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PRELIMINARY ENVIRONMENTAL ASSESSMENT OF COMBUSTION MODIFICATION TECHNIQUES:
Volume I. Summary

Interagency
Energy-Environment
Research and Development
Program Report

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This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally--compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

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by

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Program Element No. EHE624A

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
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Washington, D.C. 20460

FOREWORD

The report summarizes results generated during the first 6 months of EPA Contract 68-02-2160: "Environmental Assessment of Stationary Source NO_x Combustion Modification Technologies." The EPA Project Officer is J. S. Bowen and the Deputy Project Officer is R. E. Hall of the Combustion Research Branch, IERL/RTP. This report was prepared by Aerotherm Division of Acurex Corporation. Principal Contributors were: A. Balakrishnan, C. Castaldini, Z. Chiba, R. M. Evans, J. E. Ferrell, H. B. Mason, G. R. Offen, G. G. Poe, K. Salvesen, A. B. Shimizu, L. Waterland and K. J. Wolfe. Additionally, subcontract support was provided by H. M. Utidjian and P. Atkins of Equitable Environmental Health Inc., and G. Lauer, A. Lloyd and R. MacGregor of Environmental Research and Technology Inc. The Program Manager was W. H. Nurick; H. B. Mason was the Project Engineer. C. B. Moyer provided technical review.

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SECTION 1

INTRODUCTION

This is the first in a series of 11 special reports to be documented in the "Environmental Assessment of Stationary Source NO_x Combustion Modification Technologies" (NO_x E/A). The NO_x E/A is a 36-month program which began in July 1976. The program has two main objectives: (1) to identify the multimedia environmental impact of stationary combustion sources and NO_x combustion modification controls; and (2) to identify the most cost-effective, environmentally-sound NO_x combustion modification controls for attainment and maintenance of current and projected NO_2 air quality standards to the year 2000. The first objective addresses the need to evaluate the environmental soundness of current control technology, as well as to identify potential environmental stresses of advanced techniques being developed for application in the 1980's and 1990's. The second objective draws on the above results in combination with process studies and air quality models to rank source/control combinations based on current or projected control implementation needs. These results are used both to prioritize the effort within the NO_x E/A and to guide the control development program. This report documents the initial program results of compiling and evaluating data on sources, controls, pollutants, and impacts to be considered, and of defining program priorities on source/control combinations and effluent stream/impacts.

1.1 BACKGROUND

As a result of the 1970 Clean Air Act Amendments a moderate level of NO_x control has been developed and implemented for a variety of stationary combustion NO_x sources. In 1971, the EPA promulgated a primary and secondary National Ambient Air Quality Standard (NAAQS) for NO_2 of 100 $\mu g/m^3$ (annual average). At that time, the EPA NO_x abatement strategy for attaining and maintaining the NAAQS for NO_2 relied heavily on NO_x controls for mobile sources. As mandated by the Clean Air Act, light-duty vehicle (LDV) emissions were to be reduced by 90 percent to a level of 0.25 g NO_2/km (0.4 g/mile) by 1976. Stationary sources were to be regulated through EPA Standards of Performance for New Stationary Sources (NSPS), which would be set as technology became available on the basis of the best system of emissions reduction. To date, NSPS have been set for gas-, oil- and bituminous coal-fired large steam generators and nitric acid plants. NSPS have been proposed for lignite-fired large steam generators and gas turbines, and are in preparation for stationary IC engines and intermediate-sized steam generators. A more stringent standard for bituminous coal-fired large steam generators is also being prepared. Additional standards for new or existing sources can be set through State Implementation Plans (SIPs) as required to attain and maintain air quality in Air Quality Control Regions. As part of these SIPs, stationary source NO_x controls have been applied to new and existing utility boilers, large industrial boilers and gas turbines.

The stationary source regulatory program described above is leading to widespread application of current control technology. A major part of the NO_x E/A program will be directed at evaluating these applications to identify the incremental environmental impact resulting from the use of NO_x controls. Additionally, process engineering studies will be conducted for the use of NO_x controls on the major equipment categories. These studies will quantify the cost, efficiency impact and operational impact of the use of current NO_x control technology. The result will be a ranking of source/control combinations based on overall environmental, economic and operational impact. This information is intended to support control developers and users in selecting the most appropriate control techniques to meet regulatory standards. The results of the NO_x E/A will also contribute to the broad program of assessments of energy systems and industrial processes which is being administered by EPA's Office of Research and Development. This assessment program involves a series of coordinated efforts to evaluate the environmental impact and control potential of multimedia effluents — air, land and water — from current and emerging energy and industrial processes. The results of these efforts will define pollution control development needs and priorities, identify economic and environmental trade-offs among competitive processes, and will ultimately guide regulatory policy.

In addition to the assessment of current control technology noted above, the NO_x E/A will also evaluate emerging technology with potential for application in the 1980's and 1990's. It has recently been determined that there is a potential need for advanced stationary source NO_x control technology in the 1980's and 1990's to maintain NO_2 air quality. This technology is in addition to that described above as part of the original NO_x abatement strategy formulated following the 1970 Clean Air Act Amendments. The recent change in the NO_x abatement strategy has resulted from

- Relaxation of the stringent mobile source emission standard with the emphasis in NO_x control switching to stationary sources

- Projections of high stationary source NO_x emissions in the 1980's and 1990's due to
  - Projected rapid growth of stationary sources
  - Increasing stationary source use of coal and other fuels with high NO_x potential
- Emergence of advanced energy systems with potential environmental problems
- Consideration of additional NO_2 air quality standards which may necessitate additional implementation of control technology

Although the revised NO_x abatement strategy is still under development, it appears that advanced control technology beyond that currently available will be needed to maintain the current NAAQS or to attain and maintain additional NO_2-related air quality standards. Part of the NO_x E/A program will evaluate this emerging technology to identify potential environmental stresses which should be considered in the control development program. As part of this effort, a systems analysis, involving air quality modeling, will be conducted to indicate the best combination of current and emerging control techniques to maintain air quality in the 1980's and 1990's in specific Air Quality Control Regions. These results will assist in setting source/control priorities within the NO_x E/A program. They will also support control R&D groups concerned with providing a sufficient breadth of environmentally-sound control techniques to meet the diverse control implementation requirements in NO_2-critical air quality control regions. In addition, the analyses will be useful to environmental planners involved in formulating abatement strategies to meet current or projected air quality standards.

1.2 NO_x E/A SCOPE AND APPROACH

The scope of the NO_x E/A, compatible with the program requirements discussed above, encompasses the following combinations of process parameters and environmental impacts:

- Fuel combustion stationary NO_x sources: utility, industrial, commercial, and residential boilers; commercial and residential warm air furnaces; IC engines; gas turbines; industrial process combustion; advanced energy systems; and minor sources. Other sources (mobile and noncombustion) will be considered only to the extent that they are needed to determine the NO_x contribution from stationary combustion sources.
- Conventional and alternate gaseous, liquid, and solid fuels
- Combustion modification NO_x controls with potential for implementation to the year 2000; other controls (tail gas cleaning, mobile controls) will be considered only to estimate the future need for combustion modifications

- Source effluent streams potentially affected by NO_x controls
- Nonstandard operating conditions during which the emissions may be affected by NO_x controls
- Primary and secondary gaseous, liquid and solid pollutants potentially affected by NO_x controls
- Pollutant impacts on human health and terrestrial or aquatic ecology

The possible combinations of the above parameters are far too large to treat comprehensively in the program, so considerable emphasis — particularly at the program outset — is placed on screening these combinations of process parameters and potential impacts to arrive at program priorities. This screening and prioritization will allow focusing the major effort on the sources, controls, and potential impacts which are likely to be significant in the national NO_x abatement strategy. It also entails that effort in the early stages of the program will concentrate on near-term source/control needs, while emphasis will be switched later to longer range control needs to the year 2000. The comprehensive ranking of the process and impact combinations — which is the principal output of the program — will not be possible until most of the tasks in the program are complete. Throughout the effort, however, priorities will be screened on the basis of the most recent findings, which will be periodically updated and reevaluated as new data become available.

The program structure incorporating the objectives and approach described above is shown in Figure 1-1. The top half of the figure shows the effort to set preliminary source/control priorities which is covered in this report. The rectangular boxes denote specific subtasks while the oval symbols show program output. The arrows show the sequence of subtasks and the major interactions among tasks. The bottom half of the figure shows the major program effort which will be initiated subsequent to this report.

The two major program tasks are: Environmental Assessment and Process Engineering (Task B5); and Systems Analysis (Task C). Each of these tasks is designed to achieve one of the overall objectives of the NO_x E/A program cited earlier. In Task B5, the environmental, economic, and operational impacts of specific source/control combinations will be assessed. On the basis of this assessment, the incremental multimedia impacts from the use of combustion modification NO_x controls will be identified and ranked. Task C will in turn use the results of Task B5 to identify and rank the most effective source/control combinations to comply, on a local basis, with the current NO_2 air quality standards and projected NO_2-related standards. As shown in Figure 1-1, the

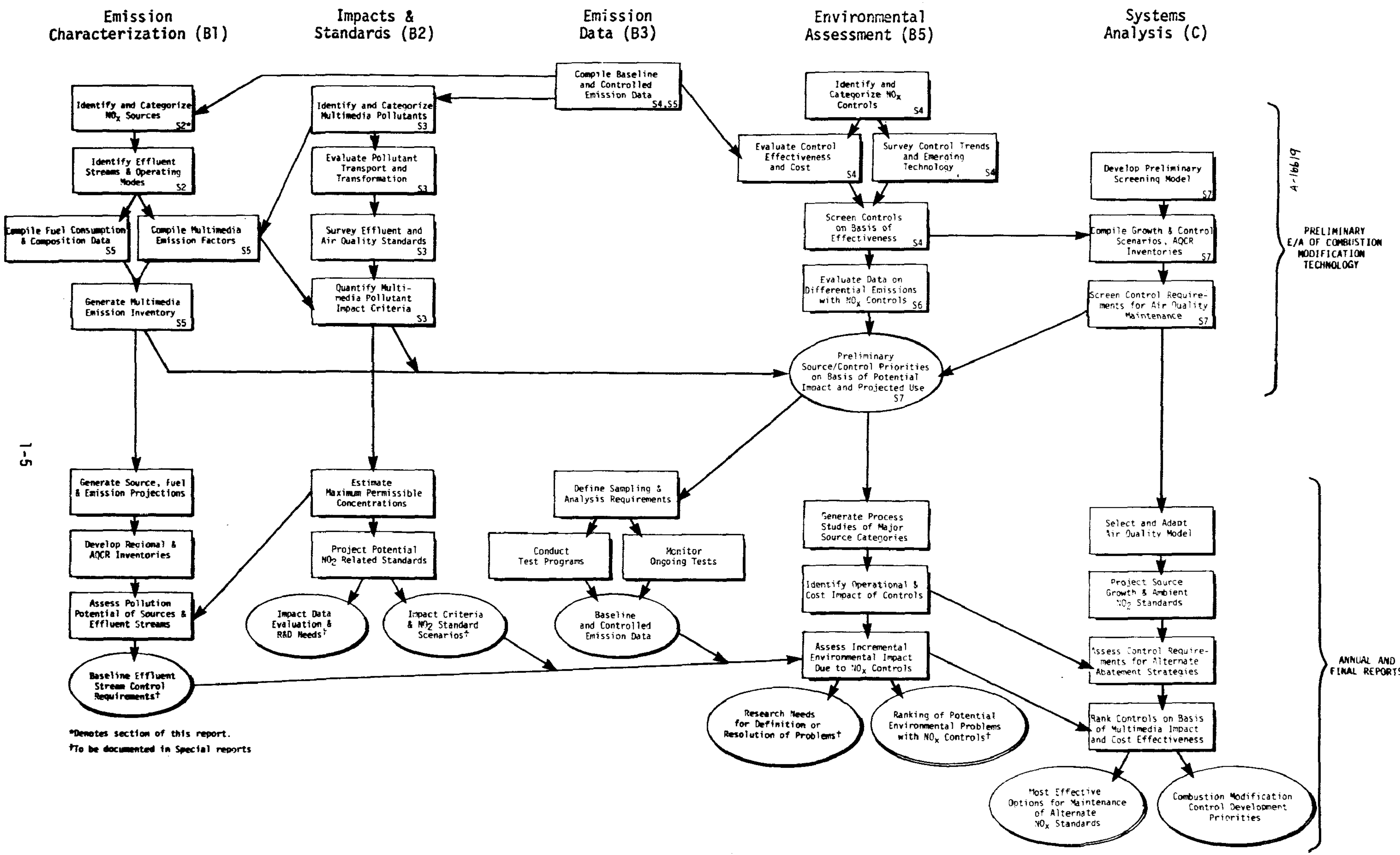

Figure 1-1. NO_x E/A approach.

key tasks supporting Tasks B5 and C are Baseline Emissions Characterization (Task B1), Evaluation of Emission Impacts and Standards (Task B2), and Emission Data (Task B3). An additional support task of this program — Identification and Characterization of Alternate Clean Fuels for Area Sources (Task B4) — has been omitted for clarity.

The initial work on this NO_x program began with the compilation of process data and multimedia emissions data for stationary NO_x sources. Both uncontrolled baseline emission data as well as data for sources using NO_x controls were compiled. Process and emission data based on test results from related programs will continue to be incorporated as they become available throughout the duration of the program.

These data were used to initiate the following preliminary characterizations and data evaluations: stationary source equipment and effluent streams, as well as baseline multimedia emissions (Task B1); multimedia primary and secondary pollutants and impacts (Task B2); and stationary source NO_x controls and incremental emissions due to control (Task B5). These characterizations and data evaluations, together with the preliminary screening of future source/control requirements (Task C), are documented in this report. This information will serve as a data base for the subsequent comprehensive process studies, as well as for refining emission inventories and impact criteria. It will also help define requirements for subsequent field test programs and assist in setting priorities for process and environmental assessment studies.

1.3 PURPOSE OF THIS REPORT

As noted above, the NO_x E/A activities documented in this report began with compiling and evaluating data and defining the program approach and priorities. This initial activity was thus a first-pass review of existing data and techniques for all areas of the program. This preliminary report will initiate these efforts and establish the approach and level of effort to be used in various subtasks. The objectives of this report are to: (1) document the scope of the NO_x E/A in terms of sources, pollutants, impacts, and controls to be considered; (2) evaluate data on impact criteria, control effectiveness, baseline multimedia emissions, and incremental impacts of NO_x controls; and (3) define preliminary priorities on source/control combinations and effluent stream/impacts to be considered. Volume II, Technical Results, contains the detailed results on each of these objectives. This summary volume focuses on the major conclusions on Objectives (2) and (3).

