United States
Environmental
Protection Agency

Industrial
Environmental
Research Laboratory-RTP

Combustion
Research
Branch

Controlling Pollution Through Combustion Research

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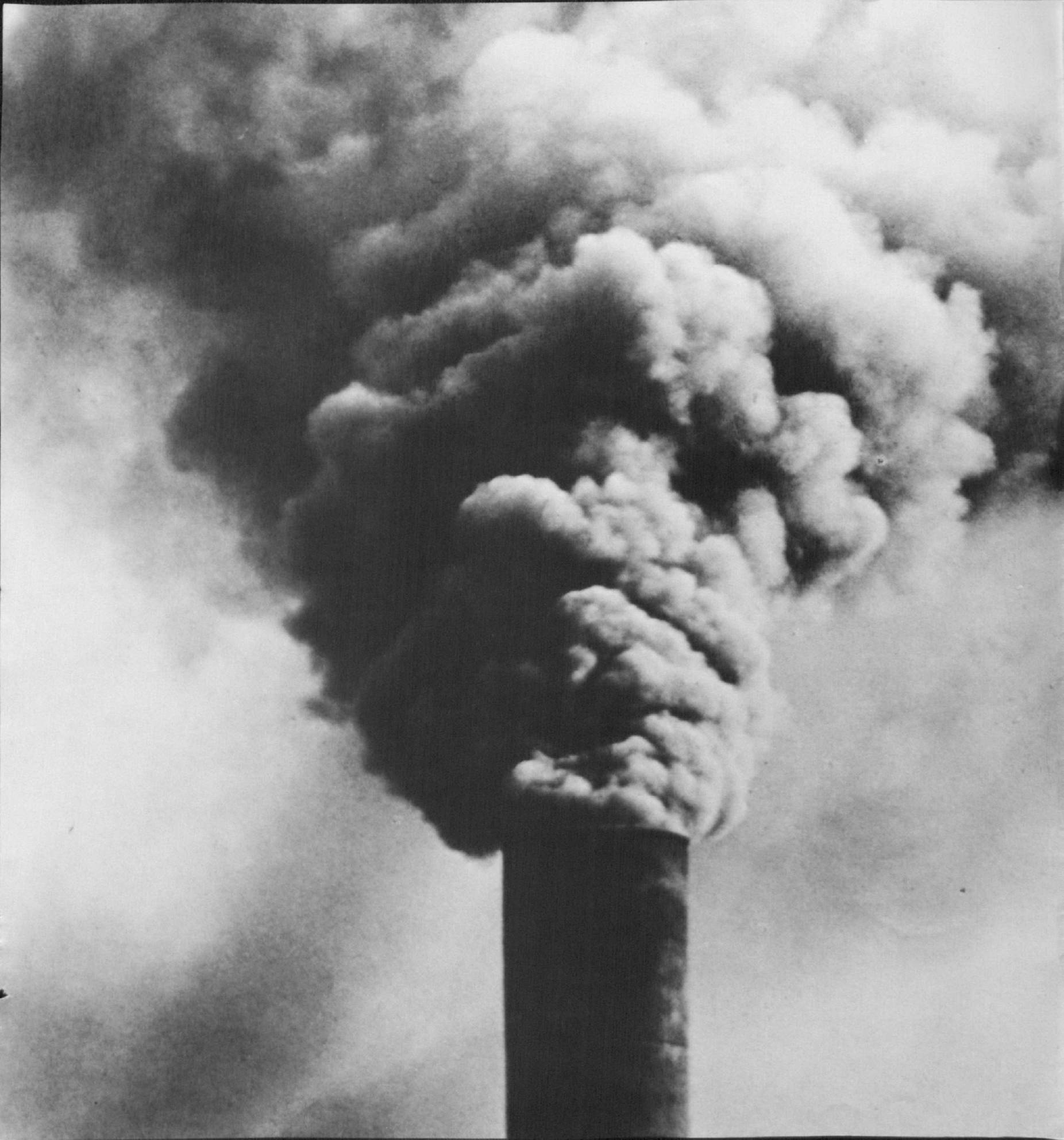
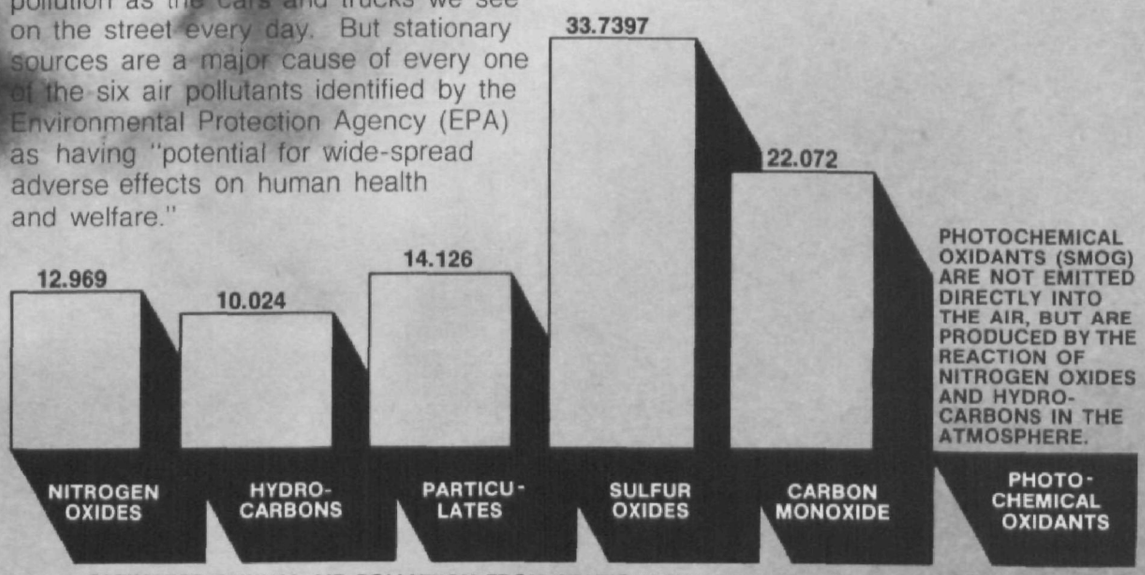


Power plants. Industrial processes like steelmaking or oil refining. Gas turbines. Big reciprocating internal combustion engines used to pump natural gas and generate power. Commercial and home furnaces.

