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ENVIRONMENTAL ASSESSMENT OF STATIONARY SOURCE NO_x CONTROL TECHNOLOGIES: First Annual Report

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EPA REVIEW NOTICE

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ENVIRONMENTAL ASSESSMENT OF STATIONARY SOURCE NO_X CONTROL TECHNOLOGIES:

First Annual Report

by

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SECTION 1

INTRODUCTION

This report summarizes the results of the first year of the "Environmental Assessment of Stationary Source NO_x Combustion Modification Technologies" (NO_x E/A). The NO_x E/A is a 3-year program to: (1) identify the multimedia environmental impact of stationary combustion sources and NO_x combustion modification controls; and (2) identify the most cost-effective, environmentally-sound NO_x combustion modification controls for attaining and maintaining current and projected NO_2 air quality standards to the year 2000. During the first year, program effort concentrated on three areas: (1) developing the methodology for environmental assessment and process engineering studies; (2) compiling data on source process characteristics, emissions, and pollutant impacts; and (3) setting program priorities on sources, controls, pollutants, and impacts. This report reviews each of these areas and summarizes our plans for future effort, with emphasis on the second year.

1.1 BACKGROUND

The 1970 Clean Air Act Amendments designated oxides of nitrogen (NO_x) as one of the criteria pollutants requiring regulatory controls to prevent potential widespread adverse health and welfare effects. Accordingly, in 1971, EPA set a primary and secondary National Ambient Air Quality Standard (NAAQS) for NO_2 of 100 $\mu g/m^3$ (annual average). To attain and maintain the standard, the Clean Air Act mandated control of new mobile and stationary NO_x sources, each of which emits approximately half of the manmade NO_x nationwide. Emissions from light-duty vehicles (the most significant mobile source) 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 by EPA standards of performance for new stationary sources (NSPS), which are set as control technology becomes available. Additional standards required to attain air quality in the Air Quality Control Regions could be set for new or existing sources through the State Implementation Plans (SIPs).

Since the Clean Air Act, techniques have been developed and implemented that reduce NO_x emissions by a moderate amount (30 to 50 percent) for a variety of source/fuel combinations. In 1971 EPA set NSPS for large steam generators burning gas, oil, and coal (except lignite). Currently, a more stringent standard for bituminous coal-fired large steam generators is being considered, based on technology developed since 1971. Standards are also being prepared for lignite-fired large steam generators, gas turbines, reciprocating internal combustion engines and intermediate-sized steam generators. Local standards also have seen set, primarily for new and existing large steam generators and gas turbines, as parts of State Implementation Plans in several areas with NO_x problems. This regulatory activity has resulted in reducing NO_x emissions from over 200 stationary sources by 30 to 50 percent. The number of controlled sources is increasing as new units are installed with factory-equipped NO_x controls.

Emissions have been reduced comparably for light-duty vehicles. Although the goal of 90-percent reduction (0.25 g NO_2/km) by 1976 has not been achieved, emissions were reduced by about 25 percent (1.9 g/km) for the 1974 to 1976 model years and now have been reduced by 50 percent to 1.25 g/km. Achieving the 0.25 g/km goal has been deferred indefinitely because of technical difficulties and fuel penalties. Initally the 1974 Energy Supply and Environmental Coordination Act deferred compliance to 1978. Recently, the Clean Air Act Amendments of 1977 abolished the 0.25 g/km goal and replaced it with an emission level of 0.62 g/km (1 g/mile) for the 1981 model year and beyond. However, the EPA Administrator has requested the option of reviewing the 0.25 g/km standard in 1983 if studies of the effect of NO_2 on human health show a review to be necessary.

Because the mobile source emission regulations have been relaxed, stationary source NO_x control has become more important for maintaining air quality. Several air quality planning studies have evaluated the need for stationary source NO_x control in the 1980's and 1990's in view of recent developments (References 1 to 7). These studies all conclude that relaxing mobile standards, coupled with the continuing growth rate of stationary sources, will require more stringent stationary source controls than current and impending NSPS provide. This conclusion has been reinforced by projected increases in the use of coal in stationary sources. The studies also conclude that the most cost-effective way to achieve these reductions is by using combustion modification NO_x controls in new sources.

It is also possible that separate NO_x control requirements will be needed to attain and/or maintain additional NO_2-related standards. Recent data on the health effects of NO_2 suggest that the current NAAQS should be supplemented by limiting short-term exposure (References 4 and 8 to 10). In fact, the Clean Air Act Amendments of 1977 require EPA to set a short-term NO_2 standard for a period not to exceed 3 hours. Currently, EPA plans to consider a short-term standard in 1978 when the NO_2 air quality criteria document (Reference 11) is updated (References 12 and 13).

EPA is continuing to evaluate the long-range need for additional NO_x regulation as part of strategies to control oxidants or pollutants for which NO_x is a precursor, e.g., nitrates and nitrosamines (References 4, 8, and 12 through 15). These regulations could be source emission controls or additional ambient air quality standards. In either case, additional stationary source control technology could be required to assure compliance.

In summary, since the Clean Air Act, near-term trends in NO_x control are toward reducing stationary source emissions by a moderate amount. Hardware modifications in existing units or new units of conventional design will be stressed. For the far term, air quality projections show that more stringent controls than originally anticipated will be needed. To meet these standards, the preferred approach is to control new sources by using low-NO_x redesigns.

1.2 PROGRAM OVERVIEW

Existing combustion modification techniques are increasingly being used, and the prospects for developing and using advanced techniques are good. Thus, there is a critical need to evaluate the environmental, economic, energy, and engineering implications of combustion modification technology. The NO_x E/A was begun in June 1976 to provide these evaluations and to specifically assess:

- The impacts, and potential corrective measures, associated with using specific existing and advanced combustion modification techniques, such as:
  - -- The change in gaseous, liquid, and solid emissions to the air, water, and land caused by NO_x controls
  - -- The capital and operating cost of NO_x controls per unit reduction in NO_x
  - -- The change in energy consumption efficiency
  - -- The change in equipment operating performance
- The priorities and schedule for NO_x control technology development considering:
  - -- The above impacts for each source/control combination
  - -- The need for controls to attain and maintain the current annual average NO_2 ambient air quality standard
  - -- The need for controls to attain and maintain a potential short-term NO_2 standard, or other NO_x-related standards such as a standard for oxidants
  - -- Alternate mobile source standards
  - -- Alternate energy and equipment use scenarios, to the year 2000, in the Air Quality Control Regions with a potential NO_x problem

The first problem evaluates the net impacts from specific combinations of stationary combustion source equipment and control techniques. The NO_x E/A addresses this question through a series of coordinated efforts to evaluate the environmental impact and control potential of multimedia effluents from current and emerging energy and industrial processes.

The assessment effort is focused in a major process engineering and environmental assessment task. This task is supported by additional tasks on emission characterization, pollutant impacts and standards, and experimental testing. Results from these tasks will be used to rank both current and emerging source/control combinations based on overall environmental, economic and operational impact. This information is intended to help control developers and users select appropriate control techniques to meet regulatory standards now and in the future. It also will define pollution control development needs and priorities, identify economic and environmental trade-offs among competitive processes, and ultimately guide regulatory policy. In this respect, the NO_x E/A will contribute to the broad program of assessments of energy systems and industrial processes being administered by EPA's Office of Research and Development.

The second problem above deals with specifying the best mix of control techniques to meet air quality goals up to the year 2000. In the NO_x E/A, this is addressed in a systems analysis task which projects air quality in specific air quality control regions for scenarios of NO_x control, and energy and equipment use. These projections, together with the control cost and impact data discussed above will suggest the most cost-effective and environmentally-sound controls. Results from the analysis are used in the NO_x E/A program to set priorities on both sources and controls. More importantly, this information will help guide R&D groups concerned with providing a sufficient range of environmentally-sound techniques to meet the diverse control implementation requirements. It will also aid environmental planners involved in formulating abatement strategies to meet current or projected air quality standards.

The interrelationships and technical content of the tasks cited above are shown in Figure 1-1. In this figure, the arrows show the sequence of subtasks and major interactions among tasks, while the circled numbers refer to sections of the report where the results are summarized. Section 4, not shown in Figure 1-1, summarizes environmental objectives development activities which support the total program.

The first year, NO_x E/A effort developed the supporting data and methodologies for conducting subsequent major program tasks: process engineering and environmetal assessment, and systems analysis. The initial effort concentrated on three general areas: compiling data on combustion sources, pollutant impacts, control techniques, and emissions; developing the environmental assessment and process engineering methodology; and setting program priorities for sources, controls, pollutants, and impacts. In this report, the first year results are presented in terms of these three areas, rather than by tasks. This approach is in keeping with the annual report format for the environmental assessments developed within IERL-RTP Energy Assessment Control Division.

Initial program efforts were recently documented in depth in a preliminary environmental assessment report (Reference 16). This report provides more detailed discussion of many program results reported herein.

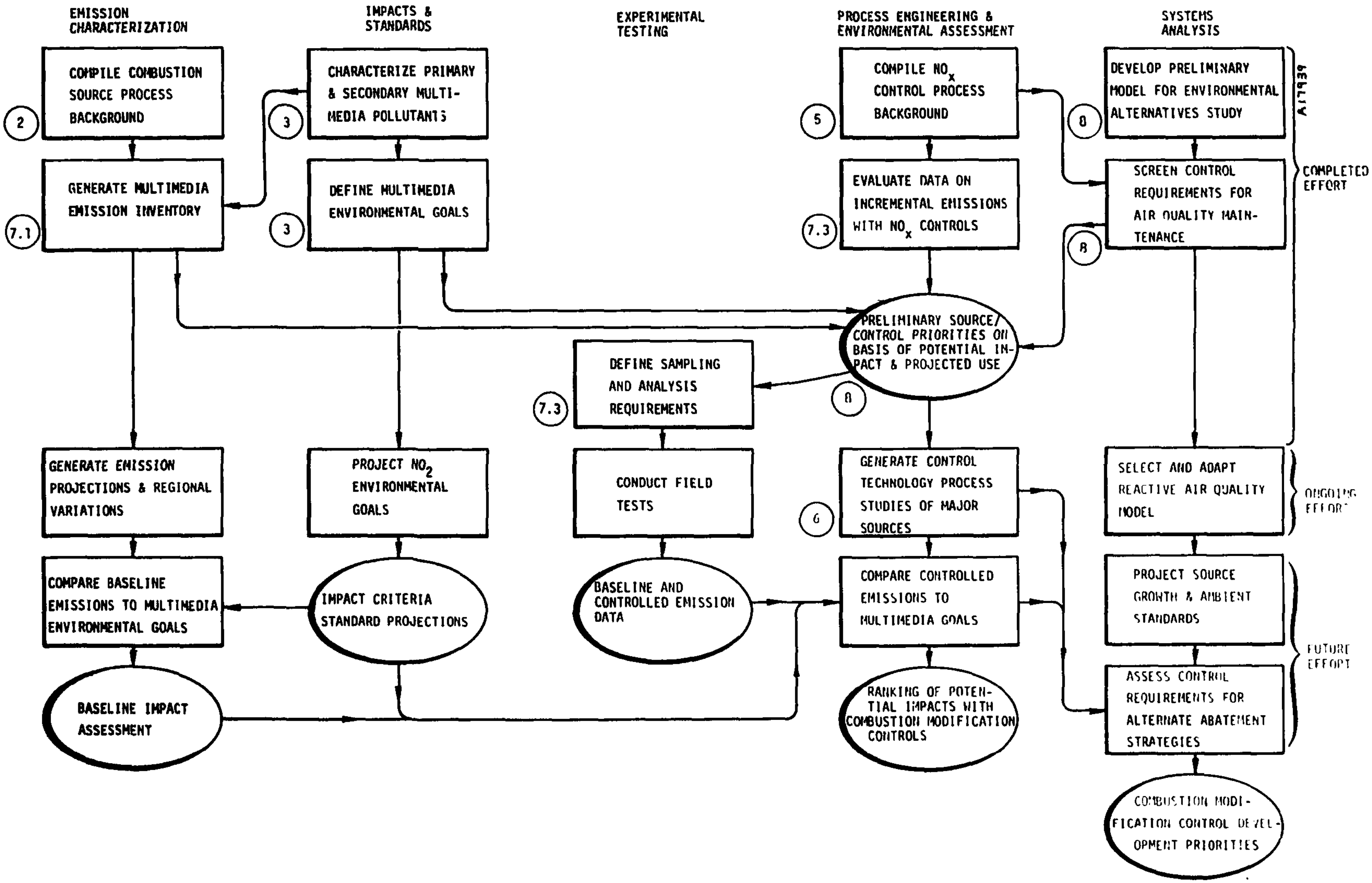

Figure 1-1. NO_x E/A approach.

SECTION 2

CURRENT PROCESS TECHNOLOGY

This section presents the preliminary characterization of NO_x sources used to order and simplify the NO_x E/A environmental assessment and process engineering studies. This characterization categorized equipment design according to characteristics that affect the formation and/or control of multimedia pollutants. Emphasis was on stationary combustion sources of NO_x. However, the other sources of NO_x also were studied, since the degree of NO_x control possible on these sources determines the extent of NO_x control needed for stationary combustion sources. The categories of equipment described in this section were used as the base for the emission inventory discussed in Section 7.1 and to rank the sources as discussed in Section 8. The source characterization performed encompassed the following steps:

- Identify significant sources of NO_x; group sources according to formative mechanism and nature of release into the atmosphere
- Categorize stationary combustion sources according to equipment and fuel characteristics that affect 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 list of equipment/fuel combinations to be carried through subsequent emission inventories, process studies, and environmental assessments
- Identify effluent streams from stationary combustion source equipment/fuel categories which may be affected by using NO_x combustion modification controls
- Identify operating modes (transients, upsets, maintenance) in which emissions may be affected 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 from biological decay and lightning make up about 90 percent of all NO_x emissions. In urban areas, however, up to 90 percent of the ambient NO_x may be 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

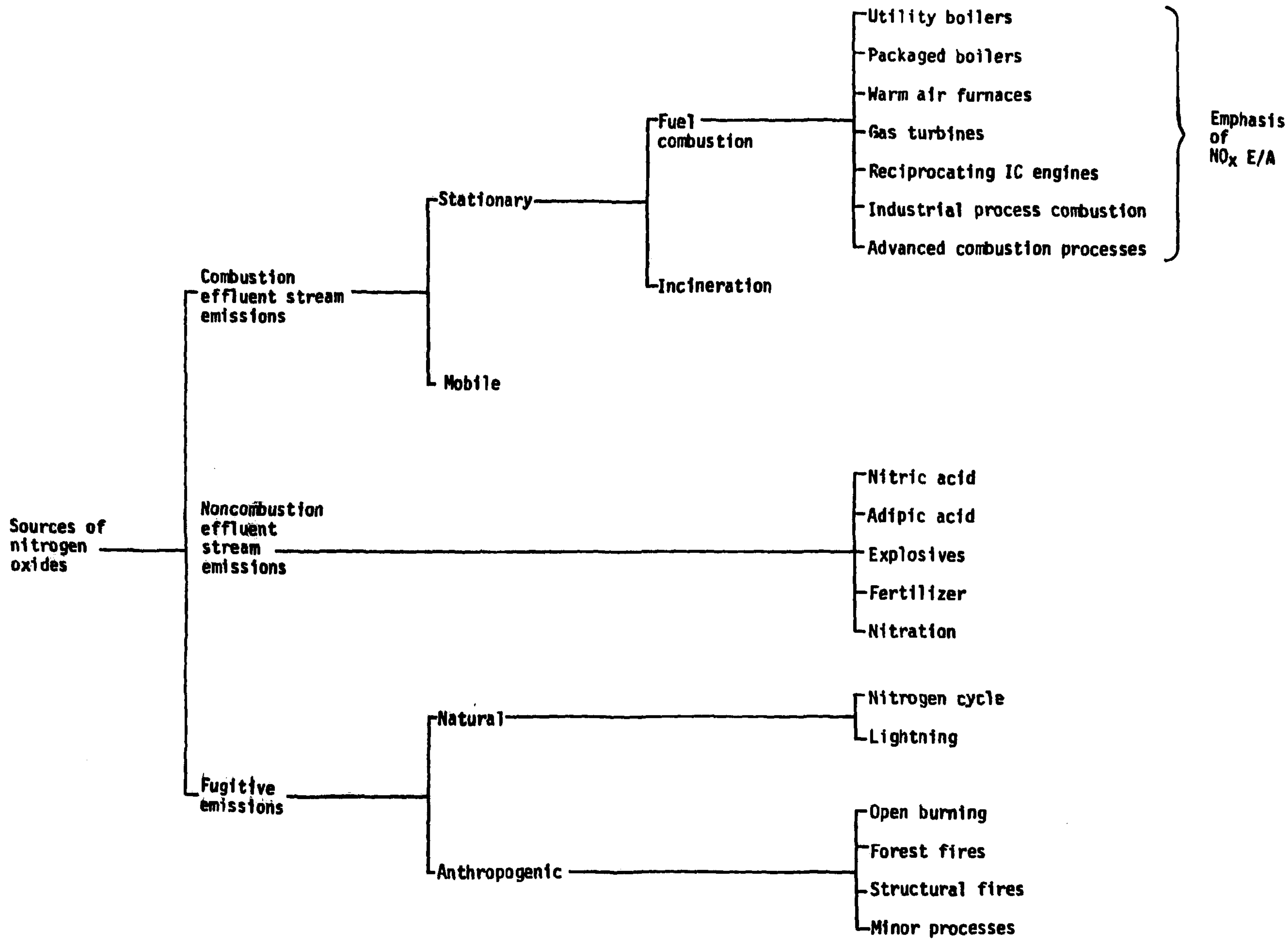

Figure 2-1. Sources of nitrogen oxide emissions.

as required to gauge the emissions and impacts due to stationary fuel combustion.

The major stationary fuel combustion source classes have been further categorized as shown in Table 2-1. This table lists the major equipment designs, types, and corresponding fuels fired, and was compiled from a survey of installed sources, process characteristics and emission data. Major source categories are discussed in the following sections.