Specific subobjectives of the Volume II report which are summarized in the subsequent sections are as follows:

- Establish categories of stationary fuel combustion NO_x sources to be assessed in the NO_x E/A (Section 2)
- Identify source effluent streams and operating modes for which the emissions may be perturbed by the use of NO_x controls (Section 2)
- Establish a preliminary set of pollutants and their impacts to be considered in the source/control environmental assessments (Section 3)
- Compile and evaluate dose/response data on multimedia pollutant impact; tabulate impact criteria for use in preliminary screening of the impact of source/effluent stream/control combinations (Section 3)
- Identify possible approaches and problems in conducting a generalized (nonsite specific) impact assessment (Section 3)
- Survey available NO_x control techniques and specify the combustion modification technology to be addressed in the program (Section 4)
- Evaluate the status, effectiveness, cost, and operational impact of current and emerging combustion modification techniques (Section 4)
- Compile and evaluate NO_x emissions data for all NO_x sources; generate controlled nationwide NO_x inventory (Section 5)
- Compile and evaluate emission data on pollutants other than NO_x for stationary fuel combustion NO_x sources; generate nationwide emissions inventory (Section 5)
- Evaluate the effect of NO_x controls on emissions of pollutants other than NO_x (Section 6)
- Define preliminary source/control priorities based on projected control implementations requirements (Section 7)
- Define preliminary effluent stream/pollutant priorities based on potential impact resulting from the use of NO_x controls (Section 7)

SECTION 2

NO_x SOURCE CHARACTERIZATION

In the preliminary NO_x E/A effort, NO_x sources were surveyed to identify appropriate source categories and operating characteristics for consideration in the environmental assessments and process studies. This source characterization encompassed the following steps:

- Identify significant sources of NO_x; group according to formative mechanism and nature of release into the atmosphere
- Categorize stationary combustion sources according to equipment and/or fuel characteristics affecting the generation and/or control of combustion-generated pollution
- Qualify equipment fuel categories on the basis of current and projected use and design trends; develop a provisional list of equipment/fuel combinations to be carried through the subsequent emission inventories, process studies, and environmental assessments
- Identify effluent streams from stationary combustion source equipment/fuel categories which may be perturbed by the use of NO_x combustion modification controls
- Identify operating modes (transients, upsets, maintenance) for which the emissions may be perturbed by NO_x combustion modification controls

The significant sources of oxides of nitrogen emitted to the atmosphere are shown on Figure 2-1. On a global basis, natural emissions due to biological decay and lightning comprise about 90 percent of emissions. In urban areas, however, up to 90 percent of the ambient NO_x is due to manmade sources, primarily combustion effluent streams. The emphasis in the NO_x E/A will be on the fuel combustion sources bracketed at the top of the figure. The remaining sources will be considered only as required to gauge the emissions and impacts due to stationary fuel combustion.

The major stationary fuel combustion sources are further categorized on Table 2-1. This table lists the major equipment design variations and fuels which are known to affect emissions based on a survey of process characteristics and emission data. This list, together with a refined breakdown of fuel type, will be used in emission inventories and ranking of potential environmental

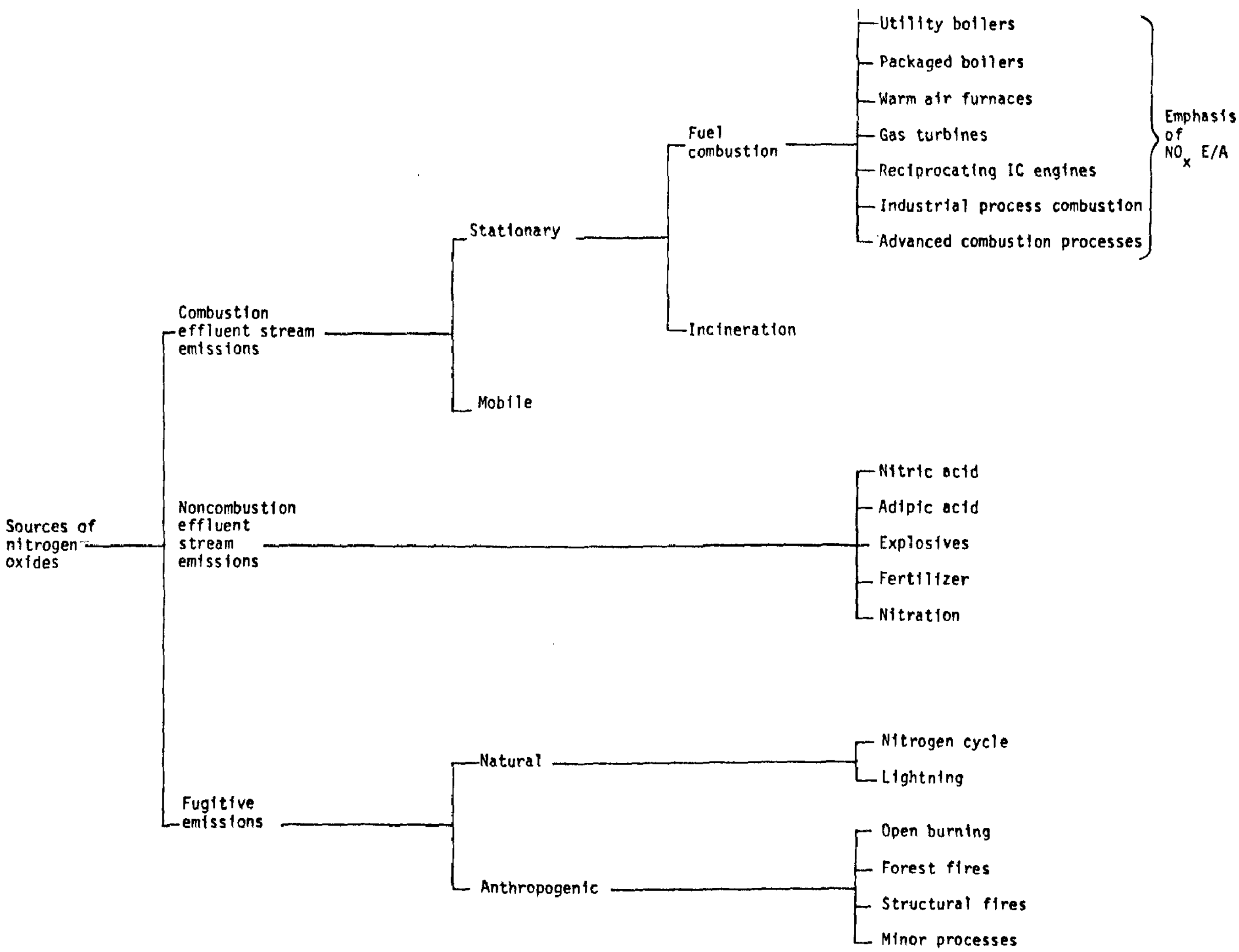

Figure 2-1. Sources of nitrogen oxide emissions.

TABLE 2-1. SIGNIFICANT STATIONARY FUEL COMBUSTION EQUIPMENT TYPES/MAJOR FUELS

	Fuel
Utility Sector (Field Erected Watertubes)	
Tangential	PC, O, G
Wall fired	PC, O, G
Horizontal opposed and Turbofurnace	PC, O, G
Cyclone	PC, O
Vertical and stoker	C
Packaged Boiler Sector	
Watertube 29 to 73 MW[a] (100M to 250 MBtu/hr)	PC, O, G, PG
Watertube <29 MW[a] (<100 MBtu/hr)	C, O, G, PG
Firetube scotch	O, G, PG
Firetube HRT	C, O, G, PG
Firetube firebox	C, O, G, PG
Cast iron	O, G
Residential	C, O, G
Warm Air Furnace Sector	
Central heaters	O, G
Space heaters	O, G
Other residential combustion	O, G
Gas Turbines	
Large >15 MW[a] (>20,000 hp)	O, G
Medium 4 to 15 MW[a] (5,000 to 20,000 hp)	O, G
Small <4 MW[a] (<5,000 hp)	O, G
Reciprocating IC Engines	
Large bore >75 kW/cyl[a] (>100 hp/cyl)	O, G
Medium 75 kW to 75 kW/cyl[a] (100 hp to 100 hp/cyl)	O, G
Small <75 kW[a] (<100 hp)	O, G

TABLE 2-1. Concluded

Industrial Process Heating
- Glass melters
- Glass annealing lehrs
- Cement kilns
- Petroleum
  - Catalytic crackers
  - Process heaters
- Brick and ceramic kilns
- Iron and steel coke oven
  - Underfire
- Iron and steel sintering machines
- Iron and steel soaking pits and reheat ovens

PC	— Pulverized coal
C	— Stoker coal or other coal
O	— Oil
G	— Gas
PG	— Process gas

[a]Heat input

impacts from combustion sources. These equipment/fuel categories will also be used as subdivisions of the process studies and for consideration in the field test program. Additionally, other factors affecting emissions such as burner design and volumetric heat release rate will also be considered in the process studies.

The equipment/fuel categories on Table 2-1 were surveyed with respect to design trends and operating characteristics which would affect their treatment within the NO_x E/A. Table 2-2 summarizes the major results. The primary design types listed are those which, on the basis of design trends, are projected to be in widespread use in the 1980's. They are thus candidates for application of NO_x controls and will be considered for detailed treatment in the NO_x E/A as further discussed in Section 7. The secondary design types listed are those which are either diminishing in use, or projected primarily for long-term application or otherwise unlikely to see widespread use of NO_x controls in the near term. These design types will be carried through the emissions inventories and assessment of pollution potential but will generally be accorded less emphasis in the process studies and field test programs. The listings of effluent streams and significant operating modes on Table 2-2 are for the most general operating conditions for a given sector and may not apply to all design/fuel combinations. The effluent streams identified on Table 2-2 were generally carried through the emission inventories for later use in ranking pollution potential from specific effluent streams. The data on the frequency and specific process conditions of nonstandard operating modes were very sparse, however. In general, nonstandard operating modes were not considered further in the preliminary assessment due to the lack of data.

TABLE 2-2. SUMMARY OF SOURCE CHARACTERIZATION

T-249a

Sector	Primary Design Types in NO_x E/A	Secondary Design Types in NO_x E/A	Effluent Streams	Significant Operating Modes	Trends
Utility boilers	Tangential, wall fired, horizontally opposed, turbo	Cyclone, vertical, stoker	Stack gas, ESP catch, bottom and superheater hopper ash, scrubber streams, ash sluicing streams	Sootblowing, on-off transients, load transients, upsets, combustion additives	Coal firing in new units; conversion to oil and coal in existing units; no new wet bottom, cyclones, stoker or vertical units
Packaged boilers	Watertubes, scotch firetube	HRT firetube, firebox firetube, cast iron and residential	Stack gas, particulate catch, hopper ash	As above	Pulverized coal and stokers in large watertubes; heavy oil and stokers in smaller watertubes; heavy oil in firetubes decreasing use of HRT and firebox firetubes
Warm air furnaces	Commercial and residential central warm air furnaces	Space heaters, other residential combustion	Flue gas	On-off cycling transient	Oil firing in new units; trend to high efficiency in new units
Gas turbines	Utility and industrial simple and regenerative cycles	Combined cycles, repowering	Flue gas	On-off transient, load following, idling at spinning reserve	Trend to higher turbine inlet temperature, larger capacity and oil firing in new units; rapid growth projected
Reciprocating IC engines	Turbocharged, naturally aspirated	Blower scavenged	Flue gas	On-off transients idling	Low growth rate of diesel units
Industrial process combustion		Process heaters, furnaces, kilns	Flue gas, particulate catch, hopper ash	Charging operations, upsets, starting transients	Increasing use of coal in kilns; some use of synthetic gases from coal

SECTION 3

POLLUTANT CHARACTERIZATION

The multimedia pollutant characterization involved the following tasks:

- Compile a list of potential pollutant species in gaseous, liquid and solid effluent streams under standard and nonstandard operating conditions; identify potential secondary pollutants from these primary pollutants
- Survey research methodology for pollutant effects on human health and terrestrial and aquatic ecology; evaluate the relevance of these methods to the NO_x E/A impact assessments
- Generate estimates of ambient pollutant concentration limits for use in screening potential impacts

These results will be used in Section 7 to assist in prioritizing effluent stream/pollutant combinations according to impact potential. Subsequently, this preliminary characterization will be expanded for use in the environmental assessments of NO_x controls.

The compilation of potential combustion-generated pollutants was categorized as follows:

- Inorganic and organic nitrogen compounds
- Inorganic and organic sulfur compounds
- Hydrocarbons
  - Alkanes
  - Alkenes
  - Alkynes
  - Oxygenated HC
  - Aromatic HC
- Trace elements

Emissions data were available for only a very few of the several hundred possible species included in the above categories. Where data were unavailable, it was generally not possible to determine which species in a class of compounds was most likely to be formed in combustion. In these cases the total class of compounds was provisionally included in the list of potential pollutants. Generally, inclusion of nonstandard operating conditions, e.g., process upsets, added a large number of potential pollutants to the list of candidates. These added pollutants were mainly those that are suspected of being emitted only under overall reducing conditions. A large number of possible secondary pollutants were identified which could be formed from the potential primary pollutants. In general, the potential for formation of secondary pollutants is highly dependent on the local composition of the atmosphere and is thus site specific.

The emphasis in the compilation of pollutant impact criteria was placed on gaseous stream pollutants which affect human health through inhalation. One reason for this emphasis is that the vast majority of combustion-generated pollutants which may be impacted by combustion modification NO_x controls are present in gaseous effluent streams. Another reason is that it is easier to identify and quantify the impacts of inhaled gaseous pollutants on human health than those of other kinds of pollutants or receptors. Additionally, the effect of inhaled pollutants is more readily generalized without regard to site-specific impact factors such as regional flora or fauna and regional food chain vectors. A survey of research methods and data for pollutant effects on human health showed there is no satisfactory current technique to quantify a maximum ground level pollutant concentration where health effects become significant. Of the available methods for estimating impact criteria, the use of occupational threshold limit values (TLV's) and lethal doses (LD50's) from animal toxicologic work appears to be the most useful for screening pollutants on the basis of potential impact. A method of relating TLV's and LD50's to ambient screening concentrations has been developed by the Research Triangle Institute for the EPA. This method was used for the list of candidate pollutants discussed previously. These results were subsequently used to screen the pollution potential of source/effluent stream combinations. It should be mentioned, however, that there are a number of limitations and qualifications in using this approach in impact assessment. These are discussed in the Volume II report.

The survey of research methods and data for pollutants effects on terrestrial and aquatic ecology showed that the use of a generalized impact criteria is far more limited than was the case for human health impacts. Most pollutant impacts on the biota are site specific in that they depend on the nature of the local terrestrial and aquatic ecosystems. Few tests have evaluated interactive impacts of associated pollutants in effluent streams or of secondary pollutants.

Additionally, criteria as to what constitutes unacceptable impact to terrestrial or aquatic ecosystems are less well defined than for human health. Because of these and other problems, the use of generalized biota impact criteria is limited in utility. The current effort gives only a very preliminary "worst case" estimate of maximum concentration limits. These limits will be further refined in preparing the special NO_x E/A report on pollutant impacts and standards.

SECTION 4

NO_x CONTROL CHARACTERIZATION

The NO_x control characterization effort in the NO_x E/A preliminary assessment was conducted to identify the source/control combinations most likely to see significant use in the near term. These results were used in Section 7 to determine the source/control priorities for the process studies on near-term control applications. The control characterization also projects the effectiveness, cost and schedule of advanced emerging control techniques. This information was used in Section 7 together with air quality models to arrive at source/control priorities for far-term application. The control characterization encompassed the following steps:

- Survey stationary source NO_x regulatory programs to show current and impending source control requirements
- Evaluate effectiveness, efficiency, cost, and operational impacts or current control technology for each major equipment category
- Identify developmental status and projected uses of emerging control technology
- Specify relative emphasis to be given to specific controls in the subsequent process studies

The survey of stationary source NO_x control regulations for new and existing sources shows that there is impending widespread application of moderate levels of combustion modification controls. Table 4-1 lists current or planned emission standards via the federal Standards of Performance for New Stationary Sources. Here, as with state or local standards for existing sources, the trend is toward regulation of smaller sources and more stringent regulations for larger sources. Utility boilers are by far the most extensively regulated source. The majority of remaining control applications are for utility size gas turbines. A few areas have regulated industrial boilers and reciprocating IC engines, but these standards are not always rigidly enforced. NO_x standards for industrial process furnaces and residential heating systems are rare and nonexistent respectively.

