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Project Summary

Environmental Assessment of Stationary Source NO_x Control Technologies: Final Report

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The five major categories of stationary sources of oxides of nitrogen (NO_x) are utility boilers, industrial boilers, internal combustion engines, gas turbines, and residential heating systems. These categories, together with industrial processes and minor sources, emitted 10.5×10^9 kg (11.6×10^6 tons) of NO_x (NO_2 basis) in 1977, approximately equaling the mobile source loading. Under contract 68-02-2160, these five source categories were subjected to a 3-year environmental assessment involving multimedia source sampling and analysis, NO_x control process engineering, and NO_x air quality/regulatory evaluations.

Field tests were conducted on two coal-fired utility boilers, an oil-fired utility boiler, two stoker-coal-fired industrial boilers, an oil-fired gas turbine, and an oil-fired residential heating system. Testing followed the EPA Level 1 protocol which includes sampling and analysis for criteria gaseous pollutants, trace metals, organics, and trace inorganic species. Tests conducted before and after modification for low-NO_x operation generally showed few adverse environmental side effects of NO_x control. Where emissions of some species were increased by NO_x control, the environmental effect was counterbalanced by the beneficial effects of NO_x reduction.

Process engineering studies were made of NO_x controls for the five source categories for both new and existing equipment. Capital and operating costs were estimated for NO_x control to various levels and the associated effects on energy, operation, and other pollutants were noted. Retrofit controls are available for most source categories, but the practical reduction efficiency is limited by operational constraints and possible CO or carbon emissions. For new equipment, NO_x can generally be reduced significantly using new designs, with a minor cost impact and negligible effect on efficiency or CO emissions.

Air quality analyses were conducted for several NO_2 sensitive areas to determine which controls may be needed to meet various existing or projected NO_x regulations. For the most probable NO_x regulatory scenarios, retrofit controls will probably be needed only on larger sources in a few areas. New source controls will be needed for a wide variety of source types and at several areas nationwide.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the

same title (see Project Report ordering information at back).

Introduction

In 1975, EPA's Industrial Environmental Research Laboratory at Research Triangle Park (IERL-RTP) started a major environmental assessment of energy systems and industrial processes. These assessments were to detect and quantify potential environmental problems with the systems or processes and identify potential control measures to reduce the environmental problems found. This information was needed by EPA and other agencies to establish R&D priorities, to support standards setting activities by regulatory groups, and to develop environmentally acceptable energy systems.

The Combustion Modification Environmental Assessment (CMEA) was started by IERL-RTP's Combustion Research Branch in June 1976 to support the overall EA program by focusing on stationary combustion sources with combustion modification techniques to control NO_x or other pollutants amenable to control through combustion process modification.

The three primary objectives of the CMEA are to:

- Identify important multimedia environmental pollutants from stationary combustion sources:
  - — Under baseline operation without combustion modification controls.
  - — And, more importantly, under controlled operation to suppress NO_x or other pollutants amenable to control through combustion process modification.
- Develop control application guidelines on the economic, energy, and operational impacts of meeting prescribed emission levels.
- Identify the most cost-effective and environmentally acceptable NO_x control techniques to achieve and maintain air quality considering:
  - — Current and anticipated air quality standards.
  - — Alternate equipment use and fuel use scenarios to the year 2000.

The effort to achieve the above objectives resulted in the generation of 20 reports which are listed in Table 1. The initial effort in the program was a preliminary environmental assessment, Reports 1 and 2, in which methodologies were developed, data were compiled and evaluated, and program priorities were set. Source priorities were further quantified in Reports 4 and 5 which documented nationwide and regional NO_x inventories and population exposure models. These priorities were used to direct the effort for the first 2 years of the contract as documented in Reports 3 and 6.

The process engineering effort in support of the second objective is documented in Reports 7-12 for the five source categories. These reports contain source characterizations, evaluations of available and emerging NO_x controls for new and existing equipment, control costs, and assessments of effects on other pollutants of low-NO_x operation. The data for the environmental assessments were taken from the field test results, Reports 13-19, and from data from other programs.

Environmental assessment field testing was conducted on the following equipment: a 180 MW coal-fired utility boiler (Kingston Unit 6), a 500-MW coal-fired utility boiler (Crist Unit 7), a 750-MW oil-fired utility boiler (Moss Landing Unit 6), a 130,000-kg/hr stoker-coal-fired industrial boiler (Site A), a 90,000-kg/hr stoker-coal-fired industrial boiler (Site B), a 60-MW oil-fired gas turbine (T.H. Wharton Unit 52), and a Blueray low-emission oil-fired residential heating system.

The air quality/regulatory evaluation supporting the third objective is documented in Reports 3, 6, and 20.

Additional environmental assessment field testing, under EPA contract 68-02-3188, began in January 1980.

