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USCG POLLUTION ABATEMENT PROGRAM: A PRELIMINARY STUDY OF VESSEL AND BOAT EXHAUST EMISSIONS

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16. Abstract

A preliminary study of exhaust emissions from Coast Guard vessels and boats indicates that the Coast Guard fleet is an insignificant contributor to air pollution on a national and regional basis. Based upon fuel usage data, emission estimates by vessel class were made for the entire Coast Guard fleet and compared to other sources of marine and land air pollution. No estimates of the effects on air quality of the two-stroke cycle outboard engine could be made due to the lack of reliable data on their emissions.

A general review of the existing air quality legislation pointed up the scarcity and contradictory nature of present laws as related to vessel emissions.

Existing monitoring instrumentation and emission control techniques were evaluated with consideration to their usefulness in a ship-board environment.

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SECTION 1. INTRODUCTION

1.1 SUMMARY

This report documents the findings of a background study of vessel and boat exhaust emissions performed for the United States Coast Guard. A thorough review of existing federal, state and local air pollution statutes is presented in order to provide a framework within which an appropriate pollution abatement program may be structured. It is shown that, at present, many of these regulations are ineffective or even contradictory. The massive effort required to meet the 1975 ambient air quality standards set by the Environmental Protection Agency is illustrated by examination of historical records of air pollution in major port cities.

The report is directed specifically toward assessment of the impact of Coast Guard vessel and boat emissions on ambient air quality, but will include an assessment of the impact of pleasure craft and merchant vessel emissions. For completeness, we recommend that a portion of the future effort on this project be directed toward characterization of two-stroke cycle gasoline (outboard) engines.

A classification of Coast Guard vessels by type shows, as was expected, that fuel useage is generally proportional to size. The high endurance cutter type (WHEC) stands out as the largest user of fuel by a substantial margin. Outboard motors are shown to be potentially significant contributors to air pollution based on the best available estimates of their number and emissions. Emission estimates are presented for specific classes of Coast Guard vessels and boats based on emission factors available in the open literature; the lack of specific data points up a need for a more accurate measurement of these factors. Instrumentation and measurement techniques suitable for obtaining these data are briefly reviewed. An outline of air pollution control equipment and techniques suitable for shipboard use is presented, followed by a discussion of measurements to be obtained in the next phase of this project.

1.2 CONCLUSIONS

1. Based on a preliminary analysis of fuel use data, the United States Coast Guard, in its entirety, is an insignificant source of air pollutant emissions owing to the small number of vessels in its fleet. (Individual vessels could, however, under certain conditions, constitute a significant point source of air pollution.)

2. There is a distinct lack of data on vessel and boat emissions. Such data is needed before any accurate assessment of the impact of these emissions can be made.

3. There is a need for data regarding the fractional contribution of waterline exhaust discharge to air pollution versus its contribution to water pollution.

4. There is a definite need for characterization of two-stroke cycle outboard engine emissions as a function of model year and power output.

5. Existing emission control technology may be applied to minimize emissions, with proper attention to the ocean environment.

1.3 RECOMMENDATIONS

Based on the conclusions reached in this report, the following recommendations can be made:

1. Initiation of two-phase emission measurement program to accomplish: Assessment of the impact of emissions based on field measurements of Coast Guard vessels obtained under operating conditions and characterization of the emissions from two cycle outboard engines and the effects of water/exhaust mixing from outboard engines and marine diesels.

2. Establishment of a cost-effective pollution control program for Coast Guard vessels based upon priorities determined upon completion of measurements.

SECTION 2. LEGISLATIVE GUIDELINES FOR AIR POLLUTION CONTROL

2.1 GENERAL DEFINITION OF TYPES AND EFFECTS OF AIR POLLUTION

A variety of definitions for air pollution exist, each expressing the individual philosophical, theoretical, practical or protective motivation of its author. 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 concentration to produce an undesirable, and hence observable, effect on man, animals, vegetation or materials. In the context of this definition, both natural and artificial (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: 1) those pollutants emitted directly from identifiable sources (called primary pollutants), and 2) 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 those in metallurgical, cement, and paper industries may be significant sources of primary air pollutants. Typical primary emissions are particulate matter, sulfur oxides, hydrocarbons, nitrogen oxides, carbon oxides, and halogen compounds. These emissions are generally associated with the combustion of fossil fuels or industrial processes. Secondary pollutants may 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. A natural example is the phenomenon of light scattering in common ground fog where the scattering centers 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 metal, 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.[2] Air pollution damage is evident in various types of leaf damage, stunting of plant growth, decreased size and yield of fruits, and the destruction of flowers.[3]

Air pollution's most dramatic effect on man is recorded in the acute episodes of Donora, London and the Mesue Valleys where both human and animal life were lost. Long, continued exposure to sub-lethal concentrations of many pollutants, and combinations thereof, are suspected to have physiological effects, but at the present time few quantitative relationships have been defined to document this fact. 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.[2]

2.2 MAJOR FEDERAL LEGISLATION

Air pollution control in the United States began in the last quarter of the ninteenth 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 that were prevalent in our industrial centers. These pollutants were controlled by means of legislation enacted on a municipal or state level requiring that smoke 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 and amount of emissions which are now controlled is almost endless.

2.2.1 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 Clean Air Act was enacted in 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. It also provided for three specific areas of research:

1. Control of motor vehicle exhaust emissions,
2. Removal of sulfur from fuels,
3. The development of air quality criteria.[4]

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

2.2.2 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 regional 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 additon to the designation of air shed regions, the Secretary of HEW was required to publish "air quality criteria" for each region, based upon scientific studies and describing the harmful effects of each pollutant upon the health and welfare of the region. 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 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 of achieving the air quality standards by source control. Primary responsibility for enforcement of the standards and implementation plans lay with state and local governments. If a case of interstate air pollution existed or if an offending state was 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, approval and implementation of 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. A federal, and hence national, emission standard was thus created which insured that the multiplicity of state standards apparent in the control of other pollutants would not occur with automobiles.

Among the shortcomings of the 1967 Act, which are cited in the literature[4], are the following:

1. Cumbersome and time consuming procedures required for the establishment of standards;

2. Inadequate funding at the federal, state, and local levels;

3. Insufficient numbers of skilled personnel available to enforce control measures;

4. Organizational problems at the federal level, where air pollution had not been accorded high priority; and

5. Failure of HEW to perform its duties to the fullest extent.

President Johnson stated 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, abatement practices were ordered to be under way no later than December 31, 1972.[6]

2.2.3 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 with the enactment of the National Environmental Policy Act of 1969 and the Clean Air Amendments of 1970.[7] 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 in motor vehicle emissions by source control through 1975 and 1976 emission standards.

Past procedure had been the establishment of air pollution standards commensurate with existing technology; now, the 1970 Act forces technology to catch up with 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 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 after 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 occurred in implementation of 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 other pollutants.

2.2.3.1 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 EPA 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 standard does not prohibit any state or region from establishing ambient air quality standards that are more stringent than the national standards.

2.2.3.2 Source Performance Standards

The federal government has preempted state and local government regulation of new steam generating plants, incinerators, acid manufacturing plants, and cement works by the establishment of 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. The act thus 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.

2.3 STATE AND MUNICIPAL LEGISLATION

The majority of air pollution control regulations enacted in this country prior to 1960 was directed toward the control and abatement of smoke and particulate matter. These pollutants were emitted principally from the combustion of coal and residual oil in our large industrial centers. Since each city or region had their own particular air pollution problems, 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 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 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] New Mexico has recently enacted a controversial smoke emission standard for locomotives.[9] Several mountain states are currently studying the New Mexico law and will probably use it as a model for their legislation.

With the establishment of a strong federal air pollution control program, it can be reasonably 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.

In conclusion, at present there are no federal regulations pertaining to vessel emissions. However, as can be seen in Table 1, many municipal, county and state regulations specifically include vessels. As has been pointed out, many of these regulations are contradictory and ambiguous. Based on historic precedent and the large number of federally operated vessels in use, effective control of vessel emissions will be difficult until the federal government provides emission regulations which are based on sound data and can be uniformly applied.

2.4 IMPLEMENTATION OF EXISTING LEGISLATION

2.4.1 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

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

Region	Emission	Regulation	Date Effective
1. 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. per 1000 lb. stack gas except for tube blowing which may exceed standard 6 minutes out of every hour.	
2. Chicago, ILL.	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 per standard cubic foot (Scf); 0.21 grains per 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
3. Cleveland, OH	Smoke	Emissions not to exceed Number 3	

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

Region	Emission	Regulation	Date Effective
		Ringelmann for 30 seconds per 4 minutes by locomotives and 6 minutes per hour by steamships.	
4. Portland, ORE	Smoke	Emissions not to exceed Number 2 Ringelmann or an opacity equal to one minute per hour; motor vehicle not to exceed Number 1 Ringelmann continuous or Number 2 in excess of 5 seconds.	1964
5. Poughkeepsie, NY	Smoke	Railroad emissions not to exceed Number 2 Ringelmann except for locomotives in motion which may emit Number 3 Ringelmann for 1 minute per 6 minutes or 4 minutes per 30 minutes if not in motion.	1951
6. 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 three minutes per 30 for tube blowing.	1967

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

Region	Emission	Regulation	Date Effective
7. Gary, IND	Particulates	Not to exceed 0.60 lbs per 10^6 BTU heat input for units less than 10^7 BTU/hour total heat input.	1967
8. New Orleans	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 misdemeaner.	1963
	Tube Blowing	Tube blowing is prohibited within the city limits.	
9. New York City	Smoke	Emissions between Number 1 and 2 Ringelmann not to exceed four minutes per hour; between Number 2 and 3 Ringelmann, not to exceed two minutes per 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 per hour if total heat input less than 10^7 BTU per 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 system, 100 ppm SO_2.	1971

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

Region	Emission	Regulation	Date Effective
	NOx	Old system, NOx limited to 150 ppm max. stack gas concentration; new system, 100 ppm NOx.	1971
10. San Francisco Bay Area	Particulates	Emission not to exceed 0.30 gr per Scf.	1962
	Hydrocarbons	Hydrocarbons losses 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
11. Los Angeles CO	Particulates	Emissions not to exceed 0.30 grains per Scf except those regulated by Rules 53 & 54 (Specific emission levels).	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 stack gas from stationary sources.	12/31/1971
		Emission not to exceed 125 ppm NOx as NO_2 stack gas from stationary source.	12/31/1974
12. Miami, FLA	Smoke	Emissions not to exceed Number 2 Ringelmann continuous or Number 3 for 3 minutes per hour.	1964

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

Region	Emission	Regulation	Date Effective
	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.	
	Fuel Oil	Grade Number 6 or other grade inferior may not be used.	1971
13. Massachusetts	Smoke	Emissions limited to Number 1 Ringelmann or Number 2 for 6 minutes per hour for stationary sources;	1971
		emission from aircraft not to exceed Number 2 Ringelmann for 10 seconds.	1972
		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.	1971
		No residual fuel may be used.	1971
14. New Mexico	Smoke	Emission from diesel-powered vehicles not to exceed Number 1.5 Ringelmann in excess of 10 seconds when operating	1971

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

Region	Emission	Regulation	Date Effective
		below 8000 ft. mean sea level; locomotives limited to Number 1 Ringelmann. Emission from diesel powered vehicles not to exceed Number 2 Ringelmann in excess of 10 seconds when operating above 8000 ft. mean sea level; locomotives included when involved in switching and yard usage or when operating above 8000 ft. mean sea level.	1971
15. New York	Smoke	No emission of an opacity greater than 20% shall be emitted in excess of five seconds. Marine Diesels excluded.	1967

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 and therefore are generally more strict.

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 industries, 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 2 is a presentation of the national primary and secondary ambient air quality standards for the United States.

2.4.2 Stationary Source Performance Standard

The federal government is in the process of establishing national source performance standards for new fossil fuel steam generating plants as required by Title I of the Clean Air Act. These standards will specify the maximum permitted emission levels of particulates, sulfur dioxide, and nitrogen oxide. Table 3 is a presentation of the proposed emission standards.

In addition to regulating new steam generating plants, emission standards for new portland cement plants, incinerators and acid manufacturing plants have been proposed.

