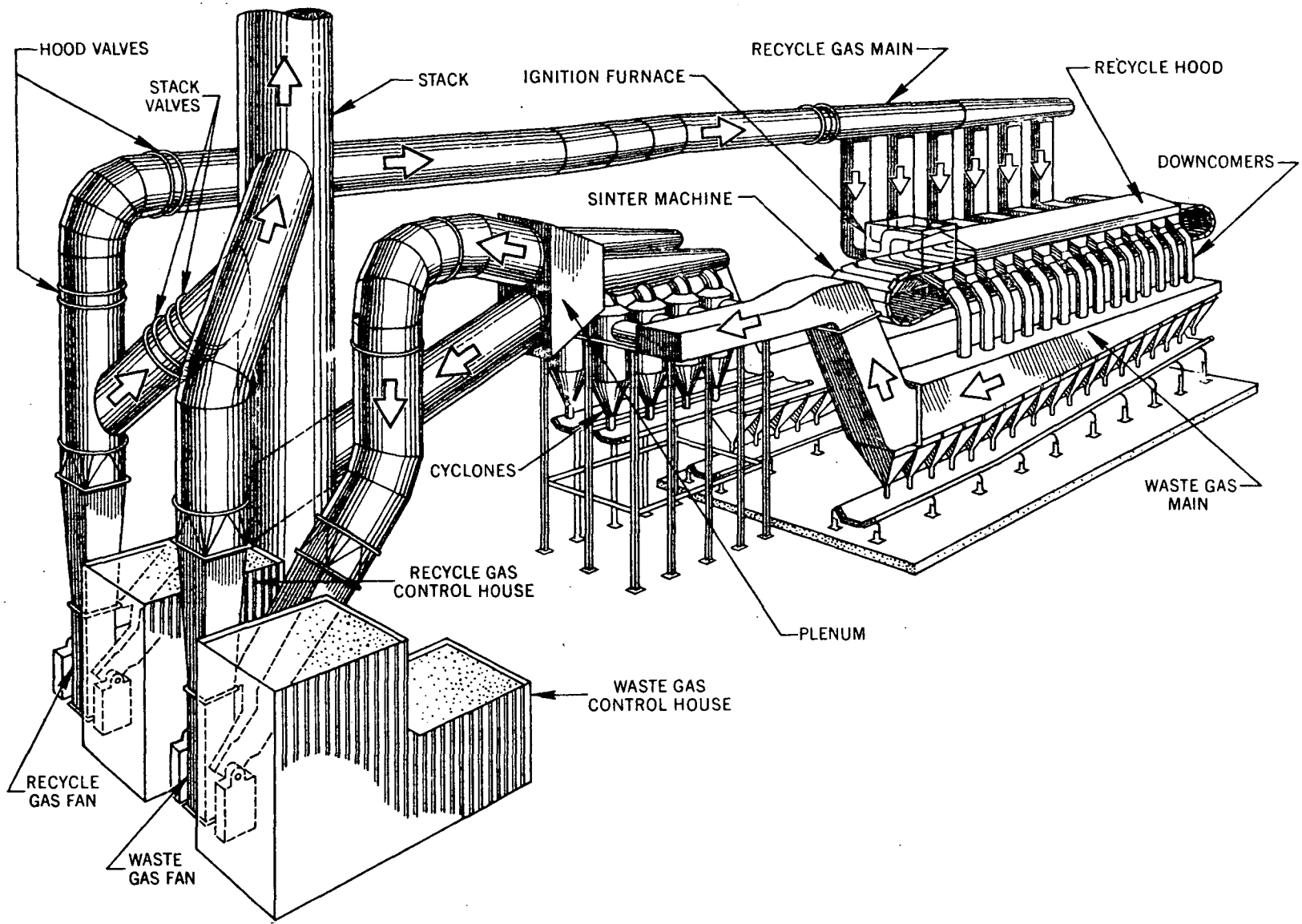
Sinter, in the iron and steel industry, is an iron-bearing material suitable for charging into a blast furnace. The sintering process combines natural

ores of fine particle size and iron-bearing wastes recovered from various other steelmaking processes (e.g., flue dust, mill scale, and settling basin solids) with coke breeze and limestone. Limestone is added to provide the required flux for the iron-bearing material when processed in the blast furnace; the coke breeze is used for ignition purposes. This raw material is then charged onto pallets, which retain the material while permitting combustion air to pass through the bed, igniting the coke breeze and fusing the other material into a cake. The cake layer is then broken, cooled, classified, and finally charged to the blast furnace to recover the iron metal.

The combustion gases and excess air handled by the main exhaust fans as a result of the sintering process force large volumes of air to pass though the long, moving sinter bed. This exit stream contains particles and gases of varying chemical composition. First-generation air pollution abatement equipment in the form of cyclone separators is incapable of achieving desired levels of pollutant control. These cyclones remove the large particles thus prolonging fan life; but the fine particles, hydrocarbons, and gaseous pollutants are not removed.

Wide experience in the United States indicates that electrostatic precipitators are not effective in controlling emissions to meet no-visible-emission standards. The problem is due both to the hydrocarbon content of the gases, and the high basicity of the particulate matter which causes increased resistivity. Baghouse tests indicate that the blinding of bags is a problem due to the moisture/hydrocarbon/dust mixture found in the exhaust gases. Wet scrubbers, at present, appear to be most likely to succeed in removing contaminants including hydrocarbons from the exhaust gases; however, substantial power is required to get the necessary pressure drop across the scrubber for these volumes of gases.

A new concept in sintering practice (see following illustration) recycles gas, after preliminary cleaning and prior to final cleaning, back to the sinter bed. Field testing information and engineering evaluations indicate that this recycling reduces both the emissions of unoxidized hydrocarbon particulates and the final gas volume being discharged. Although the emission reduction may be substantial, it is anticipated that a low-energy air pollution control system must be used along with recycling to remove remaining contaminants, primarily particulates.



Weirton Steel Division sinter plant gas recirculation system.

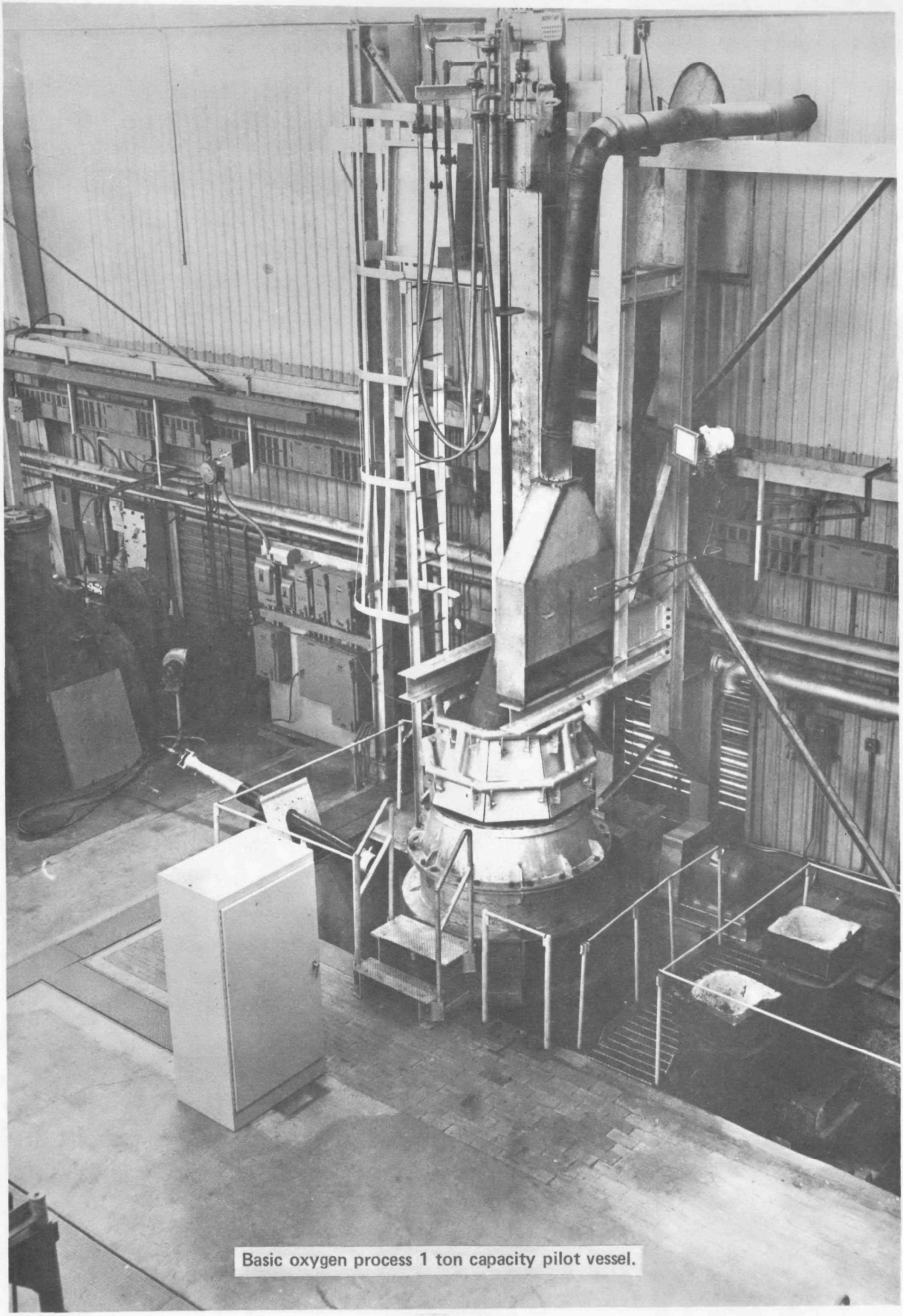
A project was initiated in mid-1973 covering two phases. Phase I consisted of an historical review and a detailed engineering design. This was completed in 1975: the final report included a theoretical analysis of recycle application to the Weirton No. 2 machine showing optimum level of recycle to be 39 percent.