The results of the characterization of current and emerging control technology for the major equipment categories are summarized on Table 4-2. These results show that current technology is

TABLE 4-1. CURRENT OR PLANNED FEDERAL STANDARDS OF PERFORMANCE FOR NEW STATIONARY SOURCES

T-213a

Source	Status	Standard	Reference
Steam generators; heat input >73 MW (250 MBtu/hr)			
Gaseous fossil fuel-fired	Promulgated 12-23-71	86 ng/J (0.2 lb/10^6 Btu)	36 FR 24877
Liquid fossil fuel-fired	Promulgated 12-23-71	130 ng/J (0.3 lb/10^6 Btu)	36 FR 24877
Solid fossil fuel-fired (except lignite)	Promulgated 12-23-71	300 ng/J (0.7 lb/10^6 Btu)	36 FR 24877
Mixed fossil fuel-fired	Promulgated 12-23-71	$\frac{86X + 130Y + 300Z^{a}}{X + Y + Z}$ ng/J	36 FR 24877
Lignite coal-fired	Proposed 12-22-76	260 ng/J (0.6 lb/10^6 Btu)	41 FR 55792
Wood residue-fired	Amended 11-22-76	Add wood residue to permissible mixed fuel firing standard	41 FR 51397
Coal-fired (except lignite)	SSEIS[b] under review	260 ng/J (0.6 lb/10^6 Btu)	
Gas turbines; heat input >10.7 GJ/hr (10.2 MBtu/hr)	Proposed 10/3/77	75 ppm (15 percent O_2)	42 FR 53782
Stationary IC engines	SSEIS under review		
Intermediate size steam generators	Under study		

[a]X, Y, and Z are the percent of total heat input derived from gaseous, liquid and solid fossil fuels

[b]Standards Support and Environmental Impact Statement

TABLE 4-2. SUMMARY OF NO_x CONTROL TECHNOLOGY

T-155a

Equipment/ Fuel Category	Current Technology				Emerging Technology		Comments
	Available Control Technique	Achievable NO_x Emission Level ng/J ($lb/10^6$ Btu)	Estimated Differential Annual Cost	Operational Impact	Near Term 1977-1982	Far Term 1983-2000	
Existing coal-fired utility boilers	LEA + OSC (OFA, BOOS, BBF); new burners	260-300 (0.6 - 0.7)	20-30¢/kW	Possible increase in corrosion & slagging & carbon in flyash	Advanced low NO_x burners	Ammonia injection; flue gas treatment	Ammonia injection, FGT potential supplement to CM if needed
New coal-fired utility boilers	LEA + OFA; new burners	215-260 (0.5 - 0.6)	10-20¢/kW	No major problem with tangential design; other designs now coming online	Low NO_x burners advanced staging concepts	Optimized burner firebox design; fluidized bed combustion; ammonia injection	Same as above
Existing oil-fired utility boilers	LEA + OSC + FGR; load reduction	110-150 (0.25 - 0.35)	$1-2/kW	Possible flame instability; boiler vibration	Low NO_x burners; oil denitrification	Ammonia injection; flue gas treatment	No new units; emission levels are limit of current technology
Existing gas-fired utility boilers	LEA + OSC + FGR; load reduction	65-85 (0.15 - 0.2)	$1-2/kW	Possible flame instability; boiler vibration	Low NO_x burner	Ammonia injection; flue gas treatment	No new units; emission levels are limit of current technology
Oil-fired industrial watertube boilers	LEA + OSC (OFA, BOOS, BBF)	85-130 (0.2 - 0.3)	1.4-1.8¢/(kg/hr)a	~1% increase in fuel consumption; flame instability; boiler vibration (retrofit)	Low NO_x burners; OFA in new unit designs; oil denitrification	Optimized burner/firebox design; ammonia injection	Current technology still being developed

(Continued on page 4-4)

TABLE 4-2. Continued

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Equipment/ Fuel Category	Current Technology				Emerging Technology		Comments
	Available Control Technique	Achievable NO_x Emission Level ng/J ($lb/10^6$ Btu)	Estimated Differential Annual Cost	Operational Impact	Near Term 1977-1982	Far Term 1983-2000	
Stoker-fired industrial watertube boilers	LEA + OFA	150-190 (0.35 - 0.45)	1.8-2.3¢/(kg/hr)[a]	Possible ~1% increase in fuel consumption; corrosion; slagging of grate (retrofit)	Inclusion of OFA in new unit design	Fluidized bed combustion; ammonia injection	Current technology still being developed
Gas-fired industrial watertube boilers	LEA + OSC (OFA, BOOS, BBF)	86-130 (0.2 - 0.3)	1.4-1.8¢/(kg/hr)[a]	~1% increase in fuel consumption; flame instability; boiler vibration (retrofit)	Low NO_x burners; OFA in new unit design	Optimized burner/firebox design; ammonia injection	Current technology still undergoing development
Industrial firetube boilers	LEA + FGR; LEA + OSC	65-110 (0.15 - 0.25)	7-14¢/(kg/hr)[a]	~1% increase in fuel consumption; flame instability (retrofit)	Low NO_x burners; OFA or FGR in new unit design	Optimized burner/firebox design	Development continuing on current technology
Gas turbines	Water, steam injection	110-150 (0.25 - 0.35)	$1-2/kW	~1% increase in fuel consumption; affects only thermal	Advanced combustor designs for dry NO_x controls	Catalytic combustion; advanced can designs	Current technology widely used

(Continued on page 4-5)

TABLE 4-2. Concluded

Equipment/ Fuel Category	Current Technology				Emerging Technology		Comments
	Available Control Technique	Achievable NO_x Emission Level ng/J ($lb/10^6$ Btu)	Estimated Differential Annual Cost	Operational Impact	Near Term 1977-1982	Far Term 1983-2000	
Residential furnaces	Low NO_x burner/ firebox design (oil)	25-40 (0.06 - 0.1)	\$0.14-0.29/ kW (\$40-80/(MBtu/ hr))	~5% decrease in fuel consumption	Advanced burner/firebox design (gas & oil)	Catalytic combustion	Current technology still being tested
IC engines	Fine tuning; changing A/F	1,070-1,290 (2.5 - 3.0)	\$0.70-2.00/kW (\$0.5-1.5/ BHP)	5-10% increase in fuel consumption; misfiring; poor load response	Include moderate control in new unit design	Advanced head designs	Technology still being tested
Industrial process furnaces	LEA	85-210 (0.2 - 0.5)	Unknown	Unknown	Low NO_x burners; development of external controls (FGR, OSC) on retrofit basis	Possible inclusion in new unit design	Control development in preliminary stages

[a]kg/hr steam produced

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dominated by combustion process modification. Emerging technology is also centered around combustion modifications. Other approaches, such as flue gas treatment, may be used in the 1980's to augment combustion modification if required by stringent emission standards.

The level of combustion modification control available for a given source depends on the importance of that source in the regulatory program discussed above. Utility boilers have been the most extensively regulated and accordingly, the technology is the most advanced. Available technology ranges from operational adjustments such as low excess air and biased burner firing to inclusion of overfire air ports or low-NO_x burners in new units. Some adverse operational impacts have been experienced with use of combustion modifications on existing equipment. In general, these problems have been solved through combustion engineering or by limiting the degree of control application. With factory-installed controls on new equipment, operational problems have been minimal.

The technology for other sources is less well developed. Effective control techniques for utility boilers are being demonstrated on existing industrial boilers. Here, as for utility boilers, the emphasis in emerging technology is on developing controls applicable to new unit design. Advanced low-NO_x burners and/or advanced off-stoichiometric combustion techniques are the most promising concepts. This holds true for the other source categories as well. The R&D emphasis for gas turbines, warm air furnaces, and reciprocating IC engines is on developing optimized combustion chamber designs matched to the burner or fuel/air delivery system. Control development for the diverse types of industrial process equipment is in a preliminary stage. To date, only minor operational adjustments have been tried.

Table 4-3 summarizes the status and effectiveness of general control techniques. As noted above, a number of techniques are applicable for operational adjustments and hardware modifications to either new or existing units. The trend, however, is toward new burners or off-stoichiometric combustion combined with low excess air. This approach yields a higher degree of control, is more cost effective and minimizes adverse operational impacts.

The final column on Table 4-3 evaluates controls with respect to their treatment in the NO_x E/A. This evaluation is discussed further in Section 7 where priorities are set on near- and far-term source/control applications. This evaluation is also used to scope the assessment of incremental emissions due to NO_x controls discussed in Section 6.

TABLE 4-3. OVERALL EVALUATION OF NO_x CONTROL TECHNIQUES

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Control Technique	Existing Applications	Effectiveness	Operational Impact	Projected Applications	Control Evaluation for NO_x E/A Effort
Low excess air (LEA)	Retrofit and new utility boilers; some use in industrial boilers	10% to 30% for thermal and fuel NO_x	Increase in efficiency; amount limited by smoke or CO at very low EA	Widespread use for efficiency increase; incorporate into advanced designs all sources	Primary emphasis near-term and far-term applications (all sources); combined with OSC & burner mods for far-term appl.
Flue gas recirculation (FGR)	Retrofit use on many gas- and oil-fired utility boilers; demonstrated on industrial boilers	20% to 50% for thermal NO_x; no effect on fuel NO_x	Possible flame instability; increased vibration	Possible use in new industrial boiler designs	Primary emphasis near-term applications large boilers; possible far-term industrial boiler application
Off stoichiometric combustion (OSC) incl. OFA, BOOS, BBF	New and retrofit use on many utility boilers; demonstrated on industrial boilers	20% to 50% for thermal and fuel NO_x	No major impact with new design; potential for flame instability, efficiency decrease, increased corrosion (coal-fired) with retrofit	Widespread use in large boilers; incorporate into advanced designs	Primary emphasis near-term and far-term applications all sources
Load reduction	Some retrofit use on gas and oil utility boilers; enlarged fireboxes on new coal units	0% to 40% for thermal NO_x	Decrease in efficiency and power output; limited by spare capacity and smoke formation	Enlarged fireboxes used in new unit design; limited use for retrofit	Secondary emphasis near-term applications (boilers); combined with OSC or burner mods for far-term appl.
Burner modifications	New and retrofit use on utility boilers; demonstrated on residential furnaces	30% to 60% for thermal and fuel NO_x	No major impact with new design; retrofit use constrained by firebox characteristics	Incorporate into advanced designs utility, industrial boilers, residential, process furnaces, GT; combine with OSC	Primary emphasis near- and far-term applications all sources

(Continued on page 4-8)

TABLE 4-3. Continued

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Control Technique	Existing Applications	Effectiveness	Operational Impact	Projected Applications	Control Evaluation for NO_x E/A Effort
Water, steam injection	Widely used for gas turbines	30% to 70% for thermal NO_x	Slight decrease in efficiency; limited by CO formation; power output increases	Use in new gas turbines; possible use in process furnaces	Primary emphasis near-term applications, gas turbines; possible far-term industrial process application
Reduced air preheat (RAP)	Widespread use in large turbocharged IC engines	10% to 40% for thermal NO_x	Slight decrease in efficiency, increase power output	Continued use in IC engines	Secondary emphasis
Ammonia injection	Demonstrated on oil- and gas-fired industrial boilers	40% to 70% for thermal and fuel NO_x	Retrofit use limited; possible adverse environmental impact	Use in large boilers in some areas (1980's)	Primary emphasis far-term application to large boilers; evaluate impact with coal firing
Fuel denitrification	Oil denitrification accompanies desulfurization for some large boilers	10% to 40% for fuel NO_x	No adverse effects	Use of oil denitrification in large boilers as supplement to CM tech.	Secondary emphasis; evaluate as alternate fuel
Fuel additives	Fuel additives for NO_x not used	Generally ineffective for direct NO_x reduction	Byproduct emissions formed	Additives for corrosion, fouling, particulate, smoke, etc. can provide increased flexibility with CM tech. on large boilers	Secondary emphasis; consider impact of additives
Alternate and mixed fuels	Combustion of low nitrogen alternate fuels being demonstrated	Varies	Varies	Combined cycles and residential and commercial heating systems	Secondary emphasis far-term application; evaluate differential impact of fuel switching; transfer results of other E/A's .

(Continued on page 4-9)

TABLE 4-3. Concluded

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Control Technique	Existing Applications	Effectiveness	Operational Impact	Projected Applications	Control Evaluation for NO_x E/A Effort
Catalytic combustion	Only tested in experimental combustors	>90% for thermal NO_x	Requires clean fuel; combustors limited by catalyst bed temp. capability	Gas turbines and residential and commercial heating systems	Primary emphasis far-term applications; compare impact to burner mods, alternate fuels
Fluidized bed combustion	Tested in pilot/prototype combustors	20% to 50% for fuel NO_x (pressurized FBC)	Requires sulfur acceptor	Combined cycle, utility boilers, industrial boilers (1980's)	Transfer results from FBC E/A; compare impact to combustion modifications, conventional combustion
Flue gas treatment (FGT)	Used in Japan on large boilers	40% to >90% for fuel and thermal NO_x	Requires temp. controls, catalyst, scrubbing soln., or oxidizing agent; possible adverse environmental impact	Possible supplement to CM for utility and large industrial boilers (1980's)	Secondary emphasis; transfer results of other studies to compare impact to combustion mods

SECTION 5

MULTIMEDIA EMISSION INVENTORY OF NO_x SOURCES

A multimedia emission inventory was generated for the stationary fuel combustion source/fuel combinations discussed in Section 2. The inventory for NO_x emissions was extended to include all other sources of NO_x (mobile, noncombustion, fugitive) in order to compare the contribution from stationary combustion sources. The NO_x inventory accounts for the degree of control applied to new and existing utility boilers. Multimedia pollutants inventoried include the primary criteria pollutants (NO_x, SO_x, CO, HC, particulates), sulfates, polycyclic organic matter (POM), trace metals, and liquid or solid effluent streams. Insufficient data were available to quantify emissions for other potential pollutants. The inventory is confined to steady-state standard operation since emission data during nonstandard operation (on-off transients, upsets, soot blowing) were generally not available.

This inventory will serve as the base for assessing potential pollution problems in the absence of NO_x controls and for weighing the incremental emission impact due to the use of NO_x controls. The inventory will also be used as the reference for the subsequent projections to the year 2000 in fuel and equipment use and stationary source emissions. Data gaps identified in the emission factor compilation highlight areas where further testing is needed in the NO_x E/A or other programs.

