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RAILROADS AND AIR POLLUTION: A PERSPECTIVE

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FINAL REPORT

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This report reflects the views of the Transportation Energy Panel which is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Federal agencies participating on TEP. The report does not constitute a standard, specification, or a regulation.

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16. Abstract

A review of existing air pollution control legislation is presented with emphasis on legislation affecting the rail industry. Locomotive exhaust emissions, especially smoke, are receiving the bulk of attention from control agencies and the general public. Railroad emissions and emission sources are identified. Railroad exhaust emissions are estimated for the nation and for a region (St. Louis, MO). Transportation modes are compared for fuel consumption per unit work performed and for the emissions associated with consuming that fuel.

Recommendations include the environmental impact analysis of diesel-electric locomotive exhaust emissions on the air quality of St. Louis, MO, and the comparison of transportation modes based on emissions per unit work performed, grams pollutant emitted per 1000 ton-mile freight moved for line haul and grams pollutant emitted per 1000-ton freight throughput for terminals.

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PREFACE

The Office of Policy and Plans has the responsibility for environmental matters for the Federal Railroad Administration, Washington, DC. To fulfill this responsibility partially, the Program Planning Division has supported this study, performed by the Environmental Measurements Branch of the DOT/Transportation Systems Center, to assess the air pollution potential of railroads.

A portion of this study is based upon a similar study performed in the Environmental Measurements Branch and sponsored by the U.S. Coast Guard Pollution Abatement Program. The author acknowledges the effort of the Association of American Railroads in funding the Battelle Memorial Institute to perform the work embodied in their report "A Study of the Environmental Impact of Projected Increases in Intercity Freight Traffic" which provided the framework for the present study.

TABLE OF CONTENTS

Section Page

TABLE OF CONTENTS (CONT'D)

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (CONT'D)

LIST OF TABLES (CONT'D)

1. INTRODUCTION

1.1 OBJECTIVE

The objective of this effort is to analyze the new environmental pollution control regulations, their effect upon the railroad industry and the methodology for evaluating railroad air pollution. Of major interest are the changes of present operating procedures that are, or will be, required to insure compliance with new legislation designed to protect the environment.

1.2 SCOPE

This report is limited to a review of current air pollution regulations and to a brief review of those railroad operations that contribute to air pollution. Suggested solutions to the problem are included. The areas of water pollution, solid waste disposal and land use are left to future efforts.

Since the entire environmental field is in such a state of flux, this work will attempt to project the various possible control regulations that may be enacted in the near future. The general trend in environmental control regulations at the present time is towards stricter legislation. More and stricter emission control regulations will be enacted and enforced in all sectors of our society. Currently, the Clean Air Amendments of 1970 are being implemented; it will require several years before the total effect of these control measures will be known.

We can expect similar plans to insure clean water, the efficient use of land and of other natural resources, the control of solid waste and of a "new" pollutant: noise. In summary, it seems quite evident that only the tip of the pollution control "iceberg" has surfaced.

2. CONTROL AND ABATEMENT OF POLLUTION

Clean air in an industrial society requires the implementation of pollution control and abatement practices. The process of enacting legislation, establishing and enforcing control regulations, instituting control measures and assessing compliance is long and complicated. To better understand how environmental control is formulated, we will examine and analyze a very simple idealized case.

2.1 GOVERNMENT AND POLLUTION CONTROL

Pollution control usually begins when a governing body (Federal, state or local) becomes aware through citizen action that some environmental dislocation (i.e., pollution) exists. The governing body may ask the general public, recognized scientists and other interested parties for their opinions on the acceptability of this dislocation. If the governing body decides that the extent of the dislocation of the environment may impair the health or welfare of the public, they must act to protect the public. When legislative bodies have enacted air pollution control legislation in the past, they have either designated a public health agency or formed an air pollution control agency to promulgate and enforce control regulations. Thus, the first step in pollution control is to obtain the legal authority to promulgate and enforce pollution control regulations, as shown in Figure 2-1.

Figure 2-1 Citizen Action Motivates Legislative Action to Grant a Governmental Agency the Power to Effect Pollution Control

The designated control agency has the formidable task of defining pollution in a legal sense and of formulating a control strategy. The control agency begins by identifing the effects of the pollutants on the public (if this has not been accomplished during the legislative phase). By identifying the effects of pollutants (cause and effect), the agency can define a level or a concentration where damage occurs. This concentration then establishes the level where pollution is defined to occur. Historically, the data available on the effects of air pollution have not been conclusive; this is a point of much controversy in current air pollution control regulations. The control agency then aims to reduce the pollutant concentration to below the <u>defined</u> level. Again, the identification of the effects of pollution and of the threshold concentrations at which these effects begin to be evident are the foundations upon which a control strategy is formulated.

After pollution has been defined, the control agency begins to identify the emission sources that are contributing to the pollution. This phase is commonly referred to as an emission source inventory. Upon completion of the source inventory, the control agency must establish the control regulations. Factors considered include the discharge amounts for each type of source, the abatement technologies that can be applied to each industry, the change in concentration needed to reduce the levels to a non-polluting state and a cost-benefit study.

With the establishment of control regulations, the polluting industries are given a period of time to comply by instituting control procedures. The agency must check the emission source after control measures have been taken to insure that the emission source is complying with the agency's regulations.

The agency must evaluate the ambient air quality before, during and after control steps have been taken. The agency determines the actual amount of reduction achieved by the control measures versus the predicted or desired reduction. The action of an air pollution control agency can be typified by Figure 2-2.

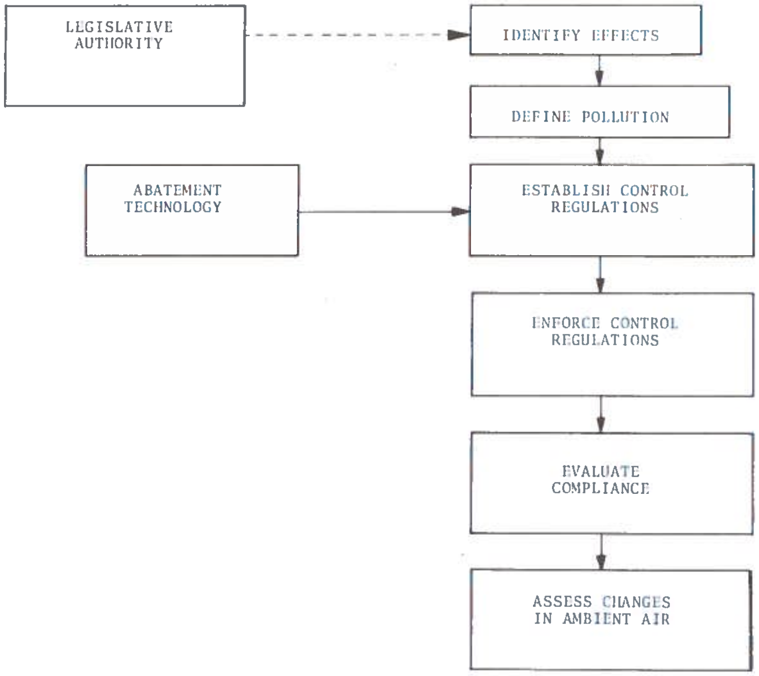

Figure 2-2 Action Taken by Air Pollution Control Agency to Achieve Pollution Abatement

2.2 INDUSTRY AND POLLUTION ABATEMENT

The role of the emission source owner is much different from the control agency's but is directly related to the agency's action. The air pollution control agency establishes the maximum permissible emission rates and the source owner must comply by reducing his emissions to meet the regulation.

Specifically, each source owner must identify and characterize his emission points and take action on those emissions exceeding the maximum established rate. Each source may pose individual problems, thus each must be characterized. The source owner must decide on the control technique to be installed in his facility that will reduce his emissions at least to the maximum legal permitted amount. He may wish to reduce his emissions below the maximum amount as a safety factor. If the life expectancy of the control equipment is substantial and the owner believes that stricter emission control regulations will be enforced during the life of the equipment, he may choose emission levels substantially below the current maximum permitted levels. The final decision on the emission goals and on the control techniques used to achieve them must be based upon an extensive cost-effectiveness study of each emission level and control technique.

Changes in operating procedures and/or the installation of control equipment is the source owner's next step. Once these tasks have been completed, tests are performed to determine the actual versus the designed performance of the control measures and to confirm compliance with the air pollution control regulations. The action of a source owner after specific control regulations are promulgated are summarized in Figure 2-3.

Air pollution and air pollution control by source emission control are complex issues. To achieve a reduction of pollutants in our environment, there must be a joint effort between the organizations demanding reduced emissions and the organizations which are expected to reduce the emissions.

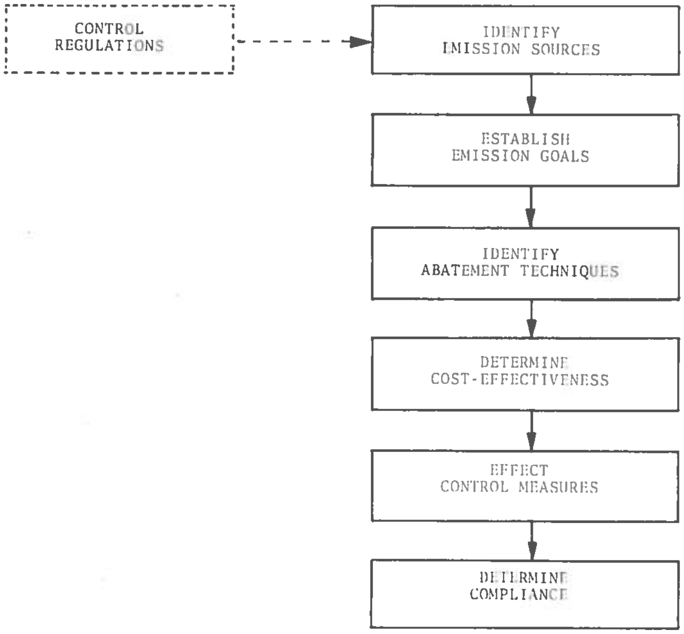

Figure 2-3 Action Taken by Owner of Pollution Source After Control Regulations Have Been Promulgated

2.3 PRESENT STATUS OF POLLUTION CONTROL

The period 1969-1971 saw a flurry of environmental control legislation enacted by the Federal and state governments. Many of these laws established control agencies in states that never had such agencies before. The majority of the legislation strengthened or created new emission regulations (Sections 3.2 and 3.3). Thus the government has reacted to a situation as outlined in Section 2.1.

The United States Congress acted in passing the Clean Air Amendments of 1970 (Section 3.2.3) and now the states are responding by adopting the control regulations required by the 1970 Amendments (Section 3.3).

During 1972, industries affected by the regulations promulgated under authorization of the Clean Air Amendments have begun to formulate control strategies for each source to be regulated.

We have thus followed the steps outlined in Figure 2-1 and are currently establishing control regulations as shown in Figure 2-2. The time sequence involved with the regulations established under the 1970 Amendments are as follows:

1970: Provide legislative authority (Federal Government)

1970-71: Establish and strengthen state control agencies (state governments)

1971: Begin formulating implementation plans; i.e., control strategy and regulations (state agency)

1972: Finalize implementation plans (state agency)

1972-75: Enforce control regulations (state agency)

1972-75: Effect control measures (industry).

The control measures authorized under the 1970 Amendments are to be effected no later than the summer of 1975. The implementation plans (control regulations) will be finalized by the summer of 1972. Thus industry will have at most approximately three years to reduce emissions to meet the new emission control regulations.

3. LEGISLATIVE GUIDELINES FOR AIR POLLUTION CONTROL

3.1 GENERAL DEFINITION OF TYPES AND EFFECTS OF AIR POLLUTION

A variety of definitions for air pollution have been devised, each expressing more or less completely its author's individual philosophical, theoretical, practical or protective motivation. For the purposes of this report we will define air pollution as an atmospheric condition resulting from the introduction of a substance or substances in sufficient concentrations to produce an undesirable (and hence observable) effect on man, animals, vegitation or materials. In the context of this definition, both natural and anthropogenic (man-made) sources may contribute to air pollution. "Pollution control" is directed only towards man-made sources of pollution.

In an effort to classify air pollutants, two groups are generally considered: (a) those pollutants emitted directly from identificable sources (called primary pollutants), and (b) those pollutants produced in the air by interactions among primary pollutants or by reaction with compounds normally present in the air (secondary pollutants). Primary air pollutants are usually associated with discharges from energy sources, although specific manufacturing processes such as metallurgical, cement and paper industries may be significant sources of primary air pollutants. Typical primary emissions are particulate matter, sulfur oxides, organic compounds, nitrogen oxides, carbon oxides, and halogen compounds. These are generally associated with the combustion of fossil fuels or with industrial processes. Secondary pollutants arise from the reaction of primary pollutants, as in the formation of peroxyacylnitrate (PAN) from hydrocarbons, ozone and oxides of nitrogen. Sulfur oxides and water may combine to form sulfuric acid aerosols.

Air pollution affects our environment by several mechanisms. Airborne particles, or aerosols, adversely affect the transmission of light, resulting in a reduction of visibility. For example, the phenomenon of light scattering by small particles is evident in common ground fog, where the light scattering centers in this instance are small water droplets. The attenuation of solar radiation due to air pollution could produce a marked effect on vegetation and global climatic conditions in general [1]. Direct damage to structural metals, surface coatings, fabrics and other materials results from exposure to high concentrations of acid mists, oxidants of various kinds and hydrogen sulfide. These air pollutants (and others, such as hydrocarbons, fluorides and ozone) account for immeasurable annual damage to food crops, forage and ornamental crops. Air pollution damage is evident in various types of leaf damage, the stunting of plant growth, the decreased size and yield of fruit and the destruction of flowers [2].

Air pollution's most dramatic effect on man is recorded in the acute episodes in Donora, London and the Mesue Valley, in which both human and animal life were lost. Continued exposure to sub-lethal concentrations of many pollutants and their combinations are suspected to have physiological effects but, at the present time, few quantitative relationships have been defined to document this suspicion. Chronic bronchitis, nasopharyngeal and optic irritation are "normal" visible physiological responses to air pollution. More subtle physiological effects are thought to include alterations in pulmonary physiology, specific enzymic inhibitions and changes in blood chemistry [3].

The psychological effects of air pollution, or the threat of air pollution episodes, cannot be discounted. Little effort has been directed toward determining the relationship between community mental health and air pollution, but such research can be expected to be initiated in the near future [3].

3.2 MAJOR FEDERAL LEGISLATION

Air pollution control in the United States began in the last quarter of the nineteenth century and gained momentum in the early part of this century. Control measures were initially directed towards the abatement of the smoke and sulfur oxides prevalent in our industrial centers. These pollutants were controlled by means of legislation enacted on a municipal or state level which required smoke to be kept below some maximum optical density ("Ringelmann Number") or that the use of specific fuels be curtailed. Air pollution legislation has always been formulated on the basis of preserving public health or welfare. Since most regulations were enacted and enforced on the state or local level, the variation in the type of emissions controlled and the maximum permitted emission level is almost endless.

3.2.1 Federal Legislation Prior to 1967

The Federal air pollution control program began in 1955, when the Department of Health, Education and Welfare (HEW) was authorized to conduct research on air pollution and provide technical assistance to municipal, county and state governments concerning air pollution[4]. In 1960, Congress authorized the Public Health Service to study the effects of motor vehicle pollution on public health. The awakening of the general public to the problem of air pollution lead to the enactment of the Clean Air Act of 1963. This Act continued Federal aid in the funding of state air pollution control programs but, more importantly, it also provided for Federal enforcement in cases involving interstate pollution. The 1963 Act provided for three specific areas of research to:

a. control motor vehicle exhaust emissions

b. remove sulfur from fuels

c. develop air quality criteria[4].

The Clean Air Act was amended in 1965 to provide stricter control of automotive emissions. The amendments to the Act in 1966 were fiscal in nature: grants to state air pollution control programs were increased.

3.2.2 The Air Quality Act of 1967

A major policy revision in the Federal air pollution control program was evidenced in the Air Quality Act of 1967. Control philosophy now centered on <u>regional</u> enforcement and control. The foundation of this approach was the designation of atmospheric, or air shed, regions across the continental United States. The next step was to divide the air sheds into air quality control regions. These air quality control regions were to include communities which showed common air pollution problems. In addition to the designation of air shed regions, the Secretary of HEW was required to publish "air quality criteria" for each pollutant, based upon scientific studies and describing the harmful effects of each pollutant upon the health and welfare of the populace. The Secretary was also required to publish "control technology" documents that would demonstrate the feasibility, cost and effectiveness of proposed pollution abatement practices. The states would then be responsible for setting the regional ambient air quality standards which set forth the maximum level of pollutants permitted in the air shed. The basis of the regional air quality standards were to be the air quality criteria issued by the Secretary of HEW. After the state air quality standards were developed and approved by HEW, the states were to establish comprehensive air pollution control implementation plans. These implementation plans were to be the mechanism for achieving the air quality standards by source control. Primary responsibility for enforcement of the standards and implementation plans rested with state and local governments. If a case of interstate air pollution existed, or if an offending state were not adequately equipped to enforce its standards, the Federal government was empowered to assume responsibility and enforce the standards.

As an example of the time-consuming process of standard setting and approval and of the formulation of an implementation plan as required by the Air Quality Act of 1967, only seventeen states had submitted standards to HEW by July of 1970 and no implementation plans had been approved by September 21, 1970.

The Air Quality Act of 1967 provided for Federal preemption in the establishment of emission standards for new motor vehicles. The reasoning of the Congress was that a Federal, and hence, national, emission standard was necessary to insure that the multiplicity of state standards apparent in the control of other pollutants would not occur in the case of automobile emissions. Congress felt that it would be impossible for the auto makers to meet all of the various possible state standards, whereas a single, strict, Federal requirement could be more easily enforced.