All of these are stationary sources of pollution. They're not as noticeable to most of us as such mobile sources of pollution as the cars and trucks we see on the street every day. But stationary sources are a major cause of every one of the six air pollutants identified by the Environmental Protection Agency (EPA) as having "potential for wide-spread adverse effects on human health and welfare."



ESTIMATED ANNUAL AIR POLLUTION FROM STATIONARY SOURCES - MILLIONS OF TONS

Much of this pollution — especially nitrogen oxides, sulfur oxides, and particulates — comes from fossil fuel combustion — the burning of coal, oil, and natural gas. Because of the growing shortage of oil and natural gas, more and more power plants and industries are switching to coal, a much dirtier fuel that produces more of every major pollutant. This means that pollution from stationary sources will get worse in the coming decades unless we do something about it now.

And we are. At the Industrial Environmental Research Laboratory (IERL) in Research Triangle Park, North Carolina — part of EPA's Office of Research and Development — a coordinated series of programs is under way to find the most effective and economical ways of controlling pollution from stationary sources.

Within IERL-RTP, the Combustion Research Branch (CRB) is playing a vital part in this effort to improve the quality of our air in economically feasible ways. The focus of CRB's programs is on reducing emissions of nitrogen oxides, one of the most harmful pollutants produced by stationary combustion sources.

Like other branches of IERL-RTP, CRB supports EPA's Office of Air Quality Planning and Standards by supplying the technical information for setting realistic, attainable standards for pollutant emissions from stationary sources.

But CRB's job doesn't stop there. By finding cost-effective ways of controlling pollution, CRB is helping utilities and industries meet national air quality standards so that our air will be fit to breathe — now and in the coming decades. And by finding more efficient ways of burning fuel — particularly coal — CRB is making an important contribution to conserving our nation's supplies of fossil fuels.

It's a big job. There are over 20,000 major stationary sources of pollution in the United States. And more are being built every year to satisfy our country's demand for electricity and industrial products. But it's a job that must be done if we are to have the kind of life we want for ourselves and our children. And it's a job that can be done — with support from all of us.

Nitrogen Oxides: A Big Problem

Today, almost 24 million tons of nitric oxide and nitrogen dioxide (NO_x) are emitted into our atmosphere every year from man-made sources. About 55 percent comes from stationary sources — mainly boilers, furnaces, reciprocating internal combustion engines, and gas turbines. Most of the remaining 45 percent is emitted in the exhaust of highway vehicles.

Most NO_x is emitted from combustion sources as nitric oxide (NO). Once in the atmosphere, much of this nitric oxide converts to nitrogen dioxide (NO_2) — a pollutant with very dangerous effects on human health.

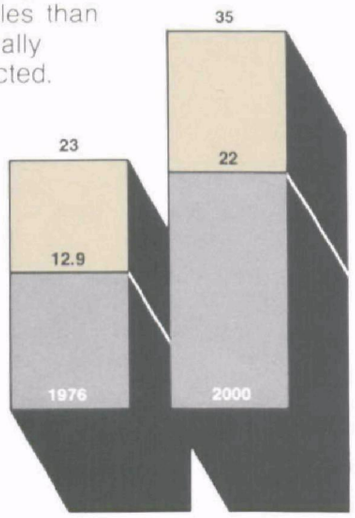
High concentrations of nitrogen dioxide have been fatal to miners, firemen, and other workers. Even at levels as low as 1 part in 1 million, nitrogen dioxide is known to be a cause of respiratory diseases like bronchitis and pneumonia — especially in children and older people. Recent studies have also linked low concentrations of NO_x with ozone depletion and high-nitrate rains. What's more, NO_x is one of the main components of photochemical smog that ruins visibility in our cities and irritates the eyes and lungs of millions of people every year.

In 1971, EPA set a National Ambient Air Quality Standard for nitrogen dioxide of 5 parts per hundred million (100 micrograms per cubic meter of air), annual average. People exposed to concentrations of NO_2 above this level run a serious risk of adverse health effects. Yet in the last few years, average annual concentrations of NO_2 have exceeded the National Ambient Air Quality Standard in several of our largest cities, including Los Angeles, Chicago, Denver, New York, and Salt Lake City.

What's more, unless more effective control techniques are applied nationwide, NO_x emissions are predicted to go even higher in the next two decades.

One reason is that controlling NO_x emissions from mobile sources has proved to be more difficult than anyone anticipated. In 1970, a national emissions standard of 0.4 gram per mile for NO_x from highway vehicles was planned to go into effect by 1976. But the technology needed to meet this standard has turned out to be expensive, and it lowers efficiency so that most cars get fewer miles per gallon.

To conserve gasoline, EPA relaxed the NO_x emissions standard for mobile sources to 2.0 grams per mile for the present. And Congress has agreed that a standard of 1.0 gram per mile is a reasonable goal until at least 1983. All of this means that more NO_x will be emitted from highway vehicles than originally expected.



ESTIMATED INCREASE IN ANNUAL NO_x EMISSIONS FROM STATIONARY AND MOBILE SOURCES WITHOUT MORE EFFECTIVE NO_x CONTROLS — MILLIONS OF TONS

MOBILE SOURCES **STATIONARY SOURCES**

At the same time, the number of power plants and industrial combustion sources in the United States is projected to increase substantially between now and the year 2000. Most of these new units will burn coal — and hundreds of existing sources may be forced to switch to coal as oil and natural gas supplies dwindle. As a result, NO_x emissions from stationary sources could jump to 70 percent of the total from man-made sources by 1985.

The conclusion is clear: NO_x emissions from stationary sources are going to have to be reduced substantially to keep our air clean in the 1980's and beyond.

CRB: A Big Part of the Solution

To develop the technology we need to control NO_X, IERL-RTP's Combustion Research Branch is attacking NO_X pollution where it starts — in the combustion process itself.

Research has shown that NO_X emissions from combustion can be reduced by as much as 75 percent by "combustion modification" (lowering the combustion temperature, limiting the amount of oxygen available, and regulating the way the fuel and air mix). Combustion modification reduces the amount of NO_X that forms as fuel burns. This makes it an economical and effective way to control NO_X compared to other techniques.