2.4.3 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 are established for each year through 1975 (or 1976, with a one year extension for NOx). 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 requires the standards to be set on the basis of protecting public health; existing technology or cost were not considered to be relevant.[4] Table 4 is a summary of emission standards for new automobiles conducted under the Federal Test Procedure for such engines.

TABLE 2.[10] NATIONAL AMBIENT AIR STANDARDS

Compound	Primary Standard	Secondary Standard
SOx	0.03ppm(1) 0.14ppm(2)	0.02ppm(1) 0.10ppm(2) 0.50ppm(3)
CO	9ppm(4) 35ppm(5)	9ppm(4) 35ppm(5)
Photochemical Oxidants	0.08ppm(5)	0.08ppm(5)
Hydrocarbons	0.24ppm(6)	0.24ppm(6)
NO_2	0.05ppm(1)	0.05ppm(1)
Particulates	75micrograms/M3(7) 260micrograms/M3(2)	60micrograms/M3(7) 150micrograms/M3(2)

Notes:

1. Annual arithmetic average
2. Maximum 24 hour concentration, not to be exceeded more than once per year
3. Maximum 3 hour concentration, not to be exceeded more than once per year
4. Maximum 8 hour concentration, not to be exceeded more than once per year
5. Maximum 1 hour concentration, not to be exceeded more than once per year
6. Maximum 3 hour concentration (6 to 9a.m.) not to be exceeded more than once per year
7. Annual geometric mean.

TABLE 3.[11] PROPOSED NEW STATIONARY SOURCE PERFORMANCE STANDARDS FOR FOSSIL FUEL STEAM GENERATING PLANTS OF MORE THAN 250 x 10^6 BTU/HOUR TOTAL HEAT INPUT

Compounds	Standard (Maximum Permitted Emissions)
Particulates	0.20lbs/10^6 BTU heat input(1) Number 1 Ringelmann or an opacity of 20% or greater except that a shade as dark. Number 2 Ringelmann or an opacity of 40% is permitted for not more than 2 minutes in any hour; excludes uncombined water.
SO_2	0.8lb/10^6 BTU heat input(1)(2) 1.2lb/10^6 BTU heat input(1)(3)
NOx	0.20lb/10^6 BTU heat input(1)(4) 0.30lb/10^6 BTU heat input(1)(2) 0.70lb/10^6 BTU heat input(1)(3)
Monitoring instruments required on stack:	1) smoke detector and recorder when liquid or solid fuel is used 2) continuous SO_2 monitor and recorder when liquid or solid fuel is used 3) continuous NOx monitor and recorder

Sulfur content of all solid and liquid fuels must be determined.

Notes:

1. Maximum 2 hour average
2. If liquid fuel is burned
3. If solid fuel is burned
4. If gaseous fuel is burned

TABLE 4.[12] EMISSION STANDARD FOR NEW AUTOMOBILES

Model Year	HC(1)	CO(2)	NOx(3)
	grams per mile under FTP(4)		
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

(1) Hydrocarbons

(2) Carbon monoxide

(3) NOx = total oxides of nitrogen

(4) Federal Test Procedure

TABLE 5.[13] EMISSION STANDARDS FOR HEAVY DUTY DIESEL ENGINES

Model Year	Smoke Opacity % Acceleration Mode	Lugging Mode
1971	40	20
1972	40	20
1973 (proposed)	20	15 50% peak power mode
1973 (proposed)	HC 3.0gm/BHP-hr (grams/Brake-Horsepower hour)	
1973 (proposed)	CO 7.5gm/BHP-hr	
1973 (proposed)	NOx 12.5gm/BHP-hr	

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 5 is a presentation of current and proposed emission standards for new heavy duty diesel engines tested under the Federal Test Procedure.

The auto and diesel standards are intended to control the maximum emission permitted by federal regulation. 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 6 is a summary of required or proposed California standards that must be fulfilled in addition to satisfying the Federal standards.

TABLE 6.[14] EMISSION STANDARDS REQUIRED BY CALIFORNIA IN ADDITION TO FEDERAL STANDARDS

Model Year (in which standard becomes effective)	Standard
1972 Auto or and	HC = 1.5gm/mile NOx = 3.0gm/mile (1) HC = 3.2gm/mile NOx = 3.2gm/mile (2) HC = 1.4gm/mile NOx = 3.2gm/mile CO = 19gm/mile (1) (3)
1973 Auto	Octane requirement not to exceed 91 RON, 100% end of line testing.
1973 Heavy Duty Diesel	HC + $NO_x \leq$ 16gm/BHP-hr CO $\leq$ 40gm/BHP-hr
1974 Auto	NOx = 1.3gm/mile (2)
1975 Heavy Duty Diesel	HC + NOx $\leq$ 5gm/BHP-hr CO $\leq$ 25gm/BHP-hr

Notes:

(1) Tested by 1970 Federal Test Procedures (FTP)

(2) Tested by 1972 FTP

(3) Required end of line testing of 25% of autos in one hot cycle.

2.4.4 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 judgment, 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 late 1971 or early 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.

2.4.5 Proposed Regulation of Two-Stroke Cycle Outboard Engines

Senator Gaylord Nelson introduced Senate Bill 2096 on June 18, 1971 (See Appendix A). This bill would require exhaust emission standards for all two-cycle outboard motors by June 30, 1972. Senator Nelson's major concern is the amount of raw fuel and partially oxidized hydrocarbons that is vented from the crankcase of the motor into the water. The bill is proposed to be amended to the Federal Water Pollution Control Act. The Secretary of the department in which the Coast Guard is operating will be responsible for enforcement of the emission regulations.

The significance of this bill lies in fact that it would constitute the first regulation of exhaust emissions from small water craft. If enacted, emission standards will be proposed or in existence for automobiles, trucks, aircraft, and small vessels on a national scale and diesel-electric locomotives on a regional level. Exhaust emission standards would then be in effect for all mechanical means of transportation.

2.4.6 Federal Facilities

The desire to make all federal facilities and activities model pollution control and abatement installations has been indicated in several Executive Order 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 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 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 upon a new Presidential determination of need.

TABLE 7.[15] EMISSION STANDARDS FOR FEDERAL FACILITIES

Pollutant	Regulation
Smoke & 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 distillate of organic liquids having a vapor pressure of 1.5 psi or more will be stored in pressure tanks or in containers equipped with a floating roof or vapor recovery system.

2.5 VESSEL EXHAUST EMISSIONS

The impact of vessel exhaust emissions in a metropolitan harbor area such as Boston or New York has been difficult to ascertain. Most metropolitan air pollution emission inventories neglect vessel emissions, possibly due to the lack of reliable information on emission rates. It is generally assumed that the pollutant load from vessels on a metropolitan area air shed is substantially lower than that of the air pollution emitted from other sources such as stationary power generators, automobiles, or industries. The contribution of vessel exhaust emissions to air pollution is about the same order of magnitude as aircraft or railroad emissions.

Annual averages of suspended particulate matter in major United States cities are readily available, whereas average concentrations of gaseous pollutants are not. When comparing earlier data on suspended particulate matter levels with the current primary ambient air quality standard of 75 $\mu gm/m^3$, it may be seen that 57 major cities exceeded the standard for the years 1961-1965.[16] There were nine cities with annual averages in excess of 150 $\mu gm/m^3$ and 28 cities with averages in excess of 125 μ gm/m^3. A listing of major U.S. ports and their respective suspended particulate levels (in the first columns of Table 8) reveals that only one city, Miami, met the current standard. Only five cities out of the twenty-one had levels below 100 μ gm/m^3. Hopefully with the implementation of new control measures, the suspended particulate levels in these cities will decrease. At the present time, it is not known if the specific control of vessel exhaust emissions will be required in any regional air pollution control implementation plans.

There should exist a relationship between the annual tonnage handled by a port and the number and/or size of vessels visiting the port. Hence, one would expect to find a definable correlation between the tonnage handled and the air pollution caused by the vessels. To ascertain this correlation, the type and number of ships visiting the port, the period of the visit, and the emission rates must be known. The tonnage of cargo handled by the respective ports in 1968 is shown in Table 8. Undoubtedly, some portion of the suspended particulate matter and other pollutants in the air shed of the harbor can be attributed to the vessels in the area, but this quantity has not been determined.

The contribution to air pollution by Coast Guard vessels in any air shed is a function of the number and type of vessels, their operating duty cycle, and the type of fuel used in relation to other sources in the area. At this writing, it is difficult to quantitatively assess the impact of Coast Guard or other vessels exhaust emissions on air quality, since the appropriate emission measurements have not been made.

Total pollution arising from vessels could affect the environment on either a local (micro scale) or global (macro-scale) basis. Most vessel pollution problems are not considered to be

TABLE 8. PARTICULATE LEVELS AND SHIPMENTS FROM MAJOR UNITED STATES PORTS

PORT	SUSPENDED PARTICULATE LEVEL (μ gm/m^3 (15) GEOMETRIC MEAN 1961-65	IN THOUSANDS OF SHORT TONS OF SHIPMENTS IN 1968 [17]			
		IMPORT	EXPORT	RECEIPTS	SHIPMENTS
GREAT LAKES PORTS					
1. Buffalo	126			14,008	629
2. Chicago	177			13,974	9,552
3. Cleveland	134			22,515	557
4. Detroit	143			31,162	1,182
5. Duluth-Superior	(1)			3,590	34,132
6. Milwaukee	133			4,470	1,822
7. Toledo	105			6,871	27,464
ATLANTIC PORTS				COASTWISE	
8. Portland, ME	(1)	22,669	1	3,766	568
9. Boston	134	8,495	735	11,124	1,248
10. New Haven	97	2,796	207	6,354	1,630
11. New York City	135	53,589	6,767	28,316	21,076
12. Albany	91.5	784	266	2,126	24
13. Baltimore	141	19,069	5,290	3,645	1,403
14. Miami	58	1,298	302	315	183
15. Delaware (Wilmington)	(154)	50,405	3,084	28,912	8,017
GULF COAST PORTS					
16. Houston	101	5,085	11,508	2,634	15,554
17. New Orleans	93	6,711	21,057	1,798	26,266
PACIFIC PORTS					
18. Long Beach }	145.5	3,745	4,966	3,133	2,380
19. Los Angeles }		5,230	4,746	6,635	5,840
20. San Francisco	80	6,117	5,898	15,340	8,317
21. Seattle	77	2,419	1,354	2,921	999

NOTE:
(1) Data not available

of the order of magnitude necessary to produce noticeable global pollution, except for major oil discharges. Oil discharges are presently controlled by international treaty and federal regulation.[18] Sewage discharge regulations have been proposed at the federal level with enforcement responsibilities delegated to the Coast Guard. The probability of vessel exhaust emissions being regulated by international treaty are remote at this time, but the possibility of federal regulation is not. The original Senate draft of the Clean Air Act of 1970 provided for emission standards for all vessels. That provision was modified to cover only commercial vessels, and subsequently in conference the entire provision for vessel emission standard was deleted.[18]

A major factor affecting the selection of vessel emission standards must be the cost-effectiveness of the control necessary to achieve the standard. Meaningful quantitative relationships between control cost and pollution reduction are absolutely necessary in order to assess the full impact of emission standards. Of primary importance in achieving this goal is the measurement of actual emission rates. With known emission rates, it is possible to calculate the environmental impact of one or several vessels. From this calculation the cost-effectiveness of various control methods and overall fleet emission levels can be determined. This information is pertinent to the establishment of any vessel emission standard.

SECTION 3. CLASSIFICATION AND FUEL USAGE OF VESSELS AND BOATS

3.1 GENERAL

Having established a framework of legislation regarding air pollution, and in preparation for considering an emissions inventory of the Coast Guard fleet, it is necessary to develop a system of classifying vessels and boats. This section presents the vessel classification system and discusses fuel usage data obtained from historical records. When a type of vessel is discussed, this terminology refers to a group of vessels of somewhat similar design, all with the same general mission; a class refers to a group of vessels of generally identical design. Thus the High Endurance Cutter is a type, abbreviated WHEC, composed of four classes: 378, 327, 311, and 255.