The emission inventory was generated through the following sequence:

- Compile fuel consumption data for the categories of combustion sources specified in Section 2
  - Subdivide fuel consumption based on fuel-bound pollutant precursor composition
- Compile multimedia emission data
  - Base fuel-dependent pollutant emission factors on trace composition of fuels
  - Base combustion-dependent pollutant emission factors on unit fuel consumption for specific equipment designs
- Survey the degree to which NO_x, SO_x, particulates are controlled

- Generate emissions inventory
- Rank sources according to emission rates; compare to results of previous inventories

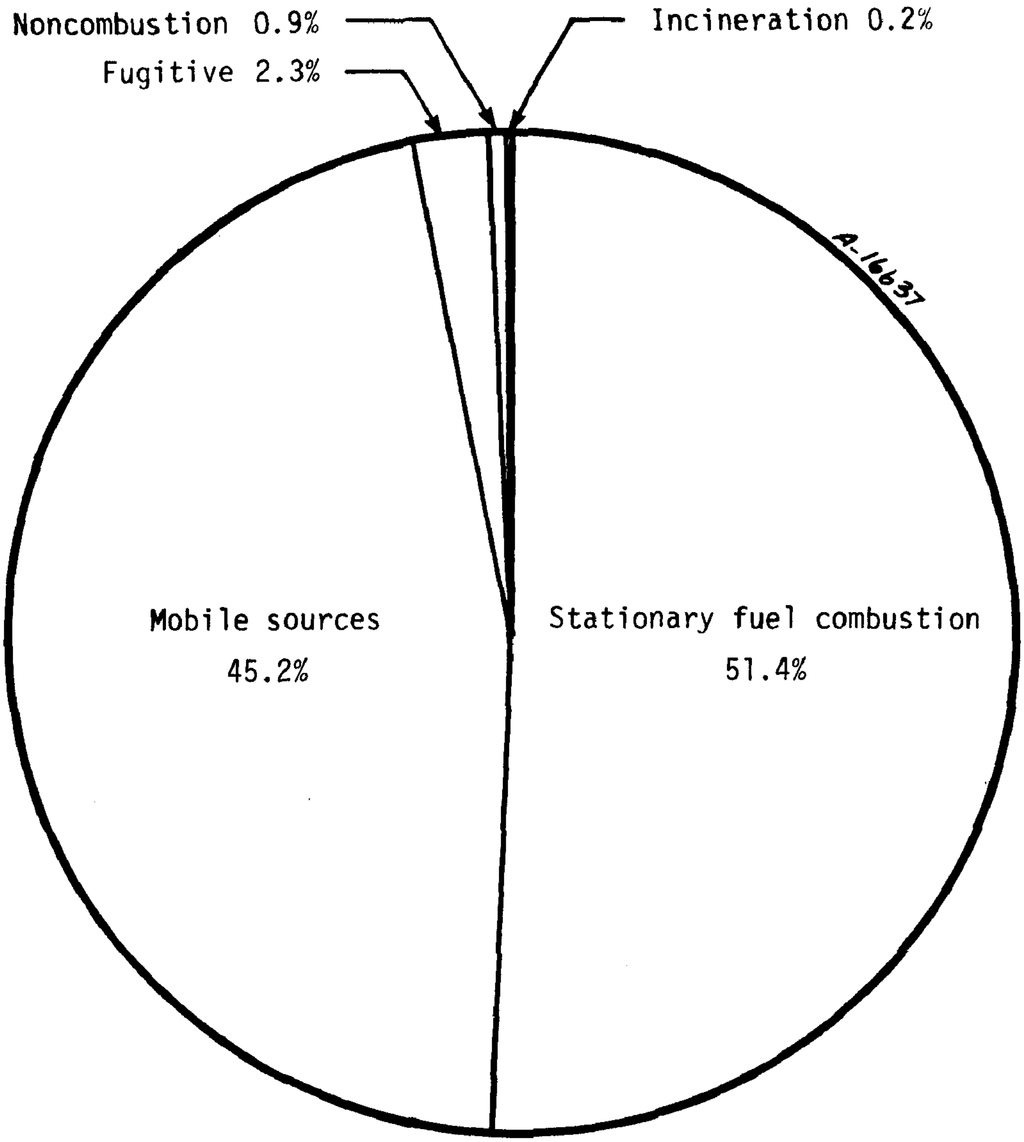
Volume II of this report gives a detailed breakdown of fuel consumption emission factors and total emissions for each equipment/fuel combination. This summary is confined to sector emission totals.

The distribution of anthropogenic NO_x emissions is shown on Figure 5-1 for 1974, the most recent year for which complete fuel consumption data were available. Stationary source emissions are further subdivided by sector in Figure 5-2 and by fuel type in Table 5-1. The utility boiler emission estimates account for the reduction resulting from the use of NO_x controls. Based on a survey of boilers in areas with NO_x emission regulations, it is estimated that application of NO_x controls in 1974 resulted in a 3.1 percent reduction in nationwide utility boiler emissions. This corresponds to a 1.6 percent reduction in stationary fuel combustion emissions. Reduction due to use of controls on other sources was negligible in 1974.

In general, the stationary source NO_x emission total and the distribution among equipment types for 1974 show little change relative to earlier inventories for the year 1972. Also, the current inventory shows generally good agreement with recent inventories done by EPA's Office of Air Quality Planning and Standards and other groups. One exception is for industrial packaged boilers. Here, recent estimates by various groups differ by as much as a factor of 2, due primarily to uncertainty in total fuel consumption for this sector.

The emission inventory results for other pollutants are shown on Table 5-2. The data quality for the criteria pollutants is regarded as good and the results of the current inventories agree reasonably with other recent inventories. The data for the noncriteria pollutants and liquid or solid effluent streams, however, were sparse and exhibited large scatter. The emission factors for POMs, for example, varied by as much as two orders of magnitude. Table 5-2 thus shows a high and low estimate for total POM emissions. There are several ongoing field test programs which are sampling noncriteria pollutants. The current inventory will be updated with these results before the impacts of these emissions are assessed.

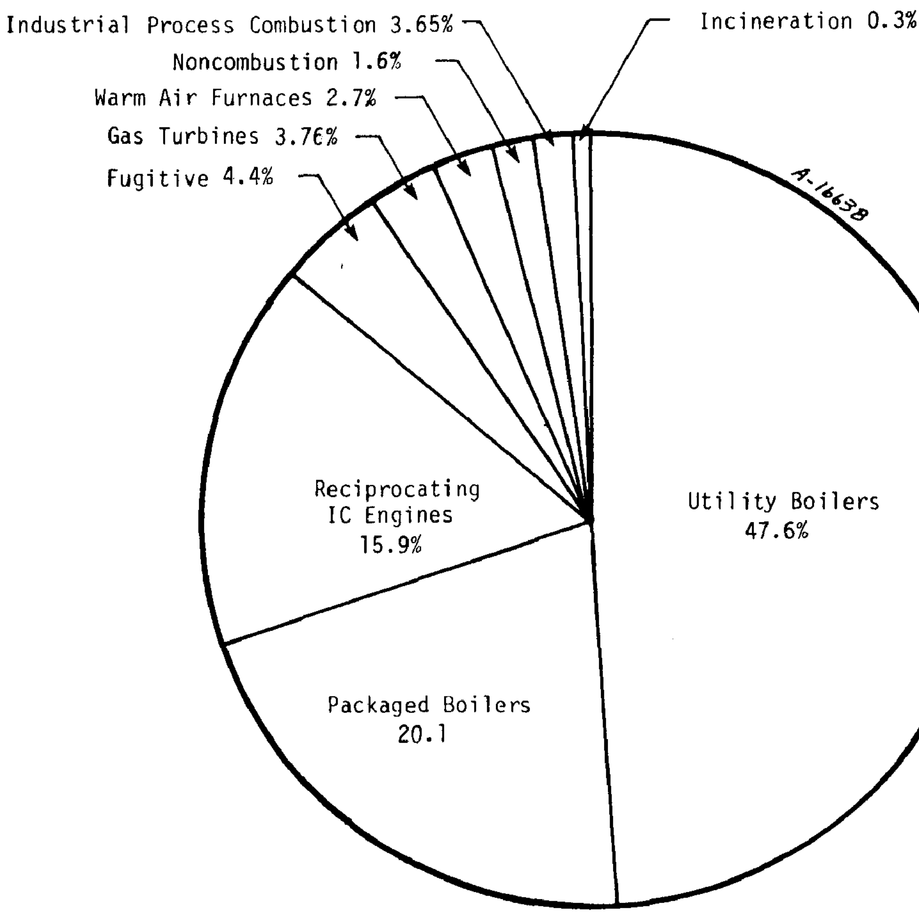
Table 5-3 ranks equipment/fuel combinations by annual nationwide NO_x emissions and lists the corresponding ranking on fuel consumption and emissions of criteria pollutants. Although there were over 70 equipment/fuel combinations inventoried, the 30 most significant account for over 90 percent of NO_x emissions. The ranking of a specific equipment/fuel type is dependent both on total installed capacity and emission factors. A high ranking, therefore, does not necessarily imply that a given



1974 Stationary Combustion Source NO_x Emissions

	1,000 Mg	1,000 tons	Percent Total
Stationary Fuel Combustion	10,954	12,070	(51.4)
Fugitive Emissions	498	548	(2.3)
Noncombustion	193	212	(0.9)
Incineration	40	44	(0.2)
Mobile Sources	9,630	10,600	(45.2)
TOTAL	21,315	23,474	100

Figure 5-1. Distribution of anthropogenic NO_x emissions for the year 1974 (stationary fuel combustion: controlled NO_x levels).



1974 Stationary Combustion Source NO_x Emissions

	1,000 Mg	1,000 Tons	Percent Total
Utility Boilers	5,566	6,122	47.6
Packaged Boilers	2,345	2,383	20.1
Warm Air Furnaces	321	353	2.7
Gas Turbines	440	484	3.76
Reciprocating IC Engines	1,857	2,040	15.9
Industrial Process Combustion	425	470	3.65
Noncombustion	193	212	1.6
Incineration	40	44	0.3
Fugitive	498	548	4.4
TOTAL	11,685	12,861	100

Figure 5-2. Distribution of stationary anthropogenic NO_x emissions for the year 1974 (stationary fuel combustion: controlled NO_x levels).

TABLE 5-1. SUMMARY OF 1974 STATIONARY SOURCE NO_x EMISSIONS BY FUEL

Sector	Coal	Oil	Gas	Total
Utility Boilers	3,564 (31.0)	848 (7.4)	1156 (10.1)	5566 (47.6)
Packaged Boilers[a]	679.7 (5.9)	886 (7.7)	779 (6.8)	2344.7 (20.1)
Warm Air Furnaces		129 (1.1)	190 (1.6)	320 (2.8)
Gas Turbines		309 (1.9)	133 (1.0)	442 (3.8)
Reciprocating IC Engines	—	456[b] (3.9)	1400 (12.2)	1856 (16.2)
Industrial Process Heating	—	—	—	425.8 (3.64)
Noncombustion	—	—	—	193 (1.7)
Incineration	—	—	—	40 (0.34)
Fugitive	—	—	—	498 (4.3)
Total	4,243.7 (37.0)	2,628 (22.1)	3,658 (31.7)	11,685

[a]Includes steam and hot water commercial and residential heating units
[b]Includes gasoline

TABLE 5-2. 1974 SUMMARY OF AIR AND SOLID POLLUTANT EMISSION FROM STATIONARY FUEL BURNING EQUIPMENT

	NO_x[b]	SO_x	HC	CO	Part	Sulfates	POM	Dry Ash Removal	Sluiced Ash Removal
Utility Boilers	5,566	16,768	29.5	270	5,965	231	0.01 – 1.2	6.18	24.78
Packaged Boilers	2,345	6,405	72.1	175	4,930	146	0.2 – 67.8	4.41	1.07
Warm Air Furnaces & Misc. Comb.	321	232	29.7	132.6	39.3	6.4	0.06	--	--
Gas Turbines	440	10.5	13.7	73.4	17.3	a	a	--	--
Recip. IC Engines	1,857	19.6	578	1,824	21.5	a	a	--	--
Process Heating	425.8	1005	166	10,039	6,216.7	a	a	--	--
TOTAL	10,954	24,440	889	12,514	17,190	382	69	--	--

[a]No emission factor available

[b]Controlled NO_x

[c]Based on 80 percent hopper and flyash removal by sluicing methods; 20 percent dry solid removal

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TABLE 5-3. NO_x MASS EMISSION RANKING OF STATIONARY COMBUSTION EQUIPMENT AND CRITERIA POLLUTANT AND FUEL USE CROSS RANKING

	Sector	Equipment Type	Fuel	Annual NO_x Emissions (Mg)	Cumulative (Mg)	Cumulative (Percent)	Fuel Rank	SO_x Rank	CO Rank	HC Rank	Part Rank
1	Utility Boilers	Tangential	Coal	1,410,000	1,410,000	13.1	1	1	7	16	2
2	Reciprocating IC Engines	>75 kW/cyl	Gas	1,262,000	2,672,000	24.8	21	>30	4	1	>30
3	Utility Boilers	Wall Firing	Coal	946,000	3,618,000	33.5	3	2	6	23	5
4	Utility Boilers	Cyclone Furnace	Coal	863,500	4,481,500	41.5	6	3	12	9	13
5	Utility Boilers	Wall Firing	Gas	738,300	5,219,800	48.4	4	>30	13	28	>30
6	Utility Boilers	Wall Firing	Oil	481,000	5,700,800	52.8	8	9	17	27	18
7	Utility Boilers	Horizontally Opposed	Gas	378,700	6,079,500	56.3	14	>30	24	>30	>30
8	Reciprocating IC Engines	75 kW to 75 kW/cyl	Oil	325,000	6,404,500	59.4	>30	>30	3	3	26
9	Packaged Boilers	Watertube >29 MW	Gas	318,500	6,723,000	62.3	16	>30	29	19	>30
10	Packaged Boilers	Watertube Stoker <29 MW	Coal	278,170	7,001,170	64.9	7	4	11	4	1
11	Utility Boilers	Horizontally Opposed	Coal	270,800	7,271,970	67.4	23	5	>30	>30	7
12	Packaged Boilers	Watertube >29 MW	Oil	232,480	7,504,450	69.5	26	16	>30	26	22
13	Utility Boilers	Tangential	Oil	208,000	7,712,450	71.5	12	10	27	>30	19
14	Packaged Boilers	Firetube Scotch	Oil	203,990	7,916,440	73.4	11	11	>30	>30	16
15	Packaged Boilers	Watertube <29 MW	Gas	180,000	8,096,440	75.0	5	>30	>30	22	>30
16	Utility Boilers	Horizontally Opposed	Oil	177,900	8,274,340	76.7	>30	17	>30	>30	27
17	Packaged Boilers	Watertube <29 MW	Coal	164,220	8,438,560	78.2	>30	8	>30	>30	9
18	Industrial Process Comb.	Forced & Natural Draft Refinery Heaters	Oil	147,350	8,585,910	79.6	>30	29	>30	18	21
19	Utility Boilers	Tangential	Gas	146,000	8,731,910	80.9	13	>30	>30	>30	>30
20	Packaged Boilers	Firetube Firebox	Oil	139,260	8.871,170	82.2	17	13	>30	>30	20

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TABLE 5-3. Concluded

Sector	Equipment Type	Fuel	Annual NO_x Emissions (Mg)	Cumulative (Mg)	Cumulative (Percent)	Fuel Rank	SO_x Rank	CO Rank	HC Rank	Part Rank
21 Packaged Boilers	Watertube Stoker	Coal	125,350	8,996,520	83.4	>30	7	28	29	8
22 Gas Turbines	4 to 15 MW	Oil	118,500	9,115,020	84.5	30	>30	15	14	>30
23 Packaged Boilers	Watertube <29 MW	Oil	116,430	9,231,450	85.6	27	15	>30	>30	23
24 Warm Air Furnaces	Central	Gas	106,300	9,337,750	86.5	2	>30	10	8	25
25 Packaged Boilers	Firetube Stoker <29 MW	Coal	102,040	9,439,790	87.5	29	6	>30	10	6
26 Packaged Boilers	Firetube Scotch	Gas	98,010	9,537,800	88.4	19	>30	>30	>30	>30
27 Gas Turbines	>15 MW	Oil	97,400	9,635,200	89.3	>30	>30	>30	30	>30
28 Reciprocating IC Engines	>75 kW/cyl	Oil	94,000	9,729,200	90.2	>30	>30	22	13	>30
29 Industrial Process Comb.	Forced & Natural Draft Refinery Heaters	Gas	92,608	9,821,808	91.0	15	>30	>30	7	30
30 Utility Boilers	Vertical and Stoker	Coal	90,900	9,912,708	91.9	>30	12	>20	>30	>10

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source is a high emitter. In general, coal-fired sources rank high in SO_x and particulate emissions while IC engines dominate the emissions of CO and hydrocarbons. The NO_x emission ranking is used in Section 7, together with estimates of potential environmental impact and projected control application, to set program priorities on source/fuel combinations.