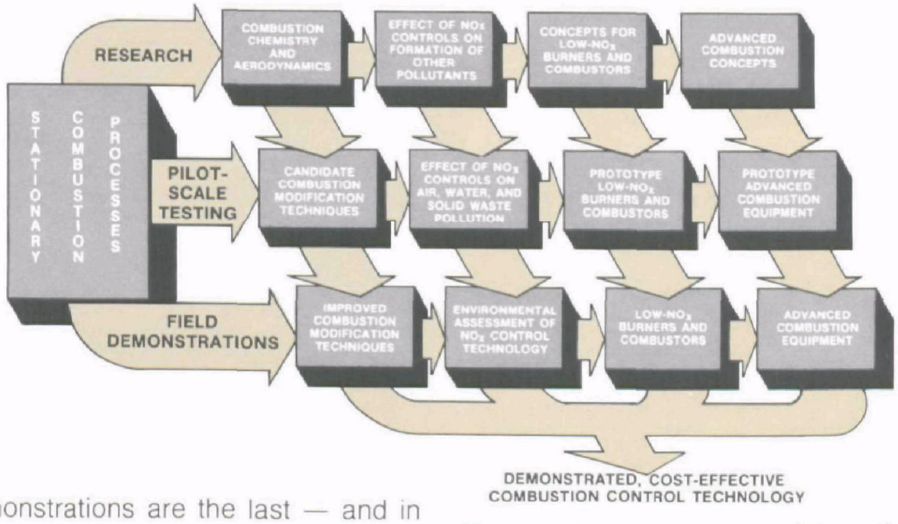
To find workable combustion modification techniques for stationary sources, CRB begins with fundamental research into the basic chemical and aerodynamic mechanisms involved in combustion. This research is helping us understand the factors that cause NO_X to form, and how to control NO_X without increasing emissions of other pollutants.

Along with fundamental research, CRB also sponsors advanced research into new low-NO_X designs for combustion equipment, alternate fuels, and advanced combustion concepts. The ideas being generated in this research will make it possible to reduce pollution dramatically and burn coal and other fuels more efficiently 10 to 20 years from now.

The second major component of CRB's program is pilot-scale testing. Here, a wide variety of combustion modification techniques has been tried out under controlled conditions in the laboratory.

The goal is to reduce NO_X without causing operating problems, shortening equipment life, or increasing emissions of other pollutants. Any technique that passes the hurdle of pilot-scale testing must also make it possible to burn fuel as efficiently as — or more efficiently than — today's equipment.

PROGRAM OVERVIEW

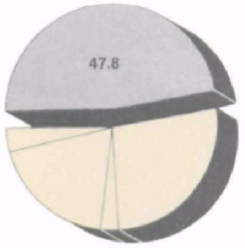


Field demonstrations are the last — and in many ways the most important — leg of CRB's NO_X control program. This is where techniques that look promising in the laboratory are evaluated on full-scale equipment to make sure they can do the job under actual working conditions. During these demonstrations, emissions of NO_X and other pollutants, as well as fuel economy, are carefully measured. Any adverse effects on equipment or operation are also noted. The result is reliable control technology that equipment manufacturers and users can count on.

In all, CRB has underway more than 30 separate programs to develop effective and economical ways of controlling NO_X. They cover all the major types of stationary sources in the United States, from small home furnaces to utility boilers that stand 10 stories high. Some of these programs are conducted in-house at IERL-RTP laboratories. Others are being carried out through contracts with private companies, grants to universities, and cooperative agreements with the recently formed Department of Energy (formerly the Federal Energy Administration and the Energy Research and Development Administration).

CRB also cooperates with owners and manufacturers of combustion equipment. Most CRB programs are planned with input from the combustion equipment industry. And CRB regularly tests prototype equipment for industry to determine the effectiveness of new designs in reducing emissions of NO_X and other pollutants.

It's a systematic, step-by-step approach to a complicated technical problem. And it's working.



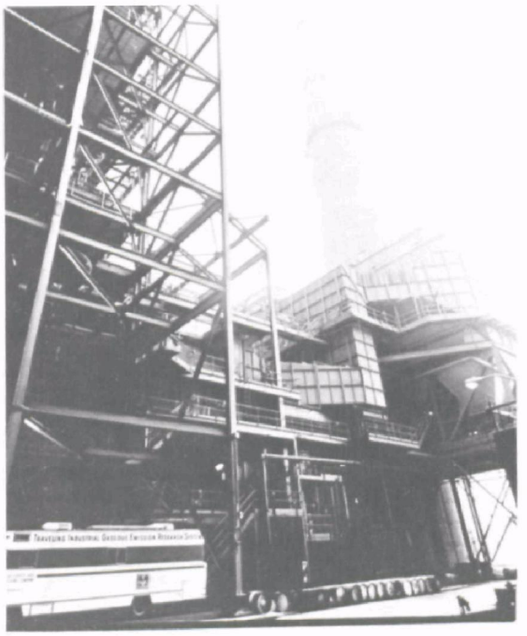
Utility and Large Industrial Boilers

These giant boilers are used by utilities and industries to produce steam for power generation, manufacturing, and dozens of other industrial processes. The largest of them can produce over 10 million pounds of steam an hour — or over a million kilowatts of electricity — more than enough energy to supply a city of half a million people.

Without controls, a single coal-fired boiler may emit up to 120 tons of NO_x into the atmosphere daily. An estimated 6 million tons of NO_x are emitted every year from utility and large industrial boilers in the United States — almost half of the NO_x from all stationary sources combined.

Unfortunately, unless emissions standards for coal-fired boilers are tightened, NO_x emissions from utility and large industrial boilers will almost certainly increase. The present standard for large coal-fired boilers is 0.7 pound of NO_x for every 1 million Btu's of heat produced — compared to 0.3 pound of NO_x for oil-fired boilers and 0.2 pound for gas-fired units. Because more and more utility and industrial boilers will be burning coal in the years ahead, NO_x emissions from these sources could swell to 200 percent or more above today's levels.