2.1 UTILITY BOILERS

Utility boilers are field-erected watertube boilers with capacities greater than 25-MW electrical output. These boilers generally burn pulverized coal, residual oil, and natural gas. Recent designs have multifuel capabilities, using coal as the primary fuel. Although there is a large variety of specific boiler designs, the primary design characteristic affecting NO_x emissions is the firing pattern. The three generic firing types are tangential, horizontally-opposed, and single wall. Generally, tangential boilers and a variation of horizontally-opposed boilers known as Turbofurnace have furnace mix burner designs, in which fuel and secondary air are mixed in the furnace. Single wall and horizontally-opposed boilers generally have register mix burner designs, where secondary air and fuel are premixed in the burner register.

Three other firing designs exist in older equipment, but these designs are not presently being used in boilers sold for utility applications. The cyclone furnace was designed to fire pulverized coal, especially slagging coals, but also is used for oil and gas. Inflexibility in its normally high operating temperatures has made this design obsolete for all but high sodium lignite firing. Another design, the vertical furnace boiler, was popular before the advent of waterwalled combustion chambers. The third design, stoker firing, is seldom used in utility boilers because of capacity limitations and high costs.

A design survey of the installed population indicated that wall-fired boilers make up almost 60 percent on a number basis; tangential, 20 percent; vertical and stoker, 10 percent; horizontally-opposed, 8 percent; and cyclones, 3 percent. However, this distribution does not reflect respective importance from a NO_x standpoint. For example, wall-fired units are generally smaller boilers, while horizontally-opposed boilers are primarily large capacity designs. In addition, vertical, stoker, and cyclone boilers are obsolescent.

Utility boilers produce gaseous, liquid, and solid effluents. The flue gas stream contains combustion-generated air pollutants, ash particles, and volatile fuel contaminants. Liquid streams include the ash sluicing water, for coal-fired dry bottom boilers, the molten ash stream for wet bottom boilers, and the scrubber waste stream if a scrubber is used. Solids include hopper ash from particulate control devices, and bottom ash from boilers that do not use sluicing water.

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

Utility Sector (Field Erected Watertubes)	Fuel
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] (100 M 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

TABLE 2-1. Concluded

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
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 soaking pits and reheat ovens	

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

[a]Heat input

Typical operating conditions for utility boilers are: volumetric heat release of 104 to 250 kW/m^3 for coal-firing and 208 to 518 kW/m^3 for oil or gas boilers; furnace pressures from -50 to 1000 Pa; and excess air levels of 25 percent for coal, 10 percent for oil, and 8 percent for gas.

Trends in utility boiler design show pulverized coal becoming the dominant boiler fuel, with balanced draft combustion chambers increasingly being used. Also, in recent years orders for two boilers of moderate capacity have become more common than single orders for a very large boiler.

2.2 PACKAGED BOILERS

The packaged boiler category includes all industrial, commercial, and residential packaged boilers. Generally, these boilers have capacities less than 73-MW thermal input (250 MBtu/hr). There are only a few package boilers with larger capacity and these are sufficiently similar to the smaller units to be included in this category.

Packaged boilers are constructed in watertube, firetube, cast iron, and shell designs; each design has a fairly distinct capacity range. These boilers are fueled primarily by residual and distillate oil, natural gas, and stoker coal. In addition, liquid and solid waste fuels and process gases are sometimes burned.

Package watertube boilers span the larger capacity range of this equipment sector. A single burner generally is used, but multiple-burner units also exist. Burners are always mounted on a single wall. Although stoker-fired package watertube boilers currently make up less than 15 percent of the installed population, there is increasing interest in using them because of the desire to shift to coal-firing. Pulverized coal units are available currently, but generally are too expensive.

In firetube boilers, combustion products are directed from the combustion chamber through straight tubes submerged in water. Because they are sensitive to fouling, firetube boilers normally burn fuel oils and natural gas, rather than coal or other high ash fuels. Large firetube boilers burn mainly residual oil and natural gas, while smaller boilers burn natural gas and distillate oil.

The other types of package boilers (cast iron and shell boilers) are minor equipment types in terms of installed capacity. They are used primarily to supply low-pressure steam or hot water for air and water heating systems.

Flue gases usually are the only combustion-related effluent from packaged boilers. If pulverized or stoker coal, solid wastes, or other high ash fuels are burned, both liquid and solid effluents are produced when ash collection and flue gas cleanup systems are used.

Operating conditions for package boilers vary greatly according to equipment design, capacity, and application, and therefore only very general operating conditions can be given. Usually, these boilers operate at atmospheric combustion chamber pressure and at excess air levels somewhat higher than utility boilers. Combustion efficiency also is usually less than that of utility boilers.

Recent trends show a strong movement toward large capacity package watertube boilers with multifuel capabilities. In addition, pulverized coal boilers are becoming more commonly used in the large capacity range.

2.3 WARM AIR FURNACES AND OTHER COMMERCIAL AND RESIDENTIAL COMBUSTION EQUIPMENT

This source category is made up of residential and commercial warm air furnaces used for comfort heating, and miscellaneous commercial and residential appliances used in cooking, refrigeration, air-conditioning, clothes drying, and the like. Emphasis in the NO_x E/A has been on characterizing warm air furnaces, which come in two basic types: space heaters, where the unit is located in the room or area it heats; and central heaters, which use ducts to transport and discharge warm air into the heated space.

According to U.S. Census statistics for 1970, over 55 percent of the nation's heating units were warm air furnaces. About 67 percent of these units burned natural gas, while 23 percent burned distillate fuel oil. Coal, wood, and various bottled, tank, or LP gas accounted for the remaining 10 percent of fuel used. Despite a continuing trend recently toward burning natural gas in commercial and residential warm air furnaces, the fraction of equipment using this fuel is expected to drop from 37 percent in 1974 to 35 percent by 1985, and to 32 percent by 2000 (Reference 17).

Flue gases are generally the only combustion-related effluent from warm air furnaces. For rarely used, solid-fueled furnaces, solid waste consisting of dry ash would be produced.

One of the most important characteristics of all comfort heating devices is their cyclic operation. Typical residential warm air heaters go through two to four cycles per hour, with an overall on-time generally less than 50 percent. Cyclic operation is important for two reasons: first, emissions during startup and shutdown may be substantially higher than during continuous operation; and second, the thermal efficiency of these furnaces is substantially lowered by heat losses to the flue between cycles.

2.4 GAS TURBINES

Gas turbines are rotary internal combustion engines fueled mainly by natural gas, diesel or distillate fuel oils, and occasionally by residual or crude oils. These units range in capacity from 30 kW (40 hp) to 100 MW (134,000 hp) heat input and may be installed in groups for larger power output.

Gas turbines have been extremely popular in the past decade. They have relatively short construction lead times, low initial cost, light weight, low vibration level, ease and speed of installation, and low physical profile (low buildings, short stacks, little visible emissions, quiet operation). In addition, factors like remote operation, low maintenance, high power-to-weight ratio, and short startup time have added to their popularity.

Large-capacity gas turbines can range up to 100 MW (134,000 hp), while combined-cycle and multiple turbines can range up to 1230 MW. These equipment types are used almost exclusively by electric utilities. Medium capacity units have capacities up to 15 MW (2000 hp) and are generally used for standby electrical generation, pipeline pumping, and industrial power generation. Gas turbines less than 4 MW (5000 hp) capacity are used for pipeline pumping and standby electrical generation, but these units represent less than 5 percent of the total installed gas turbine capacity.

Stationary gas turbines are normally operated at constant speed and output. Combustion normally occurs at equivalency ratios of about 1.5 and at high pressure (up to 10 atmospheres).

Large gas turbine designs have recently tended towards higher capacities and improved heat rates. Because of their improved heat rate and fuel flexibility, combined-cycle turbines seem to be the preferred design for intermediate or base load applications in the future. Simple-cycle turbines will be preferred for peaking. Also, because of the trend in utilities (which purchase over 90 percent of the turbine capacity currently sold) toward larger turbines, and the movement in the oil and gas industry toward smaller turbines, fewer medium-capacity gas turbines will be sold.

2.5 STATIONARY RECIPROCATING IC ENGINES

Reciprocating IC engines for stationary applications range in capacity from 750 W (1 hp) to 48 MW (50,000 hp) heat input. These engines are either compression ignition (CI) units fueled by diesel oil or a dual-fuel combination of natural gas and diesel oil, or spark ignition (SI) engines fueled by natural gas or gasoline. These engines are popular because of their versatility, load following characteristics, high efficiency, and capability for remote operation. They are used for applications ranging from shaft power for large electrical generators and pipeline compressors to small air compressors and welders.

Large bore IC engines are typically high power, low or medium speed, 4-stroke CI units fueled by diesel oil or dual fuel. However, many natural gas-fueled 2- and 4-stroke SI units also exist in this capacity range. Dual-fueled engines and natural gas-fueled spark ignition engines account for 93 percent of all the fuel consumed by these large capacity engines. Most of these engines are used to drive compressors in the oil and gas industry.

The primary manufacturers of medium capacity units also make similar engines for trucks, tractors, and construction equipment. As a result, medium power stationary engines tend to be modified mobile engines, with rotative speeds greater than 1000 rpm. Engines in this capacity range usually burn either diesel or gasoline rather than natural gas. They are used mainly in construction, agriculture, and industry for shaft power, pumping, and compressing.

Small IC engines are mainly one- or two-cylinder units fueled by gasoline or occasionally diesel oil. They are used mainly for generator sets, refrigeration compressors for trucks and railcars, small pumps, and off-the-road vehicles.

Due to the extremely large number of designs, fuels, and applications, general operating characteristics of this source category are impossible to describe. Many factors, including air-to-fuel ratio, timing, fuel properties, compression radio, and chamber design, can influence combustion characteristics.

2.6 INDUSTRIAL PROCESS HEATING

Significant quantities of fuel are consumed by industrial process heating equipment in industries such as iron and steel production, glass manufacture, petroleum refining, sulfuric acid manufacture, and brick and ceramics manufacture. In addition, there are dozens of industrial processes such as coffee roasting, drum cleaning, paint curing ovens, and smelting of metal ores that burn smaller amounts of fuel. Fuels fired in these units include oil, natural gas, producer gas, refinery gas, and occasionally coal.

Because of the wide variety of equipment design types and fuels (especially "waste" fuels) used in this source category, few generalizations can be made. Therefore, only little effort in this program was devoted to characterizing this source class. Future efforts will characterize this category in more detail.

2.7 SUMMARY

The primary and secondary design types from the equipment categories above are summarized in Table 2-2. The primary design types were selected on the basis of design trends, and are projected to be in widespread use in the 1980's. Thus, they are candidates for applying NO_x controls. The secondary design types listed are those which are either diminishing in use or projected primarily for long term applications. In either case they will probably not require widespread use of NO_x controls in the near future.

The lists of effluent streams and significant operating modes on Table 2-2 were generally used throughout the emission inventories, and will be used later in ranking pollution potential from specific effluent streams. However, data on the frequency and specific process conditions of nonstandard operating modes were sparse.

Source characterization activities are continuing to define more precisely the high priority stationary sources of NO_x. These continuing efforts will:

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 turbofurnace	Cyclone, vertical, stoker	Stack gas, particulate catch, bottom 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; few new wet bottom, cyclones, stoker or vertical units
Packaged boilers	Watertube, 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 and trend to high efficiency in new units
Gas turbines	Utility and industrial simple and regenerative cycle	Combined cycle, 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

- Determine geographic distributions of equipment by fuel and firing type
- Refine trends in equipment design, sales, fuels, and conversion to alternate fuels
- Further characterize both liquid and solid effluents originating from stationary combustion sources
- Characterize nonstandard operating conditions in terms of frequency, duration, and effect on NO_x formation mechanisms
- Further characterize the industrial process heating sector

SECTION 3

CURRENT ENVIRONMENTAL BACKGROUND

The NO_x E/A involves separate assessments of the impacts of:

1. Multimedia pollutants from a single uncontrolled (for NO_x) source on human health and terrestrial and aquatic ecology
2. Multimedia pollutants from a single controlled source on human health and terrestrial and aquatic ecology
3. NO_x control strategies applied to sources in Air Quality Control Regions on ambient concentrations of NO_2 and oxidants

The assessment methodology for each of these consists of the following three elements:

- An emission inventory listing all multimedia effluents crossing the plant boundary (cases 1 and 2 above), or listing all NO_x emissions within an AQCR (case 3), including quantities emitted and temporal variations in emissions
- A transport analysis model which accounts for dispersion effects and chemical or physical transformations to estimate ambient concentrations
- A set of impact criteria which describes the set of acceptable ambient pollutant concentrations

NO_x E/A efforts to date have emphasized selecting suitable impact criteria. These criteria will be used in two ways. In some cases, a goal for emission levels or control system effectiveness will be specified, and the overall impact of this goal on the environment will be determined from the methodology. In other cases, a goal for pollutant ambient concentration will be specified and the requirements for emission levels or control systems will be determined from the methodology. These emission-based goals, together with health/ecology-based goals, are termed "Multimedia Environmental Goals" (MEGS).

The first year of the NO_x E/A has been spent establishing requirements for multimedia environmental goals, surveying pollutant effects research methods suitable for use in setting MEGS, and deriving preliminary health/ecology-based MEGS. The results of these efforts are summarized below.

3.1 MULTIMEDIA ENVIRONMENTAL GOALS DATA REQUIREMENTS

Ideally impact assessments in the NO_x E/A will need to consider potential pollutant impacts on:

- Human health through inhalation
- Human health through ingestion
- Aquatic plants and animals
- Terrestrial plant and animals

In these assessments, the impacts of oxides of nitrogen and secondary pollutants from NO_x (oxidants, nitrates) will be given special consideration, since they directly relate to the need for NO_x control systems. Material impacts and the impacts of noise and thermal pollution will be given secondary emphasis.

The MEGS data required in assessing the above impacts change as the program progresses. Initially, approximate impact screening concentrations are needed for the "universe" of potential pollutants emitted by sources under consideration. These screening concentrations, when compared to emission measurements or estimates, allow relative priorities to be set on sources, effluents, and pollutants. Subsequently, more detailed data on impacts and effects are needed to quantify impacts of the smaller class of sources, effluents, and pollutants given high priority in the program. At this stage, more precise analyses of potential secondary pollutants can also be made.

To date, the major effort in establishing MEGS has focused on developing the impact screening concentrations. Gaseous stream pollutants were emphasized since these include the vast majority of combustion-generated pollutants potentially affected by combustion modification NO_x controls. Initial surveys of dose-response data and discussions with pollutant impact researchers indicated that impact screening concentrations based largely on impacts on human health through inhalation would be most appropriate. These impacts are the most readily identified and quantified for gas stream pollutants. Impact on human health through ingestion depends heavily on site-specific food chain vectors, and cannot be easily generalized for screening purposes. Terrestrial and aquatic effects are also highly dependent on site-specific or regional conditions. These may be treated in the impact screening on a "worst case" basis, but such considerations offer little insight beyond that gained from using human health impacts through inhalation.

3.2 RESEARCH METHODS

A variety of research techniques has been used to evaluate pollutant toxicity. The following subsections discuss these techniques and their relevance to the current program. Research methods which evaluate human health effects are considered in the first subsection; aquatic and terrestrial effects are considered in the second.

3.2.1 Methods to Assess Ambient Pollutant Health Effects

Many research methods have been used to study the toxic effects of inhaled substances. These include long- and short-term laboratory animal studies, short-term human experiments, case reports and industrial hygiene reports, and epidemiologic studies on exposed workers and general communities. However, each of these methods is limited, and cannot unambiguously be used to estimate ambient exposure limits which protect the general population. For example, animal study is the only practical method for assessing long-term response to controlled exposure, but extrapolation to human effects is qualitative at best. Similarily, it is difficult to predict the effects of continuous long-term exposure from the results of short-term human experiments.

In view of the above, it is not surprising that the available data base on the health effects of pollutant exposure is quite limited. Clearly, it is not possible to identify with certainty an ambient concentration at which a particular health effect may be expected to occur. Conversely, it is also impossible to identify levels at which no adverse affect is expected. Indeed, for many substances considered, the published literature contains no accounts of human or animal exposures at levels that even approximate typical ambient concentrations.

Acknowledging the lack of suitable data, Research Triangle Institute (RTI) has developed a method for estimating permissible ambient concentrations for community exposure using occupational threshold limit values (TLVs) and animal LD50s (Reference 18). However, there are obvious limitations to basing permissible pollutant levels on TLVs and LD50s. For example, TLVs were established to protect a largely healthy, male adult population from intermittent exposure, whereas a permissible level should protect an entire community from continuous exposure. Likewise using animal LD50s to estimate allowable ambient levels is subject to all the difficulties inherent in extrapolating animal results to human effects.

RTI has taken these difficulties into account and has developed formulas to estimate what continuous pollutant exposure is hazardous to the health of the general public. The two equations used in the present study are $x = 1.65 \times 10^{-3}$ (TLV) and $x = 4.77 \times 10^{-5}$ (LD50) where x is defined as "the pollutant concentration (ug/m^3) for which continous exposure with 100-percent absorption causes a stationary maximum body concentration equal to 0.05 percent LD50 value of the compound, assuming a biological half-life of 30 days," and LD50 is the oral LD50 for rats.

RTI emphasizes that these estimated concentrations, x, are not applicable to known or suspected mutagens, carcinogens, or teratogens, and can be applied only to substances whose biological half-life is short compared to the average human life. In addition, these formulas, based upon a "one-compartment model with a single, first-order excretion rate," do not account for synergistic interactions between pollutants, and assume that all pollutants entering the respiratory system are retained by the body.

This approach is unavoidably simple since it makes many assumptions and uses a single expression to predict safety levels for a wide variety of pollutants. However, assumptions concerning rates of excretion, age differences in respiratory uptake, and corrections for the intermittent nature of occupational exposures are reasonable. On the other hand, assuming 100 percent absorption, even distribution of inhaled pollutants throughout the body, and the applicability of animal LD50 data to man may limit the usefulness of these calculations. Still, since no other data were available, the RTI formulas were used to generate the permissible ambient concentration levels used in the present effort.