A comprehensive review of the nature of the operational missions of each type of vessel has been completed, and an inventory of engines and other power sources on each vessel has been compiled. The nature of a specific operational mission is important, since this in large part determines the geographic location of any emissions which could lead to air pollution. Thus, although icebreakers (WAGB) and high endurance cutters (WHEC) consume the highest amounts of fuel (and thus emit the largest amount of pollutants), their impact on the environment is minimized because the vast majority of these emissions take place on the high seas, where dispersion is rapid and effective. Smaller vessels and boats, which operate consistently near the shores, can be in the opposite situation.

In reviewing the data on cutter and boat engine use, we sought to provide for maximum correlation within the Coast Guard fleet itself, and with merchant marine and pleasure craft fleets. It is also intended that the results of this project as a whole provide useful information for these vessels, and any similarities should be acknowledged at the beginning of the effort. Therefore, categorization of vessels and boats is accomplished by class or design type, with engine horsepower used as a sub-category especially pertinent to cross-referencing data for the purposes of extrapolating emission levels.

In preparing the classification and fuel usage data, the following documents proved especially useful:

- <u>Quarterly Operations Reports</u> submitted by each Coast Guard Cutter,
- <u>The Machinery Index</u>, detailing equipment installed on each vessel,

- The Register of Cutters of the USCG, publication #CG 197,

- Operating Facilities of the USCG, publication #CG 244,

- Coast Guard Boats, publication #CG 375,

- Merchant Vessels of the United States, publication #CG 408,

- Merchant Ship Register of the U.S. Navy, publication #MSLP504,

- Vessel Inventory Report, U.S. Flag Dry Cargo and Tanker Fleets, 1000 Gross Tons and Over, U.S. Department of Commerce Maritime Administration,

- Boating Statistics, publication #CG 357,

- Various publicity and information sheets available from the Boating Industries Association.

3.2 CLASSIFICATION

After review of the above information, it was seen that the existing USCG classification of vessels by class and boats by type is also best suited to the purposes of this program. This choice was dictated by consideration of the following:

1. Each class of vessel (or type of boat) in the Coast Guard fleet consists of a group similar in design, engine, mission, etc.

2. Such a categorization is compatible with the existing Coast Guard documentation system.

3. Analysis of fuel use data, etc. by class yields statistically meaningful data and provides a good basis for planning a measurements program.

3.2.1 Coast Guard Cutters

Table 9 presents a breakdown of cutter class by main engines, including the manufacturer, model number, number of engines per vessel and rated horsepower of each engine. Differences within a class are noted in the last column. Table 10 contains similar information for boilers and auxiliary engines. Table 11 is a compilation of all main and auxiliary diesel engines, main engine steam boilers and gas turbines in the Coast Guard fleet (including boats) arranged by engine

TABLE 9. COAST GUARD CLASSIFICATION DATA FOR MAIN PROPULSION ENGINES

Class	Mfg.	Mod. No.	No.	Type	HP/Eng.	Applicable Vessel
WHEC 378	FM	38TD8 1/8	2	D	3600	
	P&W	FT4A-6	2	GT	18000	
327	BW		4	B		
	W		2	ST	1550	
311	FM	38D8 1/8	4	D	1600	
255	FW	D	2	B		
	W	65MW6	2	ST	~2200	
WAGW 311	FM	38D8 1/8	4	D	1600	
WAGB 310	FM	38D8 1/8	10	D	2000	
290	FM	38D8 1/8	6	D	2000	
269	FM	38D8 1/8	6	D	2000	
230	CB	GN	3	D	1700	
WMEC 210A	CB	FVBM-12-T	2	D	1580	
	Solar	T-1000S19A	2	GT	1000	
210B	Alco	16-251-B	2	D	2550	
205	GM	12-567	4	D	950	165
	GM	12-278	4	D	900	153, 166
143	GM	12-278A	2	D	900	
WPB 95A	Cummins	VT12M	4	D	600	
95B	Cummins	VT12M	4	D	600	
95C	Cummins	VT12M	4	D	600	
82A	Cummins	VT12-900M	2	D	900	
82C	Cummins	VT12-900M	2	D	900	
82D	Cummins	VT12-900M	2	D	900	
WYTM 110A	In. Rd.	S	2	D	600	
110B	GM	8-567	2	D	640	
WYTL 65A	Cat.	D-375-D	1	D	400	
65B	Wauk	6LRDCSM	1	D	400	
65C	Cat.	379-A	1	D	400	
65D	Cat.	379-A	1	D	400	
WAGO 311	FM	38D8 1/8	4	D	1600	
213	CB	GSB8ST8	4	D	950	
180	CB	GN-8	2	D	600	
WAK 339	Nord.	321T2	1	D	1700	
WLB 180A	CB	GN-8	2	D	600	
180B	CB	GN-8	2	D	700	
180C	CB	GN-8	2	D	700	
WLM 177	CB	GN-6	2	D	550	
175	FM	38D8 1/8	2	D	675	
173	Sullivan	-	2	SR	500	
	BW	1438	2	B	-	
157	Cat.	D398A	2	D	~1000	
133	Union	06	2	D	300	
WLI 122	GM	6-71	4	D	210	234
122	GM	3-71-RC	2	D	520	255
100A	Cat.	D353D	2	D	310	

TABLE 9. COAST GUARD CLASSIFICATION DATA
FOR MAIN PROPULSION ENGINES (CONT.)

Class	Mfg.	Mod. No.	No.	Type	HP/Eng.	Applicable Vessel
WLI 100B	GM	62206	2	D	520	
100C	Cat.	D353D	2	D	310	
74	GM	6-71	2	D	180	
65400	GM	62200	2	D	210	
65303	GM	62206	1	D	240	
65302	GM	6-71	2	D	180	
WLIC 75A	Cat.	D353C	2	D	310	
75B	Wauk	NKDBSM	2	D	310	
75D	Wauk	F-1905-01SM	2	D	310	
WLR 115	FM	35F10M	3	D	180	
114	GM	8-268A	2	D	420	
104	GM	8-268A	2	D	420	
80	Murphy	ME-650	2	D	240	
75	Cat.	D353D	2	D	310	
73	Gray	6-71	2	D	160	
65	Cat.	D353D	2	D	310	
65	Wauk	6NKDBSM	1	D	-	
WLV 149	CB	GSB8	1	D	920	
133	GM	6-71	4	D	110	
128	GM	2400-B	1	D	660	
115	CB	EN-8	1	D	300	
WIX 295	Nurnburg	W8V30/38	1	D	750	
125	GM	8-268A	2	D	420	
WTR 311	FM	3808 1/8	4	D	1600	

D - Diesel
GT - Gas Turbine
ST - Steam Turbine
SR - Steam Recip.
BW - Babcock & Wilcox
Cat - Caterpillar
CB - Cooper Bessemer

FM - Fairbanks-Morse
FW - Foster Wheeler
In. Rd. - Ingersoll-Rand
P&W - Pratt & Whitney
Wauk - Waukesha
W - Westinghouse

TABLE 10. COAST GUARD CUTTER BOILERS AND AUXILIARY ENGINES

Class	Mfg.	Mod. No.	No.	HP/Eng.	Boiler	Applicable Vessel
WHEC 378	GM	LL-8-567CR	2	300	Vapor Corp. RO-110-CG	
	FM	38F5 1/4	2		Vapor Corp. RO-110-CG	715
327	GM	8-268A	2	300	B&W	
	Buda	6-DTG-317	1			31
	GM	4-71-RC	1	120		35
311	GM	3-268A	2	80	B&W	
	GM	8-268A	2	300		
255	GM	3-268A	1	80		
	GM	3-268A	2			41,67,39,70,44,46,40
	Gray	4D157	1			66
	Osco-Her	298DH	1			66
	GM	3-268A	1	80		66
	Lathrop	D-60-VCG	1			69
WAGW 311	GM	3-268A	2	80		
	GM	8-268A	2			
WAGB 310	FM	38D5 1/4	4			
290	FM	38E5 1/4	4		Vapor MF5802	All
269	FM	38E5 1/4	4		Vapor MF5802	283,284,280,278
	GM	3-7 1/2	1	80		282,281
	Cat.	D-3400	1			
230	Buda	G-DTG-468	1		Vapor EV4611	
	GM	3-268A	2	80		
	Gray	64-HN-9	1			
WMFC 210A	Cat.	D343TA	2	550	Vapor R01650-S	
	Cat.	D333TA	1	300		
WMEC 210B	Cat.	D343TA	2	550	Vapor R01650-S	
	Cat.	D343TA	1	300		
205	GM	6-268A	2	200	Titusville Iron Works	165
	GM	6-71	1	200		165,166
	GM	3-268A	2	80	Aqua Chem. OB6M	153,166
	GM	8-268A	1	300		153
143	GM	6-71A	2	200	Aldrich 624-S	202
	GM	6-71A	2		Way Wol.	194
WPB 95A	GM	2061A	2	34	Way Wol. 3630-10E	
95B	GM	2712A	2	34	Way Wol. 3630-10E	
95C	GM	2061A	2	34	Way Wol. 3630-100E	
82A	GM	2064B	2	31	Repco V80	
82C	GM	2-71	2	34	Way Wol. 2128-8C	
		2151	2	34	Mocine	
82D	GM	2-71	2	34	Repco M-120	

TABLE 10. COAST GUARD CUTTER BOILERS AND AUXILIARY ENGINES (CONT.)

Class	Mfg.	Mod. No.	No.	HP/Eng.	Boiler	Applicable Vessel
WYTM 110A	GM	6912	2	200		71
	GM	6911	1	200		96
	GM	6912	1	200		96
	GM	6061A	2	200	York Shipley M-1200	61,60
	GM	6-71	2	200	Way Wol. 79230	73,97,99,98,72
110B	GM	6-71	1	200	Way Wol. 79230	90,91,92,93
	Buda	6-DTG-468	1			90
	Herc	DWXZ	1			92
	GM	2-71	1	34		93
WYTM 85						
WYTL 65A	GM	2-71	2	34		
65B	GM	2-71		34		
65C	GM	2-71		34		
65D	GM	2-71		34		
WAGO 311	GM	8-268A	2	300	B&W	
	GM	3-268A	2	142		
213	CB	FS6	2	300	Vapor AN22034	
	GM	6-71	1	90		
180	GM	6-71	2		Vapor	
	Buda	6-DTG-468	1			
WAK 339	Baldwin	D	2	450	Ames Iron Works MC90	
	Hill	4R	1	260		
WLB 189	Herc	DOOC	1			
	Herc	PHXC	1			
180A	GM	6-71	4		Vapor FBM 6053	62,300,301,291
	GM	6-71	2			270,292,277,290,302,296,303,289
	Buda	6-DTG-468	1			270,300,292,277,289,303,301,290,302,296
	Buda	6-DTG-468	2			291
180B	GM	6-71	2		Vapor V6S-20835	
	Buda	6-DTG-468	1			
180C	Buda	6-DTG-844	2		Vapor FBM 4605B	
		6-DTG-468	1			
	Buda	6-DTG-468	1			
	GM	3-268A	2			
WLM 177	Buda	6-DTG-468	2		Aldrich 642S	
175	Cat.	D-318	2		York Shipley PASTD	
	GM	6061A	2		York Shipley M1200	
173	Herc	DOOC	1		Babcock & Wilcox 1438	
	?	?	2			
157	GM	6061A	2			

TABLE 10. COAST GUARD CUTTER BOILERS AND AUXILIARY ENGINES (CONT.)

Class	Mfg.	Mod. No.	No.	HP/Eng.	Boiler	Applicable Vessel
WLM 133	Cummins	HGD	1		Aldrich DX-B-80	542,543,546,540
	Cummins	HI-600	1			542,543,546,540
	Buda	6-DTG-317	1		Buckley & Scott BS-b	545
	Cummins	H-10078	1			545
	Buda	6-DTG-468	2			547
	Cummins	HGD	1			544
	GM	3-71-RC	1			544
WLI 122	GM	2-71-G2	2			
100A	GM	6-71	2			313
	GM	2-71	1			313
	GM	2-71	3			293,316,317
	GM	2-71	2			298,315
	GM	2061A	1			298,315
100B	GM	3061A	1			
	GM	3-71	2			
100C	GM	3051	2			
80			-			
74	GM	2061(2-71)	2			
65						
WLIC 75A	Cat.	D330A	2	115		
75B	GM	3151	2			
75D	GM	3151	2			
	GM	2-71	2			310,309
WLR 115	Buda	4DTG226	1			
	GM	4045C	2			
114	GM	2-71	1		Aldrich WHO 13G	
	GM	2006	1			
	GM	3083	2			285
	Herc	DRXC	1			285
	GM	3-71	2			268
104	GM	3-71	2			213,241
	Buda	6BD273	1			241
80	GM	4-71	2			
75	GM	3-71	2			
73	Herc	DOOC	2			
65	Wauk	197DLCM	1			502
	Cat.	D330A	2	115		503,506,504
	Wauk	197DLCM	2			501

TABLE 10. COAST GUARD CUTTER BOILERS AND AUXILIARY ENGINES (CONT.)