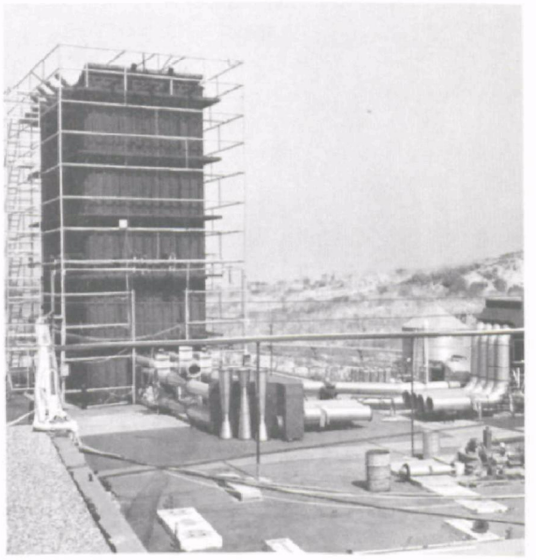
All this points up the need for a much more stringent emissions standard for large coal-fired boilers in the years ahead. But before a tighter standard can be enforced, better control techniques are needed — techniques that can reduce NO_x without corroding equipment or causing operating problems.



That's why improving existing control techniques — and developing new control techniques — for coal-fired utility and industrial boilers is CRB's highest priority.

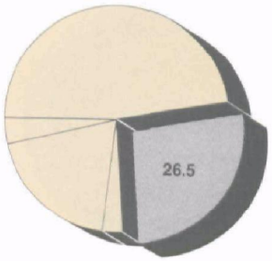
To improve current combustion modification techniques, CRB is conducting field demonstrations of full-scale coal-fired boilers with the cooperation of boiler manufacturers. These tests have already shown that properly applied combustion modification techniques can reduce NO_x emissions by 40 percent to a level well below the current emissions standard. Although long-term tests are needed to determine the effects of these techniques on boiler performance, this is a significant step toward making coal an environmentally safe fuel for our country to burn.

Equally important for the decades ahead are CRB's pilot-scale tests of advanced combustion modification techniques for coal-fired boilers. As part of this program, new burner designs are being developed that can cut NO_x emissions from coal-fired boilers by as much as 60 to 70 percent. This reduction can be achieved without wasting fuel, damaging equipment, or increasing pollutants like carbon particulates, carbon monoxide, or organics. If all goes according to schedule, these new low-NO_x burners will be demonstrated in full-scale boilers by 1980. The results of these tests will help manufacturers of these huge boilers build effective NO_x controls into their equipment at the factory, where it can be done economically.



Along with better combustion modification techniques to meet today's needs, NO_x controls are also needed for the new fuels that may be used in the 1980's and 1990's — coal-oil slurries, low-Btu gas from coal, and waste fuels. CRB's research will help ensure that these new energy-saving technologies do not create more problems than they solve.

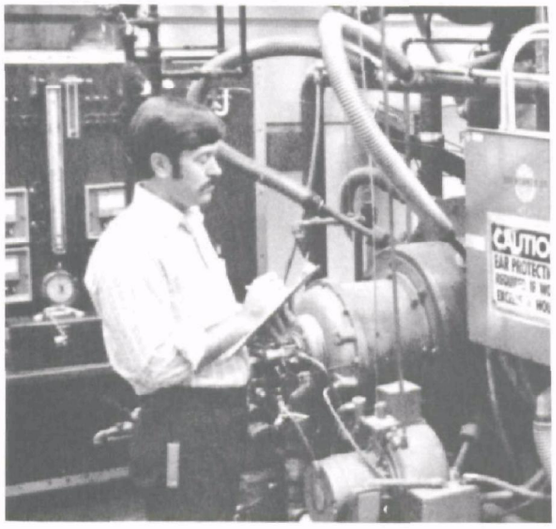
Small Industrial, Commercial, and Residential Systems



Small industrial, commercial, and residential systems are those that generate up to 100,000 pounds of steam per hour — or up to 10,000 kilowatts of electricity. They are used in dozens of industrial processes, and they produce steam or hot water for many commercial operations. In our homes, they're the boilers and furnaces that supply steam or hot air for space heating.

By itself, no single small industrial, commercial, or residential system produces much of the total amount of NO_x that pollutes our atmosphere. But since there are literally millions of these systems in businesses and homes in the United States, together they are a major source of NO_x pollution. Today, these systems emit more than a quarter of the NO_x from stationary sources every year — over 4 million tons annually.

EPA's Office of Air Quality Planning and Standards is developing New Source Performance Standards for small industrial, commercial, and residential systems. To help set these standards, CRB is measuring emissions from many different kinds of boilers and furnaces all across the country.

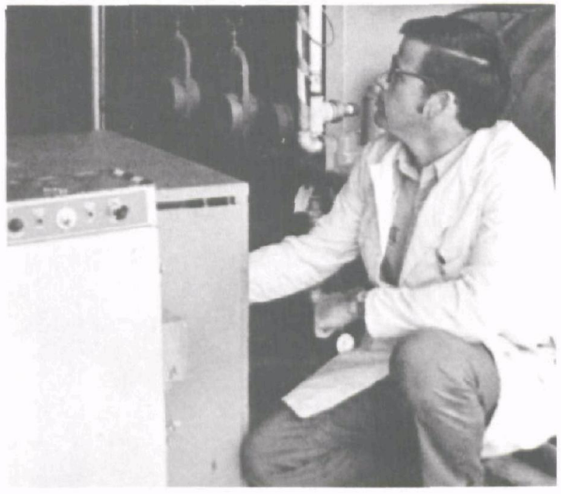


At the same time, so that businesses and homeowners will be able to meet the new standards, CRB is exploring ways of reducing NO_x emissions without increasing fuel consumption. Modifying existing small industrial, commercial, or residential systems already in operation is usually not as cost-effective as incorporating NO_x controls into new designs. So the main aim of CRB's work is to spell out guidelines for designing new equipment.

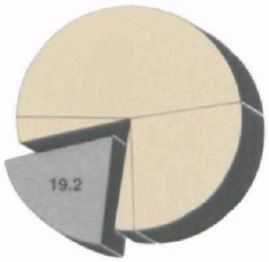
Pilot-scale tests and field demonstrations on residual-oil-fired package boilers have already shown that NO_x emissions can be reduced by as much as 50 percent with new burner and boiler designs. In addition, tests on both gas- and oil-fired boilers have demonstrated that combustion modification techniques are also very effective in preventing NO_x from forming.

Within the next few years, this new technology will be available for boiler manufacturers to draw on in designing low-NO_x equipment to replace older units now in the field.