Conclusions

Analytical results from the seven field tests were evaluated to identify differences in pollutant species composition and levels of concentration between waste streams (e.g., flue gas vs. ash streams), between sources and fuels, and between uncontrolled and controlled (for NO_x) operation. Field test results indicate that:

- For the sources tested, the flue gas stream presents the greatest potential environmental concern.
- NO_x and SO_2 appear to be the most important flue gas pollutants.
- Overall flue gas pollutant composition is improved or, at worst, not adversely affected upon applying the combustion modifications tested; changes in emissions of other pollutants due to day-to-day fuel composition changes are often of greater magnitude than those attributable to NO_x control.
- The multimedia waste streams from the sources tested are not mutagenic; in general, elicit nondetectable toxicity in bioassay testing, and the limited data for combustion modifications showed minimal effect on polycyclic organic matter (POM) levels.
- The combustion modifications tested:
  - — Have no effect on, or increase only slightly, emissions of CO and vapor-phase hydrocarbon.
  - — Have no effect on particulate mass emissions.
  - — Have no effect on, or tend to increase slightly, emitted particle size distribution.
  - — Have no measurable effect on trace element emissions or on trace element size partitioning tendencies.
  - — Have no effect on, or decrease slightly, SO_3 and particulate sulfate emissions.
  - — Have little effect on total higher molecular weight organic emissions.
  - — Marginally increase polycyclic organic matter (POM) emissions, but the emission levels remained on the order of the detection levels of the instrument.
- Emissions of the organic priority pollutants were below the detection limit for the sources tested.

It must be emphasized, though, that the sources were tested only under steady operation, in short duration tests, and that the controls tested were the currently available combustion modification technologies. Conclusions on the effects of advanced combustion modification controls, and on the potential effects on pollutants of combustion sources under unsteady or transient operation must await results from subsequent test programs.

Results from the air quality/regulatory analyses were evaluated to identify research and development priorities for combustion modification control of emissions of NO_x and other pollutants. High ranking source control priorities include:

- Further control of coal-fired utility and large industrial boilers to the 60 ng/J level through the continuation and success of ongoing programs.
- Further control of large IC engines, both spark and compression igni-

Table 1. *Summary of Documentation: Contract 68-02-2160*

Report No.	Title	Date	EPA Report No. (EPA-)
1, 2	Preliminary Environmental Assessment of Combustion Modification Techniques: Volume I. Summary; Volume II. Technical Results	October 1977 October 1977	600/7-77-119a 600/7-77-119b
3	Environmental Assessment of Stationary Source NO_x Control Technologies — First Annual Report	March 1978	600/7-78-046
4, 5	Emission Characterization of Stationary NO_x Sources: Volume I. Results; Volume II. Data Supplement	June 1978 August 1978	600/7-78-120a 600/7-78-120b
6	Environmental Assessment of Stationary Source NO_x Control Technologies — Second Annual Report	June 1979	600/7-79-147
7, 8	Environmental Assessment of Utility Boiler Combustion Modification NO_x Controls: Volume 1. Technical Results; Volume 2. Appendices	April 1980	600/7-80-075a 600/7-80-075b
9	Combustion Modification Controls for Stationary Gas Turbines: Volume I. Environmental Assessment	July 1981	600/7-81-122a
10	Combustion Modification Controls for Residential and Commercial Heating Systems: Volume I. Environmental Assessment	July 1981	600/7-81-123a
11	Industrial Boiler Combustion Modification NO_x Controls: Volume I. Environmental Assessment	July 1981	600/7-81-126a
12	Environmental Assessment of Combustion Modification Controls for Stationary Internal Combustion Engines	July 1981	600/7-81-127
13	Combustion Modification NO_x Controls for Utility Boilers: Volume I. Tangential Coal-Fired Unit Field Test	July 1981	600/7-81-124a
14	Combustion Modification NO_x Controls for Utility Boilers: Volume II. Pulverized-Coal Wall-Fired Unit Field Test	July 1981	600/7-81-124b
15	Combustion Modification NO_x Controls for Utility Boilers: Volume III. Residual-Oil Wall-Fired Unit Field Test	July 1981	600/7-81-124c
16	Combustion Modification Controls for Stationary Gas Turbines: Volume II. Utility Unit Field Test	July 1981	600/7-81-122b
17	Combustion Modification Controls for Residential and Commercial Heating Systems: Volume II. Oil-Fired Residential Furnace Field Test	July 1981	600/7-81-123b
18	Industrial Boiler Combustion Modification NO_x Controls: Volume II. Stoker-Coal-Fired Boiler Field Test — Site A	July 1981	600/7-81-126b
19	Industrial Boiler Combustion Modification NO_x Controls: Volume III. Stoker-Coal-Fired Boiler Field Test — Site B	July 1981	600/7-81-126c
20	Environmental Assessment of Stationary Source NO_x Control Technologies — Final Report	May 1982	600/7-82-034

tion, through the continuation of ongoing programs.

- Control techniques for industrial process combustion (particularly glass melting furnaces, cement kilns, and refinery process heaters) through the continuation of ongoing programs.