SECTION 6

EVALUATION OF INCREMENTAL EMISSIONS DUE TO NO_x CONTROLS

This section summarizes a preliminary evaluation of the demonstrated and potential effects of combustion modification NO_x controls on incremental emissions. The results will serve to scope and guide priorities for subsequent NO_x E/A efforts in incremental emission data compilation, impact characterization, and control process studies. Attention is focused on flue gas emissions from steady-state operation of the major sources using near-term NO_x controls, since these situations are the most important in the program and are the only ones for which any significant data exist. Subsequent effort will consider liquid and solid effluents, minor sources, and alternate or advanced NO_x controls. Also, the discussion here is concerned only with estimating incremental emission rates without regard to potential impact. Ultimately, the significance of the incremental emissions depends on the baseline uncontrolled pollutant emission rates (summarized in Section 5) and the maximum acceptable ambient pollutant concentration (discussed in Section 3) as well as other factors such as pollutant transport and transformation. Preliminary screening of potential incremental impacts due to NO_x controls, considering these factors, is summarized in Section 7.

Evaluation results on the potential for incremental emissions with NO_x controls are summarized in Tables 6-1 through 6-3 for boilers, IC engines and gas turbines respectively. The control techniques and pollutants are qualitatively classified into one of the following three groups according to potential for increased emissions:

- High potential emissions impact, where the emissions data unambiguously show that applying the NO_x control results in significantly increased emissions of a specific pollutant
- Intermediate potential emissions impact, where preliminary screening of formative mechanisms indicates that the NO_x control could conceivably cause increased pollutant emissions, but confirming data are lacking, contradictory, or inconclusive
- Low potential emissions impact, where the emissions data clearly show that specific pollutant emission levels decrease when the NO_x control is applied, or where the preliminary screening definitely indicates a similar conclusion, even though data are lacking

TABLE 6-1. EVALUATION OF INCREMENTAL EMISSIONS DUE TO NO_x CONTROLS APPLIED TO BOILERS

NO_x Control	Incremental Emission						
	CO	Vapor Phase HC	Sulfate	Particulate	Organics	Segregating Trace Metals	Nonsegregating Trace Metals
Low Excess Air	++	0	+	0	++	+	0
Staged Combustion	0	0	+	+	++	+	0
Flue Gas Recirculation	0	0	+	+	+	+	+
Reduced Air Preheat	0	0	+	0	+	0	+
Reduced Load	0	0	+	0	+	0	0
Water Injection	0	0	+	+	+	0	0
Ammonia Injection	0	0	++	+	0	+	0

Key: ++ denotes having high potential emissions impact
+ denotes having intermediate potential emissions impact, data needed
0 denotes having low potential emissions impact

TABLE 6-2. EVALUATION OF INCREMENTAL EMISSIONS DUE TO NO_x CONTROLS APPLIED TO IC ENGINES

NO_x Control	Incremental Emission						
	CO	Vapor Phase HC	Sulfate	Particulate	Organics	Segregating Trace Metals	Nonsegregating Trace Metals
Retard Ignition	++	+	0	++	+	0	0
Increase A/F Ratio	0	++	++	0	0	0	0
Decrease A/F Ratio	++	++	0	+	+	+	0
Exhaust Gas Recirculation	+	+	0	++	+	+	0
Decrease Manifold Air Temperature	0	++	+	0	0	+	0
Stratified Charge Cylinder Design	+	+	0	+	+	+	0
Derate	++	++	+	0	0	+	0
Increase Speed	+	+	0	+	+	+	0
Water Injection	+	++	0	+	+	+	0

Key: ++ denotes having high potential emissions impact
+ denotes having intermediate potential emission impact, data needed
0 denotes having low potential emissions impact

TABLE 6-3. EVALUATION OF INCREMENTAL EMISSIONS DUE TO NO_x CONTROLS APPLIED TO GAS TURBINES

NO_x Control	Incremental Emission						
	CO	Vapor Phase HC	Sulfate	Particulate	Organics	Segregating Trace Metals	Nonsegregating Trace Metals
Water or Steam Injection	++	+	0	+	+	+	0
Lean Primary Zone	0	0	+	0	0	+	0
Early Quench with Secondary Air	0	0	0	+	+	+	0
Increase Mass Flowrate	+	+	0	+	+	+	0
Exhaust Gas Recirculation	+	+	0	+	+	+	0
Air Blast/Air Assist Atomization	0	+	0	+	+	+	0
Reduced Air Preheat	0	0	+	0	0	+	0
Reduced Load	++	++	+	++	+	+	0

Key: ++ denotes having high potential emissions impact
+ denotes having intermediate potential emissions impact, data needed
0 denotes having low potential emissions impact

As Table 6-1 illustrates, applying preferred NO_x combustion controls to boilers should have few adverse effects on incremental emissions of CO, vapor phase hydrocarbons or particulates. It is true that indiscriminantly lowering excess air can have drastic effects on boiler CO emissions, and that particulate emissions can increase with off-stoichiometric combustion and flue gas recirculation. However, with suitable engineering during development and implementation of these modifications, adverse incremental emissions problems can be minimized. In contrast, incremental emissions of sulfate, organics, and trace metals have intermediate to high potential impact associated with applying almost every combustion control. For trace metal and organic emissions, substantiating data are largely lacking, but fundamental formation mechanisms give cause for justifiable concern. In the case of sulfate emissions, fundamental formation mechanisms suggest that these emissions should remain unchanged or decrease with all controls except ammonia injection. However, complex interactive effects are difficult to elucidate, and this pollutant class is sufficiently hazardous to justify expressing some concern in the present absence of conclusive data. The potential effects of post-combustion ammonia injection on plume sulfate formation deserve special attention.

Table 6-2 shows that the incremental emissions of all pollutant classes except nonsegregating trace metals have either intermediate or high potential impact when applying NO_x controls to IC engines. Of primary concern are increased CO, vapor phase hydrocarbons (HC), and particulate (smoke) emissions. Of lesser concern are sulfates, organics, and segregating trace metals from engines burning high sulfur diesel fuels.

Similarly, NO_x controls applied to gas turbines can be expected to adversely affect all incremental emissions except nonsegregating trace metals, as Table 6-3 indicates. Again, increased sulfate, particulate, organic, and segregating trace metals are of some concern in those sources firing high-sulfur diesel fuels. If residual oil firing in gas turbines increases, these concerns could become more serious. Presently, this appears unlikely due to materials problems, e.g., sulfidation with residual oils.

The incremental emission evaluations of Tables 6-1 through 6-3 are not intended to signify any potential for adverse environmental impact. Rather, the evaluation notes source/control/pollutant combinations for which emissions may increase due to the use of NO_x controls. Evaluation of potential adverse impact requires comparison of the source-generated, ambient pollutant concentration with an upper limit threshold concentration of the pollutant based on health or ecological effects. This comparison will be made in detail later in the program. Prior to that, some conclusions may be drawn on the results in this section.

In general, the data on incremental multimedia emissions due to NO_x controls are very sparse. More data are available for flue gas emissions than for liquid or solid effluent streams. Even so, the only data which allow quantified conclusions are for emissions of criteria pollutants from the major source/control combinations. Data on sulfates, trace metals and organics (POM) are sparse, experimentally uncertain, and highly dependent on fuel properties. Incremental emissions from liquid and solid effluent streams and during transient or nonstandard operation are almost nonexistent. Because of this, they have generally been excluded in the present evaluation. Test data from ongoing related programs and from the NO_x E/A test programs will be needed before the incremental emissions and impacts can be evaluated for other than flue gas emissions during standard operation.

Emissions of CO, HC, particulate (smoke) and SO_3 with or without NO_x controls have been constrained in the past for operational reasons rather than environmental impact. CO, HC and smoke emissions reduce efficiency and may present a safety hazard. SO_3 leads to acid condensation and corrosion. All of these emissions are sensitive to combustion process modifications for NO_x control. With the exception of SO_3, incremental emissions tend to increase with NO_x controls, particularly low excess air and off-stoichiometric combustion. Development experience has shown, however, that with proper engineering these emissions can generally be constrained under low-NO_x conditions. This is particularly true for factory-installed controls on new equipment. In this case, the flexibility for applying NO_x controls with minimal adverse impact is greater than for retrofit on existing equipment. In light of this situation, incremental emissions of criteria pollutants are seen more as a constraining criteria to be addressed during control development than as an immutable consequence of low-NO_x firing. Moreover, the constraint on emissions for satisfactory operational performance is generally more stringent than the constraint for acceptable environmental impact. The environmental constraints will be carried through the NO_x E/A impact assessments for all potentially significant pollutants, but they will need to be supplemented by operational constraints in some cases.

The situation for other flue gas pollutants is more uncertain. There is concern that conventional combustion process modifications — low excess air, off-stoichiometric combustion, flue gas recirculation — will increase emissions of sulfates, organics and segregating trace metals from sources firing coal or residual oil. It should be noted, however, that this conclusion is based on sparse data or, lacking that, on fundamental speculation. Clearly, more data are needed. Little is known on whether these emissions can be suitably constrained to acceptable levels during control development.

With the firing of clean fuels — natural gas and distillate oil — the main noncriteria pollutant class of concern is organics. This fact will make the testing and assessments of clean fuel sources — warm air furnaces, gas turbines, IC engines — simpler than for boilers and process furnaces firing residual oil or coal. Additionally, the clean fuel sources have no liquid or solid effluent streams. These considerations do not imply a priori that gas- or distillate oil-fired equipment are more environmentally sound. Rather, the clean fuel sources can be assessed to the same level of detail as other sources for less effort.

In conclusion, there is reasonable concern that NO_x controls will increase incremental emissions of some pollutants. More data are needed to determine if incremental emissions have a significant environmental impact and to suggest corrective action if needed.

SECTION 7

ENVIRONMENTAL ASSESSMENT PRIORITIES

The NO_x E/A program priorities summarized in this section relate directly to the needs and approach discussed in the Preface and Introduction of this report. The needs to be addressed by the NO_x E/A are:

- Assess current and impending combustion modification applications to quantify environmental, economic and operational impacts
- Assess emerging advanced technology to guide control development
  - Identify potential adverse impacts which should be addressed in the control development program
  - Estimate which controls will be needed and are most effective to attain air quality goals to the year 2000

The approach used in the NO_x E/A to address these needs gives primary emphasis early in the program to assessing current and impending control applications. Assessment of advanced technology applications will proceed at a lower level of effort early in the program but will be emphasized toward the end of the program. During the program, separate process engineering/environmental assessment reports will be generated for each major equipment category. These reports will focus mainly on current technology since it is more timely from an environmental standpoint and since it has been more extensively tested. The final report will document the assessment of far-term applications and will update the earlier assessments of near-term applications.

To support this approach, preliminary priorities are needed for:

- The sequence in which the major source categories are to be assessed and the level of effort devoted to each
- The near-term source/control applications to be assessed
- The source/control combinations to be addressed in the assessment of far-term applications, e.g., those likely to see application in this century

- The effluent stream/pollutant combinations to be emphasized in the test programs and assessments

In this report the preliminary source/control screening is conducted independently of the pollutant screening. Initially the source/control combinations are screened on the basis of significant near-term or far-term application. Pollutants for the resultant source/control combinations are then screened for potential adverse impacts. The results are then combined to set program priorities.

The earlier sections of this report summarized most of the information required to determine these four priorities. This section consolidates that information and adds estimates of near- and far-term source/control requirements to attain and maintain air quality. The priorities were then set in the sequence of the above list. The criteria used are listed below; supporting sections are indicated in parentheses.

Source Priorities

- Current and projected use of specific equipment design/fuel combinations within a source category (Section 2)
- Extent of current or impending NO_x regulations for the source category (Section 4)
- Ranking of source NO_x emissions on a national basis (Section 5)
- Relative potential for adverse environmental impacts (Section 6)
- Current and projected effectiveness of the source in urban NO_x abatement (Section 7.1)

Near-Term Source/Control Priorities

- Extent of use and effectiveness of controls for the source category (Section 4)
- Near-term need for and effectiveness of specific source/control combinations in urban NO_x abatement (Section 7.1)

Far-Term Source/Control Priorities

- Trends in source use (Section 2)
- Developmental status and effectiveness of emerging technology (Section 4)
- Far-term need for specific source/control combinations in urban areas for various control strategy options (Section 7.1)

Effluent Stream/Pollutant/Impact Priorities

- Baseline uncontrolled emissions (Section 5)
- Incremental emissions due to NO_x controls (Section 6)
- Established limits on ambient pollutant concentrations (Section 3)

Where possible, these criteria were quantified. It was not attempted at this stage, however, to carry a rigorous quantification through to numerical weighting of priorities. This is because the combined effects of the general lack of data, the early stage of the program, and the general uncertainty in the national NO_x abatement strategy make such an approach unproductive. The qualitative priorities that are set will be updated and reevaluated as new data become available and results of supporting program tasks are completed.

7.1 EVALUATION OF NO_x CONTROL REQUIREMENTS

The source/control priorities within the NO_x E/A are largely dependent on the extent to which specific sources will need to be controlled in this century to meet NO_2 air quality standards. To aid in setting these priorities, a preliminary screening model was developed to relate ambient air quality to several scenarios on source growth, control implementation and regulatory policy. The key features of the preliminary screening analysis are as follows:

- Use of the Modified Rollback Model (MRM) with provisions for variable source weighting factors
- Consideration of the Los Angeles AQCR (mobile dominated) and the Chicago AQCR (stationary dominated)
- Use of NEDS AQCR emission inventories, with some modifications, together with projections of fuel and equipment use and emissions to the year 2000; development of alternate growth scenarios based on high and low mobile/stationary growth
- Consideration of alternate base year (1972) NO_2 ambient concentrations in the MRM to account for discrepancies in air quality data
- Use of NO_x control effectiveness, cost and projected availability based on the controls characterization summarized in Section 4

This preliminary screening model was used only for the present purposes of setting priorities. Subsequently in the program, a more refined air quality model accounting for source dispersion and NO_2-oxidant chemistry will be used.

The results of the preliminary screening analysis for the Los Angeles AQCR are shown on Table 7-1. Here, the nominal growth case assumes moderate growth for stationary and mobile sources and use of a 0.62-g NO_2/km (1-g/mile) mobile source emission standard beyond 1980. The low mobile case assumes use of the statutory mobile source standard, 0.25 g NO_2/km (0.4 g/mile) beyond 1981. Two values of the base year ambient NO_2 concentrations were used: 132 $\mu g/m^3$ and 160 $\mu g/m^3$. These values represent the lower and upper limits of reported maximum annual averages from various monitoring stations and for several different four-quarter averaging periods. The source weighting factors for power plants (PP) and mobile sources (M) were varied to show the sensitivity of the results to assumptions on dispersion of NO_x from tall stacks relative to ground level sources.