In related programs, CRB is working to cut NO_x emissions from stoker coal-fired boilers. Emissions from different types of coal have been measured, and CRB is now evaluating the operating problems involved in switching from eastern high-sulfur bituminous coal to western low-sulfur coal.



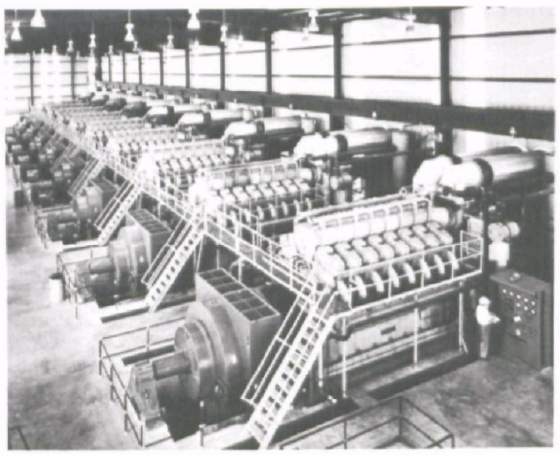
Also being developed is a new residential oil furnace that burns fuel much more efficiently and reduces NO_x emissions by more than 70 percent compared to furnaces now in use. It uses an advanced burner and carefully matched firebox to cut both NO_x and particulate emissions. A preproduction model has been constructed and is ready to be tested under normal working conditions in the field.



Stationary Engines

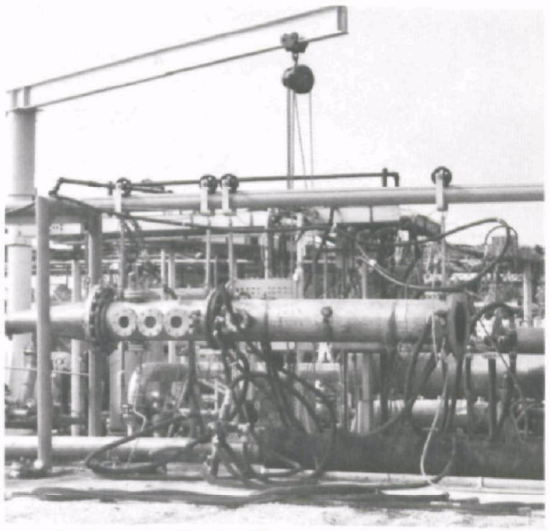
Stationary engines include both large reciprocating internal combustion (IC) engines and gas turbines. Most of these engines are used to pump gas and oil through pipelines or as standby electrical generators for factories, power stations, hospitals, and other places where dependable power is essential. Thousands of these engines are in use today across the country. And even though they burn relatively clean fuels like natural gas and distillate oils, they produce 2-1/2 million tons of NO_x every year — almost 20 percent of the total from stationary sources.

CRB's program for gas turbines is focusing on advanced controls like changing the method of fuel/air mixing and the configuration of the combustor. The goal is to reduce NO_x emissions by 75 percent for clean fuels like natural gas and light oils, as well as for dirtier fuels like heavy oils. Pilot-scale tests are being performed



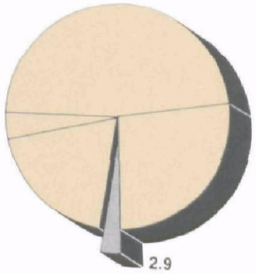
on 12 new gas turbine combustor designs with built-in dry NO_x control techniques. Based on these tests, full-scale models of the two most effective combustors will be built and tested in the field. The end result will be guidelines for designing industrial and utility gas turbines with lower emissions of NO_x, carbon monoxide, and hydrocarbons.

CRB is also investigating ways to reduce NO_x emissions from large-bore reciprocating IC engines. Both new and retrofit designs for diesel and spark-fired engines

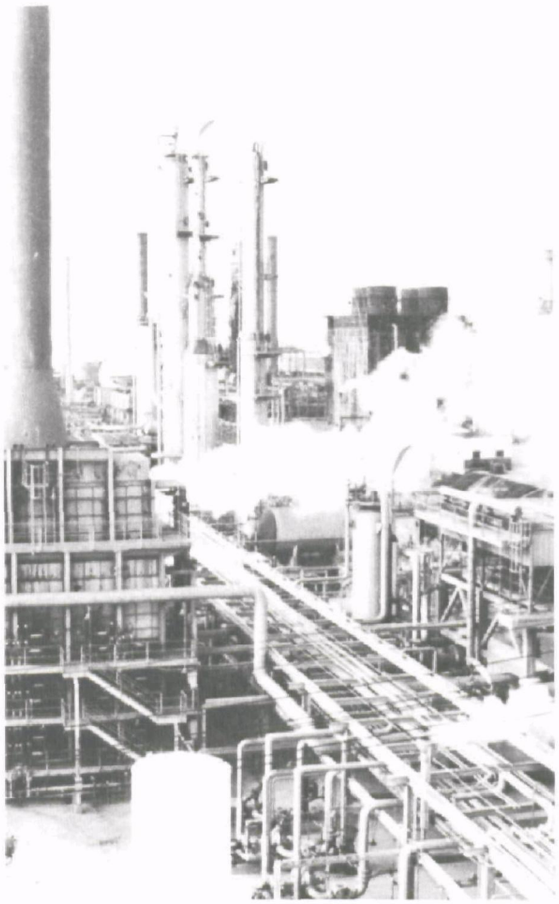


are being studied. The aim of the program is to find ways of redesigning the engine chamber so that NO_x emissions will be substantially lowered without increasing emissions of carbon monoxide, hydrocarbons, or carbon particulates. As with gas turbines, the results of these studies will be used to design new, more efficient IC engines that emit less NO_x and other pollutants.

Industrial Process Combustion



Cement kilns, woodbark boilers, open-hearth furnaces, and oil-refining process heaters are all examples of industrial process combustion. These sources emit nearly 400,000 tons of NO_x into our air every year — or about 3 percent of the annual total NO_x emissions. This is a small percentage compared to utility and industrial boilers or stationary engines.