The Phase II contract, for test and evaluation, was awarded in February 1975; the final report is scheduled for February 1978. The contractor is to perform an optimization of the recycle system, followed by an extensive emission testing and system evaluation program. Also to be tested is a large-scale gravel bed filter on the sinter plant exhaust both with and without recycle.

The recycle system was installed (at company expense) and has been operating for 18 months. Sinter machine operation and sinter quality have shown an improvement as a result of recycle. The optimization program will continue to investigate recycle rates greater than the theoretical optimum. Tests to date have shown that recycle as high as 40.7 percent can be achieved without adverse effects on sinter quality or machine operation.

The gravel bed filter system was placed in operation in February 1976, 1 month ahead of schedule. A number of problems have arisen with this first-of-a-kind installation which have delayed the start of the emissions testing program. Several problems associated with mechanical deficiencies (e.g., poorly designed backflush valve guides which resulted in insufficient cleaning of the filter beds, and inadequate filter media support screens which led to screen failures and loss of media) have been effectively resolved. The most serious problem is the growth in the physical size of the original filter media (natural garnet) due to accretion of the particulate in the gas. After this phenomenon became apparent alternative media materials were evaluated. It was found that steel grit does not "grow." All filter beds were changed over to steel grit during the fall of 1976; the filter system was restored to operation on December 1, 1976, and after 1 month's operation, there did not appear to be any increase in media size. Testing will now get underway to evaluate both the recycle system and the gravel bed filter system.

A 1976 task evaluated the desulfurization of sinter plant gases using data from power plants, a USSR sinter plant, and a Japanese sinter plant. Conceptual designs and cost estimates were made on both a normal, once-through system and a wind-box recirculation system.



Basic oxygen process 1 ton capacity pilot vessel.

IRON AND STEELMAKING

Blast Furnace Cast House Emission Control

There is a need to develop technology for controlling emissions from blast furnace cast houses. The cast house is the semi-enclosed area around the blast furnace base containing the furnace tapping equipment and molten pig iron (hot metal) and slag distribution systems. The hot metal, the principal emission source, is saturated with carbon as it exits from the furnace. Rejection of the graphite, in the form of flakes, begins as soon as the hot metal starts to cool. Thermal air currents sweep these flakes into the air. Additionally, particles of iron oxide are formed and carried away simultaneously.

In 1976, a study was completed by Betz Environmental Engineers for preliminary designs of cast house emission control schemes: first, as tailored to existing cast houses, as defined by model cast houses which encompass the existing population; and second, as an integral feature of a new installation. Each cast house/control system combination was analyzed in detail to establish the emission control potential, capital and operating costs, impact on current operating practices, potential risks involved, and follow-on development needs.

Another 1976 study on blast furance slips was completed by Battelle-Columbus Laboratories. This study focused on contributing factors to hangs and slips, determining the frequency of slips, evaluating slips as sources of air pollution, and evaluating options for control or elimination of slips.

Basic Oxygen Process Charging Emission Control

The rate of growth of the Basic Oxygen Process (BOP) for making steel has been phenomenal. In a relatively short time, it has become the dominant steelmaking process in the U.S. iron and steel industry.

The basic operations involved in producing steel by the BOP process are charging scrap, charging hot metal, oxygen blow, chemical tests, and tapping.

The emissions evolved during charging of the BOP furnace include extremely fine particles of iron oxide, hydrocarbons present on the cold metal portion of the charge, graphite particles, and volatile materials that may be present on the cold metal. These could include potentially hazardous emissions from elements such as cadmium, which is often present as plating on the metal.

IERL-RTP's approach to solving this problem was first to construct the 1 ton capacity pilot vessel facility (shown above) to be used as the vehicle for evaluating a wide range of methods to control the charging emissions.

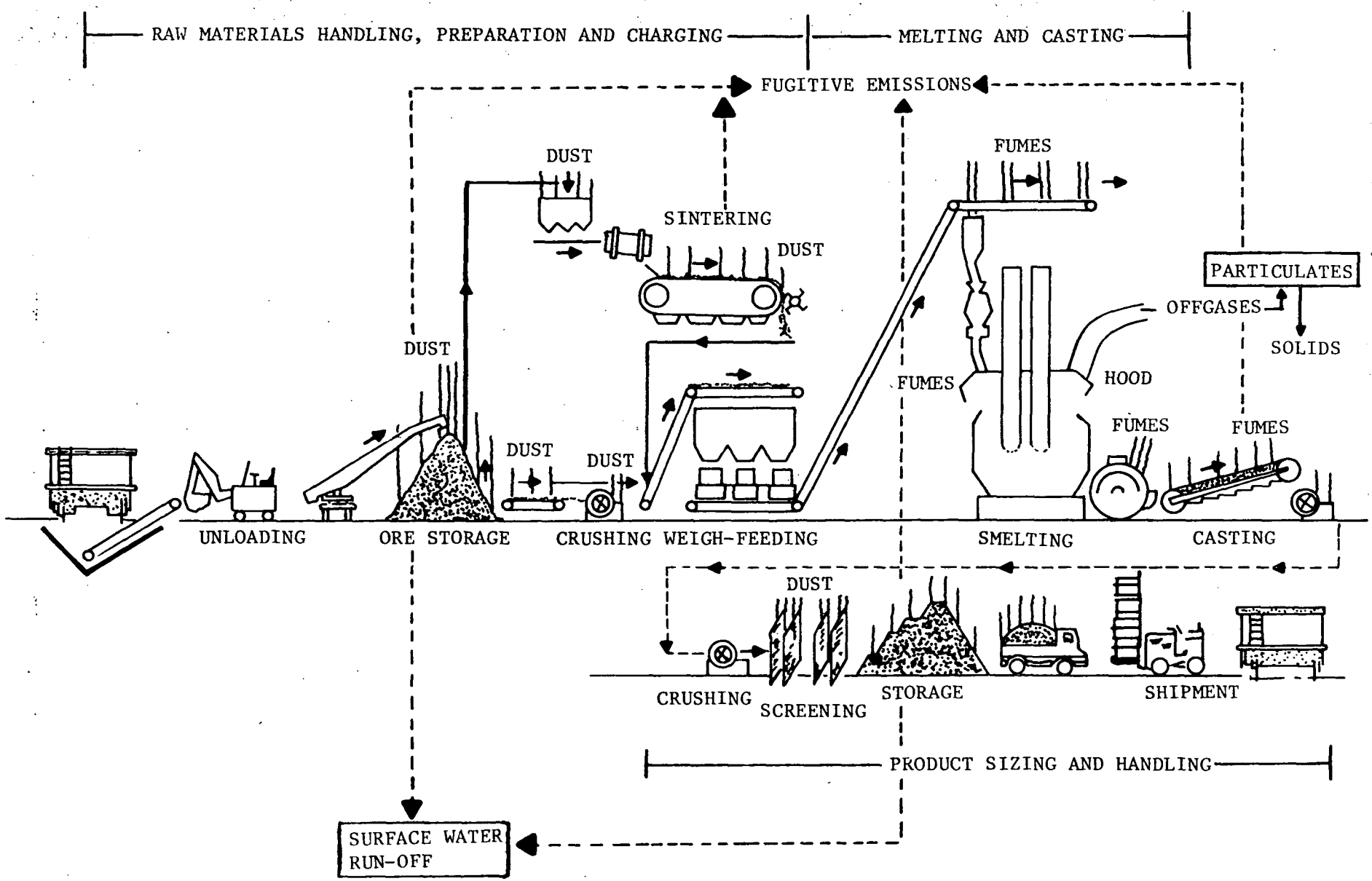
Accordingly, a contract was signed in mid-1973 with the National Steel Corporation: to review past efforts to control BOP charging emissions; to characterize operation, emissions, and BOP vessel and shop configurations; to project future construction trends; and to define charging control concepts and (from them) to develop technology for controlling the particulates, gases, and fumes emitted during charging of BOP steelmaking vessels. This development program concentrated on process modifications that will allow the emissions to be collected. Consideration was also given to suppression of the emissions within the vessel. Specifications and conceptual designs were developed for prototype emission collection systems. Additional specifications were developed for a gas cleaning system to be added to the prototype collection system. The development program is structured so that the results will be applicable to the total industry. The final report was completed in 1976.