3.2.2 Methods of Assessing Pollutant Impacts on Biota

The following three levels of evaluation are generally used to describe pollutant impact on terrestrial and aquatic biota:

- "First Estimate" Techniques, which include methods for making rapid (and preliminary) assessments of adverse effects specific chemicals may have on aquatic or terrestrial biota

- Experimental Establishment of Impact Concentrations, which includes appropriate methods for establishing experimental concentrations of specific chemicals which will cause lethal or sublethal damage in sensitive aquatic and terrestrial species

- Site-Specific Techniques, which are methods to determine whether pollutants at a particular site affect local aquatic and terrestrial ecosystems

Unfortunately all existing techniques are limited. For example, most approaches used to test a specific chemical have failed to evaluate interactive phenomena such as synergistic, additive, or antagonistic behaviors of other effluent stream chemicals. In addition, differences in the chemical tolerance of species in different areas remain unexplored. Pollutant effects on different life stages of a species are also often overlooked and sublethal effects are largely undetermined. Furthermore, effects of alternative culturing times and techniques, and the natural and acquired resistance natural populations have to particular pollutants remain unexplored. Because of these and many other limitations of available methods, conventional experimental techniques often produce data with little value for assigning "safe" or permissible levels of toxicity.

Moreover, certain site-specific techniques are rather crude and cannot incorporate the controls necessary to establish causative relationships when damage is noted. Because of these and other problems, data generated from all techniques have limited usefulness.

The current effort used only the very general first estimate procedures to set the limits derived. Future program work will rely more heavily on bioassay testing and site-specific techniques.

3.3 CONCENTRATION ESTIMATES FOR SCREENING COMBUSTION-RELATED POLLUTANTS

Using the methods described previously (and recognizing the limitations of these methods), and the available support information, preliminary screening concentrations were estimated for all potential combustion source pollutants identified. Screening concentrations were derived for both human health effects and for effects on terrestrial and aquatic biota and are reported in Reference 16. These data were then used for preliminary screening and setting priorities. The data assembled will be reviewed during subsequent impact assessment and test data collection tasks of the NO_x E/A. Results will be revised whenever new information requires. The presentation of only the calculated levels herein does not reflect the large volume of data on health effects which has been collected and reviewed.

The screening concentration values calculated were generated according to the RTI method discussed above (except when an ambient air standard existed and could be used instead). In most cases screening levels were based on occupational threshold limit values using the 8-hour, time-weighted average (TWA) TLV. In cases where a TLV was unavailable, concentrations were estimated from LD50s. Oral LD50 values for rats were preferred, followed by oral LD50 data for mice, and intraperitoneal and subcutaneous LD50s. In a few cases, TDLo (lowest published toxic dose) and LDLo (lowest published lethal dose) were used. Although the RTI formulas have been discussed previously, it should be repeated that these estimates are, at best, a rough approximation.

Subsequent to the above effort, a draft final report describing further RTI work was received (Reference 19). In general, this report extended and elaborated on the previous RTI work and largely encompassed the NO_x E/A work done to date. The methodology was essentially the same as reported previously, although the constants were changed slightly. For example, the latest report recommends $x = 2.38 \times 10^{-3}$ (TLV) in place of the previous $x = 1.65 \times 10^{-3}$ (TLV). Because of the greater scope and detail of these RTI activities, it was recommended that it be utilized instead for further work in the NO_x E/A program. This will also help in comparing the impact assessment portions of NO_x E/A to other environmental assessments sponsored by EPA/IERL-RTP.

3.4 SUMMARY AND CONCLUSIONS

The purpose of the environmental background task is to survey available pollutant impact data and from these, describe the approach and Multimedia Environmental Goals required to conduct impact assessments. A two-step approach has been selected. The first step uses approximate impact screening data for a large number of pollutant species. The second step entails a more detailed impact assessment for a smaller number of potentially hazardous pollutants.

A tentative list of screening MEGS has been compiled and used to set priorities on sources, controls, effluent streams and impacts. This list has recently been augmented with the RTI MEG data (Reference 20). Further NO_x E/A work in deriving impact screening MEGS will be limited. Most of the data will be supplied by RTI, with review to ensure that the results are appropriate for NO_x E/A assessments. The use of impact screening MEGS for ranking sources and pollutants will continue as new data become available.

Further environmental background effort centers on two tasks:

- Assess site-specific impact factors, such as regional food chain vectors, and regional terrestrial and aquatic ecology, to augment environmental alternatives analyses made using MEGS

- Survey the basis of existing standards and estimate further standards for long- and short-term exposure to NO_2, oxidants, nitrates, and other secondary pollutants for use in assessing the impact of applying NO_x control technologies

SECTION 4

ENVIRONMENTAL OBJECTIVES DEVELOPMENT

In the NO_x E/A, three assessments of pollutant impacts will be made:

- Baseline Source Analysis: Compare ambient multimedia pollutant concentrations from baseline (uncontrolled) stationary combustion sources to multimedia environmental goals (MEGS)
- Controlled Source Analysis: Compare ambient multimedia pollutant concentrations from sources controlled for NO_x to MEGS
- Environmental Alternatives Analysis (NO_x): Compare ambient concentrations of NO_2, resulting from using selected NO_x control strategies on a regional basis, to ambient air quality goals for NO_2

The first two assessments consider the impact from operating a single source and include all potential multimedia pollutants. The third assessment considers the impact from using NO_x controls on a variety of sources (typically within an Air Quality Control Region) but is restricted to NO_2 or NO_2-related pollutants, such as oxidants.

All three assessments are performed in three steps:

- Compile estimates of emissions and process data compatible with the multimedia environmental goals
- Estimate pollutant dispersion from a single source (for Baseline or Controlled Source Analyses) or from a group of sources in an AQCR (Environmental Alternatives Analysis) to relate ground level concentrations to source emissions, considering methodology, source configuration, and secondary transformations
- Generate emission based or health/ecology based MEGS for use as impact criteria

Various models are needed to relate these three steps in the methodology. The complete methodology to be used is described in the following subsections.

4.1 IMPACT ASSESSMENT PROCEDURES

Key components of the three assessments, baseline source analysis, controlled source analysis, and environmental alternatives analysis, are shown sequentially in Figure 4-1. This sequence is used iteratively throughout the NO_x E/A. In the first year, a preliminary pass through the sequence was made to set program priorities and identify data needs. This first pass is being followed by subsequent passes in which more refined models and more comprehensive emissions data and MEGS are used. Throughout the duration of the program, all assessments will be repeated as new data are obtained.

The baseline source analysis of each source serves two purposes. First, it identifies the pollutants emitted by each source category which should be evaluated further to see if a program to develop control technology is warranted. Such an assessment could include collecting additional emission data, conducting a careful dispersion analysis (or even a combined emissions and ambient air test program), or developing a better estimate of the health and welfare effects of the pollutant. Second, the baseline source analysis identifies data needs for detailed process engineering evaluations of NO_x controls. The multimedia assessment also will indicate sources that emit critical quantities of some pollutants, so that serious consideration can be given to sampling that kind of source.

The baseline multimedia assessment will use a Source Analysis Model (SAM) as described in Section 4.2. This model calculates a nationwide impact factor for each source type (e.g., horizontally-opposed coal-fired utility boilers) based on the relative importance of the ambient contribution of each emitted pollutant to predetermined permissible concentrations, existing ambient levels of those pollutants, the affected population, and the expected growth of the source type.

The Source Analysis Model is also used in the Controlled Source Analysis described in Section 4.3. In this analysis, however, more detailed consideration is given to site-specific effects such as the formation of secondary pollutants through atmospheric reaction, and regionally-dependent ecological conditions. The site-specific impact study will be conducted for fewer source/effluent stream/pollutant combinations than in the baseline source analysis. These combinations will be selected from priority ranking of potential environmental hazards using the SAM.

The Environmental Alternative Analysis is the final step in the assessment sequence. It uses the results of the source analysis models and process studies to show the most environmentally-sound and cost-effective NO_x control system for attaining air quality goals for NO_x. The environmental alternatives analysis is also iterative; a preliminary pass through the steps in this analysis has been conducted in the first year of the program. Both the preliminary and the more refined determination of the need for controls (based on attaining and maintaining NO_x-related ambient air goals) are being performed with the aid of systems analysis models, described in Section 4.4. Modified rollback was used for the preliminary evaluations and will continue to be the primary air quality model used in systems analyses. Weighting factors will be incorporated into this model to account for stack height,

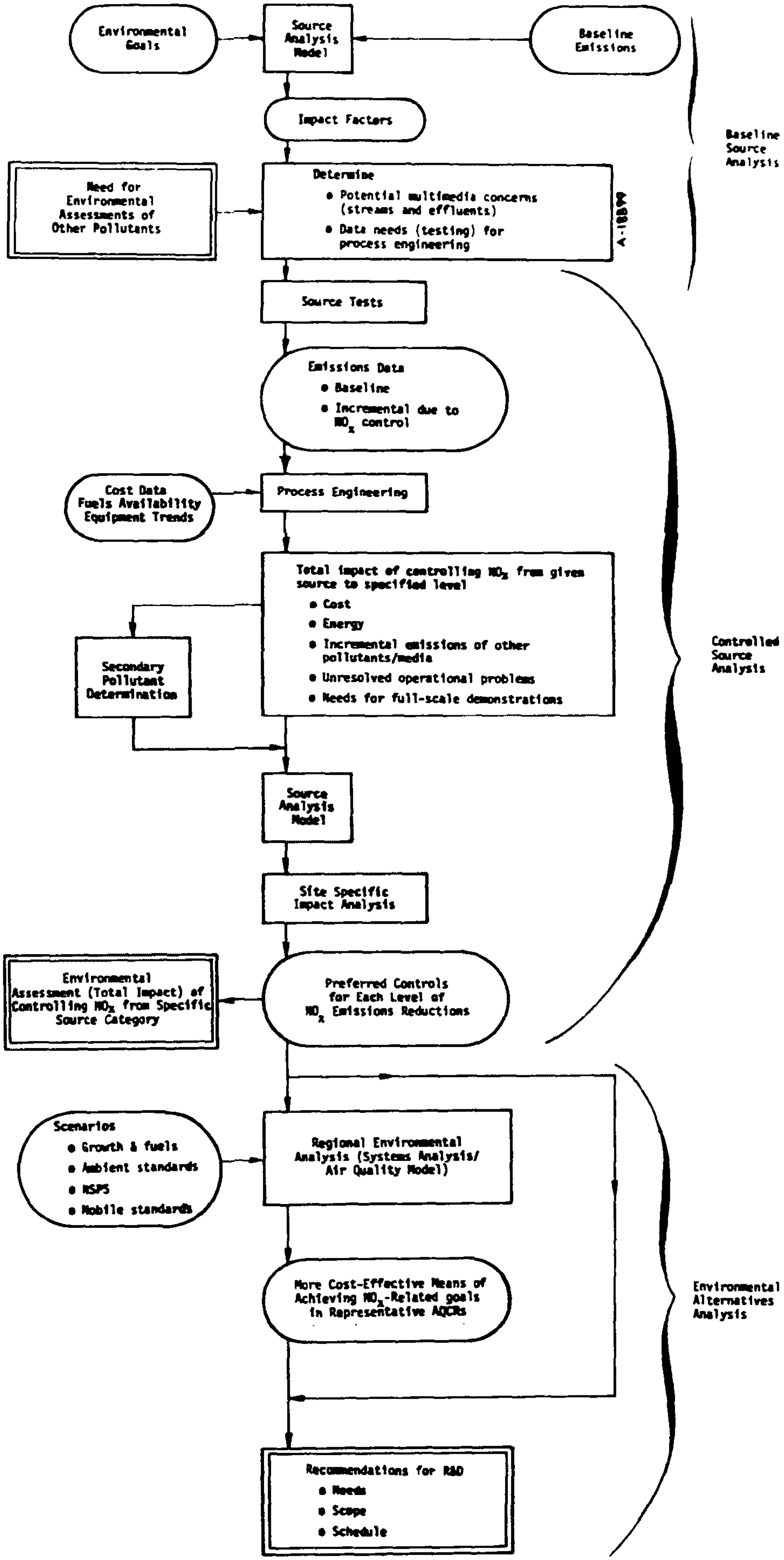

Figure 4-1. Impact assessment procedure.

patterns. These weighting factors will be derived from a limited application of photochemical dispersion models.

4.2 SOURCE ANALYSIS MODEL

The Source Analysis Model is primarily oriented towards a rapid assessment of the potential of a given source for impacting the environment. It considers the multimedia impact of each combustion source type under baseline operating conditions and, by comparing these individual assessments, ranks the sources in terms of overall pollution potential. The resulting list will guide the selection of sources for which control devices need to be developed or applied.

The following discussion describes the approach used for determining the impact of a given source type on the air, water, and land.

4.2.1 Air Impact

The impact of a gaseous effluent stream on air quality will be determined by calculating the impact of each pollutant species in the discharge and summing these individual impacts. The result is then multiplied by the number of people exposed to the effluent, to produce the impact factor for that source.

The first step is to identify a representative source with operating characteristics and physical dimensions typical of all sources in its class, (for example, wall-fired utility boilers/coal-fired). This model source would have a specific fuel consumption rate, ESP efficiency, stack height, etc. Using these data plus all necessary emission factors, the emission rate of each pollutant species is calculated. Then, using a Gaussian dispersion model (for point sources), or a Holzworth model (for area sources) the ground level concentration of each pollutant, X_{ij}, is calculated at or near the source. An intermediate indication of the relative impact of each species is given by the term

$$A_{ij} = X_{ij}/X_{Aj} \times \text{(area affected)}$$

where X_{ij} is the ground level concentration of pollutant j due to source i; X_{Aj} is a ground level concentration deemed sufficiently low to cause no harmful effects (the Research Triangle Institute-derived MEG values will be used); and the area affected is, for an area source, the ground area within which all of the sources are located. For a point source, the term takes on the form of an area integral of X_{ij}/X_{Aj} over the regions in which X_{ij} is an appreciable fraction of X_{Aj}:

$$A_{ij} = \int \left(X_{ij}/X_{Aj}\right) dA$$

where A is the area surrounding the source.

Other terms of interest can be calculated by replacing X_{ij} by $(X_{ij} + X_{jB})$, where X_{jB} is the ambient background of pollutant j near the source. This background concentration varies from region to region, but only two different values will be used: one representative of an urban area (X_{jBu}), the other of a rural area (X_{jBr}).

The resulting terms are:

$$B_{ij} = \int \left[(X_{ij} + X_{jBr}) \Big/ X_{Aj} \right] dA$$ (or the corresponding area source term)

and

$$C_{ij} = \int \left[(X_{ij} + X_{jBu}) \Big/ X_{Aj} \right] dA$$

where the integrals are taken over areas in which X_{ij} is an appreciable part of the background or in which X_{ij}/X_{Aj} is large. These intermediate impact terms calculated with the background terms result in a higher impact factor for sources which are preferentially located in high background regions.

Thus, A_{ij} is the impact due to source i of pollutant j by itself; B_{ij} is a measure of the importance of the pollutant in a typical rural setting; and C_{ij} is the corresponding measure for an urban location. A list of these factors for a particular source indicates which pollutants are a potential hazard.

The effect of all pollutants is then defined as the algebraic sum of the terms for each species:

$$A_i = \sum_j A_{ij}$$ = Unit impact of source by itself

$$B_i = \sum_j B_{ij}$$ = Unit impact of source in rural area

$$C_i = \sum_j C_{ij}$$ = Unit impact of source in urban area

The important effect of human exposure is incorporated by multiplying these cumulative impact factors by the population density (persons/square kilometer) in the exposed region and summing over the total number of urban and rural sources of type i:

$$I_i = (P_R) \cdot (NR_i) \cdot (B_i) + (P_u) \cdot (NU_i) \cdot (C_i)$$

where P_R and P_U are the average rural and urban population densities and NR and NU are the number of sources in rural and urban settings respectively. In addition, an impact factor for a single source of type i can be defined by dividing I_i by the sum of NR_i and NU_i. This new factor, I_i', still contains information on the urban/rural split of source locations.

These factors, I_i and I_i', can be used initially to rank sources in terms of their pollution potential. However, source growth rates and the estimated future trends in applying available control methods have not yet been considered, but are potentially significant. These factors will be included by doing a complete source ranking for the years 1977, 1985, 1990, and 2000, and comparing the resulting lists. In this way, the control R&D priorities can be qualified to account for sources growing or diminishing in importance.

4.2.2 Liquid and Solid Waste Impacts

Impact factors for liquid and solid effluent streams are much more difficult to determine using the above approach than those for air. Sampling data for liquid and solid waste streams are not nearly as complete as for gaseous streams, and the ultimate fate of the discharged pollutants is difficult to determine. For example, mercury waste might be sent to a settling pond where it could seep into the ground water and be absorbed by plants. The mercury in the plants could then be ingested by humans eating either the plants or meat from animals that have fed on the plants. The number of pathway scenarios for liquid and solid effluents are far more numerous than for air emissions and at present, we have no way of modeling the resulting dispersion by a method suitable for application in this assessment.

Therefore, we have resorted to calculating impact factors using the SAM/IA procedure (Reference 20). Here, the impact factor for a source is defined as

$$I = \sum_j [X_{ej}/X_{MATE}] \times F_e$$

where X_{ej} is the concentration of pollutant j in the effluent stream; X_{MATE} is a Minimum Acute Toxicity Effluent concentration determined by Research Triangle Institute (RTI) (Reference 19), and F_e is the effluent stream flowrate. The X_{MATE} values are suggested by RTI as effluent concentrations which, given minimal dispersion, will not result in harmful environmental impacts.

The results of these calculations will be used to rank the liquid and solid effluent streams.

4.3 ASSESSMENT OF INCREMENTAL IMPACTS DUE TO NO_x CONTROLS

The program efforts described above outlined our approach for assessing the baseline (uncontrolled for NO_x) environmental impact of stationary combustion sources. This section will describe the extension of baseline source impact rankings to include the incremental effects of applying combustion NO_x controls.

There are several reasons for describing incremental effects in greater depth. First, a major aim of the NO_x E/A is to assess the environmental soundness of current NO_x control technologies. Secondly, in the NO_x E/A, control technologies are to be ranked in order of preferred application based largely on relative environmental and technical soundness. Thirdly, we want to identify areas where future NO_x control R&D is needed to develop alternative or advanced control technologies to replace unsound technologies and/or increase controllability. Finally, we want to indicate areas where auxiliary control development is required to correct deficiencies in current NO_x technologies. To meet these goals, the incremental effects of NO_x controls on the environmental impact potential of stationary combustion sources must be determined.