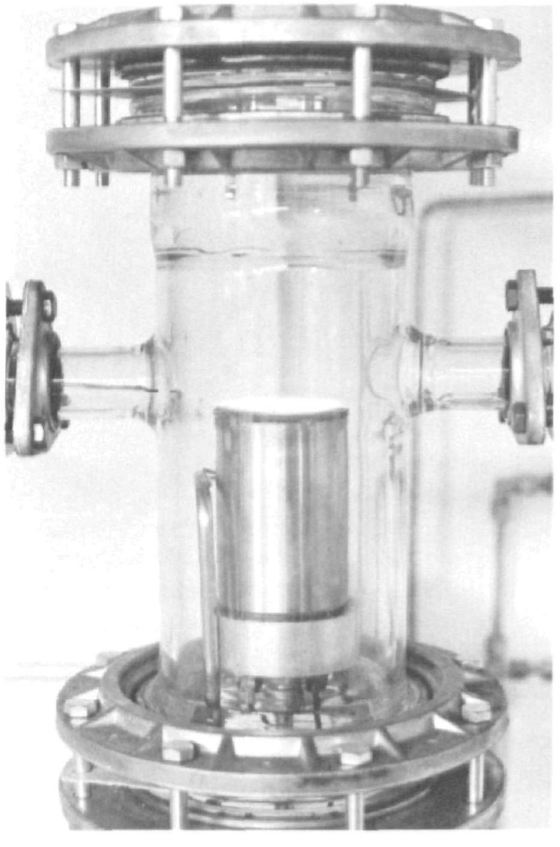
Nevertheless, NO_x pollution from industrial process combustion is a serious problem in some areas of the country where iron and steel works, oil refineries, or other heavy industries are concentrated. For this reason, NO_x from industrial process combustion is one of the targets of CRB's program.

As yet, no nationwide New Source Performance Standards have been set for industrial process combustion — mainly because of the thousands of different types of equipment that fall into this category. CRB, however, has recently taken an important first step by measuring emissions of NO_x and other pollutants from all major industrial process combustion sources, including the iron and steel, cement, aluminum, and petroleum-refining industries.

In some of these industries, afterburners are used to destroy pollutants — especially organic compounds — formed in the combustion process. However, recent research has shown that afterburners sometimes actually create NO_x as they destroy other kinds of pollutants. In a program begun in 1977, CRB is analyzing afterburner combustion systems as a first step toward developing standards for controlling NO_x without creating new environmental problems.

Fundamental Combustion Research

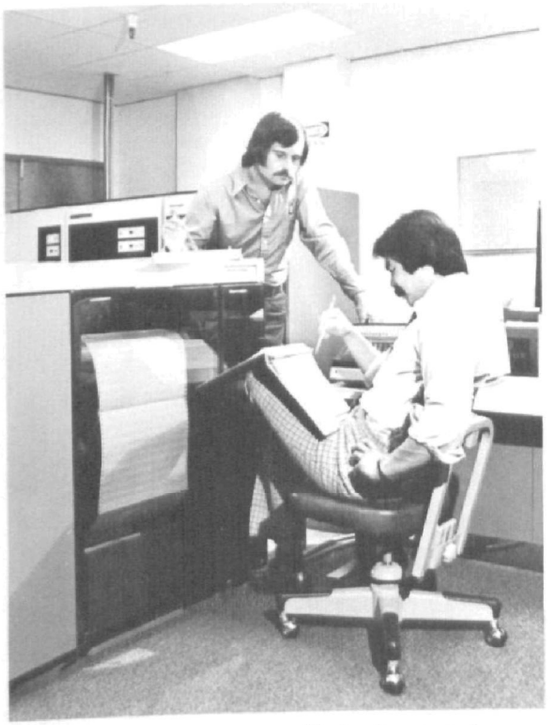
CRB's programs in fundamental research focus on the two main factors in the formation of NO_x: combustion chemistry and combustion aerodynamics. Work in the chemistry of combustion is answering basic questions about the chemical reactions that occur when fuels burn, and how temperature, fuel, and air affect these reactions. At the same time, research in the aerodynamics of combustion is examining the physical conditions in the flame zone, and how different ways of mixing fuel and air alter these conditions.



Although the primary purpose of these studies is to increase knowledge of how NO_x is formed and destroyed, CRB is also exploring how combustion chemistry and aerodynamics affect other pollutants, including sulfur oxides, hydrocarbons, carbon monoxide, and organics. This research is essential in understanding how to control NO_x without increasing emissions of other pollutants.

Thanks to fundamental research, we have a much better understanding today of how fuels burn, and of the intricate ways in which the formation of one pollutant affects others. This understanding is already helping solve the practical problems of modifying the combustion process to reduce NO_x and other pollutants. By knowing more about how the combustion process works, CRB has been able to improve combustion modification techniques and design new, more efficient low-NO_x burners. Research into the basic mechanisms of combustion will continue to play an essential part in controlling NO_x and other pollutants.

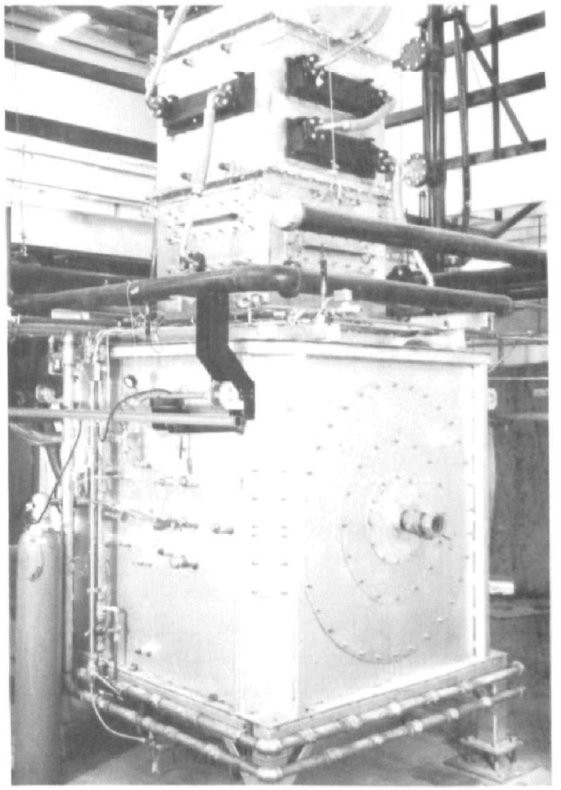
Advanced Combustion Research



As the need for more efficient ways to produce energy continues to grow, both government agencies and private industry are developing new technologies for combustion processes. CRB's advanced combustion research programs ask basic questions about these new ideas at the very beginning of development. Will NO_x or other pollutants be formed in the new process? Can those pollutants be controlled economically? How will controls affect the process? Will it still operate efficiently? Can it still be adapted to burn different kinds of fuels?