The results on Table 7-1 are presented in terms of control requirements in 1985 and 2000. The control groups cited on the table refer to the ranking shown on Table 7-2. Here the control techniques are ranked on the basis of cost effectiveness in improving air quality. The negative costs indicate a net cost savings due to improvements in fuel consumption efficiency. The most obvious conclusion from Table 7-1 is that the control level required is dominated by the assumptions on mobile source emissions. This is not really surprising since mobile sources accounted for 66 percent of the NO_x emissions in 1973. In the low mobile case the combination of low growth (1 percent per year) and stringent controls (0.25 g/km in 1981) results in a 63-percent reduction in mobile emissions in 1985 and a 66-percent reduction in 2000. This more than offsets the growth in stationary sources and results in a net reduction in total emissions of 36 percent and 38 percent, respectively. This level of reduction is enough to achieve the ambient standard except in the 160 $\mu g/m^3$ base year case. Even in the nominal mobile case, a slight increase in the weighting of the mobile sources has significant impact in 1985.

In contrast to the low mobile cases, maximum control is needed for <u>all</u> other cases in 2000, and also for the high base year ambient concentration case in the near term (1985). Both of these are again consequences of the dominance of the mobile sources — control of the stationary sources cannot yield sufficient emission reduction to offset growth and the large mobile source emissions contribution.

These results strongly suggest that all possible stationary source control methods may need to be developed. According to the results discussed above, which admittedly are based only on NO_2 ambient goals, a less vigorous approach could be justified only if <u>all</u> of the most favorable assumptions were valid (i.e., low base year concentration, low mobile growth, strict and effective mobile control, and validity of the higher mobile weighting assumption). It is unreasonable to expect that all of this will happen and imprudent to plan control development on such an assumption. For the

TABLE 7-1. SUMMARY OF CONTROL LEVELS REQUIRED TO MEET NO_2 STANDARD IN LOS ANGELES, AQCR 024

Case	BYR = 132 μg/m³		BYR = 160 μg/m³	
	PP = 1.0 MS = 1.0	PP = 0.7 MS = 1.2	PP = 1.0 MS = 1.0	PP = 0.7 MS = 1.2
Nominal Growth	1 / 3	0 / 3	3 / V	3 / V
Low Mobile	0 / 0	0 / 0	2 / 2	0 / 0
High Stationary	2 / V	0 / 3	3 / V	V / V

1985 / 2000

0 — No additional control required
1 — Controls from Group I
2 — Controls from Groups I and II
3 — Controls from Groups I, II, and III
V — Violation of NAAQS, insufficient controls to meet ambient standard

PP — Power plant weighting factor
MS — Mobile source weighting factor
BYR — Base year ambient concentration for calibration

TABLE 7-2. CONTROL PRIORITIZATION FOR LOS ANGELES (2000, EQUAL SOURCE WEIGHTING)

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	Rank	Source/Control	Cost Per Unit Change in Air Quality $10^6\$/(\mu g/m^3)$	% Red/Unit
I	1	RES. FURN NEW BURNER	-15.4	40
	2	SM COMM FURN NEW D.	-14.6	40
	3	IND (WTB) LEA	-13.9	7
	4	SM COMM FURN A.D. #1	-12.7	60
	5	COMM/INST FURN A.D. #2	-13.3	80
	6	RES. FURN A.D. #1	-11.4	60
	7	RES. FURN A.D. #2	-11.3	80
	8	IND (FTB) LEA	- 3.67	17
II	9	SM PP LEA+OSC	1.57	45
	10	IC ENGINES ADJ A/F	2.18	30
	11	[a]MED PP TO 250 PPM	2.43	16
	12	IC ENG.-NEW ADJ A/F	2.48	11
	13	IC ENG.-NEW A.D.	0.305	51
	14	[a]LA PP TO 250 PPM	2.50	16
	15	SM PP LEA+OSC+FGR	2.74	58
	16	IC ENGINE-EGR	4.10	20
	17	[a]CCGT-NEW-H20 INJ	4.13	30
	18	CCGT-NEW A.D. #1	3.38	50
	19	CCGT-NEW A.D. #2	3.94	75
	20	IND (WTB) LEA+OSC	5.00	17
	21	IND (FTB) LEA+FGR	6.57	40
III	22	LA PP C.M.+NH3 INJ	6.74	79
	23	MED PP C.M.+NH3 INJ	7.59	79
	24	SM PP C.M.+NH3 INJ	8.25	79
	25	IND (WTB) C.M.+NH3	13.4	42

[a]Required to meet present legislated emission levels.

A.D. — Advanced design
C.M. — Combustion modifications (LEA, OSC, FGR)
COMM — Commercial
CCGT — Combined cycle gas turbine
EGR — Exhaust gas recirculation
FGR — Flue gas recirculation
FTB — Firetube boiler
FURN — Furnace
H20 INJ — Water injection
I, IND — Industrial
INST — Institutional
LA — Large
LEA — Low excess air
MED — Medium
OSC — Off-stoichiometric combustion
PP — Power plant
RES — Residential
SM — Small
WTB — Watertube boiler

short term, the current combustion modification control technology might be sufficient if a favorable mobile situation exists. For the longer term, however, all the advanced control methods presently considered should be pursued, including ammonia injection, and research on even more effective methods seems justified.

The results for Chicago are shown in Table 7-3. The corresponding control ranking is given on Table 7-4. Control of stationary sources is required in all cases except for 1985 if the base year (1973) concentration of 96 $\mu g/m^3$ is appropriate. The principal reason for this (no control in 1985) is that the reduction in mobile source emissions* counterbalances the growth in stationary sources. For example, in the nominal growth case, mobile source emissions in 1985 are 123 Gg below their 1973 level; whereas, stationary sources have increased by only 112 Gg. In the high stationary growth case, however, an increase of 154 Gg for stationary sources in 1985 is enough to require a small amount of control. Even with the low base year concentration, the complete range of combustion modification controls is needed in the year 2000. For the high base year concentration cases combustion modifications and ammonia injection are not always sufficient, and even in the low mobile case combustion modification controls are needed. (The 1973 mobile emissions constitute 38 percent of the total; consequently, mobile emissions are not as dominant as in Los Angeles.)

The conclusions for the Chicago AQCR are essentially the same as for Los Angeles. For the long term all combustion modifications will be required and, in some cases, will not be sufficient to meet the annual standard. In the short term, combustion modifications are needed unless the low base year concentration is valid.

These conclusions can be qualitatively extended to many of the regions identified as Priority AQCRs and AQMAs. Those that are heavily mobile dominated will respond to stationary source control in much the same manner as Los Angeles. It is quite likely that for these AQCRs, mobile source controls (0.62 g/km) would be sufficient for the short term; however, combustion modifications on stationary sources would be required in the long term. The stationary source dominated AQCRs, particularly those in the upper half of Table 7-2, will likely require combustion modifications, and perhaps ammonia injection, in both the near term and far term. It should be emphasized that the present analysis focuses on control requirements to maintain the current annual average NO_2 NAAQS (100 $\mu g/m^3$). The control requirements to attain alternate potential standards, e.g., short-term NO_2 standard, will be evaluated later in the NO_x E/A program. The results of this evaluation could show additional control requirements over those identified here.

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*Mobile source emissions in 1985 are reduced by 50 and 57 percent of the 1973 level for the nominal and low mobile cases, respectively.

TABLE 7-3. SUMMARY OF CONTROL LEVELS REQUIRED TO MEET NO_2 STANDARD IN CHICAGO, AQCR 067

Case	BYR = 96 $\mu g/m^3$			BYR = 120 $\mu g/m^3$		
	PP = 1.0 MS = 1.0	PP = 0.5 MS = 1.2	PP = 0.2 MS = 1.0	PP = 1.0 MS = 1.0	PP = 0.5 MS = 1.2	PP = 0.2 MS = 1.0
Nominal Growth	0 / 2	0 / 2	0 / 3	3 / V	2 / V	3 / V
Low Mobile	0 / 2	0 / 2	0 / 2	2 / 3	2 / 3	2 / 3
High Stationary	1 / 3	0 / 3	0 / 3	3 / V	3 / V	V / V

Key: 1985 / 2000

0 — No additional control required
1 — Controls from Group I
2 — Controls from Groups I and II
3 — Controls from Groups I, II, and III
V — Violation of NAAQS, insufficient controls to meet ambient standard

PP — Power plant weighting factor
MS — Mobile source weighting factor
BYR — Base year ambient concentration for calibration

TABLE 7-4. CONTROL PRIORITIZATION FOR CHICAGO (2000 EQUAL SOURCE WEIGHTING)

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	Rank	Source/Control	Cost Per Unit Change in Air Quality 10^6\$/(μg/m^3)	% Red/Unit
I	1	RES. NEW BURNER	-43.8	40
	2	RES. FURN A.D.#1	-40.2	60
	3	RES. FURN A.D.#2	-38.3	80
	4	SM COMM FURN NEW D	-20.5	40
	5	SM COMM FURN A.D.#1	-18.6	60
	6	SM COMM FURN A.D.#2	-19.7	80
	7	IWTB-OIL LEA	- 3.98	6
	8	N IWTB-C LEA	- 3.47	12
	9	N IWTB-O LEA	- 2.94	10
	10	IWTB-COAL LEA	- 2.62	10
	11	PP-OIL LEA	- 0.923	16
	12	N IFTB-O LEA	- 0.673	17
	13	IFTB-OIL LEA	- 0.408	17
	14	PP-COAL LEA	- 0.397	11
II	15	N PP-C LEA+OSC 1982	0.294	14
	16	N PP-C A.D.#2 1987	0.335	43
	17	PP-COAL LEA+OSC	0.709	22
	18	N IFTB-O LEA+FGR	0.789	40
	19	N IWTB-O LEA+OSC	0.821	20
	20	N IWTB-O A.D.#2 1983	0.712	50
	21	N IWTB-C LEA+OSC	0.918	24
	22	N IFTB-O A.D.#2 1985	1.01	67
	23	PP-OIL LEA+OSC	1.04	45
	24	IWTB-COAL LEA+OSC	1.76	20
	25	N IWTB-C A.D.#1 1985	1.79	40
	26	IFTB-OIL LEA+FGR	1.94	40
	27	PP-OIL LEA+OSC+FGR	1.97	58
	28	IWTB-OIL LEA+OSC	2.39	17
III	29	IWTB-COAL C.M.+NH3	4.29	60
	30	PP-COAL C.M.+NH3	4.51	55
	31	N PP-C A.D.#2+NH3	4.56	71
	32	N IWTB-O A.D.#2+NH3	5.22	75
	33	PP-OIL C.M.+NH3	5.25	79
	34	N IWTB-C A.D.+NH3	6.14	70
	35	IWTB-OIL C.M.+NH3	6.46	58
	36	G.T. (PEAK) H2O INJ	11.16	30

N — New
C — Coal
O — Oil
A.D. — Advanced design
C.M. — Combustion modifications (LEA, OSC, FGR)
COMM — Commercial
CCGT — Combined cycle gas turbine
EGR — Exhaust gas recirculation
FGR — Flue gas recirculation
FTB — Firetube boiler
FURN — Furnace
H2O INJ — Water injection
I, IND — Industrial
INST — Institutional
LA — Large
LEA — Low excess air
MED — Medium
OSC — Off-stoichiometric combustion
PP — Power plant
RES — Residential
SM — Small
WTB — Watertube boiler

The conclusions for the required control levels for both Los Angeles and Chicago are very similar to those of other studies, for example, the DOT study (Reference 7-1) and an EPA study (Reference 7-2). Both of these studies reported that neither Los Angeles nor Chicago could achieve the ambient standard with even maximum stationary source control and 0.25 g/km mobile controls. The results here indicate that it may be possible in favorable circumstances. The primary differences between the present analysis and the two cited above are in the growth rates and the base year ambient levels for which the models were calibrated. The DOT study allowed stationary sources to grow at 3.9 percent per year. The EPA study considered 5 percent per year growth and a base year concentration of 182 $\mu g/m^3$. Because of growth restrictions in Los Angeles an effective annual growth of about 1 percent per year for the aggregate of the stationary sources was used in this work. In Chicago, electric power plant growth was much less than 3.9 percent, primarily because of growth in nuclear capacity. These factors account for the difference between never meeting the standard and possibly meeting the standard. These differences also help to illustrate the influence of the basic assumption (growth rate, base year concentration, and source weighting factors) on the quantitative results. However, the qualitative conclusions, stated below, remain the same.

The conclusions of this portion of the analysis can be summarized as follows:

- NO_x controls for residential furnaces and small commercial furnaces yield substantial reductions in fuel use and can significantly effect the break-even point in the cost for stationary source control strategies
- The order in which controls should be implemented is significantly influenced by the fuel savings features of the control method and, of course, the availability of the technology
- For the short term, combustion modifications for stationary sources will be needed for most of the priority AQCRs. Both retrofit and "new design" controls should be developed — particularly those that also result in an energy savings.
- For the long term, all combustion modifications and ammonia injection will be required. This may be the case even for the minimum mobile source emissions case (low growth 0.25 g/km).

7.2 SUMMARY OF SOURCE/CONTROL PRIORITIES

This section combines the results of Section 7.1 with those of other sections to set NO_x E/A program priorities on sources and source/control combinations. The source priorities will be used to determine the order in which the process engineering and environmental assessment studies will be conducted for the major source categories (utility boilers, industrial and commercial boilers, gas turbines, commercial and residential warm air furnaces, IC engines and industrial process combustion equipment). The source priorities will also guide the level of effort to be devoted to the study of each major source category and to individual design types within the category. These studies will focus primarily on near-term source/control applications; far-term application of emerging technology will be studied later in the program. The source/control priorities will be used to determine which source/control combinations will be given major or minor emphasis in the near-term process studies and which will be emphasized in the far-term studies. The source/control priorities will also guide the field test program. Other factors such as site availability and the potential for teaming arrangements will also have a significant role in the test priorities.

The source prioritization used the following sequence:

- Subdivide major source categories (utility boilers) into source/fuel categories (coal-fired utility); further subdivide to major design types (tangential) likely to be extensively controlled for NO_x, and minor design types (vertical) not likely to be extensively controlled due to dwindling use and/or lack of control flexibility
- Assess the extent to which controls are in use or are planned for each source/fuel category
- Rank source/fuel categories on basis of nationwide mass emissions of NO_x
- Assess the relative baseline environmental impact potential for each source/fuel category
- Identify the relative effectiveness of near-term and far-term source control implementation in maintaining air quality in urban areas

Table 7-5 summarizes the results of this prioritization sequence. The prioritization is largely qualitative due to the uncertainty and lack of data in these areas. The considerations which were made in constructing Table 7-5 are summarized below.