Class	Mfg.	Mod. No.	No.	HP/Eng.	Boiler	Applicable Vessel
WLV 149	GM	3-71	2		York Shipley N-193	
	GM	2-71	3			
133	GM	2-71	6		York Shipley N-1935	532
	Herc	DOOB	2			500
	Herc	DWXD	2			500
	GM	2-71	2			523
	GM	6-71	2			523
128	GM	4-71	3			612
	GM	24001	4			612
	Cummins	HSGA	3			604,605
	GM	6-71	2			189,196
	GM	4064	3			613
	GM	24001	1			613
115	GM	2-71	3			
	I.H.	UDF	2			
WIX 295	GM	2-71	1			
	GM	2061	1			
	GM	6-71	3			
	Nordberg	4FS2CF	1			
125	GM	3-71	2			
WTR 339	Hill	4R	1			
	Nordberg	-	1			
311	GM	3-268A	2			
	GM	8-268A	2			
221	GM	3-268A	3			

TABLE 11. LIST OF DIESEL ENGINES IN CG CUTTERS & BOATS BY MANUFACTURER

Mfg.	Type	No.	Total Mfg.	% of Total
Alco	251-B	20	20	-
Atlas	8-KMT-668-OR	3	3	-
Baldwin	VO	3	3	-
Buda	4BDMR153	83		
	4DTG226	2		
	4DTMR	1		
	6-DCG-468	2		
	6-DCG-844	32		
	6-DTG-317	3		
	6-DTG-468	41		
	6-BD-273	3		
	6-DTMR-468	5		
	6-DTMR-HR6	1	174	8.9%
Caterpillar	D-318	2		
	D-13000	1		
	D-320A	3		
	D-330A	9		
	D-333TA	14		
	D-3400	1		
	D-343TA	26		
	D-353C	12		
	D-353D	20		
	D-398	2		
	D-398A	4		
	D-4300	1	95	4.9%
Cerlist	3M	17	17	-
Cooper Bessemer	FS6	4		
	FVBM12-T	10		
	GN6	2		
	GN8	68		
	GND8	10		
	GSB	2		
	GSB8	9	105	5.4%
Cummins	H-10078-C111	1		
	HGD	8		
	HI500	2		
	HRS-6-M	18		
	HSGA	6		
	HNS-6-M	3		

TABLE 11. LIST OF DIESEL ENGINES IN
CG CUTTERS & BOATS BY MANUFACTURER (CONT.)

Mfg.	Type	No.	Total Mfg.	% of Total
Cummins	JNS-6-N	9		
	V6-220M	11		
	V6-220MTW	23		
	V8-300	7		
	VT12-600M	52		
	VT12-900M	53		
	VT6-280M	17		
	VT6-350MTW	12		
	VT8-370	3		
	VT8-370M	44	284	13%
Dana Star	4CL8-3.00-6	1	1	-
Fairbanks-Morse	35F10M	6		
	38D5 1/4	4		
	38D8 1/8	98		
	38E5 1/4	2		
	38TD8 1/8	12	150	7.7%
GM	12-278	16		
	12-567	4		
	12V71TW	1		
	2-71	56		
	2002	3		
	2006	5		
	2030	1		
	2061A	11		
	2205H6	1		
	24001B	9		
	3-268A	53		
	3-53	23		
	3-71	36		
	3061A	2		
	3083	2		
	3151	10		
	4-71	46		
	4045C	4		
	4061A	4		
	4064B	3		
	5062	7		
	6-110	4		
	6-268A	2		
	6-278A	2		
	6-71	352		
	6-DTG-468	2		
	6061A	13		

TABLE 11. LIST OF DIESEL ENGINES IN CG CUTTERS & BOATS BY MANUFACTURER (CONT.)

Mfg.	Type	No.	Total Mfg.	% of Total
GM	6061N	5		
	6071ATW	1		
	6071E	1		
	6072	1		
	6120T	26		
	6121TS	8		
	62200	2		
	62206	4		
	64-HN-9	2		
	6911	1		
	6912	3		
	6V53	58		
	71-64HN9	4		
	7122	1		
	8-268A	55		
	8-567	8		
	LL-8-567CR	10	862	44%
Gray	64-HN-9	21		
	4D129	38		
	4D157	8		
	6VYTL	1	68	3.5%
Hercules	DJXC	1		
	DOO8	2		
	DOOC	8		
	DRXC	1		
	DWXD	5		
	PHXC	1	18	-
Hill	4R	2	2	-
Ingersoll-Rand	S	18		
	UD14	2		
	UDF	2	22	1.1%
Kermuth	4-226	2	2	-
Kohler	5-DM-61-1	1	1	-
Lathrop	D-60-VCG	88		
	D110V	1	89	4.6%
Murphy	M-11	1		
	ME-165	2		
	ME-650	4	7	-

TABLE 11. LIST OF DIESEL ENGINES IN
CG CUTTERS & BOATS BY MANUFACTURER (CONT.)

Mfg.	Type	No.	Total Mfg.	% of Total
Nordburg	? 32112 4FS2-CE	1 1 1	3	-
Osco Hercules	218DH	12	12	-
Perkins	MDH107M	1	1	-
Scripps	4-166	6	6	-
Union	06	14	14	-
Waukesha	197DLCM 195DLCM 6NKOBSM F-1905-DS1M NKDBSM	4 2 6 10 6	28	1.4%
		Total	1947	

TABLE 11. LIST OF DIESEL ENGINES IN CG CUTTERS & BOATS BY MANUFACTURER (CONT.)

Alco Ind. Inc.
Loco. & Eng. Prod. Div.
3 Nott St.
Schenectady, N.Y. 12305

Buda
Allis Chalmers Div. EE
Eng. Div.
Box 563
Havey, Ill. 60426

Cooper Bessemer
Box 751
Mt. Vernon, Ohio 43050

Fairbanks-Morse
Colt Industries
Power Systems Div.
Beloit, Wis. 53511

Detroit Diesel Eng. Div.
GM Corp.
13400 West Outer Dr.
Detroit, Mich. 48228

Ingersoll Rand Co.
11 Broadway
New York, N.Y. 10004

Murphy Diesel Co.
5317 W. Burnham St.
Milwaukee, Wis. 53219

Nordberg Mfg. Co.
Dept. TR
P.O. Box 383
Milwaukee, Wis. 53201

Scripps Marine Eng. Co.
203 McMillen Rd.
Grosse Point, Mich. 48236

Waukesha Motor Co.
St. Paul Ave.
Waukesha, Wis. 53186

Atlas Engine Works Inc.
Gibsonburg, Ohio

Caterpiller Tractor Co.
100 N.E. Adams
Peoria, Ill. 61602

Dana
P.O. Box 1209
Ft. Wayne, Ind. 46801

Gray Marine Eng. Div.
Continental Motors
12700 Kercheval Ave.
Detroit, Mich. 48215

Hercules Eng. Inc.
Market & 11th S.E.
Canton, Ohio 44702

Kermuth Eng. Works
12820 Simms Ave.
Hawthorne, Calif. 90250

Perkins Eng. Inc.
Wixom, Mich. 48096

Osco Motors Corp.
Souderton, Pa. 18964

Union Diesel Eng. Co.
2121 Diesel St.
Oakland 6, Calif. 94606

type and manufacturer. The address of the manufacturer as well as the relative fraction of engines of that manufacture in the fleet are given.

As will be noted from examination of Tables 9 and 10, there exist some differences within a given class, especially among auxiliary engines and boilers. Recognition and evaluation of the significance of these differences are important to the establishment of a statistically meaningful field measurements program. In this regard, attempts were made to contact all manufacturers of engines in the Coast Guard fleet in order to supplement existing data. These initial attempts frequently evoked negative replies, especially in regard to obsolete engines. Major manufacturers such as Caterpillar, Cummins and General Motors are able to supply the needed data and, in some cases, can supply emissions data. In such cases it will be possible to limit the extent of measurements to a verification of this data and application of the data to a typical engine operating cycle.

Early in the project it was recognized that visits to representative vessels of each type were desirable. Information was sought to verify previously/acquired data, and with regard to specific questions of engine usage, mission profile, layout of engine rooms, engine maintenance procedures and the detailed problems which might be involved in carrying out a measurements program on each vessel. Some of the more pertinent facts established in this manner include:

1. Major engine overhauls in the Coast Guard fleet are now carried out on the basis of the results of a spectroscopic analysis of engine oil, which indicates the amount of metal wear achieved in the engine.

2. Engines are generally operated at idle power as little as possible in order to avoid carbon buildup and, in some cases, oil buildup in the exhaust manifold with a subsequent fire hazard.

3. All engine maintenance is performed by the crews (except in the case of the new gas turbines).

4. No assessment of exhaust smoke is made except as an indicator of engine performance.

5. Boiler tubes require blowing every twelve hours, in and out of port.

To date, at least one cutter of each type based in the First Coast Guard District has been visited and the engineering officer interviewed. As the program progresses, the data contained in Tables 9 and 10 will be continually updated to reflect additions and/or changes for individual cutters.

3.2.2 Coast Guard Boats

Table 12 presents data on engines installed in Coast Guard boats, by type, in a manner similar to that given previously for cutters (Tables 9 and 10). Table 13 lists, by district, the number of each boat type in the fleet. Though included for completeness in Table 13, outboard motors are considered separately in Section 3.2.4 of this report. The majority of the engines in the boat fleet are diesel, with a few four-stroke cycle gasoline engines used in the 17' MLB (lifeboat) class.

It should be noted that many of these marine diesel engines are actually truck engines which have been specially adapted for marine use; some emission data is, therefore, available from the manufacturers. This is especially true of the General Motors Model 6-71 engine,[19] widely used in the boat fleet. Considerable data is also available, on the emissions of conventional four-stroke cycle gasoline engines.[16, 21, 22, 23] It is, therefore, anticipated that boats with conventional inboard engines will not require as extensive field measurements program as initially concieved. Discussions with boat crews brought out the following noteworthy points:

1. Engines are maintained by the crew, which is qualified to operate several different boats.

2. Engine running time can vary greatly from district to district and season to season, primarily due to the wide fluctuation in demand for search and rescue work (SAR).

3. A few boats have uniquely defined missions, such as bouy tending and laying cable, and have quite predictable engine usage.

4. The majority of the boats employ water cooled engines and exhaust systems which discharge an exhaust gas/cooling water mixture at the waterline. This presents a sampling problem in any measurement program.

5. Boats tend to be operated more frequently at idle power (due to the SAR), resulting in carbon buildup within the engine and relatively frequent demand for maintenance.