Procedures to be followed in assessing the incremental environmental impacts from using NO_x combustion controls are analogous to those described for evaluating baseline source impacts. Thus, incremental emissions data will be compared to MEGS through the source analysis model (developed as described in Section 4.2) to yield controlled impact factors as a function of the type of control and the NO_x reduction achieved. Since preliminary screening efforts indicated that available data were mostly only qualitative (especially for noncriteria pollutants), we will rely heavily on the field test programs to supply needed information on incremental emissions effects. Of course, baseline emissions data obtained in these tests will be used to refine the baseline source impact ranking.

In performing the incremental impact analysis, it is important to realize that controlled source impact is significant only when related to baseline impact and, ultimately, to multimedia environmental goals. For example, a source may have small baseline impact but large relative incremental impact for a particular NO_x control. However, its controlled environmental impact may still be small, when compared to environmental goals. Conversely, a source with large baseline impact, but small relative incremental effects may still prove to be significantly more harmful when controlled for NO_x.

Incremental effects will be evaluated with the source analysis model for combustion-generated pollutants included in the baseline analyses. Thus, more emphasis will be placed on gaseous emissions. New pollutant species identified through the testing programs (through Level 1 bioassays and any subsequent Level 2 testing) will not be incorporated into the assessment model, however, any incremental effects noted will be qualitatively treated in the controlled impact evaluations. Similarly, secondary pollutant effects will be evaluated only qualitatively. Nonpollutant impacts, such as noise or thermal pollution, will only be considered superficially, since they are generally not significantly affected by NO_x combustion controls.

Incremental impacts will be assessed for the individual NO_x controls identified as major techniques in Section 8, and for commonly used combinations of control techniques.

To obtain a more complete controlled source impact evaluation, the source analysis model/impact factor assessment described above will be extended for selected cases by performing a set of site-specific impact analyses. Present plans are to specify representative synthetic sites. Typical site characteristics will be determined from knowledge gained while compiling the baseline emission inventory, modeling baseline impact, conducting the systems analysis, and developing AQCR scenarios. Detailed environmental impact analyses, for an appropriate stationary combustion source at the site, will then be performed through subcontracted effort. In general, two scenarios will be evaluated: a baseline, uncontrolled source scenario, and a fully NO_x-controlled (using current, major technology) source scenario.

Such site-specific analyses will provide more detailed impact information, such as more definite information on secondary pollutant impacts, and impacts on terrestrial and aquatic life. Such information will allow greater insight and a wider view of incremental NO_x control effects.

The final step will be to rank control technologies according to preferred application, and identify environmentally- and technically-sound control combinations. To develop this ranking, environmental impact evaluations will be combined with economic, operational, and fuel efficiency impacts obtained through the process/cost calculations. The ranking will take into account all aspects of control application. It will identify, for a single source class, the costs of NO_x control versus degree and effectiveness of control, along with incremental environmental impacts versus degree of control.

From this ranking it will be possible to identify research and development needed to:

- Accelerate development and demonstration of current, research-scale, far-term controls
- Increase basic research on new control concepts
- Develop auxiliary controls to alleviate adverse incremental impacts of current technology controls

This evaluation of NO_x controls for single source classes is the culmination of the process engineering studies. Issues relating to source category ordering for control, and more global control development needs are treated through systems analysis, described in the next section.

4.4 SYSTEMS ANALYSIS METHODS

The goal of the systems analysis is to provide a quantitative basis for identifying the needs for future NO_x controls and thereby specifying R&D direction for developing these controls. Although the rankings of control methods for a particular source (described in Section 4.3) are extremely valuable, they do not provide information on when a particular control method will be needed or on the order in which different sources should be controlled. This information will be supplied by the systems analysis.

In the systems analysis, the costs and fuel impacts for controls for all sources are combined with predictions of air quality for a particular AQCR to evaluate the cost and effectiveness of a control strategy. This subsection discusses the methodology for the systems analyses: first, the development and content of the systems analysis, then procedures for using the model.

4.4.1 Model Development

The function of the systems analysis model is to combine the various elements that must be considered in evaluating a control strategy. These elements include the emission levels, controls data, controls prioritization, fuels data, and air quality predictions, as shown schematically in Figure 4-2. The evaluation of the control strategy is then made based on the cost of the control strategy and its resulting air quality (primarily NO_2 concentration).

The most critical element in the system analysis model is the air quality model. Candidate models differ not only in their degree of sophistication, but also in their resolution and versatility. Usually, the sophisticated models require more elaborate input data than the simpler models, a significant amount of calibration, and considerable experience to use them intelligently. On the other hand, the simpler models, which try to model the atmospheric processes in an integral manner, are based on many correlations of the available data and lack the resolution of the sophisticated models.

During the first year of the NO_x E/A, the systems analysis has been used primarily for screening and preliminary prioritization of control methods. A modified form of rollback was used to reduce the amount of emission data needed, minimize computation costs, and provide maximum flexibility in the initial phases of the analysis. Furthermore, only the NO_x-NO_2 relationship was considered, and thus, HC emissions data did not need to be collected.

The rollback model used here is given by

$$AC = k\left(\sum_i (1 - R_i)\ E_i W_i\right) + BG$$

where AC = ambient concentration (NO_2)

E_i = uncontrolled emissions from source i

R_i = reduction by control of source i

W_i = weighting factor for source i

BG = background concentration (the background concentration has been assumed to be 10 $\mu g/m^3$ for all cases)

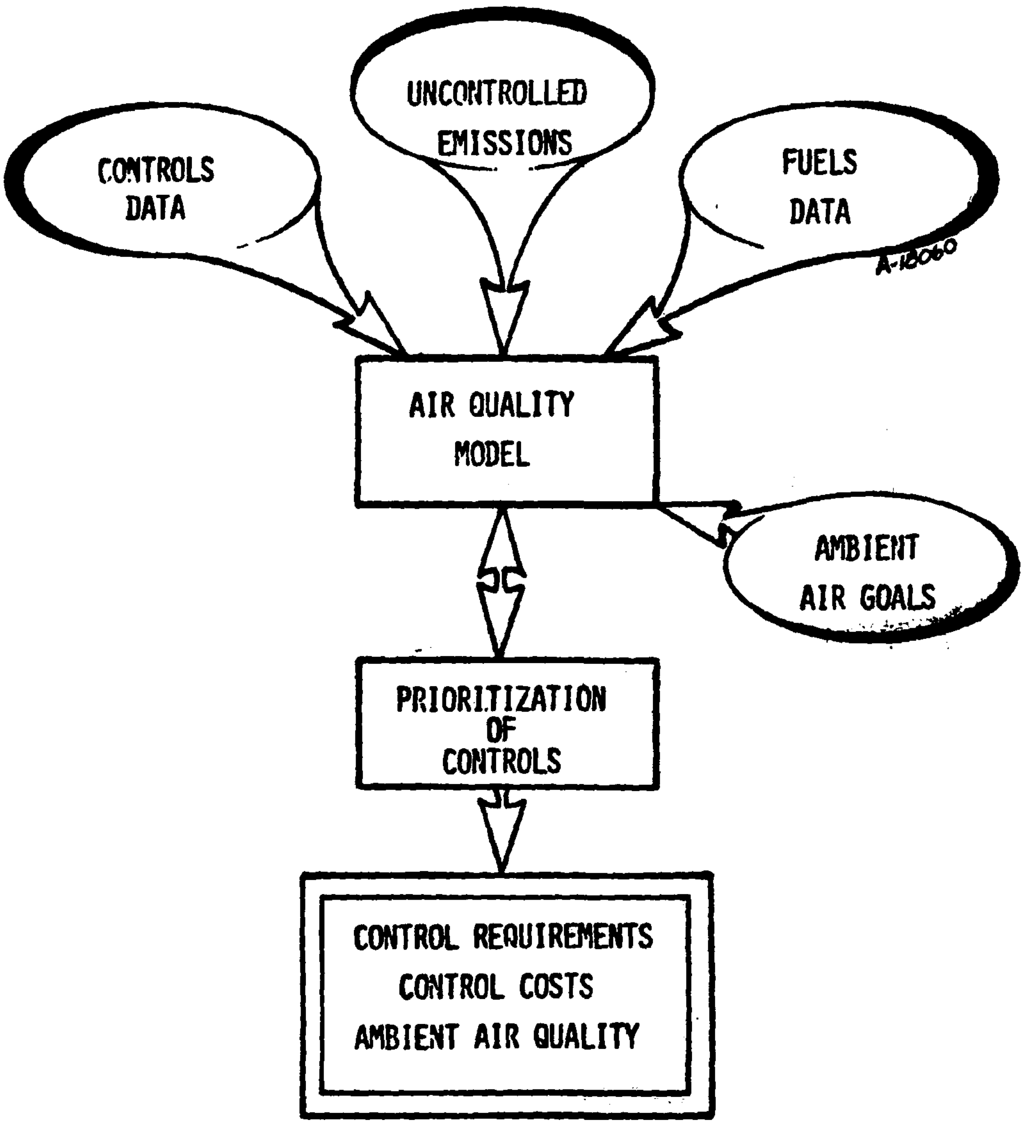

Figure 4-2. Elements of the systems analysis model.

The calibration constant, k, is determined by evaluating the equation at some "base year" for which the ambient concentration, and emissions, are known (R_i = 0).

Although factors such as stack height and relative position of source and receptor are not explicitly included in the model, they are implicitly included because the model is essentially a correlation between existing emission patterns and the resulting ambient air conditions. Moreover, in the present formulation it is possible to specify the relative importance of each source type by using the weighting factors. For example, in an AQCR with a large mixing height, emissions from elevated sources are widely dispersed and, therefore, do not have the same impact on ground level concentration as the same amount of ground level emissions. Thus, a source weighting factor less than 1.0 could be assigned to the elevated sources (e.g., powerplants) to account for stack height.*

Future program work will extend the systems analysis model to include photochemical transport models for the air quality predictions. Including photochemical transport will make the systems model more complex, but will allow geographical distribution of emissions, stack height, and meteorology to be treated directly. Both Lagrangian and Eulerian forms will be considered. Models of this form predict 1-hour NO_2 and oxidant concentrations for specific days. These short-term concentrations can be extended to annual averages by statistical methods. Because of expense, these more sophisticated models will be used only to examine selected cases. The results will be used to validate and calibrate rollback calculations.

4.4.2 Model Application

Since the intent of the systems analysis is to guide NO_x control research activities, a wide variety of emission and ambient concentration combinations must be considered so that the results are relevant to the national NO_x problem. In this subsection the rationale is presented for selecting the AQCRs to be examined and for choosing the growth scenarios. In addition, the sensitivity analysis that verifies the predictions is described.

Although air pollution in each of the 247 Air Quality Control Regions (AQCRs) is characterized by widely varying combinations of emissions sources and meteorological conditions, analysis of NO_x control strategies for each AQCR is impractical and unwarranted. Therefore, the number of AQCRs to be considered was reduced as follows:

- Identify air pollution characteristics, including meteorology, emissions, ambient air quality levels, and data availability

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*Each choice of weighting factors is equivalent to choosing a different model for the AQCR. In all cases the model must be calibrated for the base year (calculate k) before future year projections are made.

- Group AQCRs according to these air pollution characteristics

- Select one AQCR to represent each group for further analysis

The group of AQCRs to be considered was limited to those which have, or are expected to have, a NO_x problem between now and the year 2000. Each of these regions belongs to one of the following groups:

- Priority AQCRs -- AQCRs with ambient NO_2 concentrations currently exceeding the NO_2 standard when averaged over any consecutive four quarters (i.e., a rolling quarter basis rather than the statutory calendar year basis)

- Air Quality Maintenance Areas (AQMAs) -- Regions with a high probability of exceeding the standard by 1985

OAQPS has identified 30 regions which fall into these two categories (Reference 21). Although using the "rolling-quarter" method will place more regions into the priority category, it has the advantage of providing a conservative approach to identifying potential control requirements and is consistent with OAQPS thinking.

The air pollution characteristics of each AQCR for grouping purposes included: mobile versus stationary source emissions distribution, fuel type which produces the majority of stationary source NO_x emissions, dominant stationary source type, HC/NO_x emission ratio, ambient oxidant and NO_x levels, solar insolation, stability class, and quality and detail of available emissions data. Data for each of these properties are shown in Table 4-1 for the 30 NO_2-sensitive AQCRs identified by OAQPS. Three unsuccessful attempts were made to divide the AQCRs into distinctive groupings: the first sought a relationship between high mobile emissions and high NO_x/HC ratios; the second a correspondence between a high HC/NO_x ratio, a high ozone level, and a high solar insolation level; and the third a relation between high mobile emissions and high ozone levels. None of these attempts produced significant correlations. However, correlations were obtained when the regions were separated into the four groups shown in Table 4-2. The criteria for this grouping were the mobile/stationary source mix, the major stationary source type (utility or industrial), and the major fuel type responsible for NO_x emissions. All of these factors directly affect selecting the most suitable control methods for reducing NO_x emissions effectively.

The preliminary screening of control technologies considered only Los Angeles and Chicago. These are logical choices for a limited analysis, since they are the two most NO_x-critical AQCRs in the country (see Table 4-1) and they represent two opposite categories -- one is mobile source dominated, the other is stationary source dominated. St. Louis and New York City may be assessed in subsequent analyses.

TABLE 4-1. AIR POLLUTION CHARACTERISTICS OF THE NO_x IMPACTED AQCRs AND AQMAs

T-157a

City	AQCR Number	Mobile Stationary[a] (%)	Dominant Fuel[b] (%)	Stationary Combustion[c] (%)	Gifford Pasquill Stability Class[d]	HC/NO_x Ratio	NO_2 (μg/m³)	1 Hour O_3[e] (μg/m³)	Solar Insolation[f]
Los Angeles	24	66.0-M	38-G	72. -U	45%-D	1.649	182	376	H
Chicago	67	63.9-S	42-C	56. -U	58%-E	1.071	121	193	L
Philadelphia	45	54.8-S	53-0	55.6-U	—	1.142	121	157	L
Canton	174	56.4-S	80-C	55.6-U	—	1.438	120	95	L
San Diego	29	70.1-M	54-G	78.4-U	46%-D	1.678	119	189	H
Baltimore	115	58.9-M	61-0	63.9-U	49%-D	1.805	116	66	M
Detroit	123	52.5-S	62-C	65. -U	66%-D	1.340	115	115	L
Salt Lake City	220	54.3-M	33-G	58.7-I	48%-D	0.917	114	99	M
Springfield	42	54.0-M	66-0	55.3-U	—	1.308	113	341	L
New York City	43	61.2-S	82-0	56.3-U	51%-D	0.975	113	211	L
Denver	36	54.3-M	58-C	45.3-I	41%-D	0.987	110	176	M
Richmond	225	66.0-S	62-0	68.8-U	46%-D	0.917	103	181	M
Phoenix	15	76.1-M	70-G	72.7-U	46%-E	1.604	101	117	H
San Francisco	30	70.4-M	42-0	43.5-U	56%-D	1.471	101	163	M
Boston	119	53.5-S	94-0	48.6-U	70%-D	1.348	100	175	L
Atlanta	56	55.2-M	52-C	77.0-U	46%-D	1.122	100	157	M
Louisville	78	78.9-S	85-C	80.6-U	51%-D	0.843	96	122	M
St. Louis	70	75.0-S	72-C	88.3-U	57%-D	0.615	85	250	M
Cincinnati	79	56.8-S	79-C	69.9-U	—	0.972	83	118	M
Lansing	122	64.3-S	47-C	95.3-I	—	0.966	90	—	L
Dayton	173	57.3-M	67-C	51.9-U	57%-D	1.373	90	226	L
New Orleans	106	77.0-S	54-G	67.0-I	39%-D	1.171	83	136	M
Minneapolis	131	57.5-S	55-C	75.4-U	59%-D	0.632	84	190	M
Steubenville	181	90.1-S	63-C	62.8-U	—	0.139	98	107	L
Memphis	18	58.2-S	64-C	77.4-U	47%-D	0.801	81	—	M
Charleston, W. Va.	234	88.4-S	95-C	94.7-U	48%-D	0.199	85	127	M
Milwaukee	239	53.3-S	63-C	69.5-U	65%-D	2.519	81	—	L
Washington, D.C.	47	55.0-M	48-0	71.5-U	51%-D	1.052	80	180	M
Pittsburgh	197	77.1-S	90-C	83.4-U	66%-D	0.416	98	199	L
Youngstown	178	53.6-S	77-C	63.6-U	63%-D	0.855	96	226	L

[a]M — Mobile
S — Stationary

[b]Dominant source of NO_x by fuel type, % of stationary source NO_x emissions
G — Natural Gas
0 — Oil
C — Coal

[c]U — Utility
I — Industrial

[d]These values represent the percent occurrence of the dominant stability class within each AQCR.

[e]Basin average of 99 percentile measurements

[f]Average daily solar insolation:
H ≥ 16.7 MJ/m²
M ≥ 12.5 MJ/m²
L < 12.5 MJ/m²

TABLE 4-2. CHARACTERISTIC GROUPS OF NO_x IMPACTED AQCRs and AQMAs

	NO_x[a]	HC/NO_x[b]	Ozone[c]
1. Stationary – Oil – Utility			
New York City	H	H	M
Richmond	H	H	L
Boston	H	H	L
Philadelphia	H	H	L
2. Stationary – Coal – Utility			
St. Louis	M	M	M
Louisville	M	M	L
Cincinnati	M	H	L
Minneapolis	M	M	L
Steubenville	M	L	L
Memphis	M	M	--
Charleston	M	L	L
Lansing[d]	M	H	--
Pittsburg	M	L	L
Youngstown	M	M	L
3. Stationary – Coal – Utility			
Chicago	H	H	L
Canton	H	H	L
Detroit	H	H	L
Milwaukee	M	H	--
4. Mobile			
Los Angeles	H	H	H
San Diego	H	H	L
Baltimore	H	H	L
Salt Lake City	H	H	L
Springfield	H	H	H
Denver	H	H	M
Phoenix	H	H	L
San Francisco	H	H	L
Atlanta	H	H	L
Dayton	H	H	M
Washington	H	H	L

[a]High: $NO_x \geq 100$ µg/m³; Medium: $NO_x < 100$ µg/m³.

[b]High: $HC/NO_x > 0.9$; Medium: $0.45 < HC/NO_x \leq 0.9$; Low: $HC/NO_x \leq 0.45$.