<u>Source Categorization</u>

The division of the source/fuel category into major and minor design types used the results of Section 2 of this report. The major design types are those, which in the near-term, will be subject to NO_x controls. The designation "major" implies a design type will be given primary emphasis in the process studies and is a candidate for the field test program. The minor design types are either obsolete or difficult to control or otherwise unlikely to be subject to significant NO_x controls in the near term. The minor design types will be given secondary emphasis in the process studies and will not be candidates for field tests. It should be noted that minor design types are

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TABLE 7-5. EVALUATION OF NO_x E/A SOURCE PRIORITIES

Source Category	Major Design Types[a] in E/A Program	Minor Design Types[a] in E/A Program	Degree of Control Implementation	Nationwide NO_x Emission Ranking	Relative Impact Potential[b]	Source Control Need/Effectiveness[b] Near term	Source Control Need/Effectiveness[b] Far term	Source Ranking in E/A Program
Coal-fired utility	Tangential, single and opposed wall-fired, turbo	Cyclone, vertical, stoker	All new sources, moderate for existing sources	1	H	H	H	1
Oil-fired utility	Same as above	Cyclone	Extensive for existing sources	4	M	H	L	3
Gas-fired utility	Same as above		Same as above	3	L	H	L	8
Coal-fired watertube	Pulv. Stoker-spreader	Underfeed/overfeed	Low for existing, impending for new	5	H	H	H	2
Oil-fired watertube	Single and multiburner		Same as above	10	M	H	H	6
Gas-fired watertube	Single and multiburner		Same as above	7	L	H	M-L	11
Coal-fired firetube		Stoker	Same as above	14	H	M	L	14
Oil-fired firetube	Scotch	Firebox, HRT	Same as above	6	M	H	H	5
Gas-fired firetube	Scotch	Firebox, HRT	Same as above	9	L	H	M-L	12
Gas- and oil-fired gas turbines	Industrial, utility, simple cycle	Comb. cycle repowering	Moderate for existing sources, impending for new sources	11	L	H	H-M	4
Gas- and oil-fired warm air furnaces	Res., Comm. furnace	Space heaters	Increasing use for energy conservation	12	L-M	H	H-M	7
Compression ignition IC engines (diesel fuel and mixed)	Turbocharged	Blower scavenged	Negligible for existing sources; impending for new sources	8	L-M	H	M-L	10
Spark ignition IC engines	Turbocharged naturally aspirated		Same as above	2	L-M	H	M	9
Industrial process combustion	Process heaters, furnaces, kilns		Negligible	13	M-H	M	M-H	13

[a]Major refers to sources likely to be controlled for NO_x; minor refers to sources for which controls are unlikely to be implemented in the near term.
[b]H = high; M = medium; L = low

not necessarily insignificant sources of NO_x. For example, cyclone boilers emit 8 percent of stationary source NO_x and rank fourth among all stationary source design/fuel combinations (see Table 5-3). Yet, the cyclone combustion characteristics make them very difficult to control for NO_x. Their sale has been discontinued for other than high sodium lignite applications and it is unlikely many existing units will be controlled for NO_x. Other considerations made in the source categorization are as follows:

- Vertical- and stoker-fired utility boilers are obsolete; although they are amenable to some control, the current application is insignificant
- Firebox and horizontal return tube package firetube boilers are dwindling in use in favor of the scotch design; the vast majority of new sales to meet the planned NO_x standard will be of the scotch design
- Firetube stokers are dwindling in number due to cost
- The use of NO_x controls on space heaters in the near term is unlikely
- Insufficient data are available to divide industrial process combustion equipment into major and minor design types

The growth projection and design trends for this prioritization are preliminary. They will be studied in greater detail later and Table 7-5 will be updated as necessary.

Control Implementation

The information for the "Degree of Control Implementation" column on Table 7-5 is taken from Section 4. Since the assessment of current controls application is a major objective of the NO_x E/A, the degree of control implementation is a dominant criterion in setting source priorities. To date, the vast majority of stationary combustion source NO_x controls has been on utility boilers. Gas and oil units have been the most extensively controlled, but an increasing number of standards has been set recently for coal units. No new gas- or oil-fired units are being sold, so NO_x controls for coal units via the New Source Performance Standards (NSPS) will dominate in the future. Other sources with current control applications are large industrial boilers and gas turbines. NSPS are also planned for these sources along with IC engines. The lead time for implementing the standard and delivering new unit orders is typically several years. Thus, the degree of control application for these sources will not be comparable to that for utility boilers in the near term. This fact alone is sufficient to rank utility boilers as the top priority in the NO_x E/A.

Nationwide Emission Ranking

The ranking of design/fuel types by nationwide mass emissions of NO_x is given in Table 5-3. These results have been consolidated on Table 7-5 for the specific source categories listed there. Nationwide mass emissions are useful for weighting relative emission contributions of various sources and detecting emission trends independent of local variations. They are used within the EPA to set priorities on emission standards. Use of nationwide emissions does suffer a drawback, however, in that it does not account for variations among source categories in proximity to population centers and variations in regional use of specific source/fuel types. These factors were qualitatively included in the relative impact potential column. These factors will be quantified later in the NO_x E/A and used for a formal ranking of sources according to pollution potential.

Relative Impact Potential

The ranking of sources by relative impact potential was based on the multimedia emissions inventory of Section 5 and the evaluation in Section 7.3 of potential adverse impact of these emissions. Although impacts due to NO_x controls were not considered in the evaluation, the results of Section 6 were useful in relating design type and fuel to potential for emissions of specific pollutants (e.g., organic emissions from IC engines) where emission data were sparse. Additionally, the proximity of specified sources (e.g., residential furnaces) to populated areas was also considered. As shown on Table 7-5, the relative impact potential resulting from the above considerations was generally high for coal firing, medium for residual oil firing, and low with the firing of clean fuels. The borderline L-M for residential furnaces resulted from the proximity of these sources to populated areas and the potential for increased emissions during cycling transients. IC engines were also a borderline case. Even though they fire clean fuels, the emissions of organics are much higher than for other sources. Little emission/impact data are available for industrial process furnaces. They were rated M-H on the basis of fuel use.

Effectiveness of Source Control in Air Quality Maintenance

This criterion was based on the results of the air quality screening analysis discussed in Section 7.1. Separate consideration was given to near-term effectiveness and to far-term effectiveness in order to isolate effects of design trends and growth projections for source categories. The analysis in Section 7.1 showed that the need for bringing specific source categories under control is highly uncertain. The estimated control needs were found strongly dependent on growth projections, assumptions on future mobile source control, measurements of ambient concentrations of NO_2, and the relative weighting of the NO_2 air quality impact emissions from point sources (power plants) and ground level sources (mobile sources). These factors are all in a state of flux. Assuming optimistic resolution of these factors (in terms of stationary source air quality impact), only moderate control of major stationary sources will be needed in the near term (1985). Assuming moderate or pessimistic resolution of these factors, however, implies the need for extensive near-term control of stationary sources. In the far term (2000), extensive control is generally needed regardless of assumption. For purposes of setting priorities in the NO_x E/A program, the estimated control needs for moderate or pessimistic assumptions are used. This is because the NO_x E/A is largely a problem definition study and its purposes would not be served by using optimistic assumptions on the potential for adverse impact. For the moderate or worst case scenarios, the estimated near-term control needs, as shown on Table 7-5, are generally high for all source categories. For the far term, the needs are focused on extensive control of new sources. Thus, sources with dwindling new sales due to design trends or fuel availability are derated in the far term. As expected, the trend is for increasing use of coal and oil and decreasing use of gas. The projected availability of clean fuels for industrial sources and gas turbines will be examined in more detail later in the program.

It should be noted that control requirements are estimated only for compliance with the current annual average National Ambient Air Quality Standard (100 $\mu g/m^3$). Additional controls may be needed if a short-term NO_2 standard is set based on the mandates of the 1977 Clean Air Act Amendments.

Overall Source Ranking

The final column on Table 7-5 gives a qualitative ranking of the 13 source/control categories. In deciding this ranking, the degree of control implementation and the relative impact potential were given the most weight. Based on this ranking, the process and environmental assessment studies in the NO_x E/A will be conducted in the following sequence:

1. Utility and large industrial watertube boilers
2. Industrial and commercial packaged boilers
3. Gas turbines (simple cycle and combined cycle)
4. Residential and commercial warm air furnaces
5. Reciprocating internal combustion engines
6. Industrial process combustion equipment

Within each of these studies, the relative effort for specific source/fuel categories will follow the order of ranking of Table 7-5.

The source prioritization discussed above is extended on Table 7-6 to include consideration of specific source/control combinations. The table shows which source/control combinations are to receive major or minor emphasis in the six process studies of near-term applications listed above.

TABLE 7-6. SUMMARY OF NO_x E/A SOURCE/CONTROL PRIORITIES

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Source Ranking	Source	NEAR TERM EFFORT IN E/A PROGRAM: CURRENT AND IMPENDING APPLICATIONS				FAR TERM EFFORT IN E/A PROGRAM: ADVANCED TECHNOLOGY	
		Major Emphasis — Sources[a]	Major NO_x E/A Emphasis — Controls[a]	Minor NO_x E/A Emphasis — Sources[a]	Minor NO_x E/A Emphasis — Controls[a,b]	Major Emphasis	Minor Emphasis
1	Coal-fired utility boilers, existing	Tangential, opposed & single wall, turbo-fired	LEA, BBF, BOOS, OFA, low-NO_x burners	Cyclone, vertical stoker	FGR, RAP, H_2O inj., load reduction, NH_3 injection	NH_3 injection	
	Coal-fired utility boilers, new	Same as above	LEA & OFA; low-NO_x burners, enlarged firebox		FGR, RAP, H_2O inj., NH_3 injection	Advanced OFA techniques; adv. low-NO_x burners, NH_3 injection	Flue gas treatment; fluidized beds; adv. cycles
3, 8	Oil-fired, gas-fired utility boilers	Same as above	LEA, BBF, BOOS, OFA, FGR	Cyclone	RAP, H_2O inj., NH_3 injection	Advanced low-NO_x burners, NH_3 inj.	Chemically active fluid bed
2	Coal-fired water-tube, industrial-pulverized	Single or multiburner wall-fired	LEA, BBF, BOOS, OFA, low-NO_x burners		Load reduction	Advanced low-NO_x burners, advanced OFA, NH_3 injection	
	Coal-fired water-tube industrial-stoker	Spreader	LEA, OFA	Underfeed/overfeed		Factory installed OFA, NH_3 inj.	
6, 11	Oil-fired, gas-fired watertube	Single or multiburner wall-fired	LEA, OFA, low-NO_x burners		Load reduction	Adv. low-NO_x burners, adv. OFA, NH_3 inj., alt. fuels	
14	Coal-fired fire-tube stoker			Firebox, horizontal return tube	LEA		
5, 12	Oil-fired, gas-fired firetube	Scotch	LEA, FGR, OFA, low-NO_x burners	Firebox HRT	Load reduction	Adv. low-NO_x burners, adv. OFA, alt. fuels, catalytic comb.	
4	Gas- & oil-fired gas turbines	Utility, industrial simple cycle	Water injection	Combined cycle, repowering	Can modifications	Adv. can design, comb. cycles, alt. fuels, catalytic comb.	
7	Gas- & oil-fired warm air furnace	Residential, commercial furnaces	Low-NO_x burners	Space heaters		Adv. burner/ firebox des., alt. fuels, catalytic comb.	
9	Spark ignition IC engines	Turbocharged, naturally aspirated	Operational tuning, reduced inlet air temperature		EGR, derate	Chamber redesign, alt. fuels	Exhaust gas treatment
10	Compression ignition IC engine (diesel, mixed fuel	Turbocharged	Operational tuning	Blower scavenged	Derate	Chamber redesign alt. fuels	
13	Industrial process combustion	Process heaters, furnaces, kilns	LEA, load reduction, RAP, FGR, H_2O injection	Low-NO_x burners		Low-NO_x burners, OFA, alt. fuels	

[a] Major refers to sources or controls emphasized in near term control programs; minor refers to sources or controls less likely to be used.

[b] LEA = low excess air; BBF = biased burner firing; BOOS = burners out of service; OFA = overfire air; FGR = flue gas recirculation; RAP = reduced air preheat

The table also shows preliminary selection of which advanced source/control combinations will be evaluated in the later study of far-term applications. The prioritization of current technology was based directly on the information in Section 4 (see Tables 4-2 and 4-3). The prioritization considered the extent of current applications of specific source/control combinations and the cost effectiveness of a given control compared to competitive techniques. Major emphasis will be given to the majority of source/control combinations likely to see significant control in the next 5 years. The selection of advanced techniques for study in the far-term effort was also based on Section 4. The developmental status and schedule as well as the potential availability of competitive techniques were considered. The selection of advanced techniques also considered the results of Section 7.1 which showed the need for advanced combustion modifications and, possibly, ammonia injection in the 1980's and 1990's. Advanced techniques which are being covered by other assessment efforts (e.g., fluidized beds, advanced cycles) will be given minor emphasis in the far-term effort.

7.3 POLLUTANT/IMPACT SCREENING

The source/control combinations prioritized in Section 7.2 are further evaluated here to identify specific pollutants which may cause an adverse environmental impact with or without NO_x controls. These results will be used to set priorities for the sampling and chemical analyses to be done during the later field test programs. The emphasis in the pollutant/impact screening is on flue gas emissions. The data on liquid and solid effluent streams are very sparse. They will therefore be sampled during the test program to obtain the data needed for a pollutant/impact screening such as done here for flue gas emissions.

The set of pollutant classes under consideration was described in Section 6 and includes carbon monoxide, vapor phase hydrocarbons, particulates, sulfates, condensed phase organics, and trace metals. Several of these classes can be further speciated into more detailed pollutant groups, which give a better representation of potential health/welfare hazards, as was done in Section 3. For example, the vapor phase hydrocarbon class is comprised of alkanes, alkenes, alkynes, aldehydes, carboxylic acids, and aromatics. (Of course sulfates, organics, and trace metals are generally emitted as particulates, but the particulates class has been separately discussed because it is a criteria pollutant, and because more emissions data on this class of pollutants are available.)

Baseline emissions for each pollutant species group, as a function of combustion source class, were summarized in Section 5. In addition, Section 6 summarized the incremental emissions of these pollutant groups as a function of applied NO_x combustion control. The health and welfare aspects of each species/group were discussed in Section 3 in terms of developing a set of maximum ambient screening concentrations. By combining information developed in each of those sections with a dispersion model (which relates ground level pollutant concentrations to single source emission levels as a function of combustion source), it is possible to flag the pollutants from each combustion source which represent potential environmental hazards due to applying NO_x controls.

Such a summary appears in Tables 7-7 and 7-8. Table 7-7 shows baseline emissions, typical emission levels with NO_x controls, maximum ambient screening concentrations, and derived maximum allowable emission level (from the dispersion model) for the pollutant groups under consideration. The pollutant groups listed in Table 7-7 are those for which incremental emissions data are available. Table 7-8 shows a similar summary for those pollutants groups for which little or no field data exist on the incremental effects of NO_x combustion controls.

From the data presented in Tables 7-7 and 7-8, it is possible to identify those pollutant groups which are emitted at levels near, or exceeding, the defined maximum allowable emission level. For current purposes, pollutant group/combustion source combinations are flagged if emission levels with NO_x control data, or baseline emission in the absence of incremental NO_x control data (Table 7-8), exceed 10 percent of the maximum allowable level. These combinations are noted in Tables 7-7 and 7-8, and further summarized in Table 7-9.

Table 7-9 illustrates that incremental emissions from large coal- and oil-fired boilers potentially represent most significant environmental hazards. Baseline emissions of particulate, sulfates, and certain POM species from this source class currently exceed the derived maximum allowable emissions levels, while emissions of several other POM species are within an order of magnitude of the maximum limit. In addition, while emissions of total vapor phase hydrocarbons from large boilers were not identified as being of concern, emissions of several hydrocarbon classes, notably oxygenates and aromatics, were flagged. Finally baseline emissions of several trace metals from coal- and oil-fired boilers were noted as exceeding, or falling within a factor of 10 of maximum levels. It is interesting to note that six of the eight flagged elements exhibit Class II, or segregating, behavior; they tend to repartition and concentrate in fine particulate.

Large coal- and oil-fired boilers were not the only source class associated with pollutant streams of concern. Incremental total vapor phase hydrocarbon emissions from IC engines operating with dry NO_x controls exceeded 10 percent of maximum allowable emissions and therefore represent another concern. In addition, baseline emissions of several organics from residential coal stokers exceeded maximum limits. However, the use of coal firing in residential heating applications is definitely declining, so this source/pollutant combination should not be considered a priority concern.