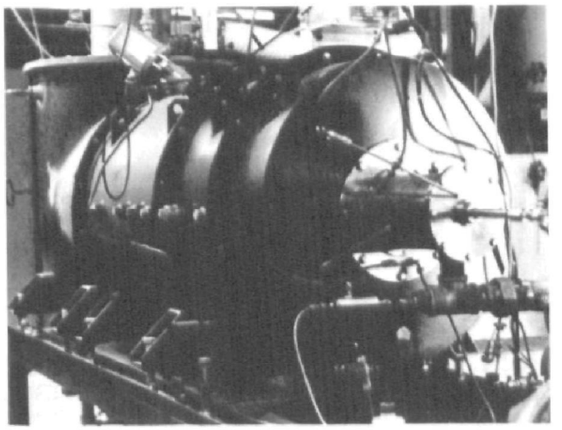
Answers to questions like these begin with theoretical studies. Computer simulations, mathematical models, and good, hard thought identify problems with proposed new technologies, and suggest avenues that may lead to solutions.

When initial studies like these show that a new idea has promise, a second stage of research begins. In this stage, laboratory-scale experiments are conducted to help researchers learn more about the basic principles of the new technology. CRB recently completed a laboratory-scale test



of methanol (methyl alcohol) as a potential low-NO_x fuel for small boilers and residential furnaces. Laboratory-scale investigations of combined-cycle combustion techniques and gas derived from coal are now underway.

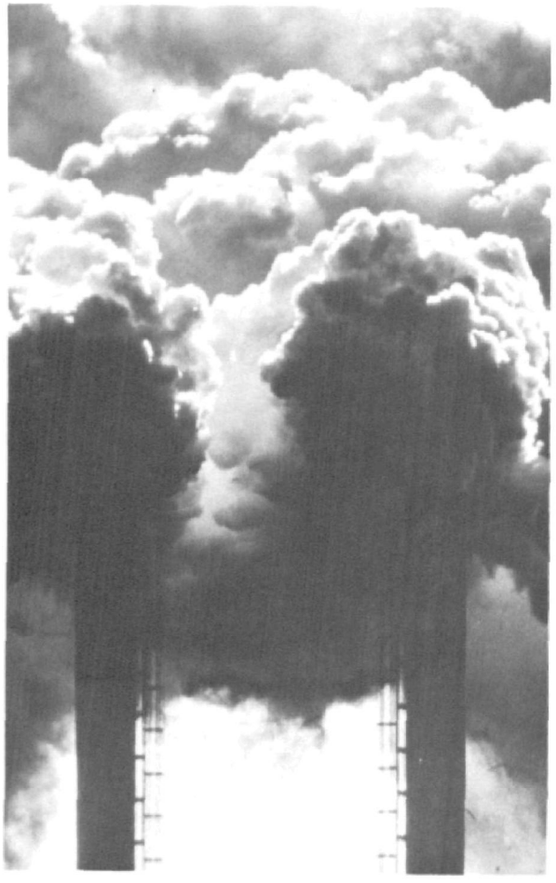
The results of these laboratory-scale experiments pave the way for the next stage of advanced combustion research: pilot-scale studies. CRB's catalytic combustion program is in this important stage of development. Materials like platinum, palladium, and cobalt oxide are being tested in a pilot-scale facility for their potential as combustion catalysts. By



making it possible to burn fuel much more efficiently at lower combustion temperatures, catalysts can reduce emissions of NO_x, carbon monoxide and hydrocarbons to very low levels. CRB's pilot-scale tests have already found one catalyst that cuts NO_x emissions from a variety of fuels by up to 98 percent.

Decades from now, much of the energy for homes, businesses, and industries may come from new technologies like catalytic combustion — techniques that are only ideas today. CRB's work in advanced combustion research is helping to make these ideas reality.

Environmental Assessment



Most of CRB's programs zero in on very specific pollution problems for specific kinds of combustion equipment. But the environmental assessment is different. It's a program designed to put CRB's work in perspective by considering the larger environmental and economic questions raised in controlling pollutants from stationary combustion sources.

One goal of this environmental assessment is to evaluate the impact that controlling NO_X from stationary sources will have on our environment, our economy, and our supplies of energy. What price will we have to pay to reduce NO_X by 25 percent? By 50 percent? By 75 percent? How will emission of other pollutants like particulates, carbon monoxide, or hydrocarbons be affected? What level of control can be achieved without causing operating difficulties and wasting fuel? Considering all the ramifications, what is the optimum level of control for each major type of equipment?

To get these answers, CRB is sifting through a tremendous amount of information on stationary sources, pollutants, controls techniques, and environmental effects. In cases where information is lacking, field tests are being conducted to gather data.

A second goal of the environmental assessment is to establish the combination of control techniques that will work best in each of the nation's Air Quality Control Regions. CRB is conducting systematic analyses of all factors that affect NO_X pollution in each of these regions — such as population, the number and kinds of stationary and mobile sources, fuels burned, wind and weather patterns, and topography. These analyses will help each Air Quality Control Region set up a realistic, workable strategy for controlling emissions of NO_X and other pollutants from sources under its jurisdiction.

CRB's environmental assessment program is an in-depth, 3-year study. When it's completed in 1979, our country will be in a much better position to make intelligent choices about controlling NO_X in the decades ahead.

Technology Transfer

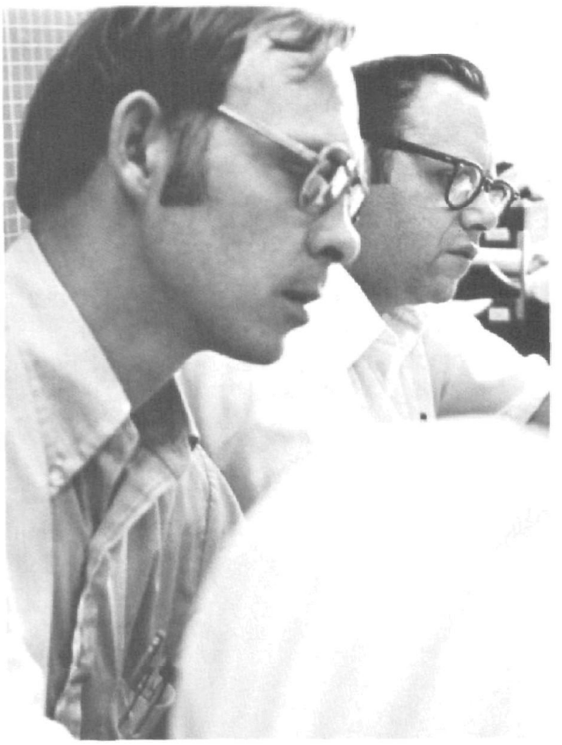
CRB's work is generating a tremendous amount of new information on better ways to control NO_x and other pollutants. To share this information as widely as possible, CRB has an active technology transfer program. Its purpose is to bring ideas and technical information to owners and manufacturers of stationary source combustion equipment, as well as thousands of people in related industries, government, and universities.