TABLE 12. COAST GUARD CLASSIFICATION DATA FOR BOATS

Type	MFG.	Mod No	No	Type	HP/eng
52'MLB	GM	6-71	2	D	170
44'MLB	Cummins	V6-200	2	D	170
	GM	6V53	2	D	186
36'MLB	GM	4-71A	1	D	100
	Buda	6DTG-468	1	D	75
	Buda	6DTMR468	1	D	100
	Cummins	VNS-6-N	1	D	90
40'UTB	GM	6-71	2	D	200
	GM	6121T	1	D	240
	Cummins	VT-6-350M	2	D	280
30'UTB	GM	6-71A	1	D	223
	GM	6021T	1	D	240
	Cummins	VT8-370M	1	D	270
	Cummins	VT6-350M	1	D	280
52'BU	GM	6-71	1	D	200
46'BU	GM	6-61N	1	D	180
	GM	6-71	1	D	200
45'BU	Cummins	HRS6-M	1	D	180
	GM	6-71	1	D	200
43'BU	GM	6-61N	1	D	180
40'BU	Gray	65HN9	1	D	225
	GM	6-71	1	D	200
	GM	6-71A	1	D	150
	Cummins	HRMS-600	1	D	225
56'Cable BT.	GM	6-71	2	D	180
39'Artic Surv	GM	5-62	1	D	-
35'LCVP	Gray	64HN9	1	D	220
35'LARC	Cummins	V8-300	1	D	300
25'MSB	GM	5032	1	D	30
	Buda	HBDMR-153	1	D	30
	Gray	4D-129	1	D	30
	Cerlist	3M	1	D	60
	Luthrop	D-60-VCE	1	D	60
24'MLB	Buda	4BDMR-153	1	D	30
	Gray	4D-129	1	D	30
	Cerlist	3M	1	D	60
	Burmeister	D-80-VCG	1	D	80
20'MLB	Gray	4D-129	1	D	30
19'TICWAN	Merc	120	1	IOG	120
M	Merc	150	1	IOG	150
18'MLB	Univ.	HF-VD	1	G	70
17'UTL	Merc	150	1	IOG	150
16'OMB	Various	Various	1	OG	35
14'UT	" "	"	1	OG	20

52-

D-Diesel
G-Gasoline
Ob-Outboard Gasoline
IOG-Inboard/Outboard Gas.

TABLE 13. BOAT INVENTORY AS OF 30 SEPT 1970 BY DISTRICT

BOAT TYPE	HQ UNITS	1	2	3	5	7	8	9	11	12	13	14	17	TOTALS
52 Ft. Motor Lifeboat											4			4
44 Ft. Motor Lifeboat		17		15	8	2	3	22		5	19		1	92
38'/40' Motor Lifeboat		3		2				9		2	11			27
40 Ft. Utility Boats (UTB)	1	24		36	11	26	20	29	9	10	18	2	2	188
30 Ft. Utility Boats (UTM)	15	14	5	32	28	18	21	38	2	6	4			183
17 Ft. Utility Motor Launch (BOSDET)	4	18	17	24	16	25	6	17	10	11	7	6		161
19 Ft. Tiewans	2	3	11		14	17	12	4	1	2	5		1	72
Buoy Boats		9		16	6	1	8	4	2		2			48
Shipboard Power Boats	6	53		38	33	24	20	15	14	16	26	23	22	290
Misc. Power Boats (36' and over)	7	2		2	4		1	1	1		2	3		23
Misc. Power Boats (Under 36')	3	8		8	8	8		4	3	4	17	3	2	68
Outboard Skiffs and Small Nonpowered Boats	22	110	141	91	60	54	55	134	22	33	88	30	56	896
Houseboats			1		1	3	1	3						9
Barges	4	1	34	2	7	6	8	6			1	4	1	74
Sailboats (Includes Aux. Powered) (ACAD)	69													69
Dingies, Tendors, etc. CG ACAD	13													13
Total	146	262	209	266	196	184	155	286	64	89	204	71	85	2217

TABLE 14. CHARACTERISTICS OF MERCHANT MARINE VESSELS

C_1 & C_2 & Misc.				Cargo C_3			
Design	Dwt[1]	H.P.	Speed[2]	Design	Dwt[1]	H.P.	Speed[2]
C_2A	10775	6000	15.5	$C_3$33	12402	11000	18
C_2A_5	10497	6000	15.5	$C_3$37	11336	11000	18
C_2	10500	6000	15.5	$C_3$37	10948	9000	17.4
SC_2	10700	6000	15.5	$C_3$37	11367	10000	18
C_1A	7992	4100*	14	$C_3$38	10967	12500	18.5
C_1A	7931	4000	14	$C_3$43	13116	10500	18
C_1B	9331	4000	14	$C_3$46	12629	13700	18.5
V_2	10700	6000	15.5	$C_3$76	11150	11700	18.6
V_3	10700	8500	16.5	C_3	12343	8500	16.5
EC_2	10750	2500+	11.0	SC_3	9644	8000	16.5
C_1M	5995	1700*	10.5	$C_3$4	12005	8500	16.5
R_2A	6148	12000	18.5	$C_3$5	11766	8500	16.5
R_2B	6966	6000	15.5	C_3BH	12550	8500	16.7
C_2S_1	8595	7500*	16.5	C_3B_2	12031	8500	16.7
R_1D	5013	5500	16.0				
R_1	5226	1700*	10.5				
C_1M	4747	1700*	10.5				

Cargo C_4 & C_5				Comb. Pass. & Tankers			
Design	Dwt[1]	H.P.	Speed[2]	Design	Dwt[1]	H.P.	Speed[2]
$C_4$57	13535	19500	21	$C_4$49	9376	18000	20
$C_4$58	12728	16500	20	C_3P	9627	8500	16.5
$C_4$60	12763	17300	21	T_5	26575	18600	18
$C_4$64	13264	17000	21	T_3	16582	7000	15.5
$C_4$65	12699	14000	20	ST_2E	16350	9000°	16.0
$C_4$66	13808	14000	20	T_2E	16628	6000°	14.5
$C_4$41a	13494	17500	20	T_1	1450	800*	10.0
$C_4$41u	14349	19200	20	T_1B_2	3925	1400*	10.0
C_4A_4	14714	9000	17				
C_4	15371	9000	17				
C_5	24427	11800	16				

Notes:

*Indicates diesel power
+Indicates reciprocating steam
°Indicates turboelectric
All others oil-fired steam turbine
1. Dead weight tons
2. In knots

3.2.3 Merchant Fleet

Table 14 outlines the characteristics of large vessels (in excess of 1000 gross tons) in the U.S. Merchant Marine fleet. There are currently 636 vessels in the fleet of over 1000 gross tons. The number of vessels in each Maritime Commission design type is given in Table 15. Most ships are powered by steam turbine, and have no direct counterparts in the Coast Guard Fleet.

TABLE 15. NUMBERS OF ACTIVE VESSELS BY DESIGN TYPE IN MERCHANT MARINE FLEET OVER 1000 GROSS TONS

Design Type	no. Active
C_1 & C_2	120
C_3	91
C_4 & C_5	110
Comb	45
T_2	25
T_3	5
St	240

3.2.4 Outboard Engines

The Coast Guard has several hundred outboard motors in its fleet. Because of a lack of specific data on their emissions, this report goes into some detail in discussing the two-stroke cycle outboard motor, since it is felt that there is a need for better understanding their emission characteristics and potential environmental impact.

The estimated number of outboard motors in use in the United States in 1970 was 7,215,000; virtually all of these (reportedly 98 percent) were of two-cycle design. This number constitutes nearly 60 percent of the total of 12,249,400 new outboard motors reported to have been sold in the U.S. since 1919. Thus, it is apparent that the outboard motor has an extremely long useful life. If a study of outboard motor emissions is to be made, upon which one may base estimates of nationwide air pollution emanating from this source, it logically should evaluate the effect of motor age on relative pollutant emission. Then, the number of motors of each age class which are still in use must be determined or, at least, estimated. (For the present, age class is assumed to be model year, until and unless a more valid basis is determined.) In addition to motor age, the size (i.e., rated horsepower) of various age classes should be considered. It seems reasonable, as a first approximation subject to correction, to expect the total pollutant emission to vary in direct proportion to motor size. The design of an experimental program to measure outboard motor emissions should weight the selection of number, age and size of motors tested so as to be reasonably representative of the total motor population in use.

Available statistics on the total number of outboard motors in use for various years probably are reasonably reliable. Data on the number of new motors sold annually, and of distribution by size, ought to be even more dependable, especially in more recent years since the formation of the Boating Industry Association. Available data are summarized in Table 16. Unfortunately, no specific data were found on the total number of motors retired from use each year, or on the distribution of these by either age or size. Therefore, to guide the design of the proposed experimental program, it was necessary to develop some rational model for estimation of outboard motor longevity, which model would have to be reasonably consistent with the available data regarding motors sold and in use.

The first assumption, necessitated by lack of alternative data, was that outboard motor longevity is independent of model year (year of manufacture); that is, the percentage of motors manufactured in 1965 which were still in use in 1970 at an age of five years was the same as the percentage of 1960 motors still in use in 1965, etc. Thus, the motor use function is said to be "stationary" with respect to model year. This seems to be reasonable, since virtually all motors manufactured since World War II, and for some years prior thereto, were made of aluminum. Granted, there probably have been improvements made in piston rings, cylinder liners, and drive gears; but these items had been quite well developed by ca. 1940, and drastic increases in such component longevity does not appear likely. In any case, the unavailability of data precluded another choice.

Next, it was necessary to decide upon a reasonable shape for the longevity function. Longevity function is defined here as the percentage of motors of any given age still in use in the year in question, presently 1970. The simplest function to use is a straight-line decrease in number of motors surviving versus age. Hovever, this assumes that any motor which survives to a given year is just as likely to survive that year as any other motor still in use at the beginning of that year. In other words, a motor manufactured in 1958 with 1400 hours of accumulated operation in 1969 would be as likely to survive to 1970 as would a motor manufactured in 1967 with only 200 accumulated operating hours in 1969. (An outboard motor test engineer has said that the typical "full power life" of modern outboards is about 1500 hours; ring wear becomes significant after that time.) Clearly such an assumption is hard to accept. A more credible assumption is that the probability of failure

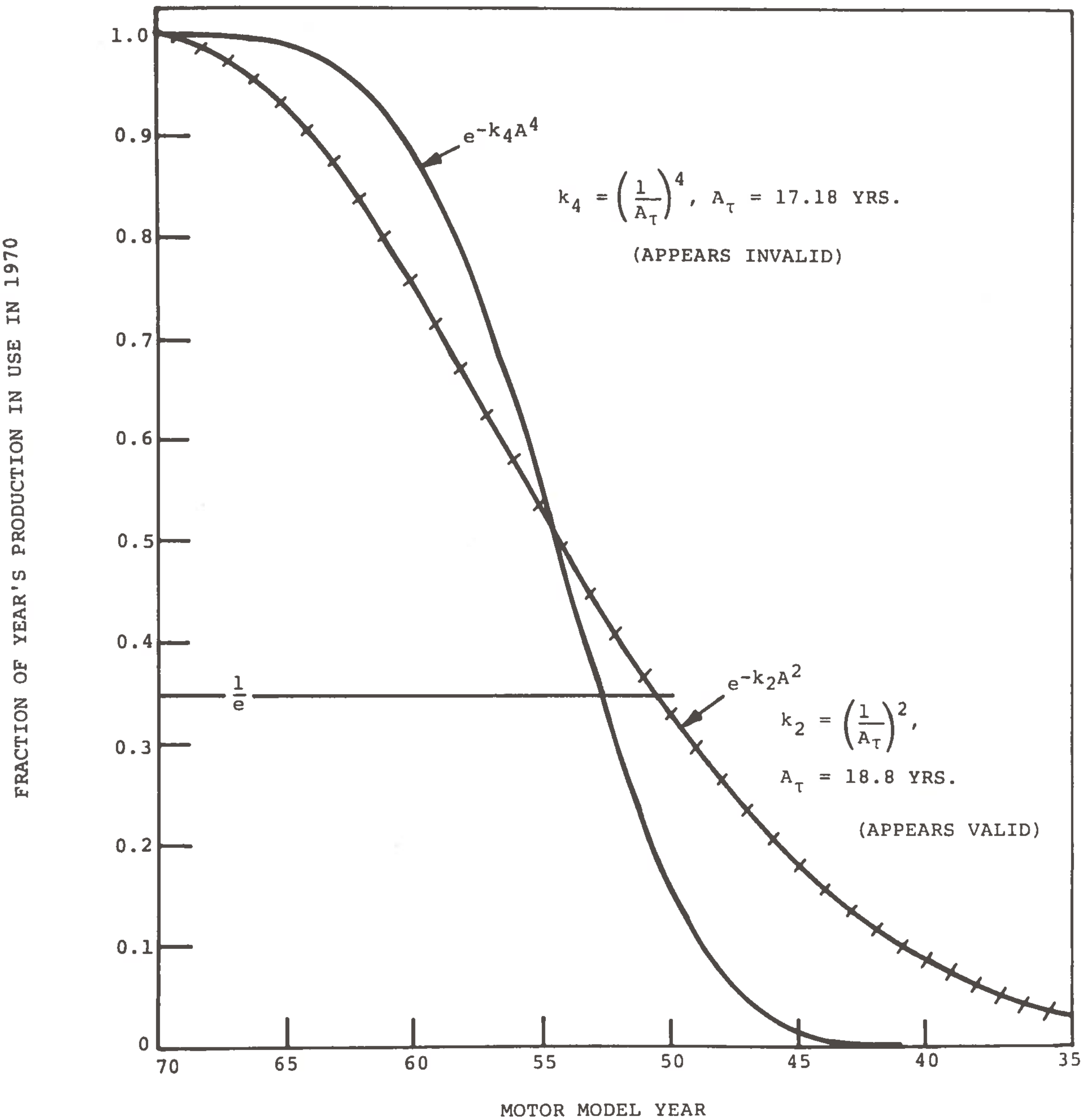
TABLE 16. SUMMARY OF AVAILABLE OUTBOARD MOTOR POPULATION STATISTICS(24,25)