Based on the information presented in Table 7-9, it is clear that further study is needed of NO_x controls which could increase emissions of:

TABLE 7-7. COMPARISON OF POLLUTANT EMISSION LEVELS WITH NO_x CONTROLS TO MAXIMUM ALLOWABLE EMISSIONS

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Pollutant Class	Combustion Source	Fuel	Maximum Ambient Concentration (ppb)	Maximum Allowable Emission Level (ppm)	Baseline Emissions (ppm)	Emissions with NO_x Controls (ppm)	Concern Flag[a]
Carbon Monoxide			9,000				
	Utility Boilers	Natural Gas		110,000	23-175	25-65	
		Oil			25-46	10-35	
		Coal			23-96	20-148	
	Industrial Boilers	All Fuels		920,000	0-110	0-220	
	Residential Units	Natural Gas		529,000	40	--	
		Oil			90	--	
	IC Engines	All Fuels		920,000	90-10,300	90-3,280	
	Gas Turbines	All Fuels		920,000	53-970	51-1,320	
Total Vapor Phase Hydrocarbons			240				
	Utility Boilers	Natural Gas		2,930	0-35	0-40 (Natural Gas, Oil, Coal)	
		Oil			0-30		
		Coal			0-40		
	Industrial Boilers	Natural Gas		24,500	10-25	0-35 (Natural Gas, Oil, Coal)	
		Oil			0-15		
		Coal			10-90		
	Residential Units	Natural Gas		14,100	20	--	
		Oil			25	--	
	IC Engines	All Fuels		24,500	60-4,600	80-6,400	+
	Gas Turbines	All Fuels		24,500	0-230	0-1,200	
			(mg/m^3)	(g/m^3)	(g/m^3)	(g/m^3)	
Particulates			0.075				
	Utility Boilers	Natural Gas		0.91	0.01	--	
		Oil			0.11	--	
		Coal			0.42-2.73	0.60-2.6	++
	Industrial Boilers	Natural Gas		7.65	0.01	<0.03	
		Oil			0.01-0.63	0.02-1.23[b]	+
		Coal			3.9-5.1	7.5-10.0[b]	++
	Residential Units	Natural Gas		4.41	0.01	0.01	
		Oil			0.03	0.03	
	IC Engines	Oil		7.65	0.02-0.04	<0.26[c]	
	Gas Turbines	Oil, Kerosene		7.65	0.03-0.08	0.04-0.09[d]	

[a] + denotes emission with NO_x controls greater than 10 percent of maximum emission level.
++ denotes emission with NO_x controls greater than maximum emission level.

[b] NO_x control by off-stoichiometric combustion.

[c] NO_x control by exhaust gas recirculation.

[d] NO_x control by derating.

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TABLE 7-8. COMPARISON OF BASELINE POLLUTANT EMISSION LEVELS TO MAXIMUM ALLOWABLE EMISSIONS

Pollutant Class/Group	Combustion Source	Fuel	Maximum Ambient Concentration (ppb)	Maximum Allowable Emission Level (ppm)	Baseline Emissions (ppm)	Concern Flag[a]
Vapor Phase Hydrocarbons[b]						
Alkanes			4,420			
	Utility Boilers	Natural Gas		54,000	<80	
		Oil			<15	
		Coal			<10	
	Industrial Boilers	Oil		450,000	<40	
		Coal			<150	
Alkenes			59,500			
	Utility Boilers	Natural Gas		725,000	<80	
		Oil			<15	
		Coal			<10	
	Industrial Boilers	Oil		Unlimited	<40	
		Coal			<150	
Alkynes			62,700			
	Utility Boilers	Natural Gas		765,000	<5	
		Oil			<5	
		Coal			<10	
	Industrial Boilers	Oil		Unlimited	<5	
		Coal			<10	
Aldehydes			2.1			
	Utility Boilers	Natural Gas		25.6	5	+
		Oil			5	+
		Coal			<10	+
	Industrial Boilers	Oil		214	2.5-200	++
Carboxylic Acids			13			
	Utility Boilers	Natural Gas		159	2.5	
		Oil			6-12	
		Coal			200	++
Aromatics (benzene and one-ring derivatives)			0.002			
	Utility Boilers	Natural Gas		0.024	<20	++
		Oil			<30	++
		Coal			<50	++
			(mg/m³)	(g/m³)	(g/m³)	
Sulfates			0.002			
	Utility Boilers	Natural Gas		0.024	0	
		Oil			0.047	++
		Coal			0.056	++
			(ppt)	(ppb)	(ppb)	
Organics (POM's)						
Anthracene			0.14			
	Utility Boilers	Coal		1.71	0.3	+
	Industrial Boilers	Oil		14.3	2	++
		Coal			0.1-0.3	
	Residential Units	Coal		8.2	0.4-1,000	++
Phenanthrene			4,000			
	Utility Boilers	Coal		50,000	0.1-0.3	
	Industrial Boilers	Natural Gas		420,000	0.04	
		Oil			0.7-3.7	
		Coal			0.3-3	
	Residential Units	Coal		240,000	9-2,300	

[a] + denotes baseline emissions exceed 10 percent of maximum allowable level
++ denotes baseline emissions exceed maximum allowable level

[b] Maximum ambient concentration and associated maximum allowable emission level for hydrocarbon species consider only primary health hazards. Effects of secondary (derived) pollutants are not considered.

TABLE 7-8. CONTINUED

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Pollutant Class/Group	Combustion Source	Fuel	Maximum Ambient Concentration (ppt)	Maximum Allowable Emission Level (ppb)	Baseline Emissions (ppb)	Concern Flag[a]
Organics (POM's) (Cont.)						
Fluoranthrene			10,900			
	Utility Boilers	Coal		133,000	0.003-0.5	
	Industrial Boilers	Natural Gas		1,110,000	0.04-3.4	
		Oil			0.02-1.8	
		Coal			0.8-10	
	Residential Units	Coal		641,000	13-350	
Pyrene			0.121			
	Utility Boilers	Coal		1.48	0.01-0.5	+
	Industrial Boilers	Natural Gas		12.4	0.5-7.5	+
		Oil			0.005-2.2	+
		Coal			0.6-4.5	+
	Residential Units	Coal		7.1	2-2,500	++
Benzo(a)pyrene			0.097			
	Utility Boilers	Coal		1.2	0.003-0.1	
	Industrial Boilers	Natural Gas		9.9	0.006-0.1	
		Oil			0.006-0.3	
		Coal			0.007-2.2	+
	Residential Units	Coal		5.7	0.008-800	++
Benzo(e)pyrene			0.097			
	Utility Boilers	Coal		1.2	0.007-0.15	+
	Industrial Boilers	Natural Gas		9.9	0.006-0.5	
		Coal			0.02-1.7	+
	Residential Units	Coal		5.7	1-330	++
Perylene			0.097			
	Utility Boilers	Coal		1.2	0.005-0.015	
	Industrial Boilers	Coal		9.9	0.35	
	Residential Units	Coal		5.7	0.1-770	++
			($\mu g/m^3$)	(mg/m^3)	(mg/m^3)	
Trace Metals						
As			0.825			
	Utility Boilers	Oil		10.1	0.004	
		Coal			0.45	
B			16.5			
		Oil		201	0.068	
		Coal			3.41	
Ba			0.825			
		Oil		10.1	0.52	
		Coal			0.65	
Be			0.0033			
		Coal		0.04	0.52	++
Bi			16			
		Coal		195	0.03	
Cd			0.00825			
		Oil		1.01	0.006	
		Coal			0.12	+
Co			0.165			
		Oil		2.0	0.27	+
		Coal			0.11	

[a] + denotes baseline emissions exceed 10 percent of maximum allowable level
++ denotes baseline emissions exceed maximum allowable level

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TABLE 7-8. CONCLUDED

Pollutant Class/Group	Combustion Source	Fuel	Maximum Ambient Concentration (μg/m³)	Maximum Allowable Emission Level (mg/m³)	Baseline Emissions (mg/m³)	Concern Flag[a]
Trace Metals (Cont.)						
Cr			0.001			
	Utility Boilers	Oil		0.012	0.68	++
		Coal			0.43	++
Cu			1.65			
		Oil		20.1	0.55	
		Coal			1.20	
Hg			16.5			
		Oil		201	0.008	
		Coal			0.23	
Mn			8.25			
		Oil		101	0.55	
		Coal			1.58	
Mo			8.25			
		Oil		101	0.55	
		Coal			0.25	
Ni			0.165			
		Oil		2.0	32	++
		Coal			0.68	+
Pb			0.247			
		Oil		3.0	0.62	+
		Coal			0.59	+
Sb			0.825			
		Oil		10.1	0.004	
		Coal			0.04	
Se			0.33			
		Oil		4.0	0.632	
		Coal			0.173	
V			0.825			
		Oil		10.1	47.5	++
		Coal			1.20	++
Zn			1.65			
		Oil		20.1	0.87	
		Coal			9.36	+
Zr			8.2			
		Oil		100	0.17	
		Coal			0.86	

[a] + denotes baseline emissions exceed 10 percent of maximum allowable level
++ denotes baseline emissions exceed maximum allowable level

TABLE 7-9. SUMMARY OF POTENTIAL POLLUTANT/COMBUSTION SOURCE HAZARDS

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Pollutant Class/Group	Combustion Source	Emission Exceeds Allowable Limit	Emission Exceeds 10% of Allowable Limit
Vapor Phase Hydrocarbons			
Total	IC Engines		X
Aldehydes	Utility Boilers, all Fuels		X
	Oil-Fired Industrial Boilers	X	
Carboxylic Acids	Coal-Fired Utility Boilers	X	
One-Ring Aromatics	Utility Boilers, all Fuels	X	
Particulates	Coal-Fired Boilers	X	
	Oil-Fired Industrial Boilers		X
Sulfates	Coal- and Oil-Fired Utility Boilers	X	
Organics			
Anthracene	Oil-Fired Boilers	X	
	Coal-Fired Residential Units	X	
	Coal-Fired Utility Boilers		X
Pyrene	Coal-Fired Residential Units	X	
	Boilers, all Fuels		X
Benzo(a)pyrene	Coal-Fired Residential Units	X	
	Coal-Fired Industrial Boilers		X
Benzo(e)pyrene	Coal-Fired Residential Units	X	
	Coal-Fired Boilers		X
Perylene	Coal-Fired Residential Units	X	
Trace Metals			
Be	Coal-Fired Utility Boilers	X	
Cd	Coal-Fired Utility Boilers		X
Co	Oil-Fired Utility Boilers		X
Cr	Coal- and Oil-Fired Utility Boilers	X	
Ni	Oil-Fired Utility Boilers	X	
Pb	Coal- and Oil-Fired Utility Boilers		X
V	Oil-Fired Utility Boilers	X	
	Coal-Fired Utility Boilers		X
Zn	Coal-Fired Utility Boilers		X

- Particulates from coal- and oil-fired boilers, e.g., off-stoichiometric combustion (OSC), flue gas recirculation (FGR), and ammonia injection (NH_3)
- Sulfates from coal- and oil-fired boilers, e.g., OSC, FGR, and NH_3
- Organics from coal- and oil-fired boilers, e.g., low excess air (LEA), OSC, and FGR
- Segregating trace metals from coal- and oil-fired boilers, e.g., LEA, OSC, and FGR
- Vapor phase hydrocarbons emissions from IC engines, e.g., all controls

7.4 FUTURE EFFORT

This report has:

1. Documented the scope of sources, pollutants, impacts, and controls to be considered in the NO_x E/A
2. Evaluated data on impact criteria, control effectiveness, baseline multimedia emissions, and incremental impacts of NO_x controls
3. Set preliminary priorities on source/control combinations and effluent stream/pollutants to be considered

These results will serve to initiate and scope future efforts to:

- Screen and rank the pollution impact potential of uncontrolled sources and effluents (B1)
  - Update the Section 5 emissions inventory
  - Develop approaches to assess emissions during nonstandard operation
  - Generate growth projections of source/fuel use and emissions
  - Expand impact analysis of Section 7.3
- Generate impact screening criteria for B1 and B5 assessments (B2)
  - Coordinate with other studies developing impact criteria; finalize human health impact criteria of Section 2
  - Decide approach to generalize terrestrial and aquatic impacts
  - Develop scenarios for alternate NO_2 air quality standards for the Task C air quality modeling
- Conduct field tests of priority source/control combinations (B3)
  - Survey candidate test sites for coal- and oil-fired utility and industrial boilers and oil-fired gas turbines using NO_x controls

- Finalize sampling and analysis requirements based on the E/A steering committee recommendations and Section 7 results

- Generate process engineering and environmental assessment reports for utility boilers (B5)
  - Expand process data and control results of Sections 2 and 4
  - Develop cost model to standardize control cost estimates
- Develop systems analysis model with chemistry and dispersion effects (C)
  - Update model inputs with cost data from B5 and regional inventories from B1
  - Expand control assessment of Section 7.1 to consider NO_2-oxidant reactions and a short-term NO_2 standard

These efforts are discussed in the Introduction and illustrated in Figure 1-1.

The data evaluations contained in this report have shown the strong need for setting priorities in all areas of the program. Serious data gaps exist for baseline and controlled multimedia emissions and impacts. These data gaps make it impossible to consider to a meaningful level all potential source/control/effluent stream/pollutant/impact combinations within the scope of the NO_x E/A. The program results will be most useful if the effort is prioritized to allow comprehensive assessment of fewer source-impact combinations. The prioritizations contained in this report have accordingly set the emphasis of the NO_x E/A as follows:

- Sources: Major emphasis on stationary fuel combustion sources firing coal or residual oil and projected to use a significant degree of NO_x controls in the near term; less emphasis on sources firing clean fuels; minor emphasis on sources which will not be controlled in the near term
- Controls: Major emphasis on most widely used current applications; less emphasis on advanced technology; minor emphasis on control techniques not widely used
- Effluent Streams and Pollutants: Major emphasis on flue gas emissions during steady-state operation; less emphasis on liquid and solid effluent streams; minor emphasis on emissions during transient or upset conditions
- Impacts: Major emphasis on human health impacts due to inhalation; less emphasis on terrestrial and aquatic impacts and on human health impacts due to ingestion via the food chain; minor emphasis on materials impacts

REFERENCES FOR SECTION 7

7-1. "Air Quality, Noise and Health — Report of a Panel on the Interagency Task Force in Motor Vehicle Goals Beyond 1980," Department of Transportation, March 1976.

7-2. Crenshaw, J. and A. Basala, "Analysis of Control Strategies to Attain the National Ambient Air Quality Standards for Nitrogen Dioxide," presented at the Washington Operation Research Council's Third Cost Effectiveness Seminar, Gaithersburg, Maryland, March 18-19, 1974.

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16. ABSTRACT The report gives preliminary methodologies, data compilation, and program priorities for assessing stationary combustion sources and NOx combustion modification technologies. Equipment characterizations and multimedia emission inventories are presented for utility and industrial boilers, commercial and residential warm air furnaces, gas turbines, IC engines, industrial processes, and advanced combustion processes. Control costs and operational, energy, and environmental impacts are compiled and discussed for current and emerging combustion modification NOx controls. Incremental emissions of CO, HC, and particulate due to NOx controls can be minimized through control development engineering. Other effluents (POMs, segregating trace metals, and sulfates) show potential for increased emissions with some combustion modifications. Significant data gaps in emissions and impacts of multimedia pollutants, with and without NOx controls, are noted. Program priorities for field tests and process studies to augment the data base are presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Internal Combustion	Air Pollution Control	13B	
Combustion	Engines	Stationary Sources	21B	21G
Combustion Control	Operating Costs	Combustion Modification		14A
Nitrogen Oxides	Coal, Fuel Oil	Emission Factors	07B	
Dust	Natural Gas	Control Costs	11G	
Boilers	Organic Compounds	Environmental Assessment	13A	07C
Gas Turbines	Inorganic Compounds		13G	

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