[c]High: $300 \leq$ Ozone < 400 µg/m³; Medium: $200 \leq$ Ozone < 300 µg/m³; Low: $100 \leq$ Ozone < 200 µg/m³.

[d]Lansing is shown in Table 7-3 to be industrial dominated. Since no utility emissions were reported, it was decided to place Lansing in Group 2.

Once an AQCR has been selected for analysis, its base year emissions must be projected to a future year. The choice of scenarios for projecting growth may heavily influence the control levels required. We have selected scenarios that represent reasonable bounds for both mobile and stationary source growth. Generally, growth rates apply to an end-use sector, such as industrial or residential; however, in this analysis they have been extended to each source within the sector. Whenever possible, growth rates specific to an AQCR are used. If specific AQCR rates are not available, state, regional or national rates are used. In addition, the influence of population growth and any local limitation on new source growth are considered. Two basic scenarios were selected for stationary sources. One case represents a moderately conservative growth influenced by conservation measures and rising energy costs, and is reasonably likely to occur. The other represents a higher growth rate closer to historical patterns. This case represents a reasonable upper bound on stationary source growth.

The growth rates of emissions from mobile sources were treated differently, since a detailed investigation of mobile source control options is not of direct interest to this study. However, the emissions contributions of the mobile sources were needed, thus two representative scenarios were used. One scenario (the nominal case) was selected to reflect historical growth in vehicle population and miles traveled, as well as a moderate emission standard. The alternate, or low, case was for a reduced growth rate (closer to the population growth rate) and an emission standard of 0.25 g/km.

The last step in the methodology is a sensitivity analysis that establishes the sensitivity of the systems analysis results to the various assumptions and input data. Part of the sensitivity can be accounted for by considering several AQCRs and growth scenarios, as discussed above. This ensures that the predicted NO_x control levels will be responsive to the majority of NO_x-critical situations which may develop in the future.

Other factors must also be considered, though. One is the choice of the air quality model. The two models discussed in Section 4.4.1 -- source weighted rollback and photochemical transport -- are very different in terms of complexity and level of physical detail. A second sensitivity consideration is in the choice of parameters used within the air quality model. As was mentioned in Section 4.4.1, source weighting factors in modified rollback models can be used to examine the sensitivity of the results to the weighting of each source. For the photochemical models, the sensitivity of the results to the initial ambient concentrations and meteorology must be considered. For both the rollback and photochemical models, the sensitivity to the base year calibration of the model also must be examined. A change in the base year calibration has the same effect as choosing a different growth scenario. These factors were considered in applying the systems model.

Applying the systems model to the selected AQCRs, including a variety of growth scenarios and model sensitivities, results in a range of control requirements for meeting future air quality goals. The requirements include the level of control necessary for the various sources, the time frame for applying these controls, and which controls are the most cost-effective. Specific results to date are presented in Section 8.

SECTION 5

CONTROL TECHNOLOGY BACKGROUND

The control technology assessment in the NO_x E/A will compile and evaluate process data to provide environmental assessments of combustion modification control technologies. The overall objectives of the assessment are to:

- Characterize current and advanced NO_x combustion process modifications and project schedules for applying them
- Assess the technical and environmental soundness of these control technologies
- Recommend R&D for filling in technological gaps and producing needed data
- Provide objective evaluations of important aspects of NO_x control systems

The results will be documented in a series of reports covering the seven major stationary source equipment categories.

The main efforts to date have involved characterization and preliminary assessment of NO_x combustion modification control technology. This assessment identified the source/control combinations most likely to be used widely in the near future and projected the effectiveness, cost, and schedule of advanced emerging techniques being developed. The results were used to determine the source/control priorities of both near- and far-term control applications for the seven main equipment categories. The results from the preliminary assessment are summarized in the following subsections.

5.1 STATUS AND PROSPECTS OF CONTROL REQUIREMENTS

The incentive for developing NO_x controls derives from two separate regulatory mechanisms: the Federal Standards of Performance for New Stationary Sources (NSPS) and the State Implementation Plans (SIPS). The NSPS are intended largely to assist in maintaining air quality by offsetting increases due to source growth. EPA sets NSPS from time to time, based on the best systems of reducing emissions. Part of the effort to develop NO_x controls is directed at developing and demonstrating the best systems of reducing emissions in support of the setting of future NSPS. The primary responsibility for attaining and maintaining air quality rests with the states. If emission standards in addition to the NSPS are required to attain and/or maintain the National Ambient Air Quality Standards in Air Quality Control Regions within the jurisdiction of the states, these standards are set through SIPS. Therefore, another part of the effort to develop NO_x controls is directed at facilitating compliance with these standards.

All Federal, state, and local standards for NO_x -- both current and impending -- are based on combustion process modifications. To date, Federal NO_x standards have been set only for utility and large industrial boilers. These standards have been based largely on demonstrated technology retrofitted to sources in areas with attainment problems. A more stringent standard is being considered for coal-fired utility boilers, based on technology demonstrated since 1971. However, revised, more stringent standards are not being considered for new gas- or oil-fired utility boilers, since no units of this type are being sold. The Federal standard recently proposed for gas turbines is also based on retrofit technology demonstrated as part of SIPS. Federal standards under study for IC engines and industrial boilers are being based on EPA and private sector control development since there have been few retrofit controls used on these sources.

Maintaining air quality in the 1980's and 1990's may require Federal NO_x regulations in addition to those existing or planned. New source controls will be emphasized, since experience has shown them to be more effective, less costly, and less disruptive than retrofitting controls on existing equipment. Thus, EPA's Office of Air Quality Planning and Standards anticipates additions to the existing Federal standards. These additions may include standards for sources not presently regulated, as well as more stringent standards for sources with current or impending controls.

5.2 COMBUSTION PROCESS MODIFICATION TECHNOLOGY

As a result of emission control regulations for new and existing stationary sources, NO_x control techniques have been developed and implemented in the past 10 years. Nearly all current NO_x control applications use combustion process modifications. Other approaches, such as modifying or switching fuels, using alternate energy systems, and treating post-combustion flue gas, as well as more advanced combustion process modifications are being evaluated for potential future use. Experience has shown that the applicability and effectiveness of combustion process modifications depend on the specific equipment/fuel combination to be controlled, and on whether the control is to be applied to existing field equipment or new units. Accordingly, control development is focusing on specific equipment categories and fuel types. In general, the following sequence of control development is being pursued for each major equipment/fuel category:

- Minor operational adjustments
- Minor retrofit modifications

- Extensive hardware changes, either retrofit or factory-installed on new units of conventional design

- Major redesign of new equipment

Progress made in this sequence varies with the importance of the source in local and national NO_x regulatory strategies.

Currently, modifying combustion process conditions is the most effective and widely-used technique for achieving 20- to 70-percent reduction in combustion-generated oxides of nitrogen. These modifications include:

- Low excess air firing
- Flue gas recirculation
- Off-stoichiometric combustion
- Load reduction
- Burner modifications
- Water injection
- Reduced air preheat
- Ammonia injection

The following paragraphs summarize the status of each of these controls.

Low Excess Air Firing

Changing the overall fuel-air ratio is a simple, feasible, and effective technique for controlling NO_x emissions from all stationary sources of combustion except gas turbines. For some sources, such as utility boilers, low excess air (LEA) firing is currently a routine operating procedure and is incorporated in all new units. Since it is energy efficient and easy to implement, LEA firing will be increasingly used in other sources. However, most sources will have to use other control methods, in conjunction with LEA, to meet NO_x emissions standards. In such cases, the extent to which excess air can be lowered will depend upon the other control techniques employed. Virtually all programs for developing advanced NO_x controls are emphasizing operating at minimum levels of excess air. Thus, LEA will be an integral part of nearly all combustion modification NO_x controls, both current and emerging, to be assessed in the NO_x E/A.

Flue Gas Recirculation

The primary near-term application of flue gas recirculation (FGR) is in gas- and oil-fired utility boilers. Future applications are limited. FGR may be used in industrial boilers as a retrofit or in new designs, but alternate approaches, such as low-NO_x burners and off-stoichiometric combustion, also are being evaluated and may prove more attractive. Techniques other than FGR are more effective for coal-fired utility boilers, gas turbines, and warm air furnaces. The effectiveness of FGR with process furnaces is under evaluation.

Off-Stoichiometric Combustion

Off-stoichiometric combustion (OSC) is a widely used technique for controlling thermal and fuel NO_x from large boilers. Near-term uses of OSC to be considered in the NO_x E/A include retrofitting on gas-, oil- and coal-fired utility boilers and using factory-installed equipment on new coal-fired utility boilers. Potential future applications to be considered include using factory installations on new industrial boilers and using advanced staging techniques for major redesigns of utility or industrial boilers.

Load Reduction

Load reduction/enlarged firebox techniques may be used in the near term as retrofits to gas- and oil-fired utility boilers and as new designs for coal-fired utility boilers. Load reduction also may be used on new and existing industrial boilers as standards are set. Because of economic and operational penalties, load reduction for existing boilers is unattractive, and is used only as a last resort to achieve compliance with standards.

Burner Modifications

New, optimized-design burners appear to be capable of reducing NO_x emissions 40 to 65 percent with gas and oil fuels. Similar, or greater, reductions are being demonstrated on prototype coal-fired units. The new low-NO_x burners are designed to mix fuel and air in a controlled pattern that sustains local fuel-rich regions, keeps the flame temperature down, and dissipates the heat quickly. Improved burner designs may well replace the external combustion modifications now in use and produce significantly lower NO_x emissions. Thus, although low-NO_x burners have limited use currently, they will be emphasized in the NO_x E/A for both near- and far-term application.

Water Injection

Water injection has been found to be effective in suppressing NO_x emissions from gas turbines and IC engines. However, water injection may decrease thermal efficiency, increase equipment corrosion, and cause other undesirable operating conditions. Therefore, it is anticipated that water injection will be replaced by advanced combustor design in the long term.

Reduced Air Preheat

Reduced air preheat for gas turbines and for boilers is not a practical way to control NO_x unless the energy in the exhaust gases can be used effectively for other purposes, such as in combined gas-steam turbine cycles. Reduced air preheat will thus be accorded low priority in the NO_x E/A because of associated efficiency losses.

Ammonia Injection

Ammonia injection does not appear to have significant near-term application for NO_x control in the U.S. However, it shows promise for far-term applications and will be given primary emphasis in the NO_x E/A for assessment of advanced concepts for the 1980's and 1990's.

5.3 ALTERNATE CONTROL TECHNIQUES

In addition to combustion modifications, NO_x can be controlled by one or more of the following techniques: flue gas treatment, fuel denitrification, fuel additives, alternate or mixed fuels, or advanced, low-NO_x combustion concepts. Each of these is briefly discussed below.

Flue Gas Treatment

The dry flue gas treatment (FGT) techniques used in Japan -- notably selective catalytic reduction with ammonia -- can probably be applied to gas- and oil-fired sources in the U.S. However, more pilot and full scale demonstration tests are needed before full application of dry processes is possible on these sources. Dry processes have yet to be demonstrated on coal-fired sources, although pilot-scale tests are currently planned. Wet processes are less well developed and more costly than dry FGT processes; however, wet processes have the potential to remove NO_x and SO_x simultaneously. Again, pilot-scale research and field tests are needed to determine costs, secondary effects, reliability, and waste disposal problems. Flue gas treatment holds some promise as a control technique if very stringent emissions standards make it necessary to greatly reduce NO_x. However, even in these instances FGT will probably be employed to supplement combustion modification.

Fuel Denitrification

Fuel denitrification of coal or heavy oils could, in principle, be used to control the component of NO_x emissions produced by the conversion of fuel-bound nitrogen. The most likely use of fuel denitrification would be to supplement combustion modifications that reduce thermal NO_x. Currently denitrification occurs only as a side effect of pretreating fuel to remove sulfur, ash, or other pollutant precursors. Preliminary data indicate that 30- to 40-percent reductions in fuel nitrogen result from oil desulfurization (Reference 22). Since these processes produce low denitrification efficiencies, they are not attractive solely for controlling NO_x. However, they may prove cost effective in terms of their total environmental impact.

Fuel Additives

Results of recent studies on fuel additives for NO_x control have been mixed. In some cases, additives significantly reduced NO emissions, while in other studies they did not. Overall, using additives for controlling NO_x is not attractive since they add to cost, cause serious operational difficulties and may lead to other flue gas pollutants. However, it has been proposed that some fuel additives may provide a peripheral benefit, by allowing increased flexibility in using combustion modification techniques.

Alternate or Mixed Fuels

Using alternate or mixed fuels to control NO_x is contingent in part on the trade-off between the costs of producing synthetic fuel and the total costs of controlling NO_x, SO_x and particulates in conventional coal firing. There is preliminary evidence that gasification may be more costly than flue gas cleaning of conventional utility systems (Reference 23).

Advanced Combustion Concepts

For new combustion systems, the combustion control technology derived from retrofitting existing units can be incorporated with new concepts not applicable for retrofit into designs optimized for low-NO_x production. This approach produces designs that potentially lower costs and are more effective than extensive retrofitting of existing units. Alternatively, the economics of using lower quality fuels necessitated by the clean fuels shortage may dictate using alternate combustion process concepts. Some concepts, such as catalytic combustion, fluidized bed combustion, and gasifier combined cycles, are being developed for their potential not only to increase system efficiency, but also to reduce total system emissions. Other alternate concepts, such as repowering and high-temperature gas turbines, are being developed mainly to increase the efficiency of current technology to reduce fuel consumption.

5.4 OVERALL EVALUATION AND CONCLUSIONS

The results of characterizing current and emerging control technology for the major equipment categories, briefly discussed above, are summarized in Table 5-1. These results show that both current and emerging technologies are also centered around combustion modifications. Other approaches, such as flue gas treatment, may be used in the 1980's in addition to combustion modification if required by more stringent emissions standards.

The level of combustion modification control currently available for a given source depends on the importance of that source in the regulatory program. Utility boilers have been the most extensively regulated and

TABLE 5-1. SUMMARY OF NO_x CONTROL TECHNOLOGY

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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	
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)	7-9¢/(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

TABLE 5-1. CONTINUED

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Equipment/ Fuel Category	Current Technology: Available Control Technique	Achievable NO_x Emission Level ng/J (lb/10^6 Btu)	Estimated Differential Annual Cost	Operational Impact	Emerging Technology: Near Term 1977-1982	Far Term 1983-2000	Comments
Stoker-fired industrial watertube boilers	LEA + OFA	150-190 (0.35 - 0.45)	9-11¢ (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)	7-9¢/ (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)	30-65¢/ (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

TABLE 5-1. 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, exhaust gas treatment	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

T-155a

accordingly, control technology for these boilers is the most advanced. Available technology ranges from operational adjustments, such as low excess air and biased-burner firing, to including overfire air ports or low-NO_x burners in new units. Some adverse impacts on operation have been experienced when combustion modifications have been used on existing equipment. In general, these problems have been solved by combustion engineering or by limiting the degree to which controls are used. Factory-installed controls on new equipment have produced only minimal operational problems.

Technology for other sources is less well developed. Control techniques effective for utility boilers are being demonstrated on existing industrial boilers. Here, as for utility boilers, the emphasis in emerging technology is on developing controls for new unit designs. Advanced low-NO_x burners and/or advanced off-stoichiometric combustion techniques are the most promising concepts for these boilers and 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 different types of industrial process equipment is in the preliminary stages and to date, only minor operational adjustments have been tried.

Continuing program efforts in the NO_x E/A will seek to extend and strengthen the background data for NO_x control process technology assembled to date. Emphasis will be given to tracking ongoing demonstration and testing of near-term control techniques, as well as to following the development of advanced controls and alternate combustion concepts.

SECTION 6

CONTROL TECHNOLOGY ASSESSMENT

A primary aim of the NO_x E/A program is to extend the process technology background discussed in Section 5 to include evaluations of the emissions and source performance impacts associated with applying these controls. In this respect the initial process data compilation serves to set the stage for further assessment efforts. This section discusses the NO_x E/A approach and efforts to perform more definitive control technology evaluations.

6.1 PROCESS ENGINEERING APPROACH

Evaluating the impacts of NO_x combustion modification controls applied to stationary combustion sources requires assessing their effects on both controlled source performance, especially as translated into changes in operating costs and energy consumption, and on incremental emissions of pollutants other than NO_x. To perform such an evaluation it is necessary to:

- Relate the application of preferred (major) NO_x controls to changes in multimedia pollutant emissions through the primary combustion parameters affected by applying controls

- Relate the application of preferred NO_x controls to demonstrated or expected impacts on controlled source operations and performance through the same parameters

- Estimate the capital and operating costs, including energy impacts of implementing NO_x control

It is desirable to use a standard format for these evaluations because it allows uniform comparisons to be made among various control strategies applied to different equipment items within a source category. Therefore, the NO_x E/A will stress developing a standard process calculation structure, which describes the kind and level of detail of process design-type calculations to be performed; and a set of standard cost calculation procedures, which specifies economic bases and cost evaluation assumptions. Once these are established, performing process/cost calculations for NO_x control application is conceptually straightforward. The control costs, operational impacts, and multimedia emissions versus degree of control for NO_x controls, applied singly and in combination, can be determined from these calculations.

The program plan developed for performing control process engineering and impact evaluations is shown schematically in Figure 6-1. Heavy reliance on initially establishing detailed calculation procedures is indicated. Brief subtask descriptions are given below.

As noted, the process procedures subtask outlines in detail the process engineering methodology to be adopted and the calculation structure to be used. Key elements include: establishing the set of base case source items (major design type/fuel combinations) to treat, establishing the level and detail of heat and material balances to perform, developing the calculation algorithms to use in performing these heat and material balances, specifying the matrix of calculations to perform, and defining methods to assess operation and maintenance impacts. Similarly, specifying cost calculations procedures includes: establishing the check list of cost items to consider, establishing the cost reporting basis, specifying the parameters required in the cost reporting scheme, (interest rates, tax procedures, depreciation, fuel cost escalation, etc.), specifying assumptions required to establish maintenance, developmental, and shakedown costs, and formulating cost calculation algorithms to interface with process calculations.