The 1967 Act had several shortcomings: (a) cumbersome and time-consuming procedures required for the establishment of standards; (b) inadequate funding at the Federal, state, and local levels; (c) insufficient number of skilled personnel to enforce control measures; (d) organizational problems at the Federal level, where air pollution had not been accorded high priority, and (e) failure of HEW to perform its duties to the fullest extent [4].

President Johnson stated in Executive Order 11,282 that it was his desire to make all Federal Facilities and activities model pollution control and abatement installations [5]. In situations where pollution was caused by Federal facilities, President Nixon's Executive Order 11,507 ordered abatement practices to be under way no later than December 31, 1972 [6].

3.2.3 Clean Air Amendments of 1970

Congress reaffirmed the national policy to abate pollution where it exists and to preserve natural resources and beauty where endangered by enacting the National Environmental Policy Act of 1969 and the Clean Air Amendments of 1970[7]. The Clean Air Amendments are the most dramatic and far-reaching pollution control legislation ever enacted in this country. Actually a series of amendments to the Air Quality Act of 1967, the 1970 Act is divided into four parts or "titles": Title I concerns air pollution caused by stationary sources; Title II regulates emissions from mobile sources (motor vehicles and aircraft); Title III embodies a variety of general provisions including a controversial "citizen suits" provision and a judicial review provision; Title IV concerns Federal research efforts into the problems of noise. By far the most controversial point of the 1970 Act is the reduction of motor vehicle emissions by source control by means of the 1975 and 1976 emission standards.

The 1970 Act was a radical shift in legislative philosophy. Past procedure had been the establishment of air pollution standards commensurate with existing technology; Congress now shifted to a policy which is forcing technology to catch up with the newly promulgated standards. The standards themselves are still conceived on the basis of protecting public health or welfare. The 1970 Act continues to emphasize the support of research and grants contained in the 1967 Act, and the concept of Federal air quality control regions is also retained. The Administrator of the Environmental Protection Agency (EPA), in assuming responsibility from the Secretary of HEW for air pollution control, was required to designate additional air quality control regions within ninety days of the enactment of the Amendments. Specific dates or milestones pertaining to designation of regions, standards, and implementation plans were established to prevent the time slippage that occured in implementing the provisions of the 1967 Act. Once all air quality control regions covering the continental United States were established, the EPA Administrator was required to publish additional air quality criteria and information on techniques for control of newly evaluated pollutants.

3.2.3.1 Ambient Air Quality Standards - An important change of the 1970 Act requires the EPA Administrator, rather than each individual state, to establish ambient air quality standards for specific air pollutants. EPA has established not only national primary ambient air quality standards but also national secondary ambient air quality standards. The national primary ambient air quality standards define levels of air quality that the EPA Administrator judges are necessary, with an adequate margin of safety, to protect the public health. National secondary ambient air quality standards define levels of air quality which the Administrator judges necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state was given nine months after the publication of the primary and secondary standards to submit to EPA implementation plans for the attainment and maintenance of the national primary and secondary ambient air quality standards. The national standards do not prohibit any state or region from establishing local ambient air quality standards that are more stringent than the national standards.

3.2.3.2 Source Performance Standards - The Federal government has preempted state and local governments in the regulation of new steam generating plants, incinerators, acid manufacturing plants and cement works by establishing new source performance standards. These standards set maximum emission levels for each type of source. Hence, a particular type of plant must meet the same emission standards wherever it is located. Such regulations prevent owners of major emission sources from exerting political influence on local or state air pollution control agencies. The Act also precludes gaining an economic advantage by relocating a plant to an area of less stringent emission standards. In addition, industry can now devote all of its resources to meeting a single standard instead of being faced with a multiplicity of (sometimes conflicting) regulations.

3.3 STATE AND MUNICIPAL LEGISLATION

Most air pollution control regulations enacted in this country prior to 1970 were directed toward the control and abatement of smoke, particulate matter and sulfur oxides. The pollutants were emitted principally from the combustion of coal and residual oil in our large industrial centers. Since each city or region had its own particular air pollution problems and economic and political interests, control regulations were not uniform. In fact, the number of different control regulations for a given pollutant may approach the number of political regions enacting control legislation.

Since 1960, air pollution control regulations have reflected a growing public concern for air pollution and its effects. Control regulations have become more stringent and the number of different emissions regulated has been increased. Table 3-1 is a summary of typical municipal, county and state air pollution control regulations currently in force. It is apparent at first glance that all regulations pertaining to one pollutant are not identical. In

TABLE 3-1 SUMMARY OF MUNICIPAL, COUNTY AND STATE AIR POLLUTION CONTROL REGULATIONS

REGION	EMISSION	REGULATION	DATE EFFECTIVE
Allegheny Co., PA	Smoke	Smoke appearance, density, or shade not to exceed Number 2 Ringelmann; includes railroad locomotives, boats and other vehicles.	1960
	Particulates	Particulate emission not to exceed 0.65 lb/1000 lb. stack gas, except for tube blowing which may exceed standard 6 minutes out of every hour.	
Chicago, IL	Smoke	Smoke not to exceed Number 2 Ringelmann 4 minutes out of 30 or Number 3 Ringelmann 4 minutes out of 60. Regulation applies to fuel burning equipment and diesel powered motor vehicles.	1965
	Particulates	Not to exceed 0.35 grains/standard cubic foot (scf); 0.21 grains/scf of particles 44 micron diameter or larger.	1964
	Smoke & Gases	No internal combustion engine of any motor vehicle, boat, tug, or other vehicle, except aircraft at municipal airports, while stationary or moving may emit excessive smoke, obnoxious or noxious gases, fumes, or vapors.	1966
Cleveland, OH	Smoke	Emissions not to exceed Number 3 Ringelmann for 30 seconds per 4 minutes by locomotives and 6 minutes per hour by steamships.	
Portland, OR	Smoke	Emissions not to exceed Number 2 Ringelmann or equal opacity one minute per hour; motor vehicle not to exceed Number 1 Ringelmann continuous or Number 2 in excess of 5 seconds	1964
Poughkeepsie, NY	Smoke	Railroad emissions not to exceed Number 2 Ringelmann except for locomotives in motion which may emit Number 3 Ringelmann for 1 out of 6 minutes, or 4 out of 30 minutes if not in motion.	1951
Niagara Co., NY	Smoke	Emissions not to exceed Number 1 Ringelmann if unit constructed after Feb. 1967; emissions not to exceed Number 2 Ringelmann if unit constructed before Feb. 1967. Units include stationary power boilers, locomotives and vessels. Emissions not to exceed Number 3 Ringelmann 3 out of 30 minutes for tube blowing.	1967
Gary, IN	Particulates	Not to exceed 0.60 lb/10^6 BTU heat input for units less than 10^7 BTU/hour total heat input.	1967

TABLE 3-1 SUMMARY OF MUNICIPAL, COUNTY AND STATE AIR POLLUTION CONTROL REGULATIONS (CONTINUED)

REGION	EMISSION	REGULATION	DATE EFFECTIVE
New Orleans, LA	Smoke	Release of dense smoke from a railroad engine, steamboat, steamship, tugboat, or any other self-propelled steam vessel, roller, etc., or any building, is a misdemeanor.	1963
	Tube Blowing	Tube blowing is prohibited within city limits.	
New York, NY	Smoke	Emissions between Number 1 and 2 Ringelmann not to exceed 4 minutes in an hour; between Number 2 and 3 Ringelmann, not to exceed 2 minutes in an hour; no emission to exceed Number 3 Ringelmann. If emission is emitted outside NYC, it shall be measured after it crosses into NYC jurisdiction	
	Particulates	Not to exceed 0.60 lb/10^6 BTU in an hour if total heat input less than 10^7 BTU in an hour.	1964
	S & SO_2	Fuel sulfur content not to exceed 0.3%; SO_2 emission for old systems limited to 200 ppm max. concentration of stack gas; new systems, 100 ppm SO_2.	1971
	NOx	Old systems, NOx limited to 150 ppm max. stack gas concentration; new systems, 100 ppm NOx.	1971
San Francisco Bay Area, CA	Particulates	Emission not to exceed 0.30 grains per scf.	1962
	Hydrocarbons	Hydrocarbon emissions not to exceed 50 ppm benzene or 300 ppm total organic carbon as methane; evaporative losses occurring from tank-truck filling not to exceed 0.01% of volume loaded.	1967
Los Angeles Co., CA	Particulates	Emissions not to exceed 0.30 grains per scf except those regulated by Rules 53 & 54 (Specific emission rates).	1956
	SO_2 & S	Not to exceed 0.2% (volume) in stack gas; sulfur content of fuel not to exceed 0.5% by weight.	1965
	NOx	Emission not to exceed 225 ppm NOx as NO_2 of stack gas from stationary sources.	1971
		Emission not to exceed 125 ppm NOx as NO_2 of stack gas from stationary sources.	1974
Miami, FL	Smoke	Emissions not to exceed Number 2 Ringelmann continuous or Number 3 for 3 minutes in an hour.	1964
	Soot, Cinders, Noxious Acids, Fumes & Gases	No emission permitted that may be detrimental to any person, or to the public, or to endanger the health, comfort, and safety of any such person, or to cause injury or damage to property or business.	1964
	Fuel Oil	Grade Number 6 or other grade inferior may not be used.	1971

TABLE 3-1 SUMMARY OF MUNICIPAL, COUNTY AND STATE AIR POLLUTION CONTROL REGULATIONS (CONTINUED)

REGION	EMISSION	REGULATION	DATE EFFECTIVE
Massachusetts	Smoke	Emissions limited to Number 1 Ringelmann or Number 2 for 6 minutes in an hour for stationary sources; emissions from aircraft not to exceed Number 2 Ringelmann for 10 seconds.	1971
		Diesel locomotives may not idle continuously in excess of 30 minutes.	1972
	Fuel	Sulfur content of fuel limited to 1% in areas outside of Boston and 0.5% for Boston. No residual fuel may be used.	1971
New Mexico	Smoke	Emission from diesel powered vehicles not to exceed Number 1.5 Ringelmann in excess of 10 seconds when operating below 8000 ft. mean sea level (msl); locomotives limited to Number 1 Ringelmann below 8000 ft. msl	1971
	Smoke	Emission from diesel powered vehicles not to exceed Number 2 Ringelmann in excess of 10 seconds when operating above 8000 ft. msl; locomotives included when involved in switching and yard usage or when operating above 8000 ft. msl.	1971
New York	Smoke	No emission of an opacity greater than 20% shall be emitted from any diesel engine, excluding marine diesels.	1967
Colorado	Smoke	Emission from diesel powered motor vehicles operating on a roadway at an altitude below 8000 ft. msl may not exceed 30% opacity; opacity not to exceed 40% when operating above 8000 ft. msl.	1971
	Smoke	Emissions from diesel powered locomotives not to exceed 20% opacity for a period more than 10 seconds when operating below 8000 ft. msl, opacity not to exceed 40% for a period in excess of 10 seconds when operating above 8000 ft. msl.	1971
	Smoke	Emissions from diesel powered locomotives engaged in switching and yard use not to exceed 40% opacity for a period more than 10 seconds.	1971

TABLE 3-1 SUMMARY OF MUNICIPAL, COUNTY AND STATE AIR POLLUTION CONTROL REGULATIONS (CONCLUDED)

REGION	EMISSION	REGULATION	DATE EFFECTIVE
New Jersey	Smoke	Emission from mobile sources not to exceed Number 2 Ringelmann or 40% opacity in excess of 10 consecutive seconds. Mobile sources are defined to include, but are not limited to, aircraft, locomotives operating on rails, tractors, earth moving equipment, hoist and mobile power generators.	1972
	Smoke	Emission from marine steam boiler not to exceed Number 1 Ringelmann or 20% opacity.	1972
	Open Burning	No person shall cause, suffer, allow or permit a salvage operation by open burning.	1971
		No person shall cause, suffer, allow or permit the disposal of rubbish, garbage or trade waste or buildings or structures by open burning.	1971
	Hydrocarbons	Evaporation control required depending upon vapor pressure of substance and amount stored.	1972
St. Louis, MO	Smoke	Visible emission from any internal combustion engine not permitted in excess of 10 consecutive seconds.	

fact, regulations covering the same geographical area may even be contradictory. For example, Niagara County, New York, regulates smoke emissions from all sources including marine diesels, whereas New York State specifically excludes regulation of marine diesels[8]. Colorado and New Mexico have recently enacted a controversial smoke emission standard for locomotives[9,10]. Several mountain states are currently studying these laws and will probably use them as a model for their own legislation.

With the establishment of a strong Federal air pollution control program, it can be expected that states will begin to enforce regulations currently on the books and new laws will be passed in order to meet the requirements contained in their regional air pollution control implementation plans.

TABLE 3-2 NATIONAL AMBIENT AIR STANDARDS [11]

COMPOUND	PRIMARY STANDARD	SECONDARY STANDARD
SOx	0.03ppm[a] 0.14ppm[b]	0.02ppm[a] 0.10ppm[b] 0.50ppm[c]
CO	9ppm[d] 35ppm[e]	9ppm[d] 35ppm[e]
Photochemical Oxidants	0.08ppm[e]	0.08ppm[e]
Hydrocarbons	0.24ppm[f]	0.24ppm[f]
NO_2	0.05ppm[e]	0.05ppm[a]
Particulates	75 $\mu g/m^3$[g] 260 $\mu g/m^3$[b]	60 $\mu g/m^3$[g] 150 $\mu g/m^3$[b]

Notes:

a. Annual arithmetic average.
b. Max. 24 hour concentration, not to be exceeded more than once a year
c. Max. 3 hour concentration, not to be exceeded more than once a year
d. Max. 8 hour concentration, not to be exceeded more than once a year
e. Max. 1 hour concentration, not to be exceeded more that once a year
f. Max. 3 hour concentration (6 to 9 a.m.) not to be exceeded more than once a year
g. Annual geometric mean

TABLE 3-3 NEW STATIONARY SOURCE PERFORMANCE STANDARDS FOR FOSSIL FUEL STEAM GENERATING PLANTS OF MORE THAN 250 x 10^6 BTU/HOUR TOTAL HEAT

EMISSION	STANDARD (MAXIMUM PERMITTED EMISSIONS)
Particulates	0.10 lbs/10^6 BTU HEAT INPUT[a] An opacity of 20% continuous An opacity of 40% is permitted for not more than 2 minutes in any hour; excludes uncombined water.
SO_2	0.8 lb/10^6 BTU heat input[a,b] 1.2 lb/10^6 BTU heat input[a,c]
NOx	0.20 lb/10^6 BTU heat input[a,d] 0.30 lb/10^6 BTU heat input[a,b] 0.70 lb/10^6 BTU heat input[a,c]

Notes:

a. Max. 2 hour average
b. If liquid fuel is burned
c. If solid fuel is burned
d. If gaseous fuel is burned

3.4 IMPLEMENTATION OF EXISTING LEGISLATION

3.4.1 Primary and Secondary Ambient Air Quality Standards

Under Title I of the Clean Air Act of 1967, as amended, the Federal government, through the Environmental Protection Agency, has established national primary and secondary ambient air quality standards. Primary ambient air quality standards are designed to insure an atmosphere of such a quality that it will not endanger the public health. The secondary ambient air quality standards are designed to protect the general health or welfare from known or anticipated adverse effects.

National primary and secondary ambient air quality standards are to be achieved by having each individual state submit an implementation plan to EPA for each air shed region within its jurisdiction. Abatement practices and control measures required of industry, business and private individuals must be specified in the implementation plans. Typical of such regulation is the specification of the sulfur and ash content of fossil fuels to be used within the air shed. The primary ambient air quality standards are to be achieved no later than July 31, 1975.

Primary and secondary standards have been promulgated for sulfur oxides, carbon monoxide, photochemical oxidants, hydrocarbons, nitrogen dioxide and particulates. Table 3-2 is a presentation of the national primary and secondary ambient air quality standards for the United States.

3.4.2 Stationary Source Performance Standards

The Federal government has established national source performance standards for new fossil fuel steam generating plants as required by Title I of the Clean Air Act. These standards specify the maximum permitted emission levels of particulates, sulfur dioxide, and nitrogen oxides. Table 3-3 is a presentation of the emission standards. Besides these standards, the following requirements apply. Monitoring instruments required on stack are: (a) smoke detector and recorder when liquid or solid fuel is used; (b) continuous SO_2 monitor and recorder when high sulfur content liquid or solid fuel is used, and (c) continuous NOx monitor and recorder. In addition, the sulfur content of all solid and liquid fuels must be determined.

In addition to regulating new steam generating plants, the Federal government has set emission standards for new portland cement plants, incinerators and acid manufacturing plants.

3.4.3 Automobile and Diesel Performance Standard

The control of air pollution from new motor vehicles has been the major objective of most Federal air pollution control legislation. At the present time, successively more stringent performance standards for new automobiles have been established for each year through 1975 (or 1976, with a one year extension for NO_x). It became apparent that meeting these emission standards, originally proposed for implementation by 1980, would not permit the achievement of the required ambient air quality within our cities by 1975; hence the program was accelerated by shifting the 1980 standards to 1975. Under the 1967 Act, automobile emission standards were set by HEW on the basis of economic and technological feasibility, whereas the 1970 Act required the standards to be set on the basis of protecting public health; existing technology or cost were not considered to be relevant[4]. Table 3-4 is a summary of emission standards for new automobiles conducted under the Federal Test Procedure for such engines.