The field demonstration stage of CRB's research and development program is one part of this technology transfer program. These demonstrations are carried out in factories and power plants in many different parts of the country with the cooperation of owners, operators, and equipment manufacturers. They provide an excellent opportunity for people in the field to get hands-on experience with new technology as it is being developed.

Along with field demonstrations, CRB also sponsors symposiums on stationary source combustion. Representatives from government agencies, industry, and universities come together to exchange ideas and discuss the problems of controlling NO_x and other pollutants. Papers are presented about current research sponsored by CRB, and about the government's strategy for regulating pollutant emissions. These papers are published in the proceedings of each symposium, and are available to the public.

Final reports on CRB's research programs — as well as guidelines for design and operation of combustion equipment — get wide distribution through IERL-RTP's Technical Information Service and the National Technical Information Service. In addition, the results of these programs are regularly presented at meetings of professional societies, such as ASME, APCA, and AIChE.

CRB also sponsors a technical information bulletin entitled "NO_x Control Review." Published four times a year, the Review is one more part of CRB's effort to spread knowledge of the latest developments in NO_x control technology. It now reaches more than 2000 readers in government and industry.



Looking Ahead

CRB has already taken some important steps toward making our air cleaner and healthier to breathe. Major accomplishments over the last 2 years include:

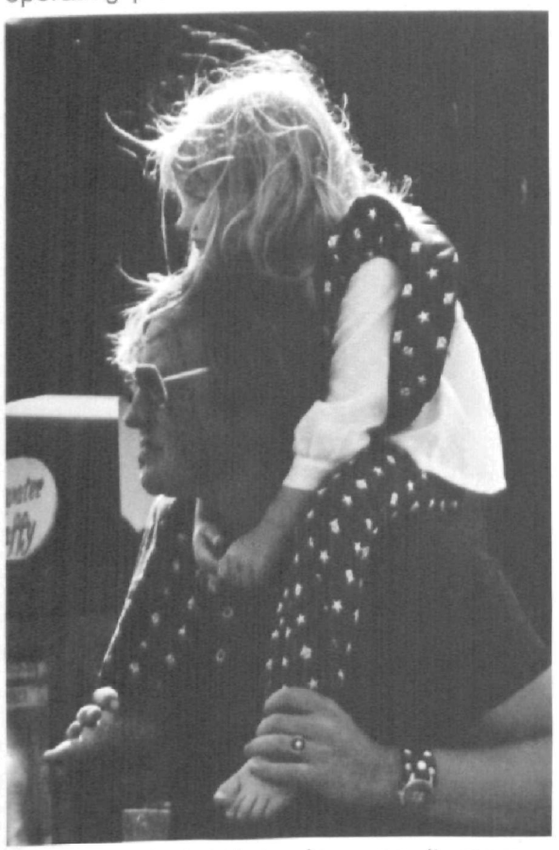
- Combustion modification techniques for coal-fired utility and large industrial boilers that reduce NO_x emissions by 40 to 50 percent with no adverse side effects.
- Pilot-scale tests of advanced pulverized coal burners for utility and large industrial boilers that lower NO_x emissions by 70 to 80 percent.
- A residual oil burner for small industrial boilers that cuts NO_x emissions by 65 to 70 percent from heavy oils with high nitrogen content.
- An oil-fired home furnace that reduces NO_x emissions by 70 percent without increasing carbon monoxide, hydrocarbons, or smoke.
- Field tests proving that NO_x emissions from small industrial boilers can be lowered significantly by combustion modification techniques and by firing methanol instead of natural gas or heavy oils.
- Pilot-scale tests of an advanced catalytic combustion system capable of reducing emissions of NO_x, carbon monoxide, and hydrocarbons by as much as 95 percent.

A great deal has been accomplished — but there's still a great deal left to do.

Over the next 5 years, CRB will be working to achieve three main goals. One of these is to demonstrate that the new low-NO_x pulverized coal burners now being pilot-tested will perform satisfactorily on full-scale utility and industrial boilers. This work is a critical part of reducing NO_x pollution in our air. Large coal-fired boilers already emit over 30 percent of all NO_x from stationary sources.
And this figure could jump to over 50 percent by the year 2000 without better controls. New low-NO_x burners should make it possible to cut NO_x emissions from coal-fired boilers by 60 to 70 percent.

Another of CRB's goals for the next few years is to significantly improve NO_x control techniques for small industrial and commercial boilers and furnaces. These units emit only 7 percent of the NO_x from stationary sources today. But with switching from oil and natural gas to coal, this percentage is expected to skyrocket in the next 10 to 20 years. To save time and money, combustion modification techniques already developed and tested for large utility boilers will be adapted to smaller equipment, especially stoker coal-fired boilers.

CRB's third goal between now and 1983 is to demonstrate the long-range effectiveness of combustion modification techniques by performance tests of a year or more on coal-fired utility and large industrial boilers in the field. These tests should show us how to burn coal more cleanly and efficiently, without increasing operating problems such as corrosion,



fouling, and slagging. As a result, many coal-fired boilers that might have to be phased out for lack of adequate NO_x controls may be kept in operation. And oil-fired boilers may be switched to coal without causing additional pollution problems.

All three of these programs will play an essential part in our country's switch from oil and natural gas to coal. Unless we have the technology to control NO_x and other pollutants to safe levels, energy independence can only come at the cost of a more polluted atmosphere. With CRB's help, we will be able to take advantage of our nation's supplies of coal — and keep our air clean and healthy in the years ahead.

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