Data compilation efforts assemble and correlate process operation data, multimedia emissions, and cost information needed for performing the process/cost calculations. The control application design task involves the actual engineering design required to retrofit a standard field unit (e.g., boiler) to incorporate selected NO_x control techniques. Such designs will be performed to aid in defining precise capital equipment cost data for major control applications.

Once the calculational and evaluation procedures are well defined, and all requisite data assembled and standardized, process/cost calculations will be performed for baseline and selected NO_x control technique applications. The matrix of calculations performed will define the cost versus degree of NO_x control curves for the set of standard equipment items treated. Results from the calculations will help identify potential operational and performance impacts. Incremental emission effects and interactive effects of using combined control techniques will also be noted.

The results of the process/cost calculations are input to the impact assessment subtask. Overall control impact evaluation and preferred control technique ranking will be performed in this subtask, as discussed in Section 4.3.

This process engineering treatment will be done only for source/control combinations identified for major program emphasis in Section 8. Minor source/control combinations will be investigated less rigorously and more qualitatively through the minor source/control subtask shown in Figure 6-1.

6.2 PROCESS ENGINEERING METHODOLOGY

Program efforts to date have focused on developing procedures and compiling data for treating utility boilers (the first source class to be

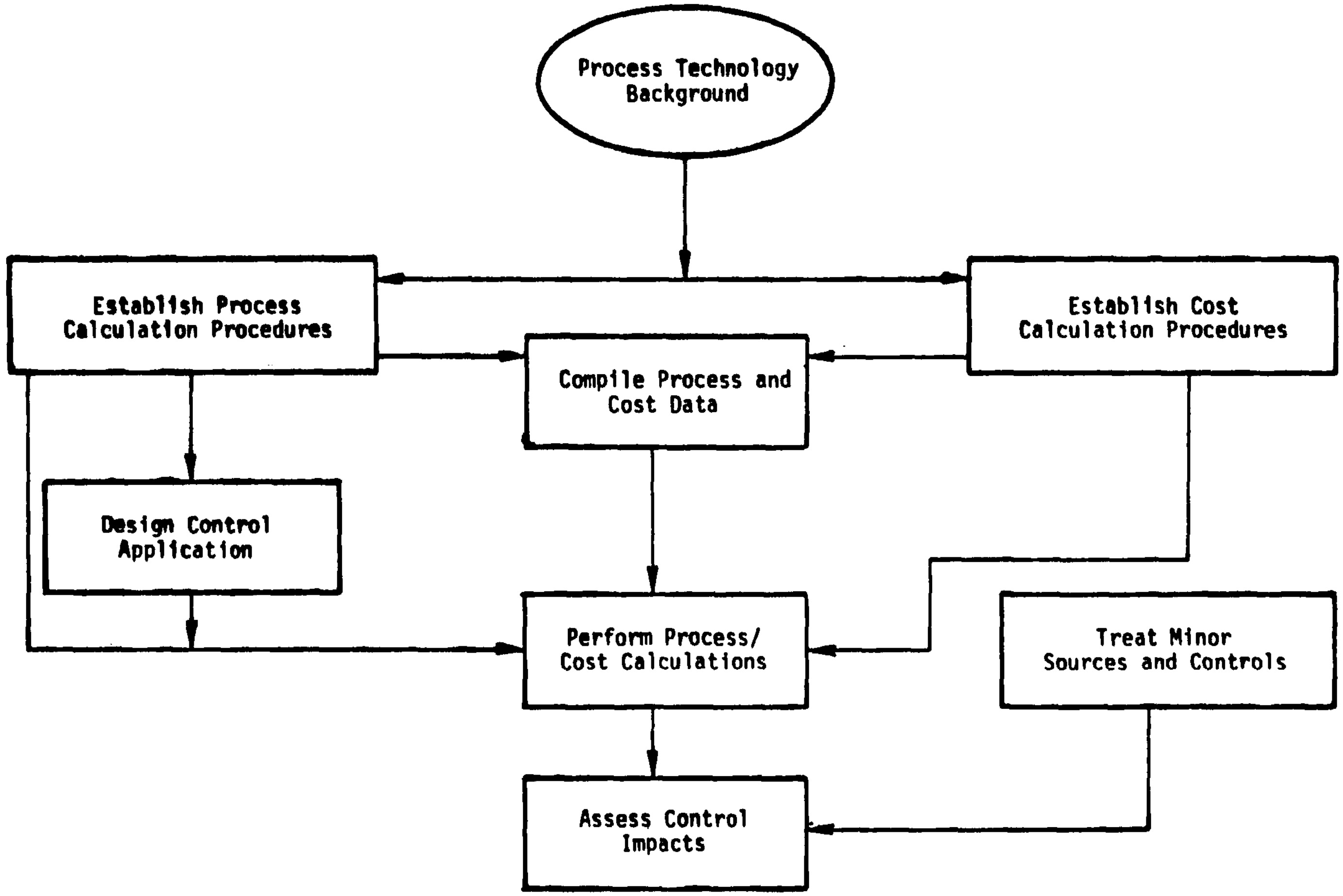


Figure 6-1. Process engineering -- subtask flowsheet.

evaluated as discussed in Section 8). In developing process calculation procedures, effort has concentrated on relating flue gas pollutant emission levels and indications of boiler performance to fundamental boiler design and operating parameters.

Stepwise linear regression analysis will be used, where possible, to correlate flue gas pollutant emissions to such variables as percent stoichiometry at the burners, volumetric heat release, surface heat release, and percent nitrogen in the fuel. Field test data assembled so far suggest that good correlations for NO_x emissions may be possible. Incremental emissions, especially noncriteria pollutants and trace species, will probably have to be assessed more qualitatively.

Boiler heat and material balances, supplemented by fundamental combustion theory and knowledge of boiler operation practice, will be used to help predict potential operational and maintenance related problems. For example, the altered boiler temperature profile resulting from firing burners out of service generally places extra demands on the superheater attemperation equipment. If installed capacity is insufficient, the boiler must be derated. Similarly, the higher levels of overall excess air generally required to prevent combustibles losses when firing burners out of service may exceed forced draft fan capacity. Again, the boiler may have to be derated. Such potential problems can conceptually be related to changes in the heat and material balance. Current efforts have been directed toward researching these relationships.

Process and emissions data on coal-fired tangential boilers have been the most complete assembled so far. Therefore, current process engineering has concentrated on this design type, fuel combination. Plans are to also treat oil- and gas-fired tangential boilers, and horizontally opposed and wall-fired design types firing coal, oil, and gas, in as much detail as available data allow. Emphasis will be placed on coal- and oil-fired equipment.

Standard boiler configurations will be identified from Federal Power Commission data stored in the EPA Energy Data System file. Emissions data from past field test programs have been assembled and are currently being organized and evaluated for sufficiency. Data from ongoing programs will continually be incorporated. Process data on other than tangential boilers have been sketchy. Continuing efforts to assemble such data from manufacturers, utilities, and subcontractors are proceeding.

In developing cost procedures for utility boilers, effort has concentrated on establishing the cost reporting basis and the set of cost items to consider. Cost calculations will be performed on an annualized unit cost basis using regulated utility economics. Items to be considered in addition to capital equipment and installation costs, and energy costs of operation include:

- Engineering and development cost estimates as a fraction of capital investment

- Startup and shakedown costs as a fraction of capital investment

- Maintenance costs as a fraction of capital investment
- Debt/equity financing of capital investment
- Taxes
- Fuel cost escalation
- Purchased power costs when the boiler is derated

Capital equipment cost estimates will follow from design efforts and will be supplemented by utility experience where data are available. Appropriate assumptions for development, maintenance, and shakedown costs will be based on user experience where possible.

SECTION 7

ENVIRONMENTAL DATA ACQUISITION

This section summarizes the assembling and organizing of multimedia emission data required to perform the NO_x environmental assessment. The results of a baseline stationary combustion source emissions inventory and the extension of that inventory to include the incremental emission effects of NO_x combustion controls are presented in the following subsections. Since, in many cases, data were insufficient, tests will be initiated to resolve the gaps. These tests are described in Section 7.3.

7.1 BASELINE EMISSIONS INVENTORY

A baseline multimedia emissions inventory was produced for all significant stationary NO_x sources. This inventory was then extended to include all other sources of NO_x (mobile, noncombustion, fugitive) to compare emissions from stationary combustion sources with those from other sources. Multimedia pollutants inventoried included the criteria pollutants (NO_x, SO_x, CO, HC, particulates), sulfates, polycyclic organic matter (POMs), trace metals, and liquid and solid effluents.

This inventory will guide subsequent NO_x E/A research by providing a base for weighing the incremental emissions impact from using NO_x controls. The inventory also serves as the reference for projections to the year 2000 for anticipated trends in fuels, equipment, and stationary source emissions. In addition, data gaps identified in compiling the emission factors highlight areas where further testing is needed in the NO_x E/A or other programs.

The emissions inventory was performed in the following sequence:

- Compile fuel consumption data for the categories of combustion sources specified in Section 2. Subdivide fuel consumption data based on fuel-bound pollutant precursor composition.

- Compile multimedia emission data

  -- Base fuel-dependent pollutant emission factors on the 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
- Produce emissions inventory
- Rank sources according to emission rates; compare the ranking to results of previous inventories

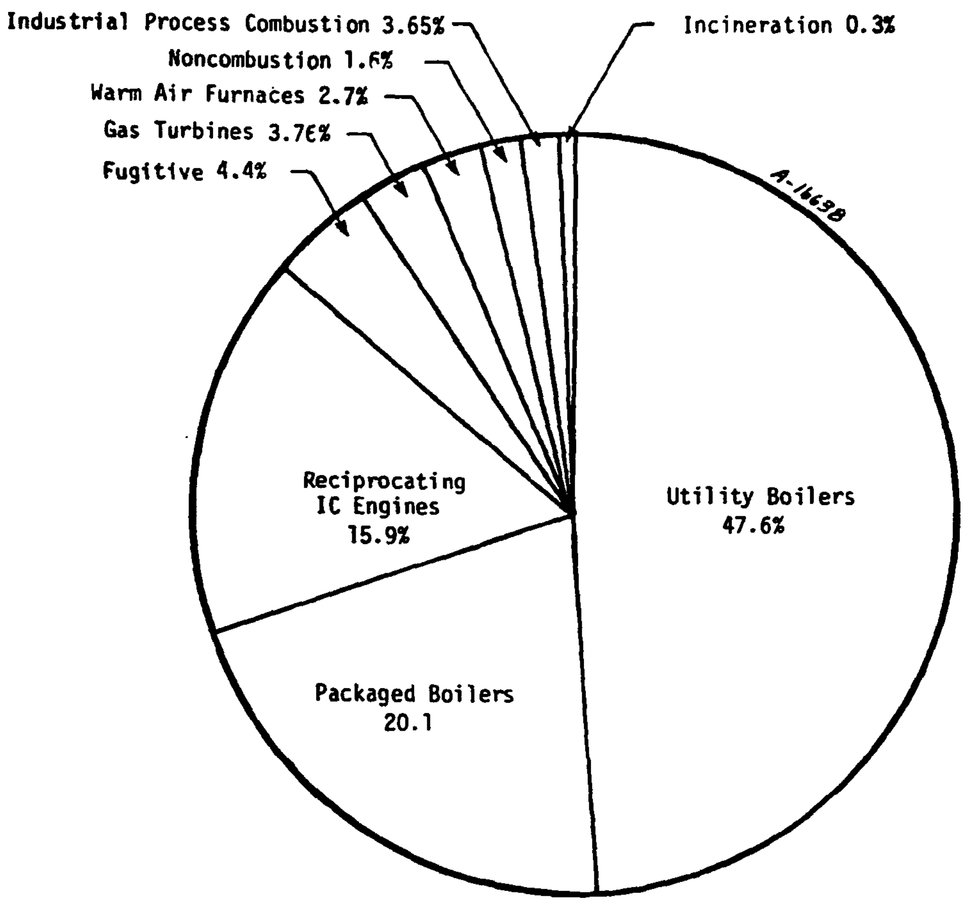
Although detailed breakdowns of fuel consumption, emission factors, and total emissions for each equipment/fuel combination were developed, only emission totals for each sector will be summarized here.

The distribution of anthropogenic NO_x emissions is shown on Figure 7-1 for the year 1974, the most recent year for which complete fuel consumption data are available. The estimates of utility boiler emissions account for the reduction resulting from using NO_x controls. From a survey of boilers in areas with NO_x emission regulations, it was estimated that using 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. Reductions from using controls on other sources were negligible in 1974.

In general, the total NO_x emissions from stationary sources and the distribution of these emissions among equipment types for 1974 show little change compared to 1972 inventories (Reference 24). The current inventory also shows generally good agreement with recent inventories conducted by EPA's Office of Air Quality Planning and Standards and other groups (References 25 through 27). One exception is for industrial packaged boilers. Here, recent estimates differ by as much as a factor of 2, primarily because total fuel consumption is uncertain for this sector.

The emission inventory results for other pollutants are shown in Table 7-1. Data for the criteria pollutants were generally good and the results of these current inventories are in reasonable agreement with other recent inventories. Data for the noncriteria pollutants and liquid or solid effluent streams, however, were sparse and scattered. For example, emission factors for POMs varied by as much as two orders of magnitude; Table 7-1 shows the range for total POM emissions. Several ongoing field test programs are sampling noncriteria pollutants. The current inventory will be updated with these results before emissions impacts are assessed as described in Section 4.2.

Table 7-2 ranks equipment/fuel combinations by annual, nationwide NO_x emissions, and lists corresponding rankings for these combinations by fuel consumption and emissions of criteria pollutants. Although there were over 70 equipment/fuel combinations inventoried, the 30 most significant combinations account for over 90 percent of NO_x emissions. The ranking of a specific equipment/fuel type depends both on total installed capacity and emission factors. A high ranking, therefore, does not necessarily imply that a given source is a high emitter; large installed capacity may offset a low emission factor to give the high ranking. In general,



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 7-1. Distribution of stationary anthropogenic NO_x emissions for the year 1974 (stationary fuel combustion: controlled NO_x levels).

TABLE 7-1. 1974 SUMMARY OF AIR AND SOLID POLLUTANT EMISSION FROM STATIONARY FUEL BURNING EQUIPMENT (1,000 Mg)

	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	--	--

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[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

TABLE 7-2. NO_x MASS EMISSION RANKING OF STATIONARY COMBUSTION EQUIPMENT AND CRITERIA POLLUTANT AND FUEL USE CROSS RANKING

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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

TABLE 7-2. 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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coal-fired sources rank high in SO_x and particulate emissions, while IC engines rank high in emissions of CO and hydrocarbons.

This emissions inventory assessment effort will culminate in a special report which will:

- Characterize stationary source equipment and fuel use
- Identify and categorize stationary source air pollutants and liquid and solid wastes
- Assess and standardize available emissions data
- Present a detailed emissions inventory with emission projections
- Identify the pollution impact potential of sources and rank sources to reflect control development needs.

As part of this report, regional inventories are being developed from the national inventory. In addition, the national inventory is being projected to 1985 and 2000 for several energy and equipment growth scenarios. A source assessment which considers population exposure, health effects, and source growth (described in Section 4.2) will be performed. This assessment will culminate in ranking stationary uncontrolled combustion sources on the basis of potential multimedia impacts.

During the remainder of the NO_x E/A program, NO_x E/A testing and the results from other related assessment programs will be closely monitored to ensure that the NO_x E/A final report reflects the most accurate and representative data available. Updates of the special report will be provided during the remainder of the NO_x E/A to disseminate the best current data to the EPA and research community.

7.2 INCREMENTAL EMISSIONS DUE TO NO_x CONTROLS

This section summarizes the preliminary evaluation of the demonstrated and potential effects of combustion modification NO_x controls on incremental emissions.* The results will help to guide priorities for subsequent NO_x E/A efforts in compiling incremental emission data, characterizing impacts, and studying control processes. In the preliminary evaluation, attention was focused on flue gas emissions from major sources operating at steady-state conditions and using near-term NO_x controls. These situations were considered the most important to the program, and were the only ones for which significant data existed. Subsequent effort will consider liquid solid effluents, minor sources, and alternate or advanced NO_x controls.

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*Incremental emissions are the changes in emission levels of combustion-generated pollutants other than NO_x, which can be ascribed to using a NO_x control.

It is important to note that efforts to date have been concerned only with estimating incremental emission rates, with little regard to potential impact. Ultimately, the significance of the incremental emissions will depend on baseline, uncontrolled pollutant emission rates, maximum acceptable ambient pollutant concentrations, and other factors such as pollutant transport and transformation. The preliminary screening of potential incremental impacts due to NO_x controls, considering these factors, is summarized in Section 8.

The preliminary evaluation was performed in three steps. In the first step, preliminary screening, changes in the levels of incremental emissions were qualitatively linked to the combustion conditions resulting from using specific NO_x controls, based on knowledge of pollutant formation mechanisms. Of course, this preliminary screening represented only informed speculation based on what was known about how combustion NO_x controls act, and how combustion-generated pollutants are formed. But it was used only to screen the matrix of control/pollutant pairs for expected adverse emission effects, and thereby guide priority setting for future study in the absence of supporting data.

The second step sought to substantiate the postulates formed in the preliminary screening by compiling and evaluating data from field tests in which incremental emission data were collected. Data were very limited, and insufficiencies were noted.

The third step followed from the first two and grouped control technique/pollutant pairs into the following three groups according to their 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 emission impact, where preliminary screening of formative mechanisms indicates that NO_x control could conceivably cause increased pollutant emissions, but confirming data are lacking, contradictory, or inconclusive

- Low potential emission impact, where the emissions data clearly show that specific pollutant emission levels decrease or are unaffected when the NOx control is applied, or where the preliminary screening definitely indicates a similar conclusion, even though data are lacking

Tables 7-3 through 7-5 show these groupings for boilers, IC engines, and gas turbines, respectively.

As Table 7-3 illustrates, using preferred NO_x combustion controls on boilers should have few adverse effects on incremental emissions of CO, vapor phase hydrocarbons, or particulates. Although indiscriminately lowering excess air can drastically affect boiler CO emissions, and particulate emissions can increase with off-stoichiometric combustion and flue gas

TABLE 7-3. 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 7-4. 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 7-5. 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

recirculation, with suitable engineering during development and careful implementation, these incremental emissions problems can be minimized.