TABLE 3-4 EMISSION STANDARDS FOR NEW AUTOMOBILES[13]
grams/mile under Federal Test Procedure (FTP)

MODEL YEAR	HC	CO	NO_x
1972	3.4	39	No Standard
1973	3.4	39	3.0
1975	0.41	3.4	3.0
1976	0.41	3.4	0.4

Exhaust emission levels have also been established for heavy duty diesel engines. Similar to the automotive standards, the diesel emission standards become more stringent each succeeding model year. For the present model year, only smoke emissions are regulated. By 1973, emissions of smoke, hydrocarbons, carbon monoxide and nitrogen oxides will be regulated if the proposed regulations are approved. Table 3-5 presents current and proposed emission standards for new heavy duty diesel engines tested under the Federal Test Procedure.

The auto and diesel standards, derived from Federal legislation, are intended to control the maximum emissions from these sources. It should be emphasized that states, through their clean air implementation plans, may request a waiver from the Federal standards and require more stringent state standards. To date only the State of California has been granted such a waiver. Table 3-6 is a summary of required or proposed California standards that must be fulfilled in addition to satisfying the Federal standards.

3.4.4 Aircraft Emission Standards

Title II, Part B, of the Clean Air Act of 1970 directs the EPA Administrator to study the impact of aircraft emissions on the air quality of the United States. He is also to determine the feasibility of controlling such emissions. The EPA Administrator, in conference with the Federal Aviation Administration, is to issue proposed emission standards for any air pollutant arising from aircraft operation which, in his judgement, causes or contributes to air pollution which endangers the public health or welfare.

Proposed emission standards for aircraft engines are expected to be published in 1972. It is expected that national aircraft emission standards for carbon monoxide, hydrocarbons, nitrogen oxides and smoke will be proposed at that time. Regulation and enforcement will be the responsibility of the FAA.

TABLE 3-5 NATIONAL EMISSION STANDARDS FOR HEAVY DUTY DIESEL ENGINES [14]

Smoke Opacity%[a]

MODEL YEAR	ACCELERATION MODE	LUGGING MODE
1971	40	20
1972	40	20
1973 (proposed)	20	15
1973 (proposed)	HC 3.0gm/BHP-hr[b]	
1973 (proposed)	CO 7.5gm/BHP-hr	
1973 (proposed)	NOx 12.5gm/BHP-hr	

Notes:

a. Smoke opacity not to exceed a 50% opacity peak in either mode
b. Grams/Brake-horsepower hour

TABLE 3-6 EMISSION STANDARDS REQUIRED BY CALIFORNIA IN ADDITION TO FEDERAL STANDARDS [15]

MODEL YEAR (IN WHICH STANDARD BECOMES EFFECTIVE)		EMISSION STANDARD
1972 (Auto)		HC = 1.5gm/mile NOx = 3.0gm/mile[a]
	or	HC = 3.2gm/mile NOx = 3.2gm/mile[b]
	and	HC = 1.4 gm/mile NOx = 3.2gm/mile CO = 19gm/mile[a,c]
1973 (Auto)		Octane requirement not to exceed 91 RON, 100% end of line testing
1973 (Heavy Duty Diesel)		HC + NOx < 16gm/BHP-hr CO ≤ 40gm/BHP-hr
1974 (Auto)		NOx = 1.3gm/mile[a]
1975 (Heavy Duty Diesel)		HC + NOx ≤ 5gm/BHP-hr CO ≤ 25gm/BHP-hr

Notes:

a. Tested by 1970 Federal Test Procedures (FTP)
b. Tested by 1972 FTP
c. Required end of line testing of 25% of autos in one hot cycle

3.4.5 Federal Facilities

The desire to make all Federal facilities and activities model pollution control and abatement installations has been indicated in several Executive Orders and legislative Acts. Executive Order 11282 specified the maximum amounts of visible emissions (smoke), sulfur oxides, particulates and evaporative losses permitted from Federal facilities. Table 3-7 is a summary of emissions permitted.

Section 118, Title I, of the Clean Air Act states that all Federal facilities will comply with Federal, state and local requirements to control and abate air pollution to the same extent that any other person is subject to such requirements. Hence, all Federal facilities are expected to meet the requirements laid down in the various regional air quality control implementation plans unless they are specifically exempted by Presidential Order. The President may exempt any Federal emission source if he determines it to be in the paramount interest of the United States to do so. The President is to report to Congress each January all exemptions granted during the preceding calendar year, together with his reasons for granting the exemptions. Exemptions are granted for a maximum period of one year, with additional exemptions possible if the President makes a new determination of need.

3.4.6 Air Pollution Alerts

Air pollution alerts are called when the concentration of pollutants in an air shed exceeds predetermined values. St. Louis has established three alert stages[17]. The Yellow Alert is called when the pollutant concentration approaches the maximum allowable concentration that does not endanger public health (Table 3-8). The preventive action required includes a ban on burning refuse, the restriction of unessential vehicle traffic, and the reduction of operations by certain industrial and business emission sources, as shown in Table 3-9.

The Concentration of pollutants during the Red Alert poses a serious health hazard to all the citizens of the air shed. Emergency action includes strictly limiting the use of motor vehicles, maximum reduction of emissions by industrial sources and prepara-

TABLE 3-7 EMISSION STANDARDS FOR FEDERAL FACILITIES [16]

POLLUTANT	REGULATION
Smoke and Particulates	Emission not to exceed Number 1 Ringelmann for new units of 10^9 BTU/hr total heat input. Emission not to exceed Number 2 Ringelmann for old units of 10^9 BTU/hr total heat input. Standard does not apply to start-up, cleaning of flues or to soot blowing.
SOx	Facilities will burn lowest sulfur content fuel reasonably available. In designated Air Quality Control Regions, facilities will burn appropriate fuel.
Fuel Storage	Gasoline, or volatile petroleum distillates of organic liquids having a vapor pressure of 1.5 psia or more, will be stored in pressure tanks or in containers equipped with a floating roof or vapor recovery system.

TABLE 3-8 AMBIENT AIR CONCENTRATIONS NECESSARY FOR ALERTS (ST. LOUIS, MO.) [17]

ALERT[a]	PARTICULATES Times SO_2[b,c]	SO_2ppm[c]	PHOTOCHEMICAL OXIDANTS[d] ppm	COppm[e]	PARTICULATES COH $\mu g/m^3$[c]	NOxppm
Yellow	0.2	0.3	0.1	15	3/375	0.6[d] 0.15[c]
Red	0.8	0.6	0.4	30	5/625	1.2[d] 0.3[c]
Emergency	1.2	0.8	0.6	40	7/875	1.6[d] 0.4[c]

Notes:

a. The Alert will be initiated when anyone of the concentrations is met or exceeded

b. The product of the hourly SO_2 concentration in ppm and the hourly particulate concentration in COH per 1000 linear feet

c. 24 hour average

d. 1 hour average

e. 8 hour average

tion for implementation of emergency plan. The Red Alert Plan objectives are stated in Table 3-10.

An Air Pollution Emergency occurs when a dangerous health hazard exists in the air shed. The reductions in emissions required during an Emergency Alert are more stringent than in a Yellow or Red Alert. Specific requirements are given in Table 3-11.

TABLE 3-9 YELLOW ALERT PLAN OBJECTIVES (ST. LOUIS, MO.) [17]

AIR CONTAMINANT SOURCE	REQUIREMENTS FOR PLAN
Electric Power Generating Facilities	a. Reduction of emission by utilization of fuels having low ash and sulfur content. b. Soot blowing and boiler lancing to be allowed only during periods of high atmospheric turbulence (12:00 P.M. to 4:00 P.M.). c. Reduction of emissions by diverting electric power generation facilities outside of area for which the Alert is called.
Process Steam Generating Facilities	a. Reduction of emissions by utilization of fuels having low ash and sulfur content. b. Soot blowing and boiler lancing to be allowed only during periods of high atmospheric turbulence (12:00 P.M. to 4:00 P.M.). c. Reduction of steam load demands consistent with continuing the operation of the plant.
Manufacturing industries of the following (SIC) group designations: Paper and Allied Products Industries - Group 26 Chemical and Allied Products Industries - Group 28 Petroleum Refining and Related Industries - Group 29 Stone, Glass, Clay and Concrete Product Industries - Group 32 Primary Metals Industries - Group 33 Grain Industries - Group 20	a. Reduction of air contaminant emissions by curtailing, postponing, or deferring production and allied operations. b. Stop all trade waste disposal practices which emit particulates, gases, vapors or malodorous substances including incineration. c. Reduction of heat load demands for processing to a minimum.
Other manufacturing facilities required to submit alert plans by the Executive Secretary	a. Reduction of air contaminant emissions by curtailing or deferring production and allied operations. b. Stop all trade waste disposal practices which emit particles, gases, vapors or malodorous substances including incineration. c. Reduction of heat load demands for processing to a minimum.
Private, public and commercial refuse disposal operations	a. Stop all open burning including disposal of diseased trees and burning at fire fighting schools, except as required for disposal of hazardous materials or other emergency needs. b. Operation of incinerators shall be limited to the hours between 10:00 A.M. and 2:00 P.M.
Transportation	The unnecessary operation of any motor vehicle should be restricted.

TABLE 3-10 RED ALERT PLAN OBJECTIVES (ST. LOUIS, MO.) [17]

All Yellow Alert plans shall be continued. In addition, the following steps shall be taken:

AIR CONTAMINANT SOURCE	REQUIREMENTS FOR PLAN
Process Steam Generating Facilities.	a. Maximum reduction of air contaminant emissions by utilization of fuels having the lowest ash and sulfur content. b. Maximum utilization of periods of high atmospheric turbulence (12:00 P.M. to 4:00 P.M.) for soot blowing and boiler lancing. c. Prepare to implement the "emergency" plan submitted to the Executive Secretary.
Manufacturing industries of the following SIC group designations: Paper and Allied Products Industries - Group 26 Chemicals and Allied Products Industries - Group 28 Petroleum Refining and Related Industries - Group 29 Stone, Glass, Clay and Concrete Product Industries - Group 32 Primary Metal Industries - Group 33 Grain Industries - Group 20	a. Maximum reduction of air contaminant emission by (if necessary) postponing production and allied operations. b. Maximum reduction of heat load demands for processing. c. Prepare to implement the "emergency" plan submitted to the Executive Secretary.
Other manufacturing facilities required to submit Alert plans by the Executive Secretary.	Maximum reduction of air contaminant emissions by (if necessary) postponing production and allied operations.
Private, public and commercial refuse disposal operations.	Stop operation of all incinerators.
Transportation	Car pools and public transportation must be used in place of unnecessary motor vehicle operation.

TABLE 3-11 AIR POLLUTION EMERGENCY PLAN OBJECTIVES (ST. LOUIS, MO.) [17]

All Yellow and Red Alert plans shall be continued. In addition, the following steps shall be taken:

AIR CONTAMINANT SOURCE	REQUIREMENTS FOR PLAN
Process steam generating facilities.	a. Maximum reduction of air contaminant emissions by reducing heat and steam load demands to values consistent with preventing equipment damage. b. Maximum utilization periods of high atmospheric turbulence (12:00 P.M. to 4:00 P.M.) for soot blowing and boiler lancing.
Manufacturing Industries of the following SIC group designations: Paper and Allied Products Industries - Group 26 Chemicals and Allied Products Industires - Group 28 Petroleum Refining and Related Industries - Group 29 Stone, Glass, Clay and Concrete Product Industries - Group 32 Primary Metal Industries - Group 33 Grain Industries - Group 20	Elimination of air contaminant emissions from the manufacturing operations by ceasing, curtailing, postponing or deferring production and allied operations to the extent possible without causing injury to persons or damage to equipment.
Other manufacturing facilities required to submit alert plans by the Executive Secretary	a. Elimination of air contaminant emissions from the manufacturing operations by ceasing, curtailing, postponing or deferring production and allied operations to the extent possible without causing injury to persons or damage to equipment. b. Maximum reduction of heat load demands for processing.
Private, public and commercial operations	The following places of employment, if notified by the Executive Secretary, shall immediately cease operations: a. Mining and quarrying operations, b. Construction projects except as required to avoid emergent physical harm, c. Manufacturing establishments except those required to have in force an air pollution alert plan, d. Wholesale trade establishments, e. Governmental units, except as required to implement the provisions of these regulations and other operations essential to immediate protection of the public welfare and safety, f. Retail trade and service establishments except pharmacies, food stores and other similar operations providing for emergency needs, g. Other commercial service operations such as those engaged in banking, insurance, real estate, advertising, etc., h. Educational institutions, and i. Amusement and recreational facilities.
Transportation	Motor vehicles shall only be used for private and public emergency needs.

4. RAILROAD AIR POLLUTION

Many types of railroad operations discharge materials into the atmosphere that contribute to air pollution: direct exhaust emissions, fuel evaporation, car salvage, open burning in right-of-ways, braking operations, cargo evaporation and entrainment, tank flushing and cleaning. The application of herbicides and defoliants in the rights-of-way is usually considered more of a water or soil pollution problem than one related to air pollution. Several local and state air pollution control agencies have regulated exhaust emissions and open burning (Section 3.3). For the electrical subways in our larger cities, the Federal government has established maximum emission rates for electrical generating plants (Section 3.4.2).

4.1 EXHAUST EMISSIONS

4.1.1 General

The deleterious emissions from diesel engines, gas turbine engines and boilers consist principally of hydrocarbons (HC), oxides of nitrogen (NO_x), carbon monoxide (CO), oxides of sulfur (SO_x) and particulate matter.

The majority of hydrocarbons are biochemically inert. Tests have indicated no debilitating effects from exposure to levels below 500 ppm, but the aromatic hydrocarbons can produce undesirable side effects at levels greater than 25 ppm. Hydrocarbons are active in the formation of photochemical smog, with resultant membrane and eye irritation.

Nitrogen dioxide (NO_2) is a highly toxic compound after as short as one-hour exposures at levels greater than 300 ppm. Long-term effects caused by continuous low-level exposures are not well known or understood. As with hydrocarbons, NO_2 is active in the photochemical smog reactions which cause eye and membrane irritation.

Carbon monoxide (CO) affects the oxygen-carrying capabilities of the blood. Since blood hemoglobin has a much greater affinity for CO than oxygen, exposure to concentrations in excess of 200 ppm for longer than one hour results in considerable impairment of body functions. There is no evidence to indicate that long-term exposure to low levels of CO has any cumulative effect in humans.

Sulfur dioxide (SO_2) reacts with water and is oxidized by atmospheric oxygen to form sulfuric acid mist, a major eye and lung irritant. The effects of sulfuric acid on humans are dependent on droplet size of the mist (whether or not they are in the respirable size range) and the pH of the droplet. It has been noted that SO_2 in concentrations above 5 ppm can adversely affect bronchial passages.

Particulate matter affects the human body in a variety of ways. Particulates may cause respiratory interference, produce toxic effects by their intrinsic toxicity (e.g. beryllium) or, in the case of "smog" particles, carry reactive substances on their surface into the respiratory tract.

4.1.2 Railroad Locomotives

4.1.2.1 Diesel Emissions - The diesel engine is operated in a fuel lean condition with excess oxygen available in the combustion chamber. Although the overall engine air/fuel ratio is high, there may exist pockets of varying air/fuel ratios within the cylinder charge. Those pockets where the air/fuel ratio is lower than the average ratio contribute to incomplete combustion and can result in increased hydrocarbon and carbon monoxide emissions.

Recent work has indicated that a large percentage of diesel engine hydrocarbon emissions is due to the residual fuel that remains at the injector tip after the injection is completed [18]. The tip fuel droplet is only partially combusted and the remainder is exhausted, thus contributing to hydrocarbon emissions.

Nitrogen oxides are formed by the oxidation of the nitrogen contained in the fuel itself and by the oxidation of atmospheric nitrogen. Atmospheric nitrogen reacts only at relatively high temperatures. Thus, as engine load increases, so does the peak flame temperature in the cylinder and increased nitrogen oxide emissions result.

Carbon monoxide diesel exhaust levels are controlled, in part, by the air/fuel ratio. As a diesel engine approaches full load conditions, carbon monoxide emissions may increase dramatically as the available oxygen is depleted in the fuel-rich pockets. Compared to gasoline engines, the diesel engine generally shows relatively low carbon monoxide emission.

The sulfur oxides emitted by a diesel are directly related to the sulfur content of the fuel. Generally, SO_2 exhaust gas concentration is not measured from internal combustion engines, as it may be accurately calculated from fuel analysis data. The sulfur content of #2 distillate fuel, the fuel commonly used by the railroads, is limited to 1% by weight. This would correspond to 400 ppm SO_2 in the exhaust at 25:1 air/fuel ratio and 100% combustion. Normally, #2 fuel contains much less than 1% sulfur.

Particulate matter from diesels consists of carbon (soot) and hydrocarbon aerosols from incomplete combustion of the diesel fuel and lubricating oils. Smoke can be of particular importance because of its high public visibility and psychological impact.

Odor is another problem relating to hydrocarbon and particulate emission. Various authors have attempted to define odor, but the meanings of "burnt", "oily" and "musty" used in these definitions leave much to be desired[19]. Proper combustion eliminates much of the hydrocarbon and particulate problem, along with some of the odor problem.

The operation of naturally aspirated diesel engines at altitudes much above sea level (for instance 5000 feet) may cause excess fuel to be injected into the cylinders. In turn, a diesel engine operating with more fuel than normal may consequently emit large quantities of smoke, hydrocarbon and particulate matter[20]. Turbocharging helps to alleviate this problem, but turbocharging may also produce a momentary fuel-rich condition when the throttle is increased. The turbocharger lags the fuel injectors in time and does not instantaneously increase the air charge to the cylinder.