Pollutant priorities were evaluated by comparing waste stream concentrations to target concentrations used for pollutant prioritization in this environmental assessment study. Higher priority flue gas stream pollutants include vapor-phase SO_3 and condensed sulfate, organic acids, and trace elements such as As, Be, Cd, and V. Higher priority ash stream pollutants from coal-fired sources are the trace elements Fe, Mn, Cr, Ni, Be, Ba, Pb, and occasionally As, Se, Tl, and Sn.

Results

Detailed test results from the program are documented in the field test and environmental assessment reports listed in Table 1.

Test results indicate that SO_2 and NO_x emissions are probably the most important pollutants from all the combustion sources tested. These emissions are especially high from coal-fired sources. Other high priority species in most tests include CO, As, and SO_3 (vapor phase). The only organic emissions of potential significance noted were those of carboxylic acids. Several other trace element species and condensed sulfate were flagged in several tests, although these were not universally noted.

The highest priority species in the ash streams from coal-fired sources were Fe and Mn, followed by Cr, Ni, Be, and Ba. Interestingly, Pb levels were high only in particle collector ash streams, particularly the electrostatic precipitator (ESP) hopper ash, suggesting that Pb partitions to more concentrated levels on passage through a boiler.

In general, changes in the overall flue gas pollutant composition due to NO_x control are less significant than those resulting from day-to-day variations in fuel composition (especially sulfur). When fuel variations are accounted for, NO_x control application either reduces key flue gas pollutant levels, or (at worst) does not adversely affect them.

Since few data existed on the effects of NO_x control on combustion source polycyclic organic matter (POM) and other organic emissions, and since several species in this pollutant class are quite genotoxic, priority was given to obtaining data on these emissions in the field test program.

Table 2 shows total sampling train organic determination data for the tests performed. Infrared analysis of sample extracts showed the organic species in the samples were in the aliphatic hydrocarbon, ether, ester, aromatic, and carboxylic acid categories. The data in the table indicate that emission of these higher molecular weight organics remains relatively unchanged with NO_x control application, as is the case also for CO and HC emissions. The seemingly high levels of organic compound emissions in the Blueray residential furnace test are primarily unburned fuel oil. This was a result of the on/off cycling of the furnace during the test.

Additional organic analyses were made with gas chromatography/mass spectrometry (GC/MS) speciation of at least 11 POM species and several other organic priority pollutants. Results showed that there is a marginal increase in POM emissions with NO_x control application. The emission levels were generally of the order of the detection level of the instrument. In the analyses for the organic priority pollutants, none of these species were found within the detection limits.

Bioassay testing was performed on samples taken during the Crist Unit 7, Moss Landing Unit 6, Site B, and gas turbine lowest NO_x tests. Table 3 summarizes results from all the bioassay tests performed. The data in the table show that discharge streams tested had nondetectable mutagenicity and nondetectable-to-low toxicity.

Table 2. *Effects of Controls Tested on Flue Gas Organic Emissions*

		Organic Emissions (mg/dscm)		
			Intermediate	
Test	Control[a]	Baseline	NO_x	Low NO_x
Kingston Unit 6	BOOS	0.124	—	0.834
Crist Unit 7	BOOS	4.23	2.320	0.722
Moss Landing Unit 6	FGR, BOOS/FGR	4.38	1.37	1.43
Site A	OFA	1.00	—	1.79
Site B	LEA	0.924	—	1.37
T.H. Wharton Unit 52	WI	1.30	—	1.10
Blueray Furnace	New design	—	—	26.3

[a]*BOOS: Burners out of service; FGR: Flue gas recirculation; OFA: High overfire air; LEA: Low excess air; WI: Water injection.*
— Source not tested under this condition.

Table 3. *Bioassay Test Data with Low NO_x Combustion Modifications*

		Bioassay Result[a]					
			Cytotoxicity		Rodent		
Test/Sample	Control[b]	Microbial Mutagenesis	RAM	WI-38	Acute Toxicity	Freshwater Algae	Freshwater Fish
Crist Unit 7	BOOS						
>3 μm flyash		Neg	ND	—	—	—	—
<3 μm flyash		Neg	L	—	—	—	—
Bottom ash		Neg	ND	—	ND	ND	ND
KSP hopper ash		Neg	ND	—	ND	ND	ND
Moss Landing Unit 6	BOOS/						
XAD-2 extract	FGR	Neg	—	M	—	—	—
Site B	LEA						
Bottom ash		Neg	ND	—	ND	ND	ND
KSP hopper ash		Neg	L	—	ND	—	—
Gas Turbine	WI						
XAD-2 extract		Neg	—	L	—	—	—

[a]*Neg: Negative; ND: Not detectable; L. Low toxicity; M: Medium toxicity.*
[b]*Total flue gas DS cited.*
—Test not conducted.
[b]*Refer to Table 2.*

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The complete report, entitled "Environmental Assessment of Stationary Source NO_x Control Technologies: Final Report," (Order No. PB 82-249 350; Cost: $25.50, subject to change) will be available only from:
National Technical Information Service
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