A project started in 1975 by Dravo Corporation evaluated the composition, quantities, methods of disposal, and resource recovery state-of-the-art for sludges and dusts collected by air and water pollution control equipment in the steel industry. This study was completed in 1976.

A follow-on study assessed the potential for the creation of environmental problems from the disposed residues from steelmaking furnaces. This 1976 study by the Research Triangle Institute examined chemical and physical properties of the residues, assessed the leaching of hazardous metals and organics from the residues, and examined the potential for metals to migrate through soil, water (both surface and subsurface), and air.

Ferroalloy Production

The ferroalloy industry's principal source of emissions is the submerged arc electric furnace. (See ferroalloy production process diagram, following.) In this furnace, ferroalloys are usually smelted by reducing the ore with carbon, producing both the desired metallics and substantial quantities of CO (in some cases, more CO is produced than metallics). Gases evolved from ferroalloy furnaces entrain large quantities of particulates which, because of the high temperatures involved in the reaction zone, are primarily in the submicron size range. Domestic ferroalloy furnace practice has been to leave the furnace top open, thus allowing the CO to mix with large volumes of air and burn above the furnace. This mixture is then collected and treated with conventional particulate control equipment before being vented to the atmosphere.



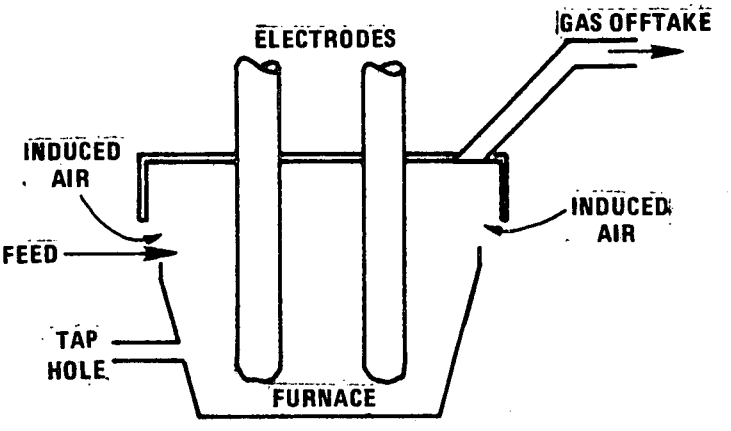
Ferroalloy production process.

Some newer furnaces in Europe and Japan are hooded tightly so that no excess air is entrained in the furnace off-gas and combustion does not take place above the furnace. When such a system (known as a totally enclosed furnace) is used, the volume of gas is decreased by 20 to 200 times, since excess air is not entrained. This decreased quantity of emissions can be cleaned to the same level as emissions from an open furnace; therefore, total particulate emitted is decreased by approximately the same factor of 20 to 200. Additionally this gas, which is no longer burned over the furnace, can then be used as a low-Btu fuel after cleaning.

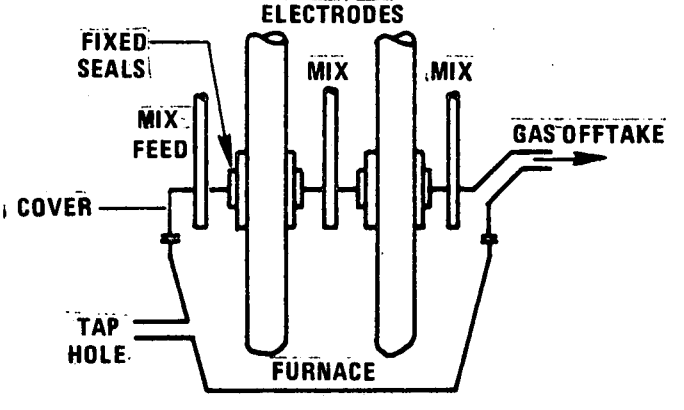
United States ferroalloy producers hesitate to install totally enclosed furnaces (diagram follows), feeling that they may reduce the ability to change from one ferroalloy product to another. (The standard of performance reflects this industry position.) Under contract to IERL-RTP, Battelle-Columbus Laboratories published a report, "A Study of Ferroalloy Product Flexibility," in 1975 that essentially supported the industry's arguments. Battelle concluded in general: (1) that totally enclosed furnaces are not as flexible as open furnaces of the same size; (2) that large furnaces are less flexible than smaller ones; (3) that research should be undertaken to investigate approaches (such as the substitution of iron ore pellets for ferrous scrap) to smooth out furnace operation, thereby improving the flexibility problem; and (4) that EPA should undertake an investigation of the overall pollution problems (including air, water, and solid wastes) associated with ferroalloy production.

A number of ferroalloy furnace particulate emission samples were obtained from EPA's Office of Air Quality Planning and Standards for detailed analysis. These samples had been taken in conjunction with the development of New Source Performance Standards for ferroalloy furnaces. However, they were never analyzed for specific organic constituents or trace metals. Subsequent tests performed by Battelle-Columbus Laboratories identified extremely high concentrations of polycyclic organic materials (POM) in samples from totally enclosed ferromanganese furnaces. Since the samples had been in storage over a year before analysis and the exact history of the samples is not known, further testing and analysis is being accomplished to confirm these preliminary results.

Depending on the outcome of the tests and how thoroughly the POMs are destroyed by flaring and by conventional wastewater treatment, a decision will be made as to the priority to be given this problem in future programs.



Open-hooded ferroalloy furnace.



Enclosed ferroalloy furnace with fixed seals.

SURFACE PREPARATION AND FINISHING

As a result of hot-forming operations, a black oxide scale is formed on the surface of the steel. This scale must be removed prior to the finishing steps. Pickling is normally used for scale removal.

Pickling is accomplished by immersing the steel in acid baths (usually using hydrochloric or sulfuric acid) and then rinsing with water to remove the excess acid. The content of metal salts increases in the bath to the extent that the acid must be replenished. Waste streams from the process include the acid waste (pickle liquor) and the acidic rinse water. These wastes can present considerable environmental problems.

In 1974, a 3 year grant was awarded to Crown Chemical for the development of a closed-loop recycle system for waste sulfuric acid pickle liquor. The process, designed to eliminate all discharges from the pickling process, uses: a continuous countercurrent ion exchange contactor for iron recovery from a ferrous sulfate feed, nitric acid stripping, air oxidation, and a hydrolizer.

Many basic steel products require surface treatments prior to use. One of these is tinning. Wastes from the tinning operation are usually handled in the same manner as pickling. A project, started in 1973 and finished in 1976, assessed the use of countercurrent rinsing using a compartmentalized rinsing tank to reduce the amount of water required and to facilitate recovery of chemicals from the wastewater. Thus, this system reduces the amount of blowdown and increases the concentration of the plating solution in the blowdown, making it easier to treat subsequently.