4.1.2.2 Locomotive Profile - The United States locomotive fleet is composed of 99% diesel-electric and 1% electric locomotives. The industry currently employs slightly over 27,000 locomotives[21]. A description of the types and uses of these 27,000 locomotives is given in Table 4-1. Most of the locomotives manufactured before 1961, and all of the switchers, have naturally aspirated engines, while most of the locomotives manufactured after 1961 are turbocharged. It has been estimated that one-third of the U. S. locomotive fleet is turbocharged and two-thirds naturally aspirated. The design (manufacturer) was estimated to be 80% General Motors and 20% General Electric[23].

TABLE 4-1 LOCOMOTIVE PROFILE (1970)[22]

USE TYPE	Passenger		Freight		Multi-Purpose		Switcher		Total	
	Quant.	Avg. HP	Quant.	Avg. HP	Quant.	Avg. HP	Quant.	Avg. HP	Quant.	Avg. HP
Diesel	1140	2038	6300	2339	13605	2057	5709	1080	26754	1914
Electric	18	3861	120	3741	118	4567	14	794	270	3957

By assuming that a remanufactured locomotive is equivalent to a new unit, it is possible to estimate the age distribution of the country's locomotive fleet. The median age is taken to be 15 years for the diesel electric-locomotive as shown in Figure 4-1. This age supports the conclusion that the average life expectancy of a locomotive is long and suggests difficulty in attempting extensive retrofitting of locomotives to reduce exhaust emissions.

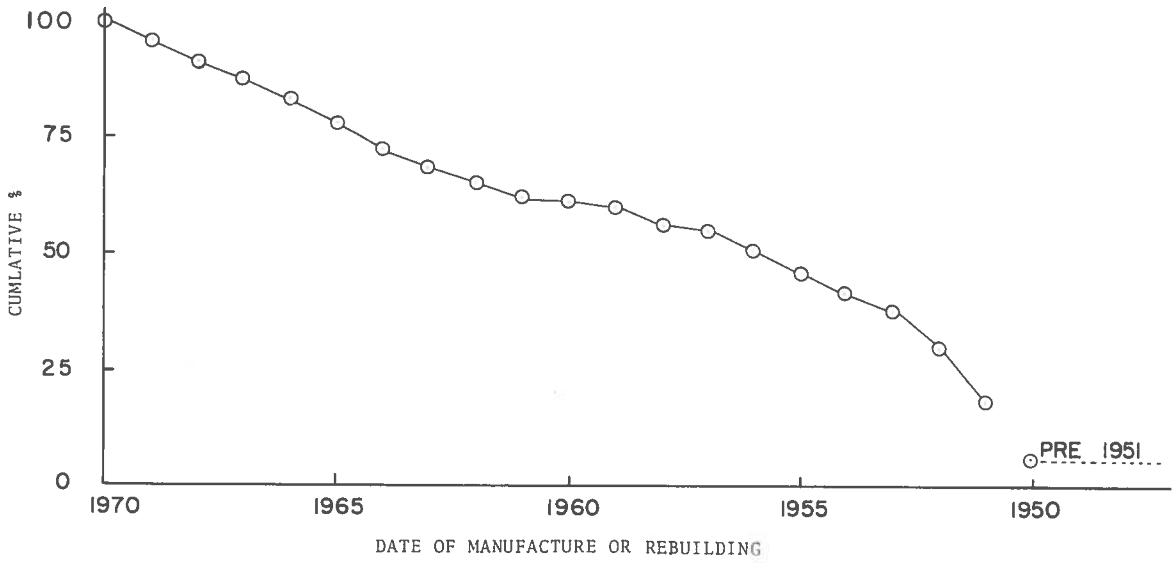

Figure 4-1 Railroad Diesel-Electric Locomotive Age Distribution [21]

4.1.2.3 Duty Cycles - Diesel-electric locomotives can be statically tested by placing an artificial load on the output of the generator. Several duty cycles have been suggested to determine the exhaust emissions under static testing[24]. These duty cycles are the average time spent at each power setting or load condition for the particular type of locomotive. A recent exhaust emission study used duty cycles from the Electromotive Division (EMD) and the Atchison, Topeka and Santa Fe (ATSF) to measure exhaust pollutants (Tables 4-2 and 4-3). With the exception of the yard switcher, the ATSF and EMD duty cycles are similar. The horsepower output at Idle is the power required for the auxiliaries. The Dynamic Brake horsepower is assumed to be the same horsepower developed in throttle position 1.

TABLE 4-2 EMD DUTY CYCLE [24]

THROTTLE SETTING	TIME %
8	30
7	3
6	3
5	3
4	3
3	3
2	3
1	3
Idle	43
Dynamic Brake	8
TOTAL	100

TABLE 4-3 ATSF DUTY CYCLE [24]

THROTTLE SETTING	TIME % BY TYPE		
	Heavy SD-45	Medium GP-38	Yard Switcher GP-20
8	24	20	Nil
7	2	1	Nil
6	3	2	1
5	2	2	1
4	3	2	2
3	3	3	4
2	3	4	5
1	5	5	10
Idle	46	59	77
Dynamic Brake	9	2	None
TOTAL	100	100	100

4.1.2.4 Emission Factors - Exhaust emission factors for diesel-electric locomotives have been reported by several researchers [24,25,26,27]. These factors are expressed in several units: gram pollutant/horsepower hour, pound pollutant/1000 pound fuel, pound pollutant/1000 gallon fuel and parts pollutant per million parts exhaust gas (ppm). The fuel use by the rail industry is reported in gallons per year; thus all emissions factors presented in Table 4-4 have been converted to lb pollutant/1000 gal fuel. Emission factors in gm pollutant/hp-hr were converted by assuming 0.4 lb fuel consumed/hp-hr and a fuel density of 7.3 lb/gal (#2 distillate). Emission factors reported in ppm were converted by equating the sulfur dioxide concentration in ppm to the emission factor in lb/1000 gal with the same sulfur content fuel. Thus for 0.4% sulfur fuel, the emission factor of SO_2 is about 57 lb/1000 gal. The reported ppm concentration was 152 ppm SO_2 for 0.4% sulfur fuel. The conversion factor obtained was:

$$\frac{57 \text{ lb/1000 gal}}{152 \text{ ppm}} = 0.375 \frac{\text{lb/1000 gal}}{\text{ppm}}$$

For an NO_x concentration of 1200 ppm, the emission factor is:

$$1200 \text{ ppm} \times 0.375 \frac{\text{lb/1000 gal}}{\text{ppm}} = 450 \text{ lb/1000 gal}$$

The emission factors in Table 4-4 display substantial variability. The more recent rates are higher than rates published two to four years ago. The emission factors from the Southern Pacific (SP) Report entered in Table 4-4 were condensed from Table 4-5 which were measured and adjusted for various duty cycles. The major observation in Table 4-5 is that the California standards for 1975 for the total unburned hydrocarbons and the oxides of nitrogen are significantly below the minimum exhaust concentrations in the best performing engine tested, regardless of the duty cycle employed. (See Appendix A for California Standards or Section 3.4.3.)

TABLE 4-4 DIESEL LOCOMOTIVE EMISSION FACTORS

lb/1000 gal fuel

Source	CO	HC	NO_x	HC + NO_x	SO_2^{a}	Duty Cycle
SP Report[24]	124	-	-	623	-	EMD
GM EMD[25]	142^b				57	EMD
	185^c	26	405	431		
GE [26]	10		300-450		57	Idle
	75-131		562-938		57	8th notch
EPA [27]	70	50	75	125	52	-

Notes:

a. 0.4% S content fuel
b. Turbocharged
c. Roots blown

TABLE 4-5 LOCOMOTIVE EMISSIONS [24]

gram/hp-hr

ENGINE	EMD CYCLE		ATSF CYCLE					
			Heavy		Medium		Switcher	
	CO	NO+NO_2 +HC	CO	NO+NO_2 +HC	CO	NO+NO_2 +HC	CO	NO+NO_2 +HC
SD45^a SP-8803	1.2	13.5	1.4	13.8				
SD45^a SP-8816	2.5	13.4	2.8	13.7				
GP-38^b ATSF-3514	4.5	15.0			4.8	15.6	5.2	24.3
U-33-C^c SP-8608	4.5	18.4	4.6	18.5				
U-33-C^c SP-8608 (Second Test)	3.2	17.0	3.3	17.1				

Notes:

a. EMD SD-45 - 20 cylinder turbocharged 2-cycle
b. EMD GP-38 - 16 cylinder roots blown 2-cycle
c. GE U-33C - 16 cylinder turbocharged 4-cycle

4.1.3 Gas Turbines

Emissions from gas turbine engines are generally of the same nature as those from diesels. It is sufficient to point out that pollutants from the gas turbine result from many of the same conditions discussed previously. In the case of particulates, considerable effort has been directed toward eliminating smoke from jet aircraft. Particulates from jets consist principally of carbon particles below 0.1 μm in diameter formed, it is thought, at least partly by the quenching burning fuel on the cold walls of the combustion chambers. It has been shown that redesign of the combustors can considerably lower the amount of visible smoke.

Table 4-6 presents the emission estimates for various jet turbine engines. The Turbotrain utilizes Pratt and Whitney ST6B engines for power. The manufacturer's published emission values have not been adjusted for an unknown amount of cooling (dilution) air added to the turbine exhaust. The dilution factor is unpublished, thus reducing the usefulness of the emission factors. Table 4-7 presents the emission factors for the Solar Saturn Turbine. This engine is commonly used for a stationary power generator and is installed in the Coast Guard's WMEC 210A Class Cutters.

4.1.4 Fossil Fuel Steam Generating Plants

The railroad industry uses fossil fuel steam generating power plants in large maintenance shops and is the principal power source for electric trains and subways. These installations occur in or around our larger metropolitan areas that experience severe air pollution problems and are controled by the new implementation plan regulations (Section 3.4.1).

Generally, the species of pollutants from boilers are similar to those present in the exhaust of diesels and gas turbines. However, since heavy fuel oil is usually burned, fly ash (organic and inorganic particulates) and oxides of sulfur are more of a problem than in other engine types. As with other power sources, hydrocarbons from oil fired boilers originate from incomplete combustion of fuel caused by cold surfaces quenching the flame, fuel-rich operation, poor maintenance procedures, etc.

TABLE 4-6 EMISSION FROM JET ENGINES [28]

AIRCRAFT	OPERATION	TYPICAL FUEL USAGE lb/hr	EMISSION lb pollutant/1000 lb fuel				
			CO	HC	NO_x	SO_2	PARTICULATES
Long Range Jet	Idle and Taxi	1090	91.5	64.0	<1.3		
	Landing, Takeoff Climbout	8350	0.99	0.23	5.2		
Medium Range Jet	Idle and Taxi	920	77.3	14.9	1.3		
	Landing, Takeoff, Climbout	6550	0.86	0.04	4.0		
Turbo-prop	Idle and Taxi	587	118.0	11.5	2.0	0.1	1.0
	Landing Takeoff Climbout	1660	2.3	3.2	1.0		

TABLE 4-7 EMISSION FROM TURBINES

MANUFACTURE	EMISSION ppm		
	CO	HC	NO_x
Solar Saturn[29]	1880	40	200
United Aircraft ST6B[30]	30*		37*

*Emission after unspecified dilution

Carbon monoxide levels in boiler exhausts are considerably lower than those in the exhaust of other power sources. In fact, if combustion efficiency is at a maximum, no measurable CO should be formed at all. However, CO is formed if there is insufficient oxygen in the flame region and usually results from poor air/fuel mixing. This problem is more prevalent in older, poorly maintained units.

The emission of sulfur oxides from oil or coal fired boilers is a direct function of the sulfur content of the fuel; i.e., increasing sulfur content results in increased sulfur oxide emissions.

The emission of nitrogen oxides is a function of the nitrogen content of the fuel, the peak flame temperature and the length of time the flame is at peak temperatures. Increasing any of these parameters produces increased NO_x emissions.

Particulate emissions are principally inorganic fly ash. Again, these emissions are directly related to the composition of the fuel. As the ash content increases so do the particulate emissions. Table 4-8 lists the emission factors for different types of fuel oil in various types of burners.

TABLE 4-8 EMISSION FACTORS FOR FUEL OIL COMBUSTION[27]

TYPE OF UNIT	Power Plant		Industrial and Commercial				Domestic	
			Residual		Distillate			
POLLUTANT	$lb/10^3$ gal	$kg/10^3$ l	$lb/10^3$ gal	$kg/10^3$ l	$lb/10^3$ gal	$kg/10^3$ l	$lb/10^3$ gal	$kg/10^3$ l
Particulates	8	1	23	2.75	15	1.8	10	1.2
Sulfur dioxide[a]	157S	19S	157S	19S	142S	17S	142S	17S
Sulfur trioxide[a]	2S	0.25S	2S	0.25S	2S	0.25S	2S	0.25S
Carbon monoxide	0.04	0.005	0.2	0.025	0.2	0.025	5	0.6
Hydrocarbons	2	0.25	3	0.35	3	0.35	3	0.35
Nitrogen oxides (NO_2)	105	12.6	(40-80)[b]	(4.8-9.6)[b]	(40-80)[b]	(4.8-9.6)[b]	12	1.5
Aldehydes (HCHO)	1	0.12	1	0.12	2	0.25	2	0.25

Notes:

a. S equals percent by weight of sulfur in the oil

b. Use 40 (4.8) for tangentially fired units and 80 (9.6) for horizontally fired units

4.1.5 Emission Rate Estimates

4.1.5.1 Energy Consumption - The railroads in the United States use about four billion gallons of diesel fuel per year and over one billion kilowatt-hours of electricity (Table 4-9). This amount of electricity is equivalent to the combustion of 80 million gallons of oil or 170,000 tons of coal.

TABLE 4-9 RAILROAD ENERGY CONSUMPTION (1969)[31]

ENERGY SOURCE	CONSUMPTION
Coal	1,000 short tons
Fuel Oil	33,000,000 gallons
Diesel Oil	3,924,000,000 gallons
Electricity	1,149,000,000 kilowatt-hours

4.1.5.2 National Emission Rates - The annual exhaust emissions from diesel-electric locomotives can be estimated by combining the annual fuel consumed with the proper emission factors. Several emission factors have been published for each pollutant (Section 4.1.2.4). The calculated emission rate in tons pollutant per year is a direct function of the emission factors selected from Table 4-4. Emission rates were calculated using various emission factors presented in Table 4-4 and are presented in Table 4-10. The emissions from the generation of electricity consumed by the railroads are given in Table 4-11, using the emission factors for power plants burning 1.5% sulfur content fuel. The sulfur content is based upon the assumption that the electricity will be consumed by the railroads in the larger cities that now require low sulfur fuel to be burned.

To give a better perspective to these calculated annual emissions, the national emission inventories for 1968 and 1969 are presented in Tables 4-12 and 4-13. The estimates for transportation increased in 1969 relative to 1968. The contribution of each mode of transportation is estimated for 1968 in Tables 4-14 and 4-15. The estimated railroad emissions appear to be of the same magnitude as vessels or aircraft.

TABLE 4-10 LOCOMOTIVE ANNUAL EMISSIONS (USA) 10^3 tons/year

EMISSION FACTOR SOURCE	CO	HC	NO_x	$HC+NO_x$	SO_2
SP Report	247			1235	
GMEMD	281[a] 366[b]	52	802	854	113
GE	148-259		1113-1857		113
EPA; AP-42	139	99	149	248	103
AP-73[c]	100	300	400	700	100

Notes:

a. Turbocharge.
b. Roots.
c. Railroad annual emission rate estimate[32].

TABLE 4-11 RAILROAD ANNUAL EMISSION ESTIMATE FROM ELECTRICITY GENERATION[a] tons/year

CO	HC	NO_x	$HC+NO_x$	SO_2[b]	PARTICULATE
1.4	107	3734	3841	8358	285

a. Emission factors from AP-42 [27].

b. 1.5% sulfur fuel.

TABLE 4-12 NATIONAL EMISSION INVENTORY (1968)[32] 10^6 tons/year

SOURCE	CO	HC	NO_x	SO_2	PARTICULATES
Transportation	63.8	16.6	8.1	0.8	1.2
Stationary Sources	1.9	0.7	10.0	24.4	8.9
Industrial processes	9.7	4.6	0.2	7.3	7.5
Solid Waste	7.8	1.6	0.6	0.1	1.1
Misc.	16.9	8.5	1.7	0.6	9.6
Totals	100.1	32.0	20.6	33.2	28.3

TABLE 4-13 NATIONAL EMISSION INVENTORY (1969)[33] 10^6 tons/year

SOURCE	CO	HC	NO_x	SO_2	PARTICULATES
Transportation	112	20	9	1.1	0.8
Stationary Sources	1.8	0.9	7	25	7
Industrial Processes	12	5.5	3	8	14
Solid Waste	8	2	0.3	0.2	2
Natural Sources	18	9	2	0.2	12
Totals	151	37	21	34.5	35.8

TABLE 4-14 NATIONAL EMISSION ESTIMATES FROM TRANSPORTATION (1968) 10^6 tons/year

SOURCE	CO	HC	NO_x	SO_2	PARTICULATES
Railroad	0.1	0.3	0.4	0.1	0.2
Aircraft	2.4	0.3	-	-	-
Vessels	0.3	0.1	0.2	0.3	0.1
Diesel Motor Vehicles	0.2	0.4	0.6	0.1	0.3
Gasoline Motor Vehicles	59.0	15.2	6.6	0.2	0.5

TABLE 4-15 NATIONAL RAILROAD EMISSION ESTIMATES (1968)

RAILROAD % OF	EMISSION				
	CO	HC	NO_x	SO_2	Particulate
National Transportation Emissions	0.15	1.8	4.9	12.5	17.0
Total National Emissions	0.1	0.9	1.9	0.3	0.7

TABLE 4-16 ANNUAL LOCOMOTIVE EMISSIONS (1969)

EMISSION	lb pollutant/ train-mile[a]	lb pollutant/ 1000 ton-mile[b]
CO	1.17	0.65
HC	0.35	0.20
NO_x	4.33	2.43
SO_2	0.56	0.31
Particulates	0.23	0.13

Notes:

a. Calculated using 427,116,000 train-miles and neglecting terminal operations.

b. Calculated using 762,431,000 1000 ton-miles.