YEAR	EST. NO. MOTORS SOLD (1000'S)	AVERAGE HORSEPOWER FOR YEAR	EST. NO. MOTORS IN USE (1000'S)
1970	430	31.0	7215
1969	510	33.1	7101
1968	500	31.5	6988
1967	444	30.1	6904
1966	440	29.9	6784
1965	393	28.2	6645
1964	390	30.3	6564
1963	362	30.5	6390
1962	360	30.3	6244
1961	343	29.9	6100
1960	468	27.4	5800
1959	540	23.7	5650
1958	504	20.7	5385
1957	550	16.3	5040
1956	642	14.2	4700
1955	515	12.9	4210
1954	479	10.3	3740
1953	463	9.0	3419
1952	337	8.4	3219
1951	284	8.9	3010
1950	367	6.9	2811
1949	329	6.4	2643
1948	499	(ASSUMED) 5.0	NOT AVAILABLE
1947	584	" "	"
1946	398	" "	"
1945-42	(WWII) 0	" "	"
1941-31	775	" "	"
1930-19	357.4	" "	"

will increase linearly with the age of the motor. This yields a longevity function of the form $F = e^{-kA^2}$, where F is the fraction of motors of age A years which are still in use in the year of interest; k is a constant which permits adjusting the function to fit the known data of annual production and annual total motor population. A curve of this shape, fitted to such motor data, is shown by the solid line in Figure 1. Intuitively, this curve seemed to indicate an excessive survival of very old motors. Arbitrarily then, the age dependence was raised from the second to the fourth power, which produced a longevity function of the form shown by the dashed curve in Figure 1. This function was deemed more reasonable, except that it indicated an uncomfortably small failure rate during the first few years of a motor's life.

There is no fundamental statistical premise upon which to base a selection of any of these, or of any other function, except how well they fit known facts. The last two functions were both adjusted to produce a 1970 motor population of very nearly 7,215,000. This was done by calculating F for each model year, based on age in 1970; then multiplying that F by the total number of motors sold in that model year, to obtain the number of motors of that model year assumed to be still in use in 1970, and then summing the motors in use from each model year to obtain the total estimated 1970 population. If the total differed substantially from the known 1970 figure, the k in the longevity function was adjusted accordingly and a new trial population calculated. But when both functions produced the correct total; what criterion should be used to decide which, if either, validly described outboard motor longevity?

This question was answered by using both functions to estimate the motor population in 1965, and subsequently in 1960, by operating in the same manner on motor production dating backward from those years. The results of this trial are shown in Table 17. It is clear that the $(age)^4$ relationship gives a very poor estimate of population for earlier periods. However, the $(age)^2$ function gives a good fit for 1965, and a somewhat less satisfactory fit for 1960. Considering the probable accuracy of the "known" data, and particularly the degree of accuracy required to guide preliminary design of the proposed experimental program, the latter expression was deemed satisfactory at this time. It can even be argued that the assumption of "stationarity" of the longevity function was probably not completely valid; newer motors ought to be somewhat longer-lived than earlier models. Thus a stationary longevity function based on inclusion of late-model motors, when applied exclusively to a significantly earlier models, should produce a moderately high estimate of surviving population. Such was the observed result of the $(age)^2$ function.



POSTULATED RELATIONSHIPS, ASSUMED STATIONARY VS. MODEL YEAR, ADJUSTED TO PRODUCE TOTAL OF 7,215,000 IN 1970

Figure 1. Outboard Motor Longevity Vs. Age (Postulated Relationships, Assumed Stationary Vs. Model Year, Adjusted to Produce Total of 7,215,000 in 1970)

TABLE 17. SUMMARY OF OUTBOARD MOTOR POPULATION MODEL CALCULATIONS

Survival Model (S_i = no. of age A still in use)	$S_i = N_i \cdot e^{-k_4 A_i^4}$	$S_i = N_i \cdot e^{-k_2 A_i^2}$
	$k_4 = \left(\frac{1}{A_{\zeta 4}}\right)^4$	$k_2 = \left(\frac{1}{A_{\zeta 4}}\right)^2$
Characteristic Age, Years	$A_{\zeta_4} = 17.179$	$A_{\zeta_2} = 18.8$
Total Population in 1970 - Data	7215 K	7215 K
Calculated Population	7217.6 K	7213.8 K
	(0.036% high)	(0.027% low)
Total Population in 1965 - Data	6645 K	6645 K
Calculated Population	7193 K	6605.1 K
	(8.2% high)	(0.60% low)
Total Population in 1960 - Data	5800 K	5800 K
Calculated Population	6440.8K	6083.8 K
	(11.0% high)	(4.9% high)

Before presenting the resultant estimated 1970 motor population as a function of age, consideration should be given to the horsepower levels characteristic of motors of different ages. A reasonably detailed breakdown of number of motors of different horsepower ranges sold was available only for the time period from 1964 to 1970; this matter will be discussed later. For the time period 1949 to 1970, the average horsepower of all motors sold each year was found; these data are plotted in Figure 2. Since these data did not span the entire production period of interest, it was necessary to assume some representative average annual horsepower for motors produced prior to 1949. From Figure 2, it can be seen that the average motor size for the earlier years of the 1949-1970 period was tending to level off somewhere in the vicinity of 5 horsepower. In order to have some basis for inclusion of pre-1949 motor horsepower, and because the total number of such motors still in use in 1970 would be a relatively insignificant portion of the total population, an average size of 5 horsepower was arbitrarily assumed for all motors produced between 1919 and 1948 inclusive.

The relative contribution of each age class to the total 1970 outboard motor pollutant emission then can be estimated (as a first approximation) as follows: The number of motors of a given model year calculated to be still in use in 1970 is multiplied by the average size of all motors sold in that year.

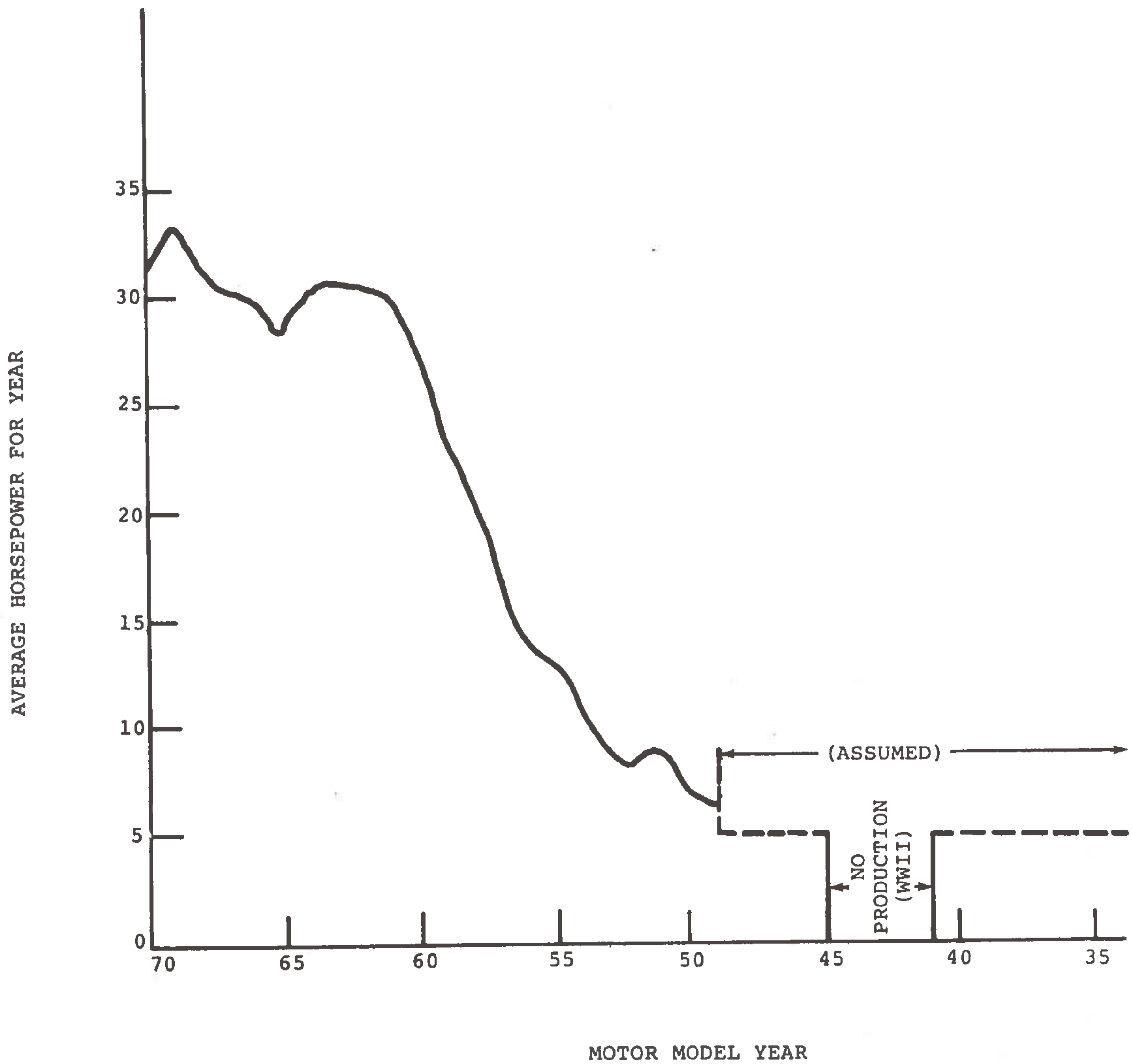


Figure 2. Average Horsepower of All Outboard Motors Sold Per Year (Source of Data, Ref. 26)

This "population horsepower" still in use in 1970 for that model year then is added to similar data for all model years comprising a significant percentage of the 1970 population. The sum is the estimated "total population horsepower" in 1970; i.e., the total power which would be produced if the entire 1970 motor pop-population were operated simultaneously at full throttle. The relative contribution of any model year in 1970 then is simply the ratio of that year's population horsepower to the 1970 total population horsepower. This quantity should provide a more valid measure of the air (or water) quality degradation attributable to a given model year in 1970 than would the simple numerical percentage of individual motors still in use.

The results of these calculations are presented in Figures 3 and 4. Figure 3 shows the estimated number of motors of each model year still in use in 1970. The vertical scale at the right of the figure shows the percentage of the 1970 total population represented by any model year's surviving motors. For reference, the upper curve shows the total annual sales of new outboard motors vs. model year. During the four years of World War II, of course, no motors were sold. Figure 4 is most useful in guiding the design of an experimental program for evaluation of outboard motor emissions. The solid curve in this figure shows the cumulative total by model year of motors which were still in use in 1970 (based upon the assumed longevity function described above). It permits ready determination of the percentage of all operational motors included in a time period dating from 1970 back to any given year. For example, taking all motors through 1961 but excluding all prior to 1961 would exclude 50% of the population, hence would include 50%; through 1954 would exclude 17.5%, hence include 82.5%; etc. The lower, dashed curve in this figure provides a similar capability for total population horsepower (hence, presumably, an approximation to total outboard motor pollution). Taking all motors through 1961 would exclude about 34% of the total population horsepower, hence it would include about 66%; through 1954 would exclude about 4%, hence include about 96%; etc. The population horsepower curve falls off more rapidly than the total number curve because a given number of the earlier motors, with lower average horsepower than later models, generate less horsepower than an equal number of average later motors.