FUGITIVE EMISSIONS AND SURFACE RUNOFF

During the past several years, it has become increasingly obvious that significant amounts of particulate and gaseous emissions are being emitted to the atmosphere from sources other than the stacks in a number of industrial operations. An investigation performed by The Research Corporation (TRC) for EPA indicates that several metallurgical processes are included in those industries which most characteristically demonstrate a high degree of fugutive emissions. Several additional EPA investigations have similarly suggested the need for fugitive emission research and the development of control techniques for metallurgical processes.

IERL-RTP contracted with Midwest Research Institute (MRI) in June 1975 for the first phase of a program which is intended to define or develop techniques

or systems for the control of fugitive emissions from a number of metallurgical processes. The purposes of Phase I are: (1) to characterize fugitive emission sources in integrated iron and steel plants, primary copper and lead smelters, and iron foundries; (2) to prioritize these emissions; (3) to determine the environmental impact of these emissions; and (4) to make recommendations for future research, development, and/or demonstration projects to aid in the reduction of fugitive emissions from those sources determined to be most critical.

Thus far, MRI has identified the specific fugitive emission sources within the subject industries and prepared generalized process diagrams indicating these sources. An effort is currently being made to quantify each of the identified emissions. It is expected that this project will be completed in 1977.

Surface runoff from steel mills has become of increasing concern due to an awareness that runoff can have a potentially serious environmental effect. A current contract with The Research Corporation (TRC) is evaluating sources of surface runoff within the iron and steel industry, assessing the overall problem of runoff, determining the contribution of individual sources to the overall problem, and determining control technology needs. It is anticipated that this project will be completed by mid-1977.

ABNORMAL OPERATING CONDITIONS

Operational "upsets" are frequent causes of violation of air and water pollution standards. To supplement and support efforts being made to minimize the adverse effects of upsets, there is a need for information concerning malfunctions and their identity, cause, resulting discharges, prevention, and minimization. A contract was awarded to the Research Triangle Institute (RTI) in 1976 to study this problem.

Under this contract, abnormal operations in coking, sintering, blast furnace ironmaking, and in open hearth, basic oxygen, and electric furnace steelmaking will be studied. Products of this study will include:

- A description of abnormal conditions, their cause, their adverse effect on pollutant discharges, and the total environmental problem that they represent.
- An evaluation of the state-of-the-art for preventing and controlling abnormal operations.
- Prioritized lists of technology development needs to increase the capability to control pollutants during period of abnormal operations.

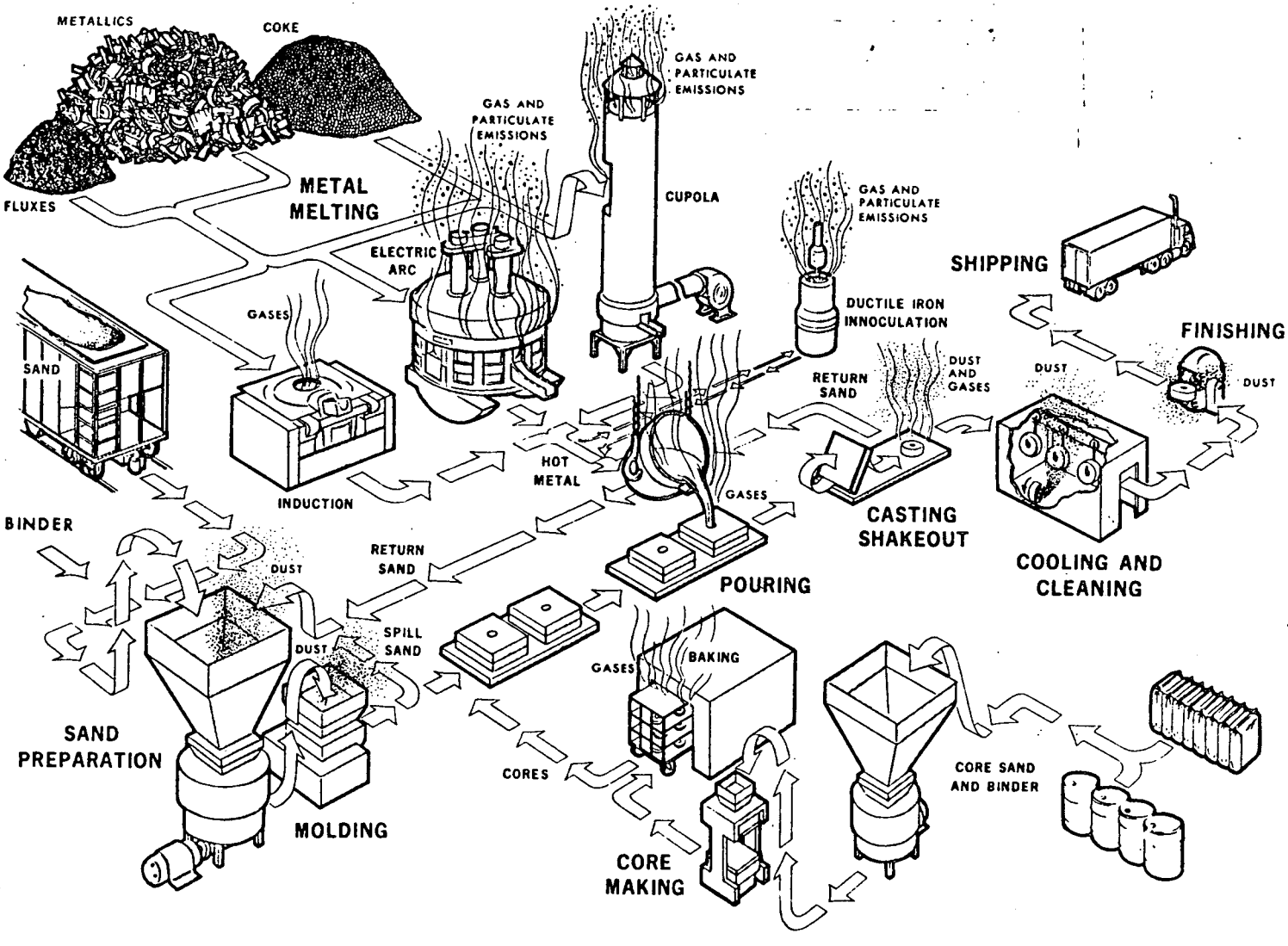
° Manuals of practice to eliminate or reduce discharge from abnormal operations and conditions.

Iron and Steel Foundry Processes

The cupola (see following illustration) is a vertical shaft furnace into which ferrous scrap and pig iron, coke, and limestone are charged. The combustion of the coke provides heat to melt the metallics, forming cast iron which is poured into molds. The limestone serves as a fluxing agent, removing impurities in the other charge materials. The cupola has been in widespread use for centuries; however, over the past 10 to 15 years its position has been severely challenged by electric arc and induction furnaces due to their relative ease of emission control. However, since the oil embargo and subsequent large increases in the cost of electrical energy, there has been a definite reversal of this trend. The control of cupola emissions is costly; technology for improving the cupola's energy utilization to offset these costs is available but has not realized widespread application in the U.S.

IERL-RTP's principal effort in this vital industry involved a program directed toward an in-depth engineering analysis of the various integrated systems for energy conservation and air pollution control which are or have been in commercial use, or which appear to offer potential for commercial development. The analysis of each system utilized actual operating data whenever possible to determine capital and operating costs, emission control capability, energy savings, and operating and maintenance procedures and requirements.

This effort showed that many foundries can achieve substantial energy savings just by paying closer attention to operating and maintenance procedures, with little or no added cost. Additionally, 20 to 30 percent coke savings can be realized either by changing to a divided blast (two rows of tuyeres, instead of the usual single row) for cold-blast cupolas, or by installing recuperators in the exhaust to recover the now-wasted heat, transferring it to the blast air. The divided blast option requires a small capital investment. The recuperator is somewhat more expensive; however, if used to replace a separately fired blast air heater (as is often the case in systems now in operation), the fuel savings will pay for the recuperator in a year or two. The final report on this effort was published in May 1976.



Iron foundry process emission sources.

Nonferrous Metallurgy

Although IERL-RTP's nonferrous smelting program was transferred to IERL-Cincinnati in late 1975, two projects in this area remained at IERL-RTP because of the nearness of their completion and this Laboratory's long-term familiarity with the projects.