The emission rates from locomotives can be expressed in absolute units or units relative to another mode. In comparison to automobiles on an annual basis, locomotive emissions are insignificant. If the emissions from locomotives are compared to diesel trucks, either on an annual basis or per unit horsepower-hour, the railroad emissions appear to be of about the same order of magnitude. Probably the best unit for intermodal line-haul comparisons would be the emissions per unit work accomplished: gm pollutant emitted/ton-mile freight moved. Emission from terminal operations can be expressed as the amount of emissions for some daily terminal throughput.

Annual line-haul freight statistics are readily available from the literature[21]. The average emissions per train mile and 1,000 ton-mile, neglecting terminal operations, are easily calculated and shown in Table 4-16.

4.2 OPEN AND CONTROLLED BURNING

4.2.1 Car Salvage

Open burning of retired railroad freight cars has long been accepted practice in the industry. This process removes combustible material from the car, preparing the metal components for scrap and salvage. Approximately 70,000 cars are retired every year and scrapped in this country[34]. About half are box and refrigerator cars which contain 3 to 7 tons of wood. The refrigerator cars may also contain combustible insulation.

Open burning is an inexpensive means to prepare the metal for scrapping. The investment required per car is only a burning area and a few gallons of gasoline or fuel oil. Ground-level open burning is affected by many variables including wind, ambient temperature, the composition, moisture content, size and shape of the debris burned and the compactness of the pile. In general, the relativel low temperatures associated with open burning increases the emission of particulates, carbon monoxide and hydrocarbons and suppresses the emission of nitrogen oxides. Sulfur oxide emission is also a direct function of the sulfur content of the debris.

Emission factors are presented in Table 4-17 for the open burning of three broad categories of waste: (a) municipal refuse; (b) automobile components and (c) horticultural refuse. The magnitude of the emissions from burning railway cars are probably between those caused by burning wood and by burning an automobile. The emission factors for automobiles in Table 4-17 include the burning of upholstery, hoses, tires, wiring etc.

TABLE 4-17 EMISSION FACTORS FOR OPEN BURNING[27]

EMISSION TYPE OF WASTE	PARTICULATES		SULFUR OXIDES		CARBON MONOXIDE		HYDROCARBONS (CH_4)		NITROGEN OXIDES	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Municipal Refuse	16	8	.1	0.5	85	42.5	30	15	6	3
Automobile Components	100	50	Neg	Neg	125	62.5	30	15	4	2
Horticultural Refuse										
Agricultural Field Burning	17	8.5	Neg	Neg	100	50	20	10	2	1
Landscape Refuse and Pruning	17	8.5	Neg	Neg	60	30	20	10	2	1
Wood	17	8.5	Neg	Neg	50	25	4	2	2	1

It is doubtful that the rail industry or the country would allow old cars to accumulate at a rate of 70,000 per year, and since open burning is unacceptable, different methods of recycling the metal products must be found. To this end, several techniques have been evaluated and two appear promising: hood incineration and water jets[34]. Hood incineration is a method of controlled burning which treats the effluent gases to a degree where they may be released to the environment without detrimental effects. The second acceptable alternative to open burning employs a high pressure water jet (70,000 psi) to destroy the wood-metal joint and in doing so, breaks up the wood.

Both of the alternative methods require increased capital investment and manpower relative to open burning. Hence, the cost of recycling will increase.

4.2.2 Rights-of-Way

The general public usually demand that the railroads remove or inhibit the growth of weeds in the track rights-of-way. The justification for weed control is based upon several factors: improved signal transmission and visibility, decreased fire hazard, decreased snow drifting in the Western portion of our country, limiting weed intrusion onto nearby farmland and, probably most of all, aesthetics.

Methods used for weed control include mowing, chemicals and controlled burning. The use of herbicides and defoliants has gained popularity in recent years. The use of these chemicals usually does not create an air pollution problem, but may create serious soil or water problems.

With the use of spark arrestors on diesel exhausts, the probability of track-side fires is diminished. Likewise, the choice of proper material for brake shoes reduces the probability of sparking during braking operations.

It is clear that the right-of-way must be properly maintained. Present methods of mowing, applications of herbicides, and use of flame torches (controlled burning) appear satisfactory.

4.2.3 Disposal of Old Ties

Traditional rail beds are constructed using treated wooden ties to support the rails. These ties require periodic replacement, creating a disposal problem. In the past old ties have been burned. In some locations there is sufficient demand in the private sector to use most, if not all, the old ties in building retaining walls, garden steps, etc. Some rail companies have experimented with chipping the ties and spreading the chips on the right-of-way[20]. Ties are normally treated with creosote or pentachlorophenol to retard rotting. These compounds could present a possible water pollution problem with surface run-off if the chips were spread in a dense manner. The major impact of abandoned ties or other equipment in the right-of-way appears to be aesthetic, though weed control may be more difficult in a cluttered right-of-way.

4.3 CONSTRUCTION AND DEMOLITION

Particulate matter is the principal emission arising out of construction and demolition activities [35]. Tearing down old buildings causes the release of large amounts of dust and dirt which can considerably increase the suspended particulate level in the surrounding air. Earth moving usually produces areas of earth stripped of vegetation. From these areas, and during the actual earth moving operations, dust and dirt are ejected into the atmosphere. The major environmental upsets of transportation construction activities also include the question of optimum land use and the possible social changes precipitated by the construction. Water pollution, caused by uncontrolled run-off of rainwater from open areas, is also a factor which must be considered. Once construction is completed, new drainage paths for water can produce further problems.

4.4 EVAPORATION, SPILLAGE, AND HANDLING LOSSES

4.4.1 Petroleum Storage Emissions

In the storage and handling of oil and its products, evaporation losses may occur that contribute to the hydrocarbon loading of the air shed. These losses may be divided into two categories: breathing loss and working loss. Breathing losses are associated with the thermal expansion and contraction of the vapor space resulting from the diurnal temperature cycle. Working losses are associated with a change in liquid level in the tank; i.e., emptying or filling operations resulting in displacement of vapors into the atmosphere.

Hydrocarbon emissions associated with railroad operations stem from two basic sources: (a) the tanks of diesel fuel, both in the yard and on the train, that are used to supply fuel for the locomotive engines, and (b) the transport of large petroleum shipments via tank cars.

There are two major types of tanks used to store petroleum products: fixed-roof tanks and floating-roof tanks. The evaporation losses from both of these types of tanks depend on a number of factors, such as type of product stored (gasoline or diesel oil), vapor pressure and average temperature of the stored product, tank diameter and construction, color of tank paint and average wind velocity of the area. An average factor can be obtained by making a few assumptions. These average factors for both breathing losses and working losses for fixed-roof and floating-roof tanks are presented in Table 4-18.

Tank car evaporative losses will be a direct function of the type of fuel, the vapor head space above the liquid surface, the temperature and the type of tank venting.

TABLE 4-18 HYDROCARBON EMISSION FACTORS FOR EVAPORATION LOSSES FROM THE STORAGE OF PETROLEUM PRODUCTS [27]

TANK TYPE[a]	TYPE LOSS	EMISSION FACTOR UNITS	TYPE OF MATERIAL STORED	
			Gasoline or Finished Petroleum Product	Crude Oil
Fixed Roof	Breathing Loss	lb/day-1000 gal Storage Capacity	0.4	0.3
		kg/1000 liter Storage Capacity	0.05	0.04
	Working Loss[b]	lb/1000 gal Throughput	11	8
		kg/1000 liter Throughput	1.32	0.96
Floating Roof	Breathing Loss	lb/day-tank	140[c] (40-210)	100[d] (30-160)
		kg/day-tank	63.5	45.4
	Working Loss	lb/1000 gal Throughput	Neg	Neg
		kg/1000 liter Throughput	Neg	Neg

Notes:

a. For tanks equipped with vapor-recovery systems, emissions are negligible.

b. An average turnover rate for petroleum storage is approximately 6. Thus, the throughput is equal to 6 times the capacity.

c. 140 (63.5) based on average conditions and tank diameter of 100 ft (30.5 m); use 40 (18.1 kg) for smaller tanks, 50 ft (15.3 m) diameter; use 210 (95 kg) for larger tanks, 150 ft (45.8 m) diameter.

d. Use 30 (13.6 kg) for smaller tanks, 50 ft (15.3m) diameter; use 160 (72.5 kg) for larger tanks, 150 ft (45.8 m) diameter.

4.4.2 Cargo Handling and Spillage

The transfer of petroleum and chemicals from tank car to storage vessel may involve substantial spillage and evaporative losses[36]. Tank cars are cleaned and flushed when the next load is different from the previous or the car is returned for maintenance. The cleaning is usually accomplished by flushing with water and/or steam. The nature of the product cleaned from the tank determines the environmental impact of cleaning. The impact may be felt in the atmosphere, if the material evaporates from the flush water, or it may contaminate the water body receiving the waste.

5. FREIGHT TRANSPORTATION

5.1 MULTIMODE OPERATION

The transport of freight in this country utilizes air, water, rail, road and pipeline modes. The movement of a shipment from its point of origin to destination may involve one or several modes. The choice of modes by the shipper will not be studied in this section, but is undoubtedly influenced by the availability of each mode, governmental regulations, economic considerations, timeliness of service, etc.

The terminal operation is an important factor in multimode operations. It is the terminal operation that permits a shipment to be transported by more than one mode. Terminals also affect a mode's overall effeciency by the time and cost involved in moving a shipment through them. For instance, it has been estimated that the average time for through traffic in the railyards of St. Louis is in excess of two days[37]. A large deviation from the mean is more serious, since it indicates a terminal operation of low effeciency. Between terminals, line haul exists; here each mode acts physically independent of the others. Information does exist for line haul operations, as shown in Figure 5-1. This information is for 1965 and shows the fuel consumption for each mode and the number of ton-miles hauled by the mode. Table 5-1 was calculated from information in Figure 5-1 for freight transport. The relative efficiency for each mode is a measure of resource (petroleum) consumption per unit work. Likewise for passenger travel, the data from Figure 5-1 were used to obtain Table 5-2.

It should be noted again that the relative efficiency for each mode is based upon fuel consumption alone; it does not consider the use of other natural resources, the type of service, labor utilization, etc.

5.2 ENVIRONMENTAL IMPACT

Our large and medium size cities are the areas in our country that chronically suffer from sub-standard quality air. The

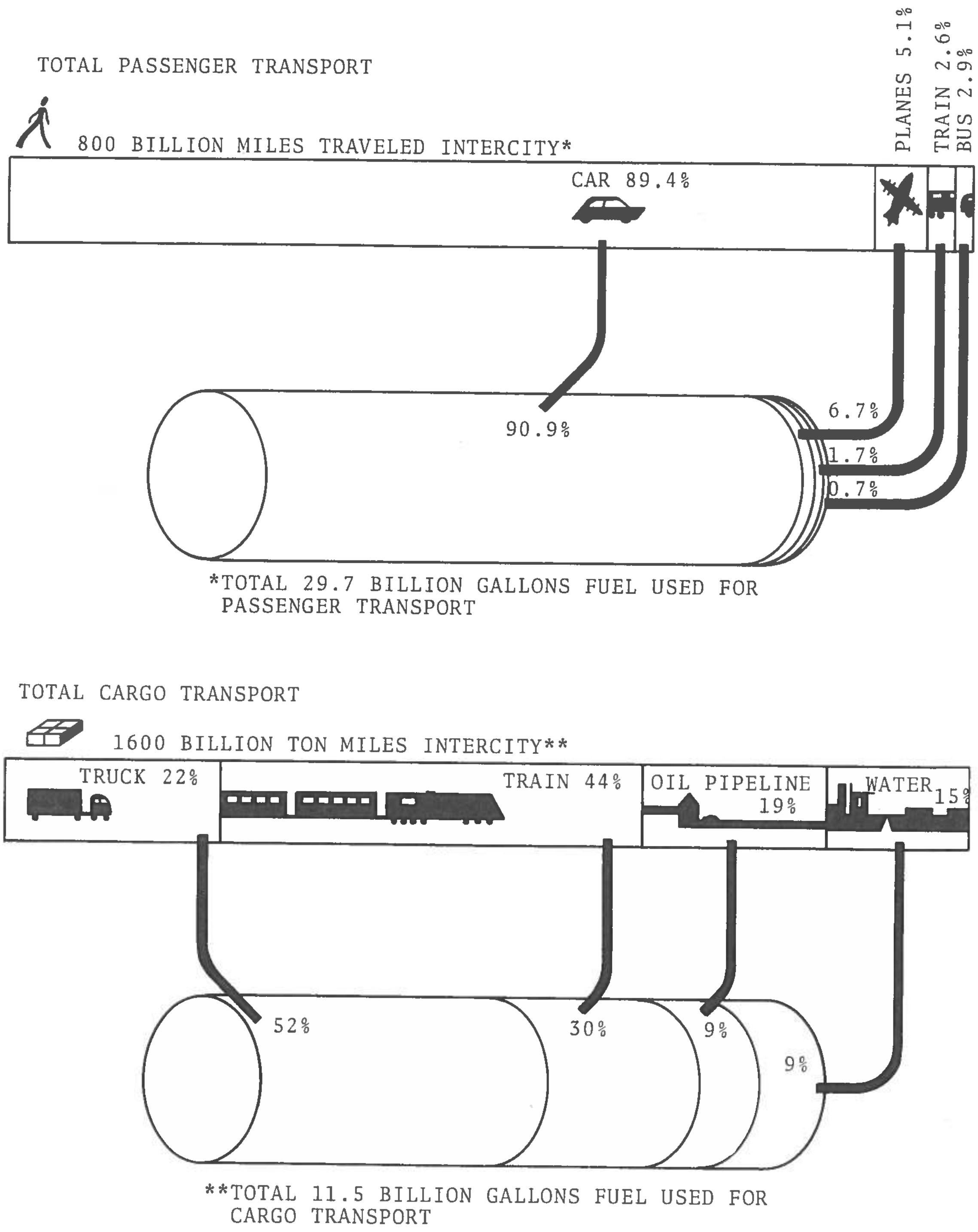

Figure 5-1 Fuel Used for Intercity Transport (1965)[38]

TABLE 5-1 MODE FUEL CONSUMPTION FOR FREIGHT MOVEMENT (1965)

MODE	FUEL CONSUMPTION gal/1000 ton-mile	RELATIVE EFFICIENCY percent
Truck	16.99	20
Train	4.90	69
Water	4.29	79
Oil Pipeline	3.39	100

TABLE 5-2 MODE FUEL CONSUMPTION FOR PASSENGER MOVEMENT (1965)

MODE	FUEL CONSUMPTION gal/1000 passenger-miles	RELATIVE EFFICIENCY percent
Air	48.77	19
Auto	37.76	24
Train	24.04	38
Bus	9.05	100

concentration of people, and hence emission sources, into a relatively small air shed, results in a build-up of a substantial concentration of emitted pollutants in the ambient air. The concentration of each pollutant is a direct function of the emission rate, removal rate and prevailing meteorological conditions in the air shed.

It is reasonable to assume that for a given location (air shed), the amount of travel by individuals and freight movement is a function of the population in the area. The energy consumed in the air shed for personal transportation and the movement of freight is a function of the number of passenger-miles and freight ton-miles and of the distribution of the travel between the modes, since each mode has a different fuel consumption per unit travel (Section 5.1).

The exhaust emissions are a function of the emission factor for the mode and the fuel consumed by the mode.

The annual tons and ton-miles of shipments for several areas of the country are available in the literature[21,39]. The data are given for SMSA production areas. Tables 5-3 through 5-7 present data for St. Louis Standard Metropolitan Statistical Area (SMSA). The distribution of traffic between rail, water and truck is fairly even. This is probably the best distribution of shipments via the three modes of any U.S. city. It should be noted that the tonnage and ton-mile figures are only for shipments that originate in the St. Louis SMSA production area. These figures were obtained by a statistical sampling of shippers in the St. Louis area. Although these data are insufficient for accurate analysis they are useful in making some estimations.

TABLE 5-3 POPULATION OF STANDARD METROPOLITAN STATISTICAL AREA (SMSA) FOR ST. LOUIS MO - IL [40]

SMSA	POPULATION	
	1970*	1960
St. Louis MO.-IL.	2,331,016	2,104,669
St. Louis City MO.	607,718	750,026
Franklin County MO.	54,452	44,566
Jefferson County MO.	103,677	66,377
St. Charles County MO.	92,661	52,970
St. Louis County MO.	946,791	703,532
Madison County IL.	246,126	224,689
St. Clair County IL.	279,601	262,509

*Preliminary

TABLE 5-4 ST. LOUIS SMSA PERCENT DISTRIBUTION OF SHIPMENTS BY MODE OF TRANSPORT[39]

MODE	All commodities		All commodities except petroleum and coal products	
	1967	1963	1967	1963
Tons of shipments......millions..	28.3	23.2	15.4	14.8
Ton-miles.............billions..	8.5	6.4	6.0	5.2
TONS OF SHIPMENTS	Percent distribution			
All modes of transport.........	100.0	100.0	100.0	100.0
Rail............................	28.4	32.5	46.5	45.8
Motor carrier....................	34.7	35.1	33.7	42.0
Private truck....................	11.2	8.8	17.1	10.9
Air..............................	-	-	-	.1
Water............................	25.4	23.1	2.1	.4
Other............................	.3	.5	.6	.8
TON-MILES				
All modes of transport.........	100.0	100.0	100.0	100.0
Rail............................	49.8	55.1	64.2	64.5
Motor carrier....................	22.3	25.0	26.8	28.2
Private truck....................	5.3	4.6	6.9	.1
Air..............................	.1	.1	.2	.1
Water............................	22.0	13.9	1.2	.6
Other............................	.5	1.3	.7	1.5

TABLE 5-5 ST. LOUIS SMSA AVERAGE LENGTH OF HAUL BY MODE OF TRANSPORT*[39]

Straight-line miles

MODE	ALL COMMODITIES		ALL COMMODITIES EXCEPT PETROLEUM AND COAL PRODUCTS	
	1967	1963	1967	1963
ALL MODES OF TRANSPORT	302	278	391	351
Rail	529	470	540	493
Motor carrier	194	198	311	235
Private truck	143	146	158	164

*Average length of haul is based on straight-line miles from plant to customer or redistribution point, weighted by tonnage shipped (i.e., ton-miles divided by tons). Rail short-line and highway direct-route distances average about 24 and 21 percent, respectively, longer than straight-line distances.