Finally it is instructive to consider, for the years 1964 through 1970 for which data are available, the relative distribution by size of outboard motors being sold. Presumably this offers some guide to the size distribution to be expected at least in the near future. Note, from Figure 4, that motors of this time period produce approximately 54 percent of the total 1970 population horsepower. The data for this period report the number of new motors sold per year in seven size classes: 0 to 3.9, 4 to 6.9, 7 to 9.9, 10 to 19.9, 20 to 44.9, 45 to 64.9, and 65 and over horsepower. The total number of motors of each class for this period was determined. The average horsepower

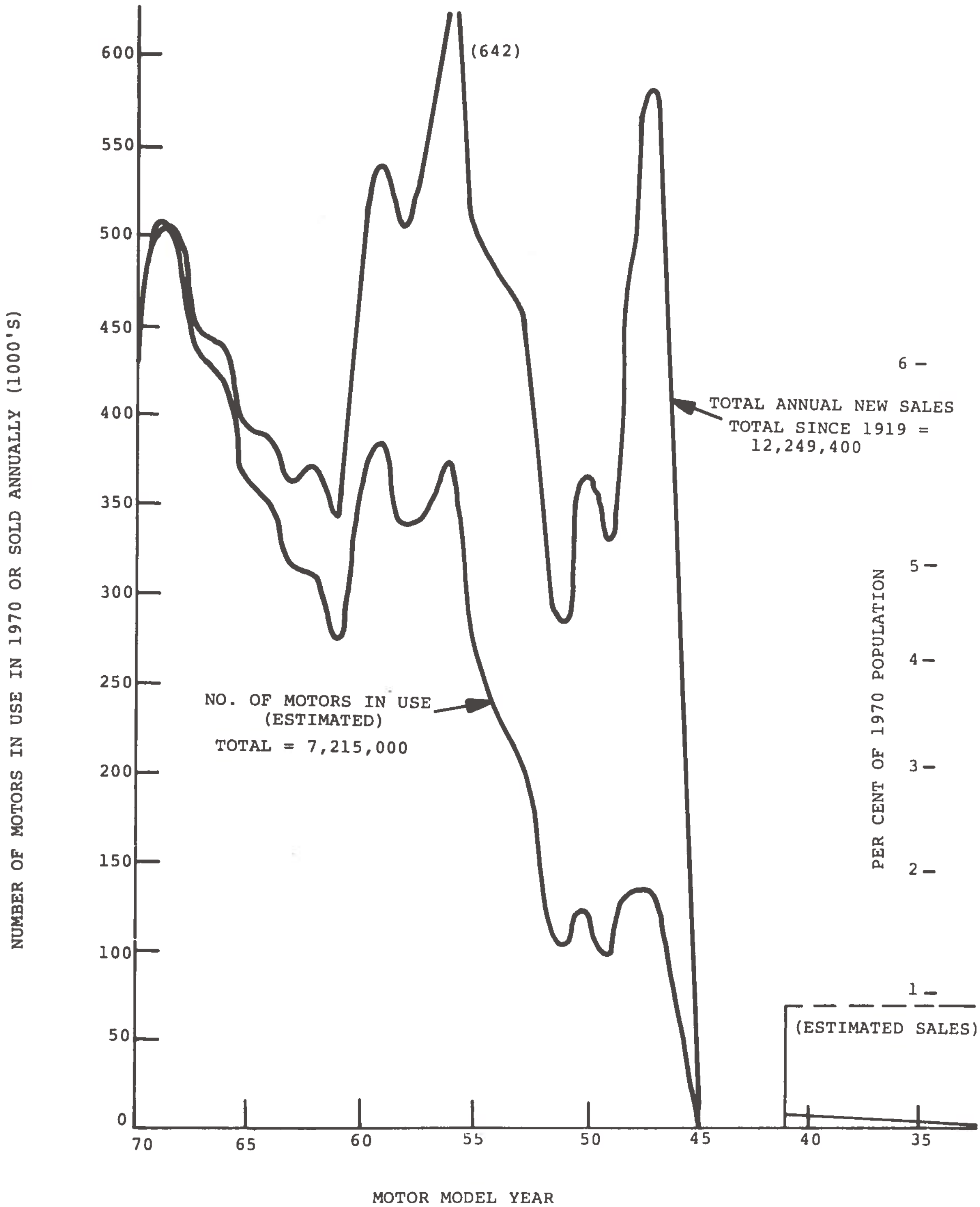


Figure 3. Outboard Motor Population
By Model Year in Use in 1970 and Annual Sales

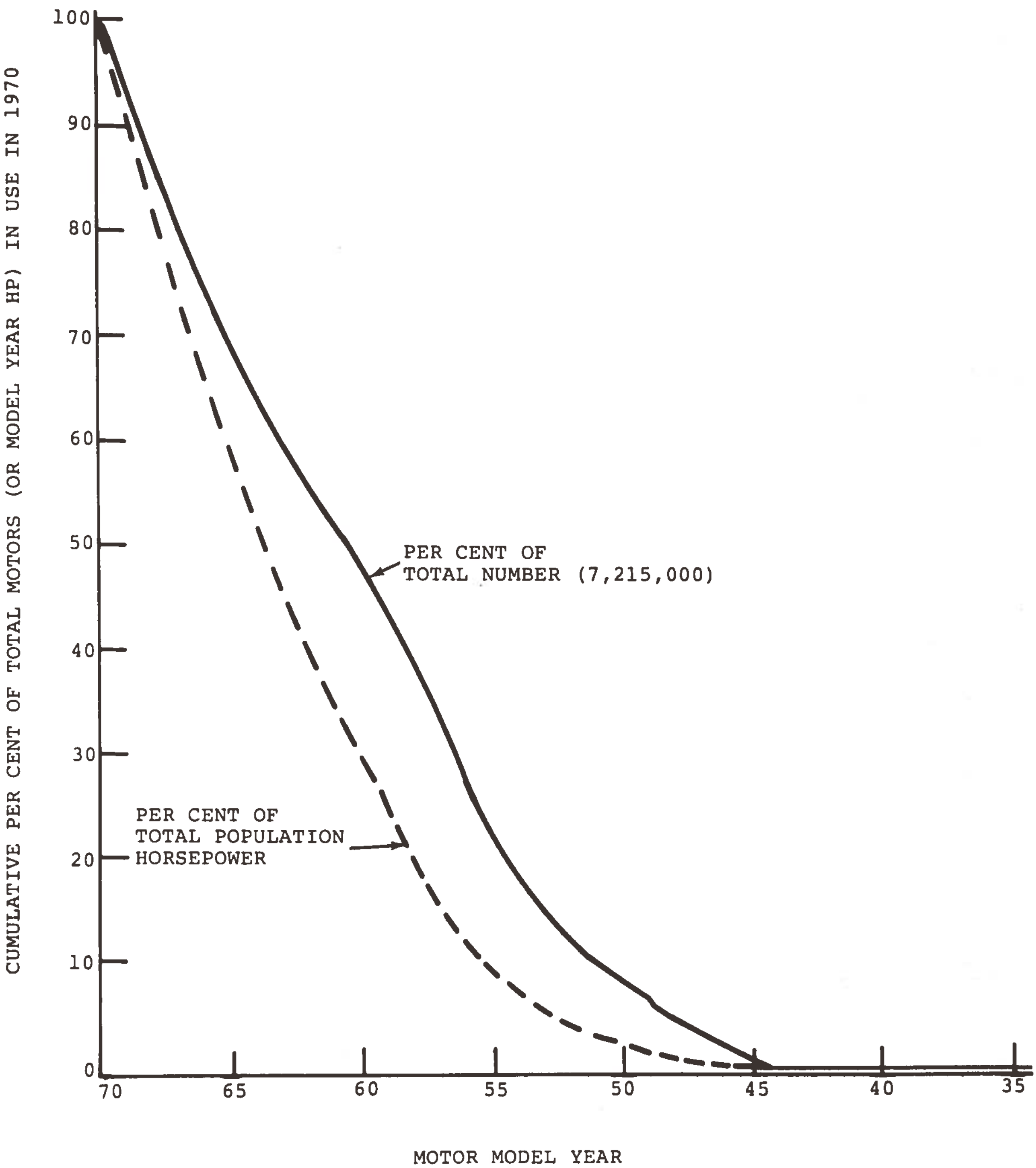


Figure 4. Outboard Motors in Use in 1970 (Estimated Population) Cumulative Percentages of Number and of Total Population Horsepower from Each Model Year

for each size class was not given; therefore, to determine a population horsepower for each class, the median size of each class was used (for the largest size class, assuming an upper limit of 125 horsepower, a median of 85 horsepower was assumed). Total number and total population horsepower were determined, and the relative contributions of each size class were calculated. These results are plotted in Figure 5. The variation in numerical distribution between classes (numerical distribution is shown by the dashed curve) is small; the four smallest classes total 51 per cent of the population, while the three largest classes total 49 per cent. However, a drastically different picture is presented by the population horsepower curve, the solid line. Here, the four smallest classes together comprise only 12 per cent of the population horsepower, while the three largest classes constitute 88 per cent; in fact, the 65 horsepower and above class by itself generates almost 44 per cent of the total. These are factors to be further considered in planning an experimental program for an outboard motor emissions survey.

3.3 FUEL USAGE BY VESSELS AND BOATS

To arrive at meaningful estimates of the emission potentials of the CG fleet and pinpoint possible areas for a future measurement program, a comprehensive survey of the fuel usage in the CG fleet was undertaken and, to a somewhat lesser degree, the fuel usage by commercial vessels and pleasure boats was also considered. This was necessary in order to place the emissions of the CG fleet in the proper perspective. Data on Navy fuel usage and missions are unavailable; Naval vessels are considered to constitute a large fraction of the total. Fuel data was gathered for all cutters in the 1st Coast Guard District and from representative samples of all classes in other districts. Owing to the large numbers of boats involved, only about half of the fuel data for boats in the 1st District was analyzed. Representative samplings of boat fuel use data from other districts are also included. All fuel data presented herein (for the Coast Guard fleet) is based on an analysis of at least five years of fuel usage data, when it was available. An effort was made to eliminate atypical years from the averaging process, such as might have occurred during the time a vessel underwent extensive repairs or was stationed in Southeast Asia.