These projects are separate efforts conducted under EPA's Special Foreign Currency Program (PL-480) in Yugoslavia to define emissions from copper, lead, and zinc smelting. The projects were conducted by the Bor Copper Institute and the Trepca Lead and Zinc Institute, respectively. Objectives of both projects are similar: (1) to determine emissions from the smelting processes under study, (2) to relate amounts of emissions to changes in feed and process conditions, and (3) to determine the effect of SO_x control equipment on emission of other pollutants, particularly hazardous particulates. An extensive sampling and analysis program was conducted to determine both the input materials and their fate in out-going streams for each smelter unit operation. Mineralogical and elemental analyses were made on all solid material streams; gaseous streams were analyzed for SO_x, NO_x, CO, CO_2, and other gaseous pollutants and for particulate mass and size distribution.

Although project final reports have been prepared by the Yugoslavs, they have had to be Anglicized by a domestic contractor to be suitable for U.S. publication. These Anglicized final reports are now being reviewed in draft form prior to official publication.

PROCESS MEASUREMENTS

The main areas of activity within IERL-RTP's Process Measurements Branch (PMB) are directed toward development of measurement methods for testing and quality assurance. The current major thrust of the PMB's work is in support of IERL-RTP's environmental assessment program.

CONTROL EQUIPMENT EVALUATION

In conjunction with efforts aimed at control equipment evaluation, two major program areas are active. These areas are Particulate Measurement and Chemical Analysis and Sampling.

Particulate Measurement

Beginning with efforts that led to the EPA method 5 mass sampling train in the mid-1960's, the PMB has been involved in developing the particulate mass measurement techniques required by control equipment engineers to evaluate particulate abatement systems. High-volume mass measurement equipment has been developed to obtain accurate samples from high-efficiency control devices in a reasonable and cost-effective period. Instrumental methods including optical transmission, charge transfer and beta gauging have been tested for use as continuous monitors for specific processes.

PMB initiated activities in 1972 to develop and apply particle sizing techniques, recognizing that the fractional efficiency of particulate control devices may be very important from a biological standpoint. In situ sizing was established as the only reliable technique due to serious problems with loss of particles in probes and changes in sample integrity. An intensive method evaluation program was initiated, and manual sizing based on inertial fractionation has been developed into a useful tool. A standard procedures manual for the use of cascade impactors has been published. Cyclone separators have been developed for obtaining large quantities of sized material for subsequent chemical and biological tests. Cyclones have been constructed with sharp cut points at as low as 0.3 microns, and a system (which can potentially replace impactors) is being built.

Instrumental techniques evaluated for particle sizing include optical single particle counters and automatic readout of inertial separators for particles greater than 0.2 microns. Diffusion/condensation and electrical mobility for ultrafines are in use and are being further developed.

Mist eliminator efficiency measurements were identified as being required to evaluate particulate and sulfur dioxide scrubbing systems. Manual methods

were adapted from solids measurements for short-term information. An instrument development program for droplet sizing was started using a hot wire detection technique. A prototype unit demonstrated the viability of the concept both in the laboratory and field situation. A second-generation unit has been developed utilizing more rugged probes. A system for automatic and continuous determination of efficiency is being developed based on the newer model.

The trends in particle measurement are toward high bulk size separation using manual methods for environmental assessments and automatic continuous mass and size for control device evaluation. The manual methods are more cost-effective for the environmental assessment activities and the basic techniques have been established. Automatic methods can drastically reduce the time and cost of parametric research studies and are also necessary for non-steady state processes.

High-Temperature/High-Pressure Sampling and Measurement

The initial efforts by PMB to develop measurement techniques for high-temperature and/or high-pressure (HTHP) gas streams were in support of the dry limestone SO_2 control process in the late 1960's. Specially designed water-cooled, gas-moderated probes were used to extract samples from the firebox to determine the reaction chemistry of the process. During the same period, a holographic system was used on a large operating boiler to determine the distribution of the limestone cloud within the boiler.

During 1972, projects were initiated on probe sampling of flames for major chemical species and on holographic interferometry for determining turbulence and temperature profiles in the flame zone. In 1973, development of a laser velocimeter for particle velocities in flames was undertaken. A contract effort has recently been started to develop *in situ* techniques for flame composition.

Particle sizing systems were designed for laboratory- and miniplant-scale fluidized-bed combustion (FBC) projects. The laboratory scheme involved sampling the whole streams while an HTHP extractive system was installed at the miniplant. Both units operated successfully.

Recently, sampling methods have been developed for permanent installation and long-term operation. The high pressures (300 psig) and temperatures

(1800°F) have significant safety problems associated with them for both the personnel and the process hardware. Two probe systems for gaseous and particulate sampling will be installed at the Exxon miniplant. A water-cooled liquid-moderated probe has also been developed for sampling high-temperature sources. Future developments in the area of HTHP will be aimed at extending the technology to include HTHP sampling and measurement in coal liquefaction and gasification processes.

Inorganic Sampling and Analysis

The Process Measurements Branch has been involved in the sampling and analysis of inorganic species since 1967. The early program focused on the manual methods for the analysis of SO_2, SO_3, HF, and NO_x emission from stationary sources. In 1968, the direction of the inorganic sampling and analytical efforts was expanded to include process measurements to support the development and engineering evaluation of limestone injection and wet limestone flue gas desulfurization programs. The process measurements which were evaluated and implemented included SO_2, SO_3, Ca, Mg, $SO_4^=$, and $SO_3^=$ analysis in scrubber process liquor streams, effluent gas from the scrubber, and inlet gas to the scrubber. Overall material balance closures for 90 percent calcium and sulfur were achieved. A program to monitor trace inorganic elements was initiated to evaluate the effects of selected elements on scrubber chemistry; e.g., oxidation of sulfite to sulfate. This program was expanded to develop and promulgate sampling and analytical systems for a broad range of inorganic elements in a variety of process streams which include liquids, slurries, solids, particulate matter, and gases.

Chemical analysis of species in low-Btu gasification dates back to 1972 when emissions from the Applied Technology molten iron combustor system were evaluated. Recently, the first-generation procedures to evaluate the environmental effects associated with coal gasification processes were published.

Technical assistance has been provided to the following programs: flue gas desulfurization (measurements of SO_2/SO_3, scrubber liquor concentrations, composition of emitted particulates); fluid bed combustion (analysis of bed material, emitted particulates, and SO_3); physical coal cleaning (development of a trace elements sampling and analytical program); and the combustion modification program (effects of low NO_x emission combustion on trace elements distributions).

In response to changing information needs of IERL-RTP, programs have been initiated in the following areas: development and promulgation of a sampling and analytical system for identification of oxidized inorganic compounds; development and promulgation of a sampling and analytical system for the quantitation of reduced inorganic species (H_2S, COS, AsH_3, H_2Se, etc.); and development of techniques to determine coal sulfur forms to support the physical/chemical coal cleaning program.

Organic Measurements

Organic materials emitted to the environment have received increasing attention, especially in the last several years. Past programs concentrated on measurements of specific compounds, such as the carcinogenic polycyclic hydrocarbons. In the last year, the emphasis of development programs has shifted to less specific, less quantitative, but much more comprehensive survey techniques. The survey methods have many applications, but are being developed primarily for application to environmental assessment programs being carried out by the engineering branches of IERL-RTP. Survey methods for a wide range of organics have been evaluated and a cost-effective system chosen for use in assessment programs. Testing and evaluation of survey methods continues, and revisions will be made when needed.

Important advances have been made in both sampling and analysis of the polycyclic organic materials (POM). The number of compounds analyzed has been increased, and heterocyclic carcinogens are now included in the analysis for POM, although they had been traditionally ignored. Sampling for organics has evolved from the use of liquid-filled impingers to the modern porous polymer adsorbent systems. Studies are underway at present to further extend knowledge of trapping efficiencies, capacities, and general properties of adsorbent materials, especially XAD-2 and Tenax GC.

A program of method evaluation and application for analysis of pollutants of special interest is underway. Analysis of polychlorinated biphenyls in stack effluent, water streams, and fish is required for several IERL-RTP programs. Sampling for these compounds does not appear to be especially problematical, but analysis techniques are very difficult and prone to error. Inter-laboratory comparisons are underway as well as close scrutiny of methods in use on IERL-RTP projects.

ENVIRONMENTAL ASSESSMENT TESTING STRATEGIES

A major effort has been initiated by the IERL-RTP to provide a comprehensive data base on the emissions from industrial and energy processes. In order to implement the field work necessary for these studies, the Process Measurements Branch has developed a phased sampling and analytical strategy to provide comparable data from the many processes to be studied. The phased approach was selected as the most cost-effective technique for insuring that potential problem areas would be identified and resources expended on the most critical problems. Strategies for fugitive emissions and biological testing have also been developed for environmental assessment programs.