TABLE 5-6 ST. LOUIS SMSA PERCENT DISTRIBUTION OF SHIPMENTS BY DISTANCE OF SHIPMENT[39]

DISTANCE OF SHIPMENT	ALL COMMODITIES		ALL COMMODITIES EXCEPT PETROLEUM AND COAL PRODUCTS	
	1967	1963	1967	1963
All distances	100.0	100.0	100.0	100.0
Under 100 miles	26.9	28.2	17.	24.9
100 to 199 miles	13.5	22.1	14.7	13.7
200 to 299 miles	27.3	20.8	19.8	19.2
300 to 499 miles	15.3	13.2	20.7	18.3
500 to 999 miles	13.7	12.5	21.	19.1
1,000 to 1,499 miles	1.6	1.6	2.	2.4
1,500 miles and over	1.7	1.6	2.7	2.4

TABLE 5-7 ST. LOUIS SMSA PERCENT DISTRIBUTION OF SHIPMENTS BY AREA OF DESTINATION[39]

AREA OF DESTINATION	1967	1963
Tons of shipments............thousands.....	28,250	23,229
Ton-miles...................millions.....	8,520	6,446
TONS OF SHIPMENTS	Percent Distribution	
All areas.............................	100.0	100.0
Production Area St. Louis SMSA*...........	18.2	17.8
Other production areas....................	19.6	63.7
All other areas...........................	62.2	63.7
TON-MILES		
All areas.............................	100.0	100.0
Production Area St. Louis SMSA*...........	1.1	1.1
Other production areas....................	37.0	36.9
All other areas...........................	61.9	62.0

*Includes only those shipments that originated in one city in this area and terminated in another city in this area.

Tables 5-8 and 5-9 have been constructed from Table 5-4. The private trucking sector had the greatest increase in the number of tons shipped in the period 1963-1967, while the rail sector had the smallest. (Private trucks are trucks operated either by the shipper or the receiver). The rail sector had a larger increase relative to trucking when the shipments are considered on a ton-mile basis, though it is still smaller than the increase in the water sector (Table 5-9). In large cities, such as Boston or New York, which do not have extensive inland waterways, the major increases in both tons and ton-miles of shipments have been in the motor carrier and private truck sector (Table 5-10).

TABLE 5-8 ST. LOUIS SMSA TONS OF SHIPMENTS
Millions

MODE	1967	1963	% CHANGE
Rail	8.03	7.54	6.5
Motor Carrier	9.82	8.14	20.6
Private Truck	3.16	2.04	54.9
Water	7.19	5.36	34.1

TABLE 5-9 ST. LOUIS SMSA TON-MILES OF SHIPMENTS
Billions

MODE	1967	1963	% CHANGE
Rail	4.23	3.53	19.8
Motor Carrier	1.89	1.60	18.1
Private Truck	0.45	0.29	55.2
Water	1.87	0.89	110.1

TABLE 5-10 BOSTON PERCENT DISTRIBUTION OF SHIPMENTS BY MODE OF TRANSPORT [39]

MODE	All Commodities	
	1967	1963
Tons of shipments......millions..	11.6	8.9
Ton-miles.............billions..	4.4	2.7
TONS OF SHIPMENTS	Percent distribution	
All modes of transport.........	100.0	100.0
Rail............................	9.9	11.7
Motor carrier...................	66.1	50.9
Private truck...................	21.5	27.8
Air.............................	.2	.1
Water...........................	1.2	7.8
Other...........................	1.1	1.7
TON-MILES		
All modes of transport.........	100.0	100.0
Rail............................	17.4	28.7
Motor carrier...................	73.4	50.0
Private truck...................	5.8	11.0
Air.............................	.4	.5
Water...........................	1.4	4.9
Other...........................	1.6	4.9

Combining the information in Tables 5-5 and 5-9, the number of ton-miles transported by each mode within 100 miles of St. Louis can be ascertained, along with the fuel consumed by using the information in Table 5-1 (Table 5-11).

TABLE 5-11. FREIGHT SHIPMENT WITHIN 100 MILES OF ST. LOUIS Millions

MODE	1967		1963	
	ton-mile	gal fuel	ton-mile	gal fuel
Rail	800	3.9	751	3.7
Motor Carrier	974	16.5	808	13.7
Private Truck	315	5.3	199	3.3

TABLE 5-12 EMISSION FACTORS FOR DIESEL ENGINES [27][a]

POLLUTANT	HEAVY-DUTY TRUCK AND BUS ENGINES		LOCOMOTIVES	
	$lb/10^3$ gal	$kg/10^3$ liters	$lb/10^3$ gal	$kg/10^3$ liters
Particulates	13	1.56	25	3
Oxides of Sulfur (SO_x as SO_2)[b]	27	3.24	65	7.8
Carbon Monoxide	225	27.0	70	8.4
Hydrocarbons	37	4.44	50	6.0
Oxides of Nitrogen (NO_x as NO_2)	370	44.4	75	9.0
Aldehydes (as HCHO)	3	0.36	4	0.48
Organic Acids	3	0.36	7	0.84

Notes:

a. Data presented in this table are based on weighting factors applied to actual tests conducted at various load and idle conditions with an average gross vehicle weight of 30 tons (27.2 MT) and fuel consumption of 5.0 mi/gal (2.2 km/liter).

b. Data for trucks and buses based on average sulfur content of 0.20 percent, and for locomotives, on average sulfur content of 0.5 percent.

TABLE 5-13 ANNUAL EMISSIONS FROM FREIGHT SHIPMENT WITHIN 100 MILES OF ST. LOUIS 10^3 lb

EMISSION	1967		1963	
	LOCOMOTIVES	TRUCKS	LOCOMOTIVES	TRUCKS
Particulates	97	283	92	221
SO_2	253	589	241	459
CO	273	4905	259	3825
HC	195	807	185	629
NO_x	292	8066	278	6290
Aldehydes	16	65	15	51
Organic Acids	27	65	26	51
TOTALS	1153	14,780	1096	11,526

Applying the emission factor for each mode to the fuel consumed yields the emissions per year within the 100-mile radius air shed of St. Louis. Caution should be exercised in the use of these results due to the information the emissions are based upon: the statistical sampling of shipments, national fuel usage, average emission factors and duty cycles, exclusion of terminal operations, etc.

The emission factors used to calculate the annual emissions are the factors published by EPA for diesel trucks and locomotives (Table 5-12). The emission factors for locomotives are substantially different for those in Table 4-4, but are used since they were published in the same table as the emission factors for diesel trucks. The calculated annual emissions, in thousands of pounds, for an area within 100 miles of St. Louis are presented in Table 5-13. The total emissions for locomotives are about 1.5 lb pollutant/1000 ton-mile and for diesel trucks about 11.5 lb pollutant/1000 ton-mile. Thus trucks produce about eight times more pollution per 1000 ton-mile than do locomotives on a pollutant weight basis.

6. CONCLUSIONS

6.1 LEGISLATION

In view of the recent emphasis placed on maintaining and improving the quality of our environment, the rail industry should expect continued and increased public scrutiny in the future. The public will be analyzing the railroads to determine any adverse impact on the environment. It is concluded that the major objections of private citizens presently center on diesel locomotive exhaust; both odor and visible emissions cause the most criticism. The smoke regulations of New Mexico and Colorado reflect these objections (Section 3.3).

Most regions have some type of smoke emission regulation, either in terms of opacity or Ringelmann number. California has recently passed strict emission regulations for diesel trucks to be effective in 1973 and 1975. There is some probability that California will enact similar legislation affecting locomotives. (The California regulations for diesel trucks are reproduced in Appendix A for information purposes.)

Atmospheric emissions from railroad operations other than direct exhaust emissions, such as open burning and evaporation losses, are generally regulated by local ordinance. Projected requirements for the future are that the current maximum permitted emission levels will be decreased. A decrease in permitted emissions will require changes in operating procedures and, possibly, installation of emission control equipment.

6.2 VISIBLE EXHAUST EMISSIONS

6.2.1 Visible Emissions

Visible exhaust emissions from diesel-electric locomotives are receiving attention from several air pollution control agencies (Section 3.3). Smoke emissions are regulated for three reasons: (a) aesthetics; (b) injury to public health, and (c) injury to public welfare. It is concluded that aesthetics are the principal motive behind the regulations in Colorado and New Mexico. (A discussion of smoke measurement techniques is presented in Appendix B for information purposes.)

6.2.2 Gaseous Emissions

Gaseous emissions from railroad operations are regulated for two reasons: (a) injury to public health, and (b) injury to public welfare. Gaseous exhaust emissions affect the ambient air quality in the air shed. The impact of locomotive emissions on ambient air quality is a function of the emission factor for locomotives, the fuel consumed by the mode in the air shed and the meteorological and topographical features of the air shed.

It is concluded that there are no accepted methods for comparing the environmental impacts of transportation modes. In Section 5.2, a method is suggested for the intermodal comparison of exhaust emissions based upon the amount of pollutants released per unit work performed (grams pollutant released per ton-mile of freight hauled).

6.3 EXHAUST EMISSION FACTORS AND RATES

It is concluded that emission factors for diesel-electric locomotives are not accurately known at this time. Duty cycles are available in the literature for line haul operations but are unavailable for terminal operations. These duty cycles are not directly applicable to every situation, but can be useful for preliminary analyses in most cases.

The environmental impact of locomotive exhaust pollutants is dependent upon their spatial and temporal location. Hence, an accurate assessment of locomotive emissions on an air shed is not possible by using annual emission rates or a national source inventory. It is concluded that emissions in an air shed due to diesel-electric locomotives are substantially less (about 1/10) than the emissions from trucks in the same air shed while carrying nearly equal ton-miles of freight (Section 5.2).

It is further concluded that more data on actual duty cycles and actual locomotive emission rates are needed in order to analyze accurately the amount of control needed for pollutants emitted from locomotives.

7. RECOMMENDATIONS

7.1 GENERAL

The trend of environmental control is toward stricter emission regulations. The rail industry would benefit from an objective evaluation of its current operations and the impact of these operations on the environment. Having a good understanding of these facts, the industry can fully stand behind realistic emission regulations when they are enacted. It is recommended that:

a. The analysis,by each railroad, of air pollutant emissions from all its operations be continued.

b. More accurate definition of exhaust emission factors and rates be established by both field and laboratory testing.

c. Uniform exhaust emission control regulations on both the local and national level be pressed for.

d. Emission control techniques be developed to meet current and future exhaust emission regulations.

Recommendations a and b, if implemented, will define the severity of the railroads' environmental problems as related to air pollution. The results of such an emission inventory and impact assessment provide the input information for Recommendation c. If the emission rates of the locomotive engines appear excessive,in light of EPA's ambient air quality standards, then control techniques must be developed. The current work by the truck manufacturers and the marine industry on diesel emissions should be applicable to the railroads. The final result of implementing these recommendations will be the transfer of leadership for environmental control of railroad operations to the railroads themselves. In short, by assuming a positive position in environmental issues, the industry could choose the best solution rather than merely follow the regulations of a governmental agency.

7.2 ENVIRONMENTAL IMPACT ANALYSIS

It is recommended that the assessment of emissions and operations by a railroad (Recommendation a) to determine their impact upon air quality be guided by the following impact assessment outline:

a. identify the emitted pollutants

b. inventory the emission sources

c. determine the spatial and temporal emission rates

d. measure the temporal and spatial concentrations of the emitted pollutants

e. determine the duration of exposure to each concentration

f. calculate probability of occurrences for concentration-duration exposures

g. determine pollutant effects of human receptors

h. investigate the possibility of emission reduction

i. formulate a control strategy

Task a has been completed by this and other reports. Tasks b, c, and d require an extensive, detailed field study to secure a data base sufficient for accurate impact assessment and would include the implementation of Recommendation b in Section 7.1 (above). Tasks e and f can be accomplished by mathematical simulation modeling of the pollutant emissions. Task g has been completed by the Environmental Protection Agency by the establishment of primary and secondary ambient air quality standards (Section 3.4.1). Tasks h and i should be a joint effort between the Federal Government and the railroad industry (Recommendations c and d).

The tasks included in impact assessment can be divided into two major study areas: emission source characterization and atmospheric dispersion modeling. The interaction between these study areas is shown in Figure 7-1. Emission source characterization provides the temporal and spatial emission rates for the

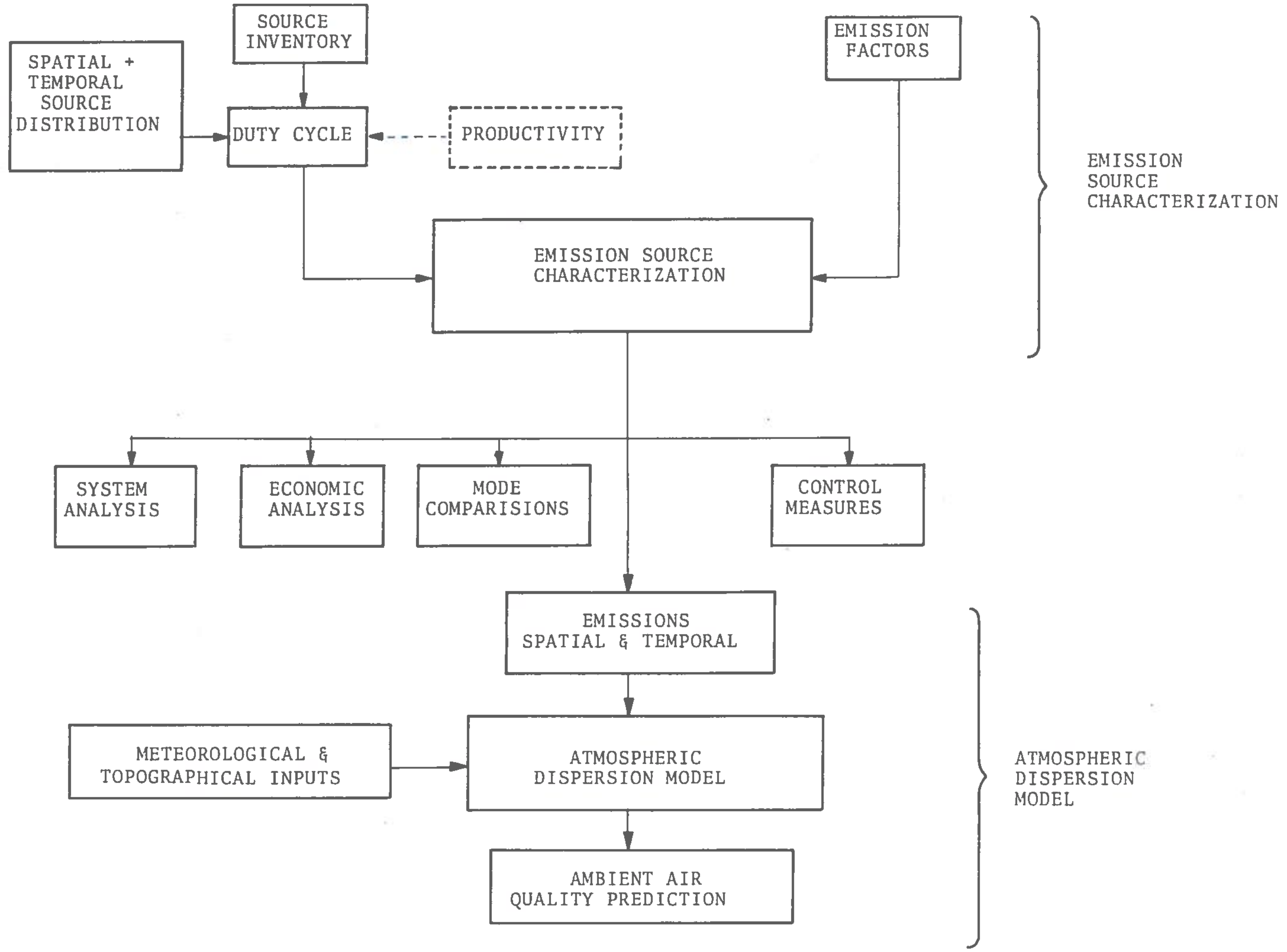

Figure 7-1 Flow Chart for Environmental Impact Assessment of Exhaust Emissions

atmospheric dispersion model. The dispersion model requires the inputs of meteorological and topographical information to predict ambient air quality. With historical meteorological data the probability of occurrences for concentration-duration exposures can be calculated.

7.2.1 Emission Source Characterization

The field study should consider a terminal operation, since such a concentration of emission sources within the central city provides a reasonable "upper bound."