In contrast, applying almost every combustion control has intermediate to high potential impact on incremental emissions of sulfate, organics, and trace metals. For trace metal and organic emissions, substantiating data were largely lacking, but fundamental formation mechanisms caused justifiable concern. In the sulfate case, fundamental formation mechanisms suggested that these emissions would remain unchanged or decreased with all controls except ammonia injection. However, complex interactive effects were difficult to clarify, and this pollutant class was considered sufficiently hazardous to justify some concern in the absence of conclusive data.

Table 7-4 shows that the incremental emissions of all pollutant classes except nonsegregating trace metals potentially increase when NO_x controls are used on IC engines. Increased emissions of CO, vapor phase hydrocarbons (HC), and particulate (smoke) are of primary concern, while sulfates, organics, and segregating trace metals from engines burning high sulfur diesel fuels are of less concern.

Similarly, certain NO_x controls applied to gas turbines can be expected, in selected instances, to adversely affect all incremental emissions except nonsegregating trace metals, as shown in Table 7-5. Again, increased sulfate, particulate, organic, and segregating trace metals are of some concern in sources firing high sulfur diesel fuels. If residual oil firing in gas turbines increases, these concerns would become more serious. Presently this appears unlikely, due to materials problems such as sulfidation.

The incremental emission evaluations presented in Tables 7-3 through 7-5 are not intended to signify potential for adverse environmental impact. Rather, the evaluations list source/control/pollutant combinations for which emissions may increase when NO_x controls are used. Evaluating potential adverse environmental impacts would require comparing source-generated, ambient pollutant concentrations with upper limit threshold concentrations of the pollutants based on health or ecological effects (as described in Section 3). These comparisons will be made in future program efforts. However, some conclusions based on the results to date are presented below.

In general, the data on incremental multimedia emissions due to NO_x controls were very sparse. Although more data were available for flue gas emissions than for liquid or solid effluent streams, the only data which allowed quantitative conclusions were for emissions of criteria pollutants from major sources employing commonly-applied controls. Data on sulfates, trace metals, and organics (POM) were few, experimentally uncertain, and highly dependent on fuel properties, while incremental emissions in liquid and solid effluents and during transient or nonstandard operation were almost nonexistent. Therefore, these data 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 incremental emissions 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 limited in the past for operational reasons rather than environmental impact. CO, HC and smoke emissions reduce efficiency and may present safety hazards. High SO_3 production can lead to acid condensation, corrosion and in many cases, to acid smut formation. All of these emissions are quite sensitive to combustion process modifications for NO_x control. Except for SO_3, incremental emissions of these pollutants normally tend to increase when NO_x controls, particularly low excess air and off-stochiometric combustion, are applied. Development experience has shown, however, that with proper engineering these emissions can be limited under low-NO_x conditions. Therefore, it should be emphasized that incremental emissions of criteria pollutants can be viewed more as a constraining criterion to be addressed during control development rather than as an immutable consequence of low-NO_x firing.

Moreover, the limit on emissions for satisfactory operation is generally more stringent than the limit for acceptable environmental impact. Of course, the environmental constraints will be carried through future impact assessments in the NO_x E/A for all potentially significant pollutants, but in many cases, they will need to be supplemented by operational constraints.

The situation for other flue gas pollutants is more uncertain. Conventional combustion process modifications -- low excess air, off-stoichiometric combustion, flue gas recirculation -- may increase emissions of sulfates, organics, and segregating trace metals from sources firing coal or residual oil. However, this conclusion has been based on sparse data or, lacking that, on fundamental speculation. Clearly more data will be needed. In contrast to CO, HC, and smoke, little is known on whether these emissions can be constrained to acceptable levels during control development.

In light of the relative scarcity of data on combustion modification effects on incremental emissions, future program test efforts, described in Section 7.3, will stress measuring these emissions. Specifically, emphasis will be placed on assessing the effects of NO_x combustion controls on flue gas emissions of SO_3, condensed sulfate, trace metals, organics, and trace species such as NH_3 and HCN, as well as emitted particle size distribution and particulate composition as a function of size. In addition, solid and liquid effluents will be collected and analyzed where appropriate. Of course, all other ongoing field test programs collecting similar data will be closely monitored.

7.3 TEST PROGRAM DEVELOPMENT

During the compilation of the baseline emission inventory and the evaluation of incremental emissions due to NO_x controls, it became apparent that data were lacking in several key areas. Most noteworthy was the virtual absence of data on the effects of NO_x combustion controls on emission levels of noncriteria flue gas pollutants and liquid and solid effluents. In response to these identified data needs, as well as additional requirements which may develop in future program efforts, NO_x E/A field test programs will be initiated.

Whenever possible, field testing will be performed as subcontracted additions to planned or ongoing tests since this is most cost-effective. However, where program needs cannot be satisfied through add-on testing, new test series will be initiated.

Efforts to date have focused on identifying specific test data needs and test add-on opportunities for characterizing utility boilers. As discussed in Section 8, the utility boiler category was ranked as having the highest environmental impact potential. Therefore, it is being treated first in the process engineering and environmental assessment studies.

Results of the first year preliminary environmental assessment and subsequent process engineering activities have identified specific data needs associated with utility boiler design types and fuel combinations. NO_x modifications to coal-fired boilers have been extensively tested in past programs, so NO_x emission levels from these boilers have been relatively well characterized. Tangential and front wall firing configurations have been especially well characterized. However, data on emissions other than criteria pollutants, and incremental emissions data due to NO_x controls are very sparse.

Baseline and controlled NO_x emissions from oil-fired boilers have also been reasonably well characterized, although more data are needed for an in-depth treatment. Front wall-firing configurations have been the most extensively tested. Again, noncriteria pollutant data, particulate data, and incremental emissions data are very limited.

Emission data for gas-fired boilers, even though somewhat limited, are sufficient for characterizing NO_x emissions. Although incremental emission data are essentially nonexistent from these sources, the need for these data is less critical. Process engineering treatments of gas-fired utility boilers will be less comprehensive because the use of gas for generating power is rapidly declining. Natural gas will probably be totally unavailable for generating power by 1985.

Based on the above, utility boiler test priorities will focus on coal- and residual oil-fired equipment, particularly tangential and horizontally-opposed firing configurations. Test matrices at each chosen site will address the data needs identified in Sections 7.1 and 7.2. Emphasis will be given to obtaining both baseline and incremental data as a function of combustion control parameters on emissions of flue gas NO_x, CO, HC, SO_2, SO_3, trace metals, organics, particulate, and particle size distribution. In addition, obtaining data on particulate composition as a function of size, specifically trace metal, condensed sulfate, and condensed organic levels, will be stressed.

In general, utility boiler testing will follow the sample test matrices illustrated in Tables 7-6 and 7-7 for vapor phase and condensed phase constituents, respectively. The "X's" in the tables represent analyses to be performed under each test condition. Level 1 sampling and analysis

TABLE 7-6. SAMPLE TEST MATRIX -- VAPOR PHASE CONSTITUENTS

Pollutant species	Sampling and analysis: Method	Sampling and analysis: Comments	Test Points[a]: Baseline high excess air	Baseline min excess air	10% FGR min EA	Max FGR Min EA	1/2 max OSC Min EA	Max OSC Min EA	Max OSC Max FGR
NO_x	Continuous monitor, chemiluminescent	Two-dimensional sampling rake giving composite sample. Sample upstream of air heater.	X	X	X	X	X	X	X
CO_2	Continuous monitor, NDIR	See above	X	X	X	X	X	X	
CO	Continuous monitor, NDIR	See above	X	X	X	X	X	X	
SO_2	Continuous monitor, UV fluorescence	See above	X	X	X	X	X	X	
O_2	Continuous monitor, NDIR	See above, also sample up and downstream of particulate collection device to calculate air in-leakage.	X	X	X	X	X	X	
SO_3	Method 8 probe/train		X	X	X	X	X	X	
Trace Metals	SASS train			X				X	
Organics > C_6	SASS train	Solvent extraction of absorbent elutrate to 8 fractions		X				X	
Particulate	Method 5 probe/train	Sample up and downstream of particulate collection device.	X	X	X	X	X	X	

TABLE 7-6. Concluded

Pollutant species	Sampling and analysis: Method	Sampling and analysis: Comments	Test Points[a]: Baseline high excess air	Baseline min excess air	10% FGR min EA	Max FGR Min EA	1/2 max OSC Min EA	Max OSC Min EA	Max OSC + Max FGR
Particle size distribution	Method 5 probe/train with cyclones, or impactors	Particle size fractionation to at least four fractions.	X	X	X	X	X	X	
Trace species HCN, HCℓ, NH_3, COS, H_2S, and HC $<C_6$	Gas grab sample	Gas chromatograph with flame ionization detector for analysis		X				X	

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[a]All test points at the same boiler load. Boiler load within 20% of rated capacity.

TABLE 7-7. SAMPLE TEST MATRIX -- CONDENSED PHASE CONSTITUENTS

Pollutant species	Sampling and analysis: Method	Sampling and analysis: Comments	Test Points[a]: Baseline high excess air	Baseline min excess air	10% FGR min EA	Max FGR Min EA	1/2 max OSC Min EA	Max OSC Min EA	Max OSC Max EA
<u>Flue gas particulate</u>									
Trace elements	Spark source mass spectroscopy or atomic absorption	Assay each particulate size fraction, both up and downstream of particle collection device catches. Assay for at least 20 elements.	X	X	X	X	X	X	X
Sulfate	Wet chemical analysis	See above	X	X	X	X	X	X	
NH_4 HSO_4	Wet chemical analysis	See above	X	X	X	X	X	X	
Organics $>C_6$	Wet chemical analysis or GC-mass spec.	Assay lumped particulate catch		X				X	
<u>Hopper ash and bottom ash</u>		Assay hopper and bottom ash separately							
Trace elements	Assay as above	See above		X				X	
Sulfate	Assay as above	See above		X				X	
NH_4 HSO_4	Assay as above	See above		X				X	
Organics $>C_6$	Assay as above	See above		X				X	

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[a]All test points at the same boiler load. Boiler load within 20% of rated capacity.

procedures (Reference 28) will be used wherever appropriate. The NO_x controls identified for major study emphasis (see Section 8) will be applied incrementally. New burner design testing, although not specifically shown in Tables 7-6 and 7-7, will also be performed. Because of their expense, certain analyses (notably organic assays) will be performed only under baseline and maximum controlled (low-NO_x) conditions to supply key data most cost-effectively. It is important to note that Tables 7-6 and 7-7 represent a general test plan that is not strictly applicable to a specific boiler/fuel combination. Thus, flue gas recirculation will not be tested on coal-fired boilers, and hopper and bottom ash sampling do not apply to oil-fired boiler testing.

In addition to the analyses noted in Tables 7-6 and 7-7, ultimate fuel analyses of samples taken before, during, and after testing will be performed. The same fuel will be fired throughout each boiler test series. The need for bioassay analyses, and the procedure to be followed when these analyses are performed, will be coordinated with the IERL working group advising environmental assessment activities.

Current plans are to conduct a series of 19 field tests using add-ons to existing programs whenever possible. The 19 tests, with an appropriate test priority reflecting the source ranking discussed in Section 8, are summarized below. Actual test scheduling may not fully reflect the priority ranking, however. The timing of test opportunities and the need to meet special report schedules may dictate the order in which tests proceed.

Priority	Test
1-4	Coal-fired utility boiler. Includes one test each of tangential, wall-fired, and horizontally-opposed fired boiler if possible.
5-7	Oil-fired utility boiler. Includes one test each of tangential, wall-fired, and horizontally-opposed fired boiler, if possible. At least one boiler should incorporate combined FGR and OSC control.
8-9	Coal-fired watertube industrial boiler. At least one spreader stoker.
10	Oil-fired gas turbine with wet controls
11-12	Advanced burner or firebox design
13	Oil-fired firetube industrial boiler
14	Oil-fired watertube industrial boiler
15	Oil-fired warm air furnace
16	Spark ignition IC engine

17	Compression ignition IC engine
18-19	Industrial process furnace, at lease one firing process gas

SECTION 8

ENVIRONMENTAL ALTERNATIVES ANALYSIS

During the first year effort, an environmental alternatives analysis was used to set priorities for the process studies, environmental assessments, and testing programs. These priorities relate directly to the program needs:

- 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

To address these needs, the program gives primary early emphasis to assessing current and impending control applications. Assessment of advanced technology applications will proceed at a lower level of effort in near-term activities, 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 these applications are most timely from an environmental standpoint, and are the most extensively tested. The final report will document the assessment of far-term applications and will update the earlier assessment 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
- The effluent stream/pollutant combinations to be emphasized in the test programs and assessments

In program work to date, preliminary source/control screening was conducted independently of pollutant screening. The source/control combinations were initially screened on the basis of significant near-term or far-term application. Pollutants for the resultant source/control combinations were then screened for potential adverse impacts, and the results were then combined to set program priorities.

Earlier sections of this report summarized most of the information required to determine these four priorities. This section consolidates that information and also estimates near- and far-term source/control requirements to attain and maintain air quality. Priorities were then set in the sequence of the preceding list. The qualitative priorities set will be updated and reevaluated as new data become avaiable.

8.1 EVALUATION OF NO_x CONTROL REQUIREMENTS

The source/control priorities within the NO_x E/A largely depend on the extent to which specific sources and controls will need to be used in this century to meet NO_2 air quality standards. To help set these priorities, the systems analysis model described in Section 4.4 was developed to relate ambient air quality to several scenarios on source growth, control implementation, and regulatory policy. For preliminary calculations we have used the source-weighted rollback model for the air quality model in the Los Angeles Air Quality Control Region (mobile dominated) and the Chicago AQCR (stationary dominated). Emission inventories were, with some modifications, taken from the NEDS file. Two scenarios each for mobile and stationary source growth were considered. In addition, the sensitivity of the results was investigated by considering two base-year annual average, ambient NO_2 concentrations for calibration of the model, and several different source weightings for powerplants and mobile sources.

The results of the preliminary screening analysis for the NO_x control needs of the Los Angeles AQCR are shown in Table 8-1. This table outlines control requirements for Los Angeles for 1985 (upper entry) and 2000 (lower entry), as a function of base year NO_2 concentration, powerplant and mobile source weighting factor, and source growth scenario. For calculations summarized in the table, the nominal growth case* assumes moderate growth for stationary sources (influenced by conservation, emissions off-set policies and rising energy costs), a 3 percent per year growth in vehicle population, and 0.62 g NO_2/km (1 g/mile) mobile source emission standard beyond 1980. The low mobile case has the same stationary source scenario but assumes 1 percent per year growth in vehicle population and an emission factor of 0.25 g NO_2/km (0.4 g/mile) beyond 1981. The high stationary source case is an extension of historical trends in stationary source growth and has the same mobile growth as the nominal growth case.

*The growth rates for each source category are given in detail in Section 7 of Reference 16.

TABLE 8-1. 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[a] = 0.7 MS = 1.2	PP = 1.0 MS = 1.0	PP[a] = 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

[a]The low emission layer in Los Angeles prevents wide dispersion of the emissions from elevated sources; therefore, the powerplants are down weighted to 0.7. Also, the highest ambient levels occur in regions of high mobile emissions. Thus the mobile sources are weighted upwards.

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

1985	
	2000

PP -- Powerplants Weighting Factor
MS -- Mobile Sources Weighting Factory
BYR -- Base Year Calibration

In addition two values for 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 powerplants (PP) and mobile sources (MS) 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 control groups cited in Table 8-1 refer to the ranking shown on Table 8-2. 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 8-1 is that the required control level is dominated by the assumptions on the 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 high (160 $\mu g/m^3$) base year cases. 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). Again, both of these are 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.

Analogous results for Chicago are shown in Table 8-3, with the corresponding control ranking given in Table 8-4. The tables indicate that control of stationary sources is required in all cases, except in 1985 for a base year (1973) concentration of 96 $\mu g/m^3$. 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 NO_x emissions constitute 45 percent of the total in Chicago; 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, combustion modifications will be required and in some cases, will not be sufficient to meet the annual standard. In

TABLE 8-2. CONTROL PRIORITIZATION FOR LOS ANGELES (2000, equal source weighting)

T-185a

	Rank	Source/Control	Cost Per Unit Change in Air Quality 10^6\$/(μg/m³)	% Reduction per 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-H2O 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
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

TABLE 8-3. SUMMARY OF CONTROL LEVELS REQURIED TO MEET NO_2 STANDARD IN CHICAGO, AQCR 067

Case	BYR = 06 $\mu g/m^3$			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[a]	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

[a]More control of stationary sources is required in this case than in the PP = 1.0 case because the effectiveness of the powerplant controls in reducing ambient air quality is significantly reduced by the low source weighting factor.

0 -- No additional control required
1 -- Controls from Group 1
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

1985 / 2000

PP -- Powerplant Weighting Factor
MS -- Mobile Sources Weighting Factor
BYR -- Base Year Calibration

TABLE 8-4. CONTROL PRIORITIZATION FOR CHICAGO (2000, equal source weighting)

T-186a

	Rank	Source/Control	Cost Per Unit Change in Air Quality 10^6\$/(μg/m³)	% Reduction per 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) H20 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
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

the short term, combustion modifications are needed unless the low base year concentration is valid.

These results strongly suggest that all possible stationary source control methods may need to be developed. According to the results discussed above, a less vigorous approach could be justified only if all 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 it is therefore imprudent to plan control development on such an assumption. For the 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 whould be pursued, including ammonia injection. Research on even more effective methods seems justified.

These conclusions can be qualitatively extended to many of the regions identified as priority AQCRs and AQMAs. Those that are 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 4-2, 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 attain alternate potential standards, e.g., a 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.

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 2) and an EPA study (Reference 1). 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 these two 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 in Los Angeles 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 powerplant 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 remain the same.

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

- 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).

It should be emphasized that these results are only tentative since they are based on a rather crude air quality model and somewhat qualitative data. Current efforts are incorporating a reactive photochemical model to include effects of NO_2-HC-oxidant reactions, source height and density, and meteorological conditions. Process data on control effectiveness and cost are also being updated through assessment of control technology. In addition, other NO_2 critical AQCRs (e.g., New York City and St. Louis) will be assessed to provide a broader base for conclusions.