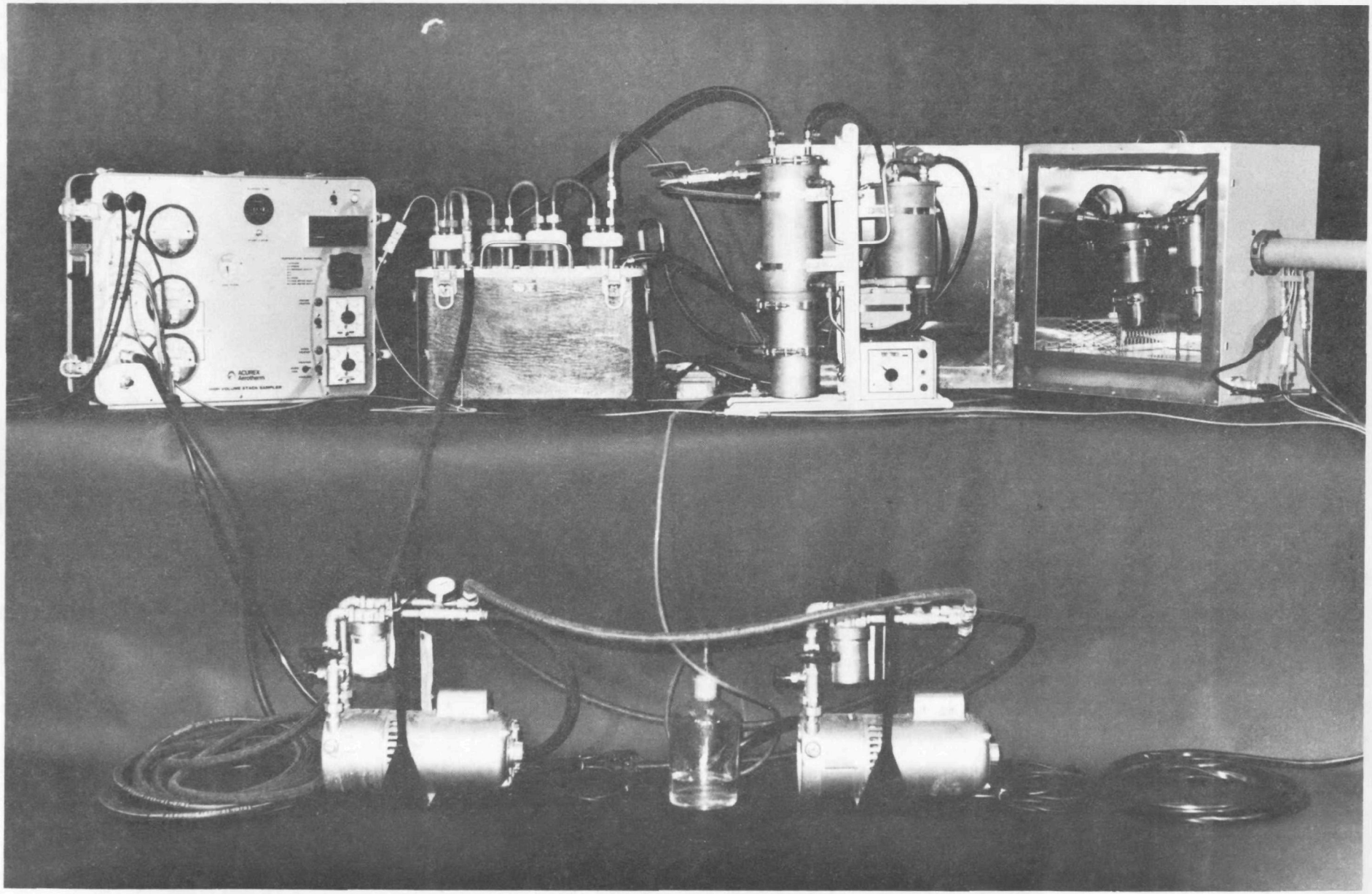
Phased Sampling and Analytical Strategy

The first phase, Level I, utilizes a series of qualitative, semiquantitative (± 2) techniques to provide preliminary prioritization of future work. The emphasis is directed toward completeness through evaluation of all potential sources of pollution. Physical, chemical and biological tests are performed on all samples collected. The estimated costs of this phase range from $25,000 to $105,000 depending on plant complexity. A sampling system for survey work has been developed and tested, and a procedures manual for Level I sampling and analysis has been issued.

A high-volume, series cyclone sampling system was developed for IERL-RTP under contract by Walter C. McCrone and Southern Research Institute. The design was fabricated and field-tested at ten industrial sites by TRW, Inc. The sampling system operated during the field tests without a major failure. A new version has been designed and construction of the prototype was begun in 1975. The complete system, designated the Source Assessment Sampling System (SASS), illustrated below, is available commercially.

Level II efforts are directed toward identification and quantification of specific compounds. Emphasis is on refinement of the data base for sources which have been shown to be potential problems by Level I screening. The costs of Level II are estimated to range from $250,000 to $1,250,000. These costs are a function of plant complexity and the number of potential problem areas identified.

Level III is envisioned as an evaluation of the time and process parameter effect on pollution problems. Based on Level II data, cost-effective measurement technologies are used to monitor specific materials during continuous process operations. Cost data has not been developed for Level III because it is a highly site-specific type of measurement.



SASS equipment for environmental assessment sampling.

Two aspects of environmental assessment receiving particular emphasis are fugitive emissions and biological testing. Development of programs in both these areas continues.

Fugitive Emissions

Fugitive air emissions are defined as those pollutants which are not emitted from stationary sources through ducts of regular cross section. For many industrial categories (e.g., oil refineries, coke plant nonferrous smelting, and coal gasification/liquefaction), fugitive emissions have been shown by use of emission rate/ambient air dispersion predictive models to be a major air problem. A program was developed to identify, validate, and promulgate sampling and data reduction strategies for these emissions. Documents have been developed for the following strategies: Upwind/Downwind, Roof Monitor, and Quasistack. The strategies address two distinctly different IERL-RTP data needs: a) environmental assessment which requires "screening" techniques and b) techniques to evaluate the efficiency of fugitive emissions control technology.

Efforts have also been initiated for the measurement of fugitive water pollution sources. Studies to develop a sampling strategy to evaluate and to determine receiving body impacts of storm water runoff from material storage piles in the iron and steel industry and from coal storage piles at power generating stations are presently in progress.

The first symposium devoted solely to fugitive air and water emissions was sponsored by PMB in Hartford, Connecticut, in May 1976.

Technical assistance on fugitive emissions will be continued and expanded. Major activities include recommendation of a fugitive air/non-point source water runoff program for a physical coal cleaning demonstration program, a fugitive emissions program for the environmental assessment of the coal gasification complex at Kosovo, and cooperation with the National Institute of Occupational Safety and Health (NIOSH) in collecting samples to evaluate the fugitive emissions potential of the Hygas process.

Biological Testing

Biological testing of IERL-RTP samples has grown from novel curiosity status to become an important part of the analysis schemes for environmental assessment programs. The most attractive feature of biotesting is that it provides direct evidence of complex synergistic, antagonistic, and bioavailability effects, which cannot usually be predicted from even the most complete chemical analysis.

Initial application of biotests to IERL-RTP samples was carried out by Health Effects Research Laboratory-RTP using the rabbit alveolor macrophage test for acute cellular toxicity. Results were sufficiently encouraging that application was made to a series of carefully obtained and fractionated particulate samples. Extensive chemical analysis was also carried out on the same series of samples, and the Bruce Ames test for mutagenic behavior was ultimately added to the test program. It was found possible to rank the acute toxicity behavior of the material, and two weakly positive tests for mutagenesis were observed. One of the mutagenic samples has since been observed to be carcinogenic when tested with the hamster embryo system.

Current and near-future work is centered about generation of approved test batteries for application to IERL-RTP projects, especially environmental assessments. A joint committee made up of members from ORD's Office of Energy, Minerals and Industry (OEMI) and Office of Health and Ecological Effects (OHEE) laboratories is responsible for recommendation of suitable methods. Draft outline methods for inclusion of initial survey studies have been received and are undergoing further review. Tests included are the rabbit alveolor macrophage cytotoxicity test, the bacterial mutagenesis test (Bruce Ames test), fathead minnow test, algae growth, mouse range finding toxicity test, soil litter microcosm, and plant stress ethylene production. This battery would give fundamental information concerning toxicity, mutagenesis (presumptive carcinogenesis), and aquatic and terrestrial ecology effects. Marine ecology tests are also being generated for application where appropriate.