The emission source characterization for the railroad terminal should begin with a source inventory of the actual number, type, condition, location and use of all locomotives operating in the terminal area. Likewise all stationary emission sources within the terminal should be identified in this manner. With a large number of locomotives in the terminal area, each locomotive type, rather than each individual locomotive, can be characterized as to its use, duty cycle and net work performed. The duty cycle includes the percentage of time spent at each power point in relation to the time of day, week and season. Such temporal data are absolutely necessary if the atmospheric dispersion model is to predict peak ambient concentration and concentration-duration exposures for each pollutant. Locomotives are moving sources; thus the duty cycle must include spatial terms that are related to the size of the terminal and the number of locomotives operating in the terminal. The work performed or productivity factor should be included so that the emissions can be expressed in units of net work: gm of pollutant/1000 ton-mile for line haul and gm of pollutant/1000 ton throughput for terminal operation.

The accuracy of ambient air quality prediction from the atmospheric dispersion model is directly dependent upon the accuracy of the model inputs, namely the emission rates, source location, and meteorological data. For useful dispersion modeling, accurate emission factors and accurate duty cycles must be known in order to produce accurate emission rates for the terminal area. A suggested format for locomotive emission factors is given in Table 7-1 and is intentionally different from that of Table 4-4. The suggested format does not express the emissions for a particular duty cycle but in terms of emissions versus load. With this more fundamental approach, the emission rate can be determined for any given duty cycle, whether yard or line haul, at any future time.

TABLE 7-1 EMISSION FACTORS OF DIESEL-ELECTRIC LOCOMOTIVE (SUGGESTED FORMAT)

Manufacturer Type x, Model yz

NOTCH SETTING	POLLUTANT gm/hp-hr; lb/1000 lb fuel; gm/hr				
	CO	HC	NO_x	SO_2	PARTICULATE
1 2 ⋮ 8					

The principal output of the emission source characterization is the emission rate, expressed in spatial and temporal terms, for use in the atmospheric dispersion model. Secondary outputs serve as input information required for a system analysis, control measures, intermodal comparisons, etc., as shown in Figure 7-1.

7.2.2 Atmospheric Dispersion Model

The atmospheric dispersion model takes the emission rate, as specified by the emission source characterization, and distributes and transforms the pollutants according to the transport and diffusion characteristics of the atmosphere to determine the duration of concentration-exposure for the area surrounding the terminal. Such models are computer programs that can be classified into four major categories according to the treatment of atmospheric dispersion theory. These categories are: (a) gradient-transfer, (b) gaussian, (c) similarity, and (d) statistical. In each model type the procedure is similar: the emissions and meteorological data are specified and the concentration profiles are calculated for the surrounding area. The calculated concentration can then be compared with the standards established by EPA to determine the impact of the emissions on public health and welfare near the terminal. A comparison with other emission sources in the air shed will define the magnitude of the regional air pollution attributable to railroad operations.

The rail industry and the Federal Government have a unique opportunity at the present time to undertake an air quality impact assessment with a minimum investment of money and time. In mid-1972 the Environmental Protection Agency began a multi-year Regional Air Pollution Study (RAPS) in St. Louis, MO. Railroad emissions will be considered in the study and, with some additional effort on the part of the rail industry, an in-depth assessment of the impact of locomotive emissions on St. Louis air quality can be ascertained. In addition, the Federal Railroad Administration is sponsoring an Areawide Railroad Consolidation and Relocation Study for the St. Louis Region. Thus, the majority of information needed for the in-depth environmental impact assessment will be already available from presently-funded programs.

The tasks that will not be undertaken by the Regional Air Pollution Study or by the Railroad Consolidation and Relocation Study identified at this time include portions of the emission source characterization described above and dispersion modeling of the terminal area. It is evident that the locomotive exhaust emission impact assessment could become an integral portion of the relocation study. The knowledge gained during such an assessment would also serve as the basis for the environmental impact statement that will be required for the relocation of the St. Louis terminals and as a case study of the air pollution problems of the railroad industry. It is recommended that such an effort be undertaken.

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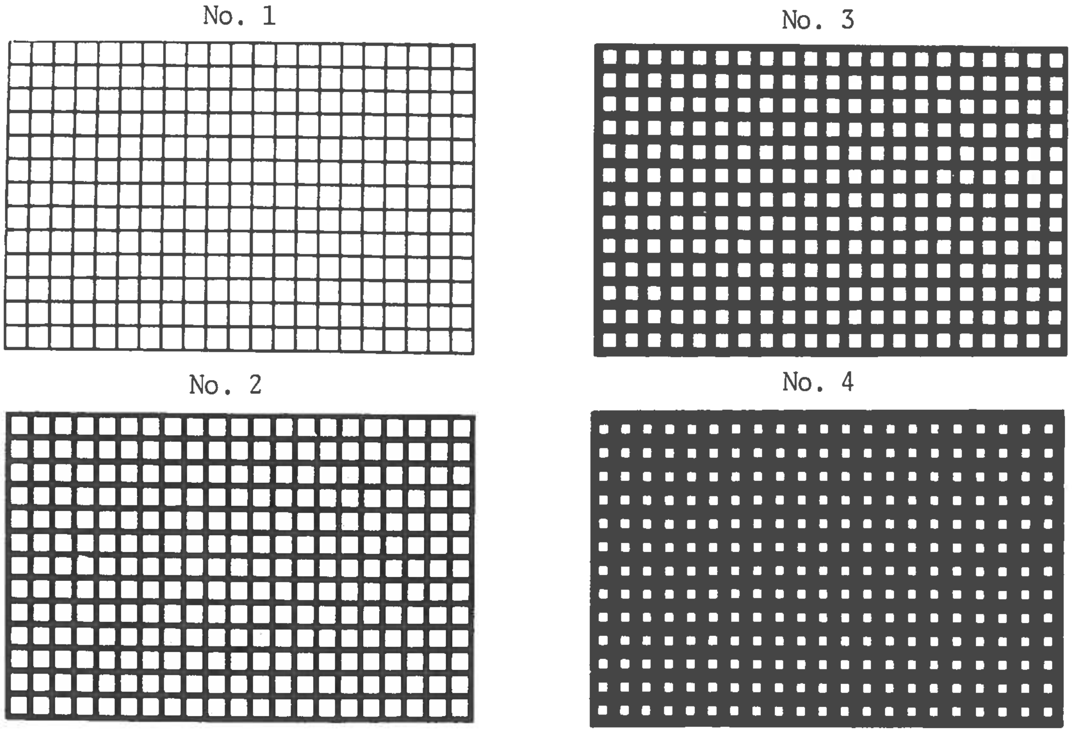


Figure B-3 Ringelmann Smoke Charts

The Ringelmann chart is placed in the line of sight between the observer and the plume under observation, preferably with the sun to the rear of the observer and the wind perpendicular to the line between stack and the observer. The chart is placed approximately fifty feet from the observer causing the lines to merge (visually) and yield shades of gray. The observer then assigns a number to the plume which most nearly resembles a corresponding chart.

Since the Ringelmann chart is large and difficult to set up for each "measurement", small, pocket-size charts have been printed (Figure B-4). This chart has an open area in the center through which the plume is observed when the chart is held at arm's length. The density of the plume is matched to the nearest chart density, and in this way a "Ringelmann number" is assigned to the plume.

The determination of smoke density by the Ringelmann method is highly subjective. The orientation of the sun and the intensity of illumination have a decided effect upon the amount of light

B.3 SMOKE MEASUREMENTS

B.3.1 Visual Methods

One of the earliest concerns about air pollution arose from the visibility of a plume originating from the combustion of fossil fuel. The visible plume may be an indication of improper fuel or combustion. The earliest efforts to evaluate plumes were based upon plume reflectance, but recently the emphasis has been placed on plume transmittance.

B.3.1.1 Ringelmann Smoke Chart - A smoke chart to be used in the field for classification of smoke according to its apparent optical properties was developed by Professor Maximilian Ringelmann in the late ninthteen century[45]. There are six "Ringelmann Charts" ranging from all white, which is equated to zero, to all black, which is assigned Ringelmann Number 5. Those between 0 and 5 have white backgrounds crossed horizontally and vertically with black lines, the width of the black lines increasing from one to the next in the series so that there is a decrease in the amount of white area avilable to reflect light. These charts are assigned Ringelmann numbers 1 to 4 representing 20 to 80% black as shown in Table B-1 and Figure B-3.

TABLE B-1 SPACING OF LINES ON RINGELMANN CHART [45]

Ringelmann Chart No.	Width of Black Lines (mm)	Width of White Spaces (mm)	Percent Black
0	All white		0
1	1	9	20
2	2.3	7.7	40
2	3.7	6.3	60
4	5.5	4.5	80
5	All black		100

reflected and the average volume concentration and the path length (b).

$$\frac{I}{I_o} = e^{-S} = e^{-Kb} \text{------------------------------------} \quad (B\text{-}10)$$

The apparent obscuration produced by a smoke plume can be assigned an opacity rating (in percent) that corresponds to the apparent visible obscuration of a plume measured in "Ringelmann number" (Section 3.1.1). The Ringelmann 1 chart has 20% black area (0% reflectance) and 80% white area (100% reflectance), corresponding to a 20% opacity. In this case,

$$\frac{I}{I_o} = 0.8 = 80\% \text{--------------------------------} \quad (B\text{-}11)$$

where I_o is incident energy and I is reflected energy. Thus, opacity is given by:

$$\text{Opacity} = \frac{I_o - I}{I_o} = 1 - \frac{I}{I_o} = 1 - T \text{------------------} \quad (B\text{-}12)$$

and is a function of the path length through the medium, the concentration of the substance causing attentuation and the ability of the substance to attenuate light by either absorption or scattering. Thus, particles make an exhaust plume visible when the amount of scattered and/or absorbed light is sufficient so that an observer can distinguish the plume from the background. The point where a plume becomes visible is dependent upon the wavelength and intensity of incident light, the number concentration of particles, the optical properties of the particles, particle size and composition, the path length of the plume, the viewing angle and the brightness and color of the background.

Since the optical properties of a plume are dependent upon many factors different from those that determine the mass concentration of particles per unit volume, optical measurements of an exhaust plume do not necessarily correlate with mass measurements.

A previous name used for "transmittance" was "transmission". Transmittance is expressed either as a percentage or decimal fraction (e.g., 0.4 or 40%).

The Bauger - Lambert Law of Photometry states that the rate of decrease in radiant energy through an absorbing medium is proportional to the loss in radiant energy of the beam; that is, the light will be diminished in a geometric progression with path length. If a thickness b of a medium decreases the light energy by one-half, a thickness 2b will decrease the energy by 3/4 (1/2 x 1 + 1/2 x (1/2 x 1)). This relationship between transmittance and path length may be expressed as:

$$T = \frac{I}{I_o} = e^{-kb} \text{-------------------------------} \qquad \text{(B-6)}$$

where b is path length and k is a proportionality constant.

Beer's Law states that the radiant energy of a beam decreases in a similar manner as the concentration of the energy absorber increases. This statement may be incorporated into Equation B-7.

$$T = \frac{I}{I_o} = e^{-abc} \text{-------------------------------} \qquad \text{(B-7)}$$

where a is the "absorptivity" of the absorbing medium, c is the concentration and b is the path length. By taking the negative $\log_{10}$ of transmittance, we define the term absorbance (A). Again, other terms formerly used were optical density and extinction .

$$A = -\log_{10} \frac{I}{I_o} = abc \text{----------------------------} \qquad \text{(B-8)}$$

Radiant energy incident on a smoke plume can be absorbed, scattered and reflected. Semi-quantative methods used in determining the amount of solid material (particles) in the plume include measuring the transmitted light (tubidimetry) or scattered light (nephelometry). The turbidity produced by a plume is given by:

$$S = -\log_{10} \frac{I}{I_o} \text{-----------------------------} \qquad \text{(B-9)}$$

where S is the turbidance (analogous to absorbance). The turbidance of the plume is determined by the total average turbidity coefficient (K), which takes into account the average absorptivity, the average scattering or extinction coefficient, the average amount

$$\frac{r_1^{\,3}}{\lambda} > \frac{r_2^{\,6}}{\lambda^4} \qquad \text{(B-4)}$$

where r_1 is the radius of a particle in the Mie region and r_2 is the radius of a particle in the Rayleigh region ($r_1 >> r_2$, $r_1 \simeq \lambda$).

B.2.4.3 Nonselective Scattering - Nonselective scattering occurs when the particle size is much larger than the wavelength of incident radiation. Large particle scattering is composed of contributions from three processes involved in the interaction of radiant energy with the scattering particle: (a) reflection from the surface of the particle with no penetration, (b) passage through the particle with and without internal reflections and (c) diffraction at the edge of the particle. Thus, nonselective scattering due to a particle is quite complex; composition and geometry determine the relative contribution of each process to the total scattering.

B.2.5 Absorption, Scattering and Transmission

When a beam of radiant energy impinges on a substance, several things may occur: (a) the radiation may pass through the substance with or without absorption of energy, (b) the direction of the beam may be altered by reflection, refraction or diffraction, and (c) energy may be scattered from the beam due to small scattering centers (particles). The absorption of energy involves a transfer of energy to the absorbing medium and is a phenomenon specifically related to characteristic molecular structures of the substances composing the medium. Reflection, refraction and diffraction are purely geometric optical phenomena.

The rate at which energy is dissipated as it traverses a smoke plume is of interest in the measurement of smoke emissions. The energy incident on the plume can be denoted as I_o and the amount of transmitted energy as I. The ratio of the transmitted energy to the incident energy is termed transmittance as expressed in Equation B-5.

$$T = \frac{I}{I_o} \qquad \text{(B-5)}$$

size and wavelength of incident radiation. The value of E rises from zero to nearly four and asymptotically approaches the value of two for large particles, as shown in Figure B-2[44].

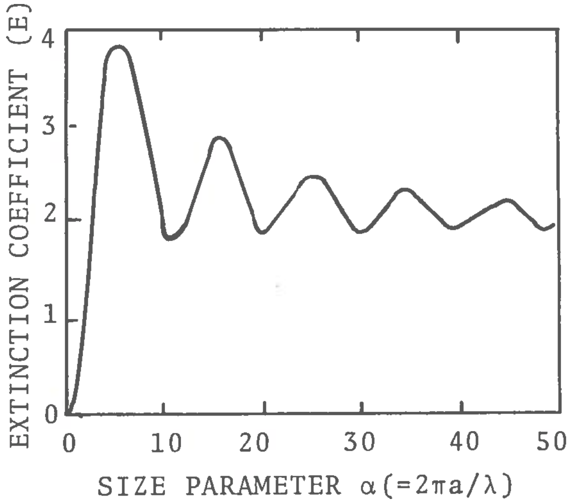


Figure B-2 Extinction Coefficient Vs. Size Parameter for Spherical Water Droplets (Radius = a). Index of Refraction, n=1.33.

The scattering coefficient is related to E by Equation B-2:

$$\sigma = N E \pi r^2 \tag{B-2}$$

where N is the number concentration and r is the radius of the particle. Thus the Mie scattering coefficient is a function of the volume to the first power (r^3) and wavelength to a minus first power (λ^{-1}).

$$\sigma_{Mie} \propto \frac{N V}{\lambda} \tag{B-3}$$

A particle whose size falls in the "Mie region" is a much more effective scattering center than a particle in the "Rayleigh region" for visible light:

respiratory system[41,42]. Thus, mass measurements are not sufficient to characterize fully the impact of particle emissions on the environment.

B.2.4 Light Scattering

Particles scatter and absorb radiant energy (light). The amount of scattered or absorbed energy is a function of the wavelength of the incident energy, the composition of the particle (which determines its index of refraction and absorptivity) and the size and geometry of the particle.

B.2.4.1 Rayleigh Scattering - The first quantitative study of light scattering by small particles was reported in 1871 by Lord Rayleigh[43]. His mathematical investigation of the problem provided a general formula for the intensity scattered light applicable to any particle whose index of refraction is different from that of the surrounding medium. The only restriction is that the linear dimensions of the particles be considerably smaller than the wavelength of the incident light. The scattered intensity was found to be proportional to the incident intensity and to the square of the volume of the scattering particle (or r^6). The most interesting result is the dependence of scattering on the wavelength of incident radiation. The volume scattering coefficient ($\sigma_{Rayleigh}$) is inversely proportional to the wavelength to the fourth power (λ^4), and directly proportional to the volume squared (V^2) and the number concentration (N).

$$\sigma_{Rayleigh} \propto \frac{NV^2}{\lambda 4} \text{ ---------------------------} \qquad \text{(B-1)}$$

Equation (B-1) is the basic equation describing Rayleigh Scattering; i.e., scattering occuring when the particle size is much smaller than the wavelength of light (λ=0.4 to 0.7μm).

B.2.4.2 Mie Scattering - When the particle size is roughly comparable to the wavelength of the incident light, Mie scattering results. The extinction coefficient (E) is a function of the particle (dN) with respect to a given change in the log of the particle radius (dlnr): $\frac{dN}{d\ln r}$. This quantity is usually plotted as $\frac{dN}{d\ln r}$ vs. lnr.

B.2.2 Composition

The composition, size and number density of particles emitted from a combustion process are determined by the type of fuel used and the combustion process itself. The particles emitted may or may not be a visible smoke. For diesel engines, the majority of particles in the exhaust are carbon with an undetermined amount of adsorbed/absorbed hydrocarbons and other gases. If the engine is operating richer in fuel than normally, the emitted exhaust gases will probably contain unburned or partially oxidized fuel droplets. Likewise, if the lubricating oil enters the combustion chamber, a portion of this oil may be exhausted as small oil droplets. Diesel fuel contains little ash, usually less than 0.05%; thus the inorganic particles in diesel exhaust are negligible if inorganic fuel additives have not been added.