8.2 SOURCE/CONTROL PRIORITIES

This section combines the results of Section 8.1 with program results presented in other sections to set NO_x E/A program priorities on sources and source/control combinations. Priority setting was done in two steps. First, source priorities were set for the major combustion source/fuel combinations. These were then used to determine the order for doing process engineering and environmental assessment studies. They were also used to guide the level of effort to be devoted to studying each major source category and to individual design types within each category.

Second, control priorities were set for each source/fuel combination. The resultant source/control priorities were used to determine which combinations will be given major or minor emphasis in the process studies and test programs:

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 (cyclones) not likely to be extensively controlled due to dwindling use and/or lack of control flexibility.

- Assess the extent controls are used 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 environment impact for each source/fuel category

- Identify the relative effectiveness of implementing near-term and far-term source controls in maintaining air quality in urban areas

Table 8-5 summarizes the results of establishing these priorities. The results were largely qualitative due to the uncertainty and lack of data in many areas. The considerations applied in constructing Table 8-5 are summarized below.

Source Categorization

The division of the source/fuel category into major and minor design types followed from results presented in Section 2 of this report. "Major" refers to conventional designs likely to be controlled for NO_x in the near term. These design types are given primary emphasis in the process studies and are candidates for field testing. The minor design types are either obsolete or otherwise unlikely to be subject to significant NO_x control in the near term. Correspondingly, minor design types are given secondary emphasis in the process studies and are generally not candidates for field tests. This does not imply that minor design types are insignificant NO_x sources. For example, cyclone boilers emit 8 percent of stationary source NO_x. Yet, cyclone combustion characteristics make NO_x control very difficult. For this and other reasons, 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. Similar considerations resulted in the following being classified as minor design types: vertical- and stoker-fired utility boilers, firebox and horizontal return tube package firetube boilers, firetube stokers, and space heaters.

Control Implementation

Information on implementing NO_x control was based on the control technology background described in Section 5. Since the assessment of current controls application is a major NO_x E/A objective, the degree of control implementation becomes a key criterion in setting source priorities. To date, only utility boilers and gas turbines have been controlled for NO_x to any significant extent. Gas and oil units have been the most extensively controlled, but control of coal units is increasing. Since no new gas- or oil-fired units are being sold, NO_x controls for coal units will dominate in the future. Large and intermediate industrial boilers are also currently controlled sources. Standards of performance for new stationary sources are planned for these sources and IC engines.

Nationwide Emission Ranking

Section 7.1 ranked design/fuel types by nationwide mass emissions of NO_x. These results are also shown in Table 8-5 for the specific source categories listed. Nationwide mass emissions are useful for weighting

TABLE 8-5. EVALUATION OF SOURCE PRIORITIES

T-250a

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	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. coal, spreader stoker	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

relative emission contributions of various sources and detecting emission trends independent of local variations. However, they do not account for variations among source categories in proximity to population centers and regional variations in the use of specific source/fuel types. These regional factors are qualitatively included in the relative impact potential column.

Relative Impact Potential

Ranking sources by relative impact potential was based on the multimedia emissions inventory discussed in Section 7.1, and the impact screening to be discussed in Section 8.3. Although incremental impacts were not considered in the evaluation, results discussed in Section 7.2 were used to relate design type and fuel to potential for emissions of specific pollutants when there were insufficient emission data. The proximity of specified sources (e.g., residential furnaces) to populated areas was also considered. The relative impact potential resulting from these considerations was generally high for coal firing, medium for residual oil firing, and low with clean fuel firing. Residential furnaces were ranked at borderline L-M because of their proximity to populated areas and their potential for increased emissions during cycling transients. IC engines were also a borderline case. Even though they fire clean fuels, organic emissions are high. Little emission/impact data are available for industrial process furnaces. They were related 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 8.1. Separate consideration was given to near-term effectiveness and far-term effectiveness to isolate effects of design trends and growth projections for source categories. The analysis discussed in Section 8.1 showed that control needs are highly uncertain for specific source categories. Estimated control needs depended strongly on growth projections, mobile source control assumptions, measurements of ambient NO_2 concentrations, and the relative weighting of point sources (powerplants) and ground level sources (mobile sources). Optimistic scenarios (in terms of stationary source air quality impact) required only moderate control of major stationary sources in the near term. Moderate or pessimistic scenarios, however, required extensive near-term stationary source control. In the far term, extensive control was generally needed regardless of assumption. Entries in Table 8-5 were based on moderate or pessimistic scenarios. Since the NO_x E/A is largely a problem definition study, its purposes would not be served by using optimistic assumptions on the potential for adverse impact. For the moderate or worst case scenarios, estimated near-term control needs 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 downgraded in the far term.

Overall Source Ranking

The last column in Table 8-5 gives the qualitative ranking of the 13 source categories. 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 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 in Table 8-5.

Once derived, the source priorities were extended to include consideration of specific source/control combinations. This source/control prioritization is shown in Table 8-6. The table also shows preliminary selection of those advanced source/control combinations which will be evaluated in the later study of far-term applications. The prioritization of current technology was based directly on results discussed in Section 5, and considered the extent of current control applications to specific sources and the cost-effectiveness of a given control compared to competitive techniques. Major future emphasis will be given to the source/control combinations likely to see significant control in the next 5 years. The selection of advanced techniques for treatment in the far-term control studies was also based on results presented in Section 5. The developmental status and schedule, as well as the potential availability of competitive techniques were considered. 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.

8.3 POLLUTANT/IMPACT SCREENING

The list of source/control combinations given priority in Section 8.2 was further evaluated to identify specific pollutants which show potential for an adverse environmental impact with or without NO_x controls. These results will be used to set priorities for samplng and chemical analyses to be performed during field test programs. The emphasis in this pollutant/impact screening was on flue gas emissions. Liquid and solid effluent stream data were quite sparse. Future field test efforts will attempt to resolve these insufficiencies.

TABLE 8-6. SUMMARY OF SOURCE CONTROL PRIORITIES

Source Ranking	Source	NEAR TERM EFFORT IN E/A PROGRAM: CURRENT AND IMPENDING APPLICATIONS				FAR TERM EFFECT: ADVANCED TECHNOLOGY	
		Major Emphasis — NO_x E/A 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 NO_x E/A Emphasis	Minor NO_x E/A 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	Flue gas treatment
1	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 injection	Chemically active fluid bed, flue gas treatment
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	Flue gas treatment
2	Coal-fired water-tube industrial-stoker	*Spreader*	LEA, OFA	*Underfeed/overfeed*		Factory installed OFA, NH_3 inj.	Flue gas treatment
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	Flue gas treatment
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 furnaces	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 redes., alt. fuels	Exhaust gas treatment
10	Compression ignition IC engines (diesel, mixed fuel)	Turbocharged	Operational tuning	Blower scavenged	Derate	Chamber redes., alt. fuels	Exhaust gas treatment
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 set of pollutant classes under consideration was described in Section 7.2 and included carbon monoxide, vapor phase hydrocarbons, particulates, sulfates, condensed phase organics, and trace metals. Several of these classes were further divided into more detailed pollutant groups, which gave a better representation of potential health/welfare hazards. For example, the vapor phase hydrocarbon class was speciated into alkanes, alkenes, alkynes, aldehydes, carboxylic acids, and aromatics. Sulfates, organics, and trace metals are generally emitted as particulates, but the particulates class was retained because it is a criteria pollutant, and because emissions data on this class of pollutants were available.

Baseline emissions for each pollutant species group, as a function of combustion source class, were summarized in Section 7.1. In addition, Section 7.2 summarized the incremental emissions of these pollutant groups, where data were available, 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 maximum ambient screening concentrations. By combining information discussed in each of those sections with a dispersion model, it was 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 8-7 and 8-8. Table 8-7 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 considered. The pollutant groups listed in Table 8-7 are those for which incremental emissions data were available. As indicated, incremental data were available only for criteria pollutants. Table 8-8 shows a similar summary for those pollutants groups for which little or no field data were found on the incremental effects of NO_x combustion controls.

From the data presented in Tables 8-7 and 8-8, it was possible to identify those pollutant groups which are emitted at levels near, or exceeding, the defined maximum allowable emission level. Pollutant group/combustion source combinations were flagged if emission levels exceeded 10 percent of the maximum allowable level. These combinations were noted in Tables 8-7 and 8-8, and further summarized in Table 8-9.

Table 8-9 illustrates that emissions from large coal- and oil-fired boilers potentially represent the most significant environmental hazards. Baseline emissions of particulates, sulfates, and certain POM species from these source classes currently exceed the derived maximum allowable emissions levels, while emissions of several other POM species are within an order of magnitude of the maximum. In addition, while emissions of total vapor phase hydrocarbons from large boilers were not identified as a 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.

Large coal- and oil-fired boilers were not the only source class associated with pollutant streams of concern. Incremental total vapor phase

TABLE 8-7. 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 (all fuels)	
		Oil			0-30		
		Coal			0-40		
	Industrial Boilers	Natural Gas		24,500	10-25	0-35 (all fuels)	
		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/m³)	(g/m³)	(g/m³)	(g/m³)	
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.

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

T-216

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 8-8. Continued

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			0.12[illegible]			
	Utility Boilers	Coal		1.46	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	++
			(ug/m³)	(mg/m³)	(mg/m³)	
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	++
BT			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

TABLE 8-8. 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	0.098	
		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	47.8	++
		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

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TABLE 8-9. SUMMARY OF POTENTIAL POLLUTANT/COMBUSTION SOURCE HAZARDS

Pollutant Class/Group	Combustion Source	Emission Exceeds Potential Hazard Threshold	Emission Exceeds 10% of Potential Hazard Threshold
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		
Ni	Oil-Fired Utility Boilers	X	
	Coal-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

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, since the use of coal firing in residential heating applications is declining, this source/pollutant combination will not be considered a priority concern.

Based on the information presented in Table 8-9, further efforts will be directed toward studying NO_x controls which could increase emissions of:

- 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

It is important to note that these results were based only on relatively qualitative screening efforts. Future activities will strive to strengthen the potential impact analyses by applying source analysis modeling as discussed in Section 4.

SECTION 9

TECHNOLOGY TRANSFER

The NO_x E/A is largely a technology synthesis program. As such, it draws heavily on technology in related areas such as environmental sciences and environmental health. The NO_x E/A, in turn, generates technology for use by control developers, users, and regulatory groups. This section highlights the input and output technology transfer activities in the program.

During the first year, the NO_x E/A evaluated the input data resources available to conduct the process and environmental assessment studies. A number of areas of insufficient data were identified. Further R&D in these areas would significantly benefit the environmental assessment effort. Since this R&D is beyond the scope of the NO_x E/A program, data gaps and supporting R&D needs were summarized in previous sections of this report, and in greater depth in the preliminary assessment (Reference 16). These are summarized below for the key supporting areas of the NO_x E/A.

- Process Technology Background
  - -- Population and design trends in industrial process combustion
  - -- Occurrence and process characteristic of nonstandard operation for all equipment types
  - -- Prevalence of mixed and alternate fuel use in utilities and industrial applications
- Environmental Background
  - -- Impacts of combustion-generated pollutants on human health and aquatic ecology
  - -- Impacts of short-term and chronic exposure to NO_2 and secondary pollutants formed from NO_2
  - -- Cross-media impacts
- Environmental Data Acquisition
  - -- Sampling and analysis procedures for organics and metallics

- -- Emissions for transient and nonstandard operation

- -- Emissions for combustion-generated liquid and solid effluents

- Environmental Alternatives Analysis

  - -- Long range transport of nitrate and ozone

  - -- Atmospheric chemistry of the formation of secondary pollutants from combustion generated primary pollutants

In addition, there are a number of other data gaps and R&D needs in the control technology area which are being addressed within the program.

The primary program output during the first year was the Preliminary Environmental Assessment Report (Reference 16). This report documents the methodologies and supporting data on source and process characterization, multimedia pollutant emissions, and impact assessments, and sets priorities on sources and combustion modification controls for further study. Other activities in technology transfer are as follows:

- Preparation of "NO_x Control Review", a quarterly technology status report on NO_x control development and implementation and regulatory strategy

- Coordination of the Second Symposium on Stationary Source Combustion held in New Orleans, August 29-September 1, 1977

- Documentation of the status of IERL developmental programs in combustion modifications for use in the IERL annual report

- Development of Source Analysis Models and Effluent Transformation and Transportation Analysis for use in the EACD environmental assessments

SECTION 10

FUTURE EFFORTS

During the second year of the NO_x E/A program, effort will center on preparation of process and impact assessment studies for the major source categories. These studies will involve process calculations of specific combustion modification/source combinations, detailed cost calculations of retrofit and new design controls and assessments of multimedia impacts and operational impact from control use. Utility boilers will be studied first, followed by industrial boilers and gas turbines. To support these studies, a major effort will be devoted to source testing. Multimedia emissions before and after the use of NO_x controls will be sampled and analyzed for the major source/control combinations. Additional support for the impact assessments will be provided by the baseline source analysis study. This study will compare ground level pollutant concentrations from sources uncontrolled for NO_x to the Multimedia Environmental Goals, denoting the threshold of potentially hazardous impacts.

The results of the above efforts will be integrated in the environmental alternatives analysis. As new results on process cost and impact are available, they will be used with the systems analysis model to update the evaluations of the extent of need for combustion modification technology in the future.

REFERENCES

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

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

3. McCutchen, G. D., "NO_x Emission Trends and Federal Regulation," presented at AIChE 69th Annual Meeting, Chicago, November 28 - December 2, 1976.

4. "Air Program Strategy for Attainment and Maintenance of Ambient Air Quality Standards and Control of Other Pollutants," Draft Report, U.S. EPA, Washington, October 18, 1976.

5. "Annual Environmental Analysis Report, Volume 1 Technical Summary," The MITRE Corporation, MTR-7626, September 1977.

6. Personal communication with R. Bauman, Strategies and Air Standards Division, Office of Air Quality Planning and Standards, U.S. EPA, October 1977.

7. "An Analysis of Alternative Motor Vehicle Emission Standards," U.S. Dept. of Transportation/U.S. EPA/U.S. FEA, May 1977.

8. French, J. G., "Health Effects from Exposure to Oxides of Nitrogen," presented at the 69th Annual Meeting, AIChE, Chicago, Illinois, November 1976.

9. "Scientific and Technical Data Base for Criteria and Hazardous Pollutants -- 1975 EPA/RTP Review," EPA-600/1-76-023, NTIS-PB 253 942/AS, Health Effects Research Laboratory, U.S. EPA, January 1976.

10. Shy, C. M., "The Health Implications of an Non-Attainment Policy, Mandated Auto Emission Standards, and a Non-Significant Deterioration Policy," presented to Committee on Environment and Public Works, Serial 95-H7, February 10, 1977.

11. "Report on Air Quality Criteria for Nitrogen Oxides," AP-84, Science Advisory Board, U.S. EPA, June 1976.

12. "Control Strategy for Nitrogen Oxides," Memo from B. J. Steigerwald, Office of Air Quality Planning and Standards, September 1976.

13. "Report on Air Quality Criteria: General Comments and Recommendations," Report to the U.S. EPA by the National Air Quality Advisory Committee of the Science Advisory Board, June 1976.

14. Personal communication with M. Jones, Strategies and Air Standards Division, Pollutant Strategies Branch, September 15, 1976.

15. "Control of Photochemical Oxidants -- Technical Basis and Implications of Recent Findings," EPA-450/2-75-005, Office of Air and Waste Management, OAQPS, July 1975.

16. "Preliminary Environmental Assessment of the Application of Combustion Modification Technology to Control Pollutant Emissions from Major Stationary Combustion Sources," Vols. I & II, Aerotherm TR-77-28, Acurex Corporation, February 1977.

17. Dupree, W. G. and J. S. Corsentino, "Energy Through the Year 2000 (Revised)," Bureau of Mines, December 1975.

18. Handy, R. and A. Schlinder, "Estimation of Permissible Concentrations of Pollutants for Continuous Exposure," Research Triangle Institute, EPA-600/2-76-155, NTIS-PB 253 959/AS, June 1976.

19. Cleland, J. G. and G. L. Kingsbury, "Multimedia Environmental Goals for Environmental Assessment (Draft)," Research Triangle Institute, January 1977.

20. Schalit, L. M. and K. J. Wolfe, "SAM I/A: A Rapid Screening Method for Environmental Assessment of Fossil Energy Process Effluents," Aerotherm Draft Report TR-76-50, Acurex Corporation, August 1977.

21. Personal communication, Mr. Alan Hoffman, Chief Monitoring Section, U.S. EPA, October 1, 1976.

22. Frey, D. J., "De-Ashed Coal Combustion Study," Combustion Engineering, Inc., October 1964.

23. Waitzman, D. A., et al., "Evaluation of Fixed-Bed Low-Btu Coal Gasification Systems for Retrofitting Power Plants," EPRI Interim Report 203-1, Electric Power Research Institute, February 1975.

24. Shimizu, A. B., et al., "NO_x Combustion Control Methods and Costs for Sources; Summary Study," EPA-600/2-75-046, NTIS-PB 246 750/AS, September 1975.

25. "Monitoring and Air Quality Trends Report, 1974," EPA-450/1-76-001, EPA Office of Air Quality Planning and Standards, February 1976.

26. Personal communication with C. Masser, National Emissions Data System (NEDS), October 1976.

27. Information from National Emissions Data System (NEDS), October 26, 1976.

28. Hamersma, J. W., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment," EPA-600/2-76-160a, NTIS-PB 257 850/AS, TRW, June 1976.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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16. ABSTRACT The report summarizes results of the first year of an environmental assessment program for stationary NOx combustion modification technologies. The first-year effort concentrated on: (1) developing the methodology for environmental assessment and process engineering studies; (2) compiling data on source process characteristics, emissions, and pollutant impacts; and (3) setting program priorities on sources, controls, pollutants, and impacts. The report reviews each area and summarizes plans for future efforts. It discusses program results and plans for stationary NOx source equipment characterization, environmental goals compilation, source analysis model development, NOx control technology characterization, process engineering methodology development, baseline multimedia emissions inventory compilation, and systems analysis model development and use.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Operating Costs	Air Pollution Control	13B	14A, 05A
Combustion	Boilers	Stationary Sources	21B	13A
Combustion Control	Gas Turbines	Combustion Modification		13G
Nitrogen Oxides	Internal Combustion Engines	Criteria Pollutants	07B	
Criteria		Emission Factors		21G
Contaminants	Assessments	Control Costs		14B

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