Application of these tests and improvement in sampling, sample handling, and the development of techniques for relating biological test data to chemical information will be necessary for some time and are included in current plans.

QUALITY ASSURANCE

The "Planning Document for Control Systems Laboratory Quality Assurance Program," prepared for IERL-RTP in December 1974, was the initial effort in this area. This report originally identified five categories of projects having common characteristics as to size, duration, objectives, and data quality requirements. Projects within a given category can thus effectively use the same general set of quality control and quality assurance (QA) practices and procedures. More recently, an IERL-RTP Data Quality Manual has been developed and issued. This manual incorporates concepts being developed in a

continuing effort to provide IERL-RTP with an effective data quality program. A sixth category has recently been added; the current list of categories is:

Environmental Assessments
Industry System Studies/Pollutant System Studies
Field Studies
Research and Bench-Scale Projects
Development of Pilot Programs
Demonstration Projects

During 1975 and early 1976, guidelines for implementation of quality assurance and quality control on demonstration projects were developed and trial-implemented in the field on the EPA/Shawnee wet limestone scrubber project. After this test, a procedures manual was issued for quality assurance on demonstration projects. A guideline document dealing with quality assurance and control on environmental assessment projects is nearing completion, and establishment of an effective laboratory-wide program continues. Procedures for QA programs will be developed for all six project categories and will be the basis for implementing quality assurance on individual projects.

Appendix A

THE INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY, RESEARCH TRIANGLE PARK

The Industrial Environmental Research Laboratory, Research Triangle Park (IERL-RTP) has completed its sixth full year of activity as part of the U.S. Environmental Protection Agency. Formerly titled the Control Systems Laboratory, it is involved in a variety of technical and management functions directly related to the research, development, and demonstration of equipment and systems designed to abate environmental pollutants from stationary sources to a level that is conducive to increased health and welfare.

Although the Laboratory officially came into being in 1970, along with EPA, as a result of Reorganization Plan No. 3 it actually predates that. Before its days with the Office of Research and Development, it was known as the Control Systems Division, part of EPA's Office of Air Programs. IERL-RTP traces its history through the Department of Health, Education, and Welfare (HEW) where, as part of the Environmental Health Service, it was the Division of Process Control Engineering (DPCE), a division of the National Air Pollution Control Administration (NAPCA). NAPCA's predecessors were the National Center for Air Pollution Control (NCAPC) and the Division of Air Pollution.

Federal involvement with air pollution control actually dates back to July 1955 when the U.S. Congress authorized a Federal program of research and technical assistance to state and local governments. At that time, the still-standing policy was established that: (1) state and local governments have a fundamental responsibility for dealing with community air pollution problems, and (2) the Federal government has an obligation to provide leadership and support.

In December 1963, Congress passed the Clean Air Act when it was evident that, although progress was being made toward a better understanding of pollution problems, comparable progress was not being made toward controlling the problems. Basically, the 1963 Clean Air Act:

- Authorizes awarding Federal grants to state and local agencies to assist in developing, establishing, or improving pollution control programs.
- Authorizes Federal action to abate interstate pollution problems beyond the reach of individual states and cities.

- Expands the Federal pollution research and development program.
- Emphasizes investigation of sulfur oxides pollution from coal and oil combustion.
- Requires the development of criteria on effects of air pollution on health and property.
- Emphasizes the role of the Federal government on controlling air pollution from its own facilities.

The next significant step was Congressional passage of the Air Quality Acts of 1967 and 1970, also referred to as the "Clean Air Act, as amended." These amendments not only called for an attack on pollution on a regional basis, but also provided a blueprint for action at all levels of government and among all segments of industry. Features of the 1970 law are:

- The entire nation is covered by 247 Air Quality Regions.
- National Air Quality Standards have been established for all pollutants covered by the air quality criteria documents.
- EPA may establish emission performance standards on new stationary sources which emit any substantial amount of pollutants so as to 'cause or contribute to endangerment of health or welfare.
- EPA is establishing National Emission Standards for Hazardous Pollutants.
- EPA may establish emission standards for new sources of pollutants which have adverse effects on health and which are not covered by National Ambient Air Quality Standards or by Hazardous Pollutant Standards.
- Emission limits have been established for designated pollutants from motor vehicles, and a time frame for achieving these standards has been defined.
- The Federal standards do not preclude the setting of more stringent air quality standards by the states.

The same 1970 law outlines a specific six-point research program to be carried out by EPA, emphasizing research into and development of new and improved methods (with industry-wide application) for the prevention and control of air pollution resulting from the combustion of fuels by:

- Conducting and accelerating research programs directed toward developing improved low-cost techniques for--
  - Control of fuel combustion by-products.
  - Removal of potential air pollutants from fuels prior to combustion.

- °° Control of emissions from fuel evaporation.
- °° Improving the efficiency of fuel combustion so as to decrease air pollution.
- °° Producing synthetic or new fuels which, when used, result in decreased air pollution.

° Providing Federal air pollution control grants and contracts.

° Determining, by laboratory- and pilot-scale testing, the results of air pollution research and studies in order to develop new or improved processes and plant designs to the point where they can be demonstrated on a large and practical scale.

° Constructing, operating, and maintaining (or assisting in meeting the cost of) new or improved demonstration plants or processes which promise to accomplish the purposes of the Clean Air Act.

° Studying new or improved methods for recovering and marketing commercially valuable by-products resulting from the removal of pollutants.

On July 9, 1970, the President sent Reorganization Plan No. 3 of 1970 to the Senate and the House of Representatives. This Plan, establishing EPA, combined certain of the pollution-control-related functions of six Federal agencies:

° The Atomic Energy Commission.

° The Council on Environmental Quality.

° The Department of Agriculture.

° The Department of Health, Education, and Welfare.

° The Department of the Interior.

° The Federal Radiation Council.

IERL-RTP'S ORGANIZATION

The position of IERL-RTP in EPA is shown in Figure A-1. The Laboratory has four main groups. The Office of Program Operations functions as a program monitoring and evaluating group. The other three groups, all programmatically (rather than functionally) oriented Divisions, are engaged in work ranging from small-scale experimental work and exploratory research, through pilot-plant-size experimental work, to prototype evaluations of equipment large enough to permit confident scale-up to full-size commercial installations. The title of each Division indicates its area of concentration.

IERL-RTP's objective is to ensure the development and demonstration of cost-effective technologies to prevent, control, or abate pollution from