B.2.3 Mass

The mass of an aerosol per unit volume is a function of the number concentration, size distribution and density of the particles. Mass per unit volume of particulate emissions is probably one of the easiest, most basic measurements used in characterizing emission rates.

This type of measurement does not, however, distinguish between 1000 particles of 1μm radius and 1 particle of 10μm radius since they have equal mass (assuming each are spheres and have equal densities). On a mass basis, one million particles of 0.1μm radius are also equal to the one particle of 10μm radius, and so on for other radii (mass $\propto$ volume $\propto r^3$).

Mass measurements usually do not detect large numbers of small particles ($r<1\mu m$) if just a few large particles ($r>1\mu m$) are present. Small particles play an important role in atmospheric photochemical reactions and are subject to deposition in the human

B.2 CHARACTERISTICS OF SMOKES AND PARTICLES

B.2.1 Size

A fossil fuel combustion engine can be characterized as a simple input-output system. Fuel and air are the inputs of the engine; waste exhaust gases, heat and work are the outputs. This simple process is illustrated in Figure B-1.

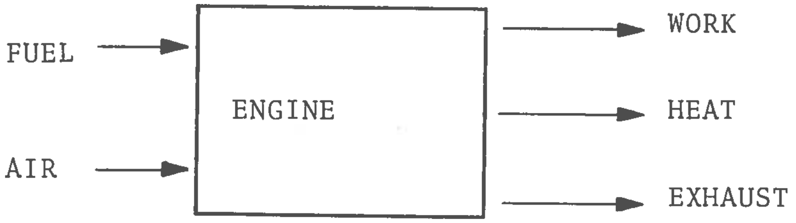


Figure B-1 Simple Fossil Fuel Engine

During the combustion process, a small amount of the fuel may not be completely consumed and is emitted with the exhaust gases. This unburned fuel is made up of both raw and partially oxidized fuel. Most fossil fuels have a non-combustible faction, termed ash. A portion of the ash is also emitted with the exhaust gases. The size of particles formed during fossil fuel combustion range roughly from 0.001 to 100μm linear dimension. The linear dimension used in the literature can be either a radius or a diameter, but the use of these terms does not necessarily imply circular or sperical shape of the particles. A particle can also be assigned a "size" based on its aerodynamic characteristics. A particle is assigned the radius r_{eq} or diameter d_{eq} of a sphere having equivalent aerodynamic characteristics and a density of 1 gm/cm^3. This is known as the "aerodynamic" radius or diameter.

Associated with particle size is the size spectrum over a given size range. This size distribution (number per given size interval) is usually expressed as the change in number of particles

APPENDIX B

SMOKE MEASUREMENT

B.1 SMOKE DEFINED

Smoke emission from fossil fuel was the first pollutant to be identified and controlled. The earliest recorded protests due to fossil fuel combustion were recorded in the thirteenth century; control measures were enforced during the fourteenth century in England[3]. In the current attempt to clean up our environment, smoke is considered a major "pollutant" evoking protests from the public which motivate control agencies to act. The railroads' major sources of smoke emissions are locomotives and steam generating plants. The requirement for "quantitative" smoke measurement is such that a detailed analysis is warranted.

Smoke is generally assumed to be a visible emission arising from the combustion of fossil fuel. A scientific definition of smoke is more specific: smoke is a gaseous dispersed system consisting of particles of low vapor pressure, excluding water droplets. This latter definition of smoke is similar to that of an aerosol: an aerosol is a colloidal system in which gas, usually air, is the continuous medium and in which particles of solid or liquid are dispersed. Since most smoke control regulations rely on visible measurement techniques, the term "smoke" in this discussion refers to visible emissions. An aerosol or particulate emission, then, is termed "smoke" when it is visible. In the following sections, the characteristics of these "visible emissions" will be explored in some depth.

Another term frequently encountered is "particulate matter". Particulate matter usually refers to an aerosol or smoke on a mass per unit volume basis. "Suspended" particulate matter is the mass of particles per unit volume of ambient air, usually expressed in $\mu g/m^3$.

Intake restriction - between maximum published clean and dirty
air cleaner restriction

Fuel temperature - 100 ± 10°F

Intake air or exhaust flow

Fuel flow

After the cycle is completed the engine must be shut down for eight hours and then the cycle is repeated.

CO and NO are measured by nondispersive infrared methods, and UBHC's are measured by a heated flame ionization detector. Apparently NO_2 emissions are ignored.

A test procedure is also given for use with a chasis dynamometer for field surveillance-type testing. However, this method has inherently larger error and is not meant to be used for approval tests.

The actual emissions test procedure begins with a warmup of at least 10 minutes. Then the engine is run for 10 minutes in each of the following modes.

Engine Speed	Percent Load + 2%
Low Idle	0
Intermediate	2
Intermediate	25
Intermediate	50
Intermediate	75
Intermediate	100
Low Idle	0
Rated	100
Rated	75
Rated	50
Rated	25
Rated	2
Low Idle	0

The first minute at each condition is to allow the operator to establish the condition, the next eight for stabilizing, and the last minute to take emission measurements. However, hydrocarbons, CO and NO must be recorded on a strip chart during the last five minutes of each mode. Only the average of the last minute is used for the calculations.

Intermediate speed is 60% of rated speed or peak torque speed, whichever is greater. The percent rated load plus 2% is presumably so the engine does not have to be run right at 100% load, an unstable condition.

Also during the last five minutes of each cycle the following must be recorded:

Engine speed
Engine torque or dynamometer load units
Intake air temperature - 85 ± 15°F
Exhaust backpressure - maximum permitted by manufacturer at maximum horsepower

The engine company is responsible for proving that its engines meet the standards. In addition, the engine manufacturer must provide evidence demonstrating the durability of the emission control systems and must make a statement in respect to the ability of the engine to maintain the emissions over the service life of the engine. Also, a statement must be made regarding maintenance procedures and equipment required to assure conformation with regulations and a description of a training program for maintenance personnel. However, there does not seem to be any statement in the standards that the original levels of emissions must be maintained for a given length of time. The standards apply only to new vehicles.

The fuels employed during testing must meet what are essentially ASTM 2-D specifications. The following are the actual specifications:

Cetane	42-50
Distillation, °F	
IBP	340-400
10%	400-460
50%	470-540
90%	550-660
End Point	580-660
Gravity, °API	33-37
Sulfur, %	0.2-0.5
Flash Point, °F, Min.	130
Viscosity, cs	2.0-3.2
Cloud and Pour Point	Adequate for operability
Nonmetallic Additives (if Desired)	Cetane improver, metal deactivation antioxidant, dehazer, antirust, pour depressant, dye, and dispersant

Prior to testing, the engine is run in accordance to the manufacturer's recommendation for performance testing. Then the engine is run for a 50-hour conditioning period at 90 ± 10% of rated load and speed.

APPENDIX A

STATE OF CALIFORNIA DIESEL EMISSION STANDARDS (1973-1975)[24]

The California Air Resources Board has set standards as of November 18, 1970, for diesel-powered vehicles. The approved standards are as follows (Subchapter 1, Article 1, Section 1943):

a. Exhaust emissions from diesel engines in new 1973 and 1974 model year vehicles over 6001 pounds gross vehicle weight shall not exceed:
   (1) Hydrocarbons plus NO_x (as NO_2) - 16 grams/bhp-hr
   (2) CO - 40 grams/bhp-hr

b. Exhaust emissions from diesel engines in new 1975 and subsequent model year vehicles over 6001 pounds gross vehicle weight shall not exceed:
   (1) Hydrocarbons plus NO_x (as NO_2) - 5 grams/bhp-hr
   (2) CO - 25 grams/bhp-hr

These standards and the following test procedures are applicable to all new diesel-powered, heavy-duty vehicles manufactured on or after January 1, 1973, to be sold in California. Actually, the engine, not the vehicle, is approved. The engines to be tested for approval are selected according to families of similar design.

Engines are considered to be of the same family if they have the same:

a. Combustion cycle (two cycle or four cycle)

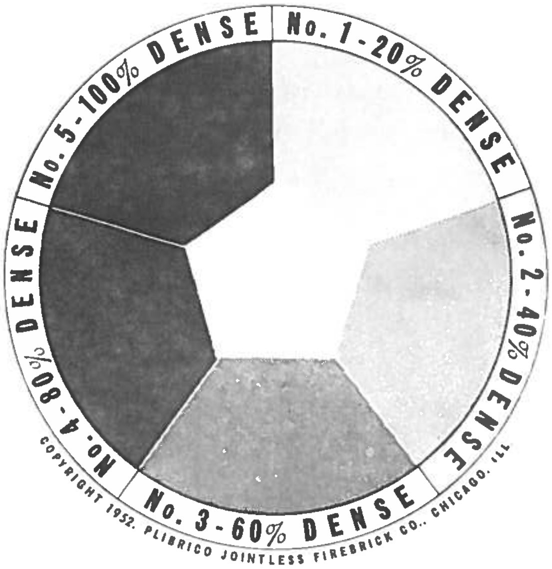
b. Combustion system (open chamber, prechamber, M-system, etc.)

c. Method of air aspiration (natural, turbocharged, supercharged)

Engines of differing numbers of cylinders, cylinder configuration, or even bore and stroke can be in the same family. Within each family, the engine selected for testing is the one with the largest projected sales volume for the United States (not California).

PLIBRICO SMOKE CHART

RINGELMANN TYPE



INSTRUCTIONS

This miniature Ringelmann smoke scale will enable the observer to conveniently grade the density of smoke issuing from the stack.

The scale should be held at arm's length at which distance the dots in the scale will blend into uniform shades.

Then compare the smoke (as seen through the hole) with the chart, determining the shade in the chart most nearly corresponding to the shade or density of the smoke. Experienced observers often record in half chart numbers. By recording the changes in smoke density, the average "percentage of smoke density" for any period of time can be determined.

Observer's line of observation should be at right angles to the direction of smoke travel.

Observer should not be less than 100 ft. nor more than ¼ mile from the stack.

Observer should avoid looking towards bright sunlight. The background immediately beyond the top of the stack should be free of buildings or other dark objects.

Figure B-4 Pocket-Size Smoke Chart[46]

reflected or transmitted. The wind and stack exit velocity determine the amount of mixing between the stack gases and ambient air, with an increase in mixing producing a decrease in apparent smoke density. The mixing of stack gases and ambient air is at a minimum at the exit of the stack; therefore it is suggested that the observer determine the smoke density at that point. If the stack gases are diluted before discharge to the atmosphere, the Ringelmann method can only determine the apparent density of the resulting mixture.

It is obvious that the Ringelmann method can be used only during daylight hours. Night observations with artificial light are difficult if not impossible. Special problems are encountered when the plume color is something other than black or a shade of gray. The presences of moisture or condensed mist further complicates plume assessment.

In summary, the Ringelmann method is dependent upon several physical parameters such as: illumination, illumination angle, viewing angle, plume width, plume color, particle size distribution, particle composition, index of refraction, reflectivity, total particle concentration and, of course, all the variables associated with a human observer. It is realized that all comparison-type guides have an inherent limitation in that equal optical properties of black smoke plumes do not necessarily reflect equal contaminant discharge to the atmosphere. The advantages of a rapid and simple application offset this limitation to some extent and result in a useful evaluation method for smoke discharges under some conditions.

B.3.1.2 Direct Observer Determination - Some air pollution control agencies use the Ringelmann chart only for the training of inspection personnel. The smoke observer is trained to judge various types of plumes according to their apparent densities. The proficiency expected after this training period is to be able to correctly estimate a plume density with an average deviation of 1/2 Ringelmann number. Once in the field, the observer depends upon his memory to judge plume density and to assign a Ringelmann number.

B.3.2 Transmittance Devices

B.3.2.1 Film Strips - Many of the faults of the Ringelmann method can be attributed to its dependence on reflected light, in comparison to methods for evaluating smoke plumes by their optical characteristics due to transmitted light[47]. To overcome these faults, standards of light transmittance have been developed. The type shown in Figure B-5 is a film strip ("negative") composed of four different shades of gray. Each shade of gray has a different transmittance (opacity) and can be correlated with the Ringelmann standard; i.e. 20% opacity is equivalent Ringelmann number 1 or 40% equated to number 2, and so on.

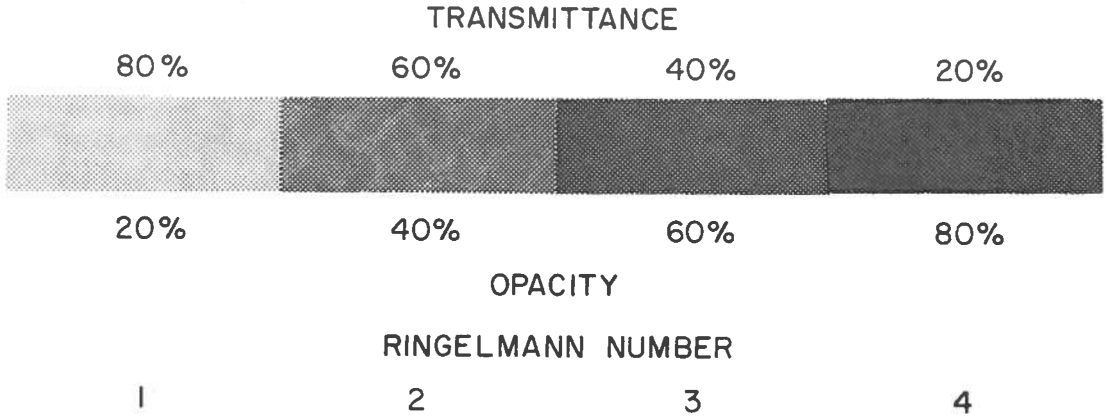


Figure B-5 Smoke Inspection Guide[45]

The film strip standard is reported to be independent of variations in illumination, while the Ringelmann method is dependent on the random diffuse background and foreground skylight[47].

B.3.2.2 Opacity Meters - One of the most popular and widely used instruments for the monitoring of stacks is the opacity meter, also referred to as a smoke or light extinction meter. The basic objective of an opacity meter is to measure directly the attenuation of a light beam caused by the exhaust plume. The instrument consists of a light source mounted on one side of the stack and a receiving unit on the other side. A beam of light is directed across the stack to the receiving unit. The receiving unit is connected to an indicating meter and/or recorder. The output may be expressed in percent opacity, percent transmittance, or equivalent Ringelmann number. The optical schematic shown in Figure B-6 is that of the U.S. Public Health Service smokemeter.

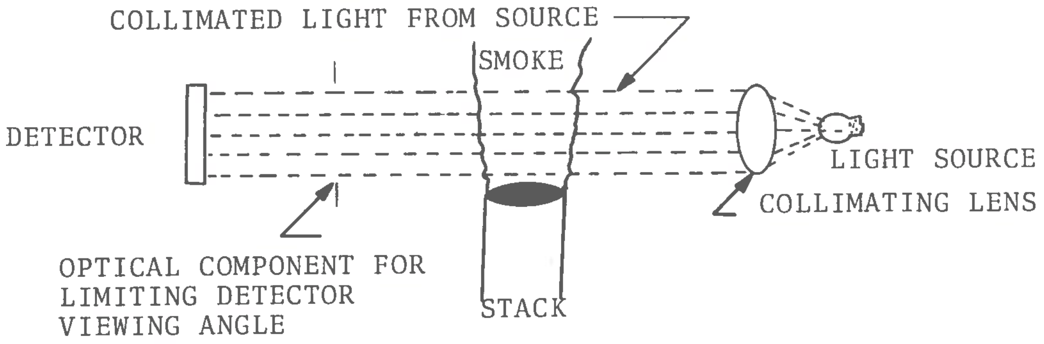


Figure B-6 USPHS Smokemeter Optical System (Schematic)

The reading obtained with an opacity meter is more quantitative than the subjective Ringelmann method. Long term variations in the light source and photodetector can be compensated for by the addition of simple electronic circuitry. By comparison, the variables encountered in using the Ringelmann method are numerous and in general uncontrollable. The performance of the human making the judgment will vary from day to day and hour to hour. The same is true for the lighting conditions.

In obtaining an opacity reading, the amount of transmitted light is measured and can usually be related to the visual appearance of the plume. However, as pointed out earlier, all of the particle and plume parameters which determine the amount of transmitted light affect the reading obtained with such a device.

B.3.3 Particle Identification

The identification of particle size and composition is a difficult task. If the individual particles are larger than a few µm, they may be collected and analyzed with light microscopy techniques. The geometry, size and, possibly, the composition may be ascertained by this method. If the particles are smaller than a few µm, an electron microscope must be employed. The most difficult task in analyzing exhaust particles via electron microscopy is the sample collection. Impactors, thermal precipitators and electrostatic precipitators have all been used with varying degrees of success[49].

Chemical identification of individual particles can be ascertained by using the sophisticated methods of microprobe and electron diffraction analysis. A composite sample of particles can be analyzed by x-ray diffraction and emission spectroscopy. It should be noted that the latter techniques reveal the chemical composition of the composite sample, rather than those of individual particles.

B.3.4 Mass Measurement

Along with opacity measurements, mass measurements of exhaust gases are common. The new stationary source performance standards set the maximum emission level in both terms of opacity and mass emissions. (Section 3.3.2).

Mass measurements are obtained by passing a known amount of exhaust gas through a filter. The filter is then removed from the holder and the mass of the collected particles determined by weighing. Knowing the total flow of the exhaust, the average mass of particulate matter per cubic meter of exhaust gas can be calculated. Recently, several automatic particle mass monitors have become commercially available. Such devices represent high capital costs (usually several thousand dollars) but have the advantage of requiring less data reduction.

Mass emission rates do not describe the visual appearance of the exhaust plume, nor would they be expected to do so.