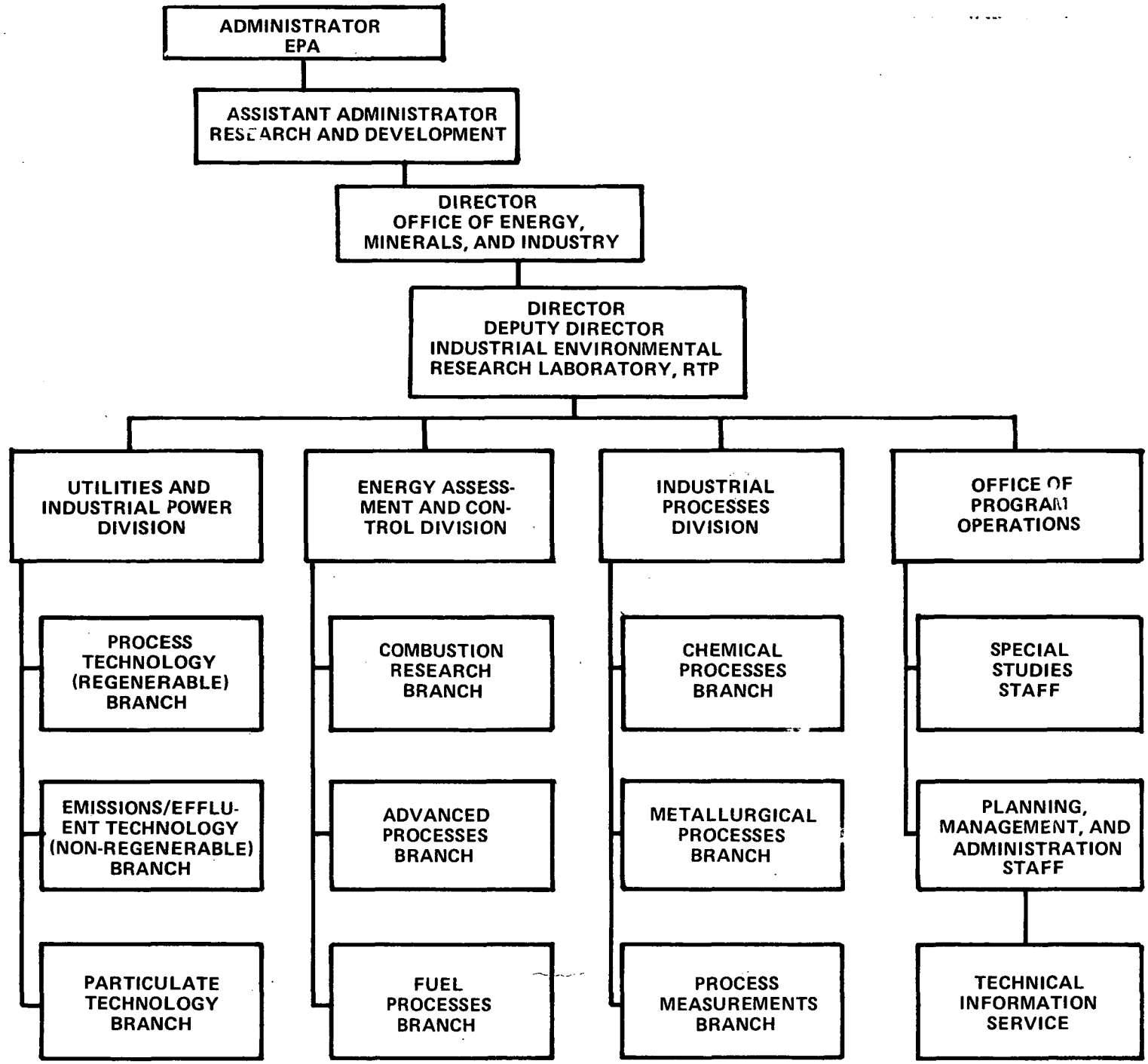


Figure A-1. Organization of the Industrial Environmental Research Laboratory, Research Triangle Park.

operations with multimedia environmental impacts associated with the extraction, processing, conversion, and utilization of energy and mineral resources and with industrial processing and manufacturing. The Laboratory also supports the identification and evaluation of environmental control alternatives of those operations as well as the assessment of associated environmental and socioeconomic impacts. IERL-RTP's program, consisting of inhouse activities, contracts, grants, and inter-agency agreements, contributes significantly to the protection of the national health and welfare through the research and development effort of timely and cost-effective pollution control technology.

It is much easier to state IERL-RTP's objective than to acquire the inputs (shown in Figure A-2) which are required to develop a rational program for this Laboratory. Fortunately, EPA "sister" laboratories possess all the necessary expertise to carry out this function.

As in most activities, problem definition is the first key event in solving the air pollution problem. EPA's regional offices play a major role in this activity by determining the research and development needs of each region. The other major inputs come from our legally mandated responsibility and other designated EPA sources. This information, along with health effects data, allows priorities to be set for pollutants. The list of pollutants (by priority) leads to industry studies which determine the sources and amounts of pollutants emitted and identify the currently available control technology.

With the Ambient Air Quality Standards fixed, regions are identified where the standards are violated. Next, the complicated problem of relating emissions to ambient concentrations of pollutants must be solved. Following the solution of the problem, IERL-RTP determines what emission reductions can be attained with best-available technology and how much this reduction will cost: modeling determines if reductions will allow Ambient Air Quality Standards to be met. If additional new technology is required, IERL-RTP can mount a research, development, and demonstration program to provide this technology, in cooperation with the private sector.

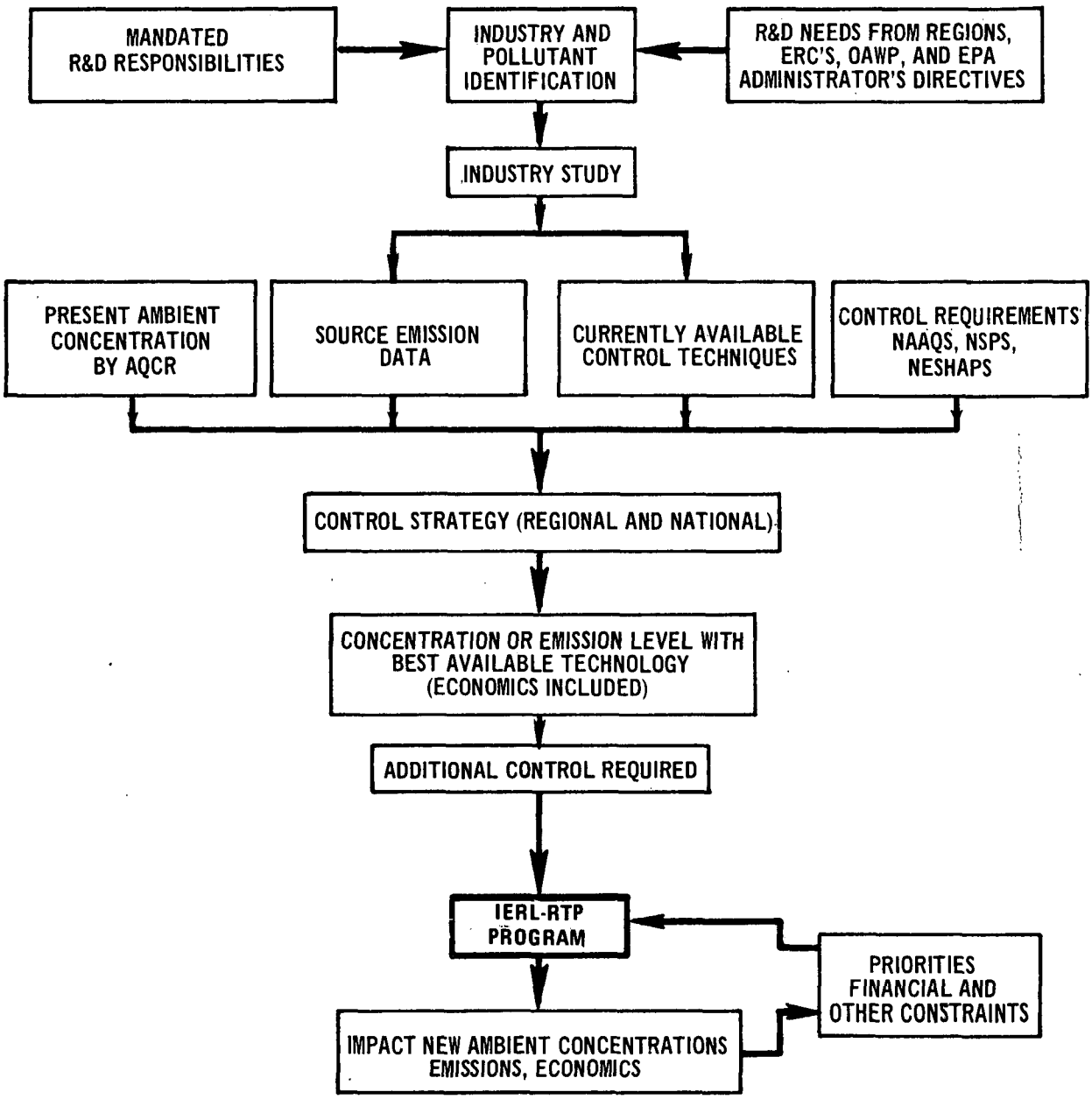


Figure A-2. The basis for IERL-RTP programs.

Appendix B

METRIC CONVERSION FACTORS

Although EPA's policy is to use metric units for quantitative descriptions, this report uses certain nonmetric units where it is felt that doing so will facilitate understanding by a majority of the readers of this report.

Readers more familiar with metric units may use the following factors to convert to that system.

Nonmetric	Multiplied by	Yields metric
atm	1.03	$kg(wt)/cm^2$
bbl	158.99	liters
Btu	252	cal
°F	5/9 (F - 32)	°C
ft	30.48	cm
ft^3	28.32	liters
gr	0.06	g
in.	2.54	cm
lb	0.45	kg
ton (short)	907.18	kg