For the commercial and pleasure fleet, surveying methods were not as extensive in that individual vessels could not be considered in the time alotted; only fuel usage by design type or engine size was considered. This sampling method is considered quite adequate for the purposes of this study. The fuel consumption data thus obtained permits an assessment of the impact of Coast Guard fleet emissions, those of other vessels and boats and is useful in cross-referencing other vessels to the

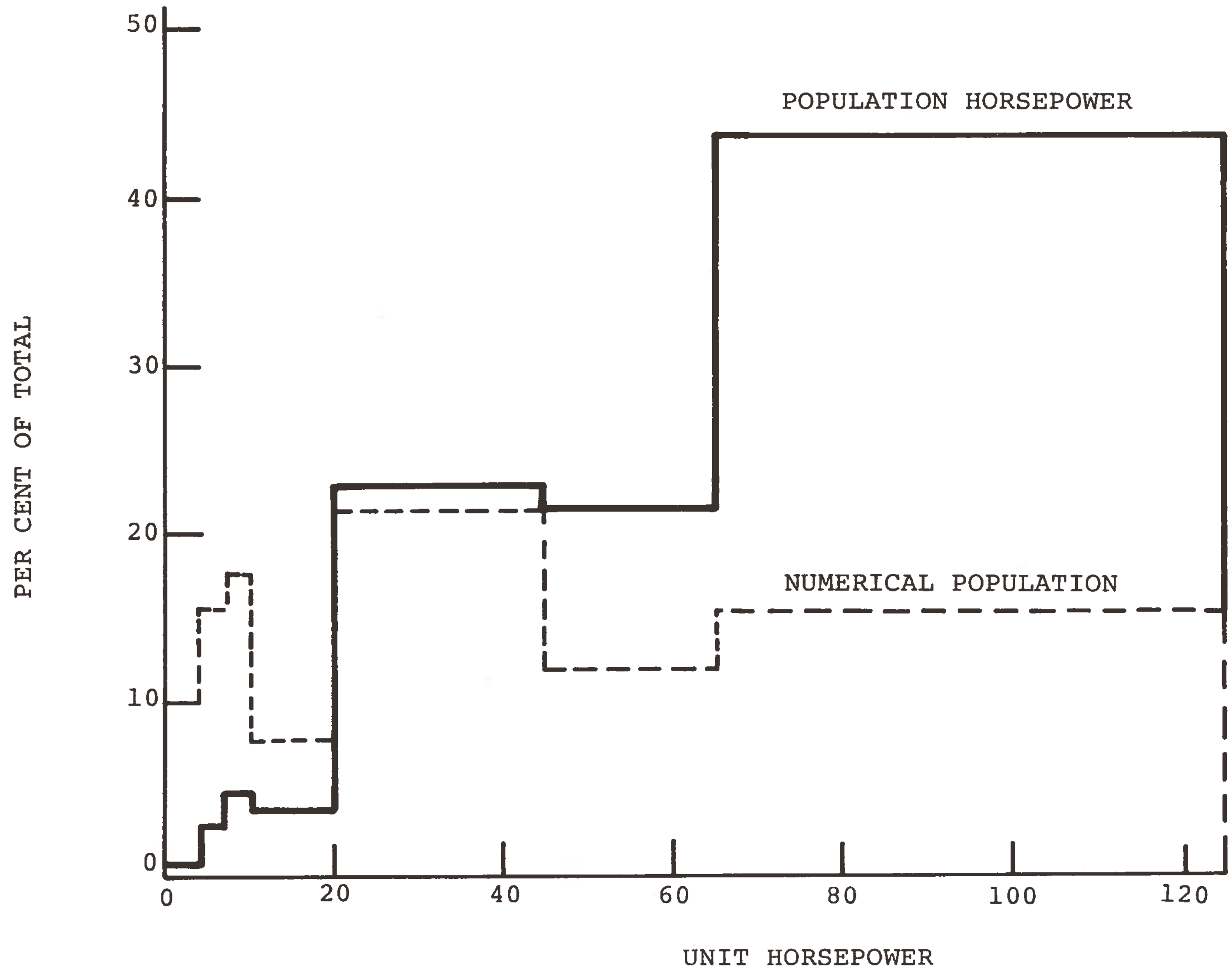


Figure 5. Distribution of Outboard Motors Sold 1964-1970 By Population Per HP Class and Population Horsepower Per HP Class Vs. Unit HP

vessels to the Coast Guard fleet.

3.3.1 Cutter Fuel Usage Data

Figure 6 shows the average fuel usage, in gal/mile by class, for the Coast Guard cutter fleet. Since the fuel consumption, as reported, does not take into account the fraction devoted to operation of hotel service boilers, auxiliary power units, etc., the use of the units of "gallons per mile" for fuel use data is the only feasible way to report these data at this time. During the next phase of the project, the emissions data will be reported in more meaningful units of useful work performed, e.g. "gallons (or pounds of pollutant) per brake horsepower-hour." The small relative contribution of hotel service boilers, auxiliary power units, etc. to overall fuel use does not seriously affect the accuracy of estimates presented herein. Extremes of fuel use are noted by the boundary bars.

For the WHEC, the fuel usage, as reported, is divided between that consumed while station-keeping and underway, as these were considered to be two distinctly different modes of operation. All WHEC in the USCG fleet were included in the sampling. In total, data on 240 various cutters were examined. Figure 7 presents the typical cutter average yearly total fuel usage by class, in gallons, for the Coast Guard fleet. These data were obtained by adding average station, underway, and in-port fuel usage. Figure 8 shows main engine shaft horsepower for a typical cutter in a particular class. Figure 9 shows the percentage of fuel used yearly by a "typical" vessel, by type, and Figures 10A and 10B present similar data by different classes within several types.

The average yearly fuel usage by the CG cutter fleet is 4.6×10^7 gal (3.2×10^8 lbs). Of this total, the First District contributes 7.4×10^7 lbs or 23%. This is undoubtably due to the high percentage of WHEC present in the 1st District. The distribution of WHEC by District is given in Table 18. These numbers are distinctly reflected in the District total of fuel usage, since the WHEC are responsible for 54% of the total fuel consumed in the cutter fleet. A substantial part of this high fuel usage is due to gas turbine operation in 378 class WHEC. The gas turbine consumes substantially more fuel per mile than the diesel engine. For example, two 3600 hp diesel engines (FM 38TD8 1/8) would require approximately 2880 lbs of fuel per hour at full power, while two 18,000 hp gas turbines (P&W FT4D) at full power would use on the order of 13,000 lbs of fuel per hour. A firm figure for the proportion of turbine usage was difficult to ascertain due to the individual preferences of the Commanding Officers. Conversations with the Engineering Officers indicated that turbine usage time could be from as low as 5% to as high as 25%. This will partially

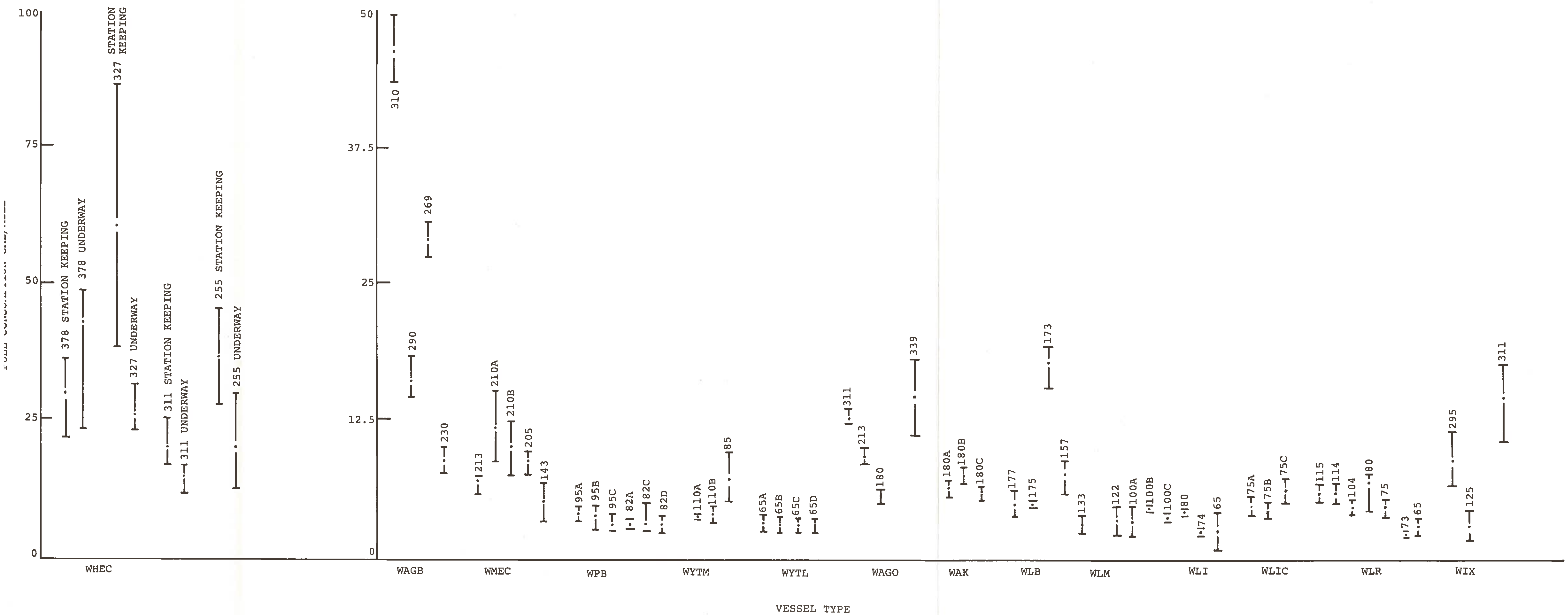
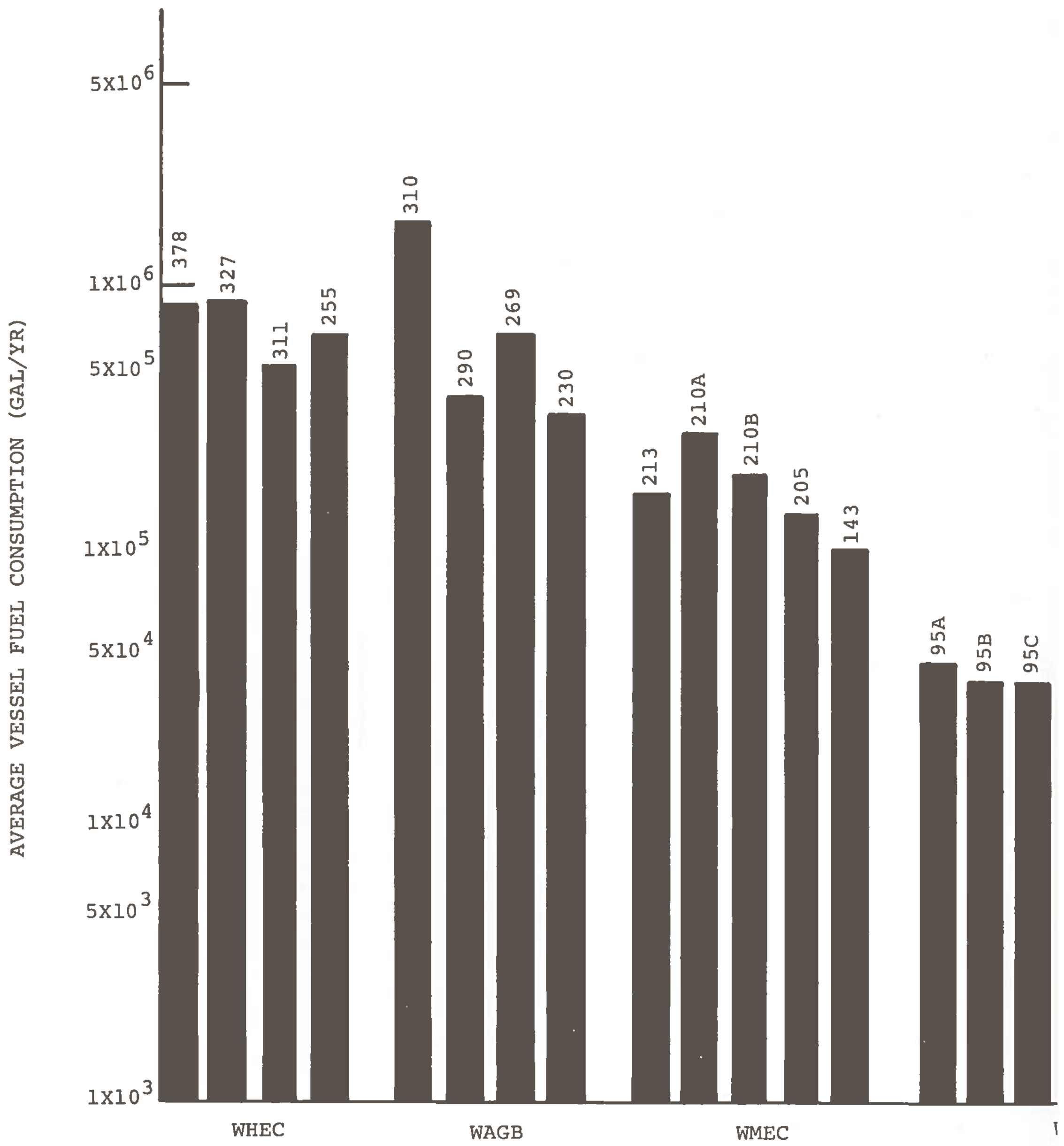


Figure 6. Average Fuel Consumption (Gal/Mile) by Class


AVERAGE VESSEL FUEL CONSUMPTION (GAL/YR)
5X10^6
1X10^6
5X10^5
1X10^5
5X10^4
1X10^4
5X10^3
1X10^3
378
327
311
255
310
290
269
230
213
210A
210B
205
143
95A
95B
95C
WHEC
WAGB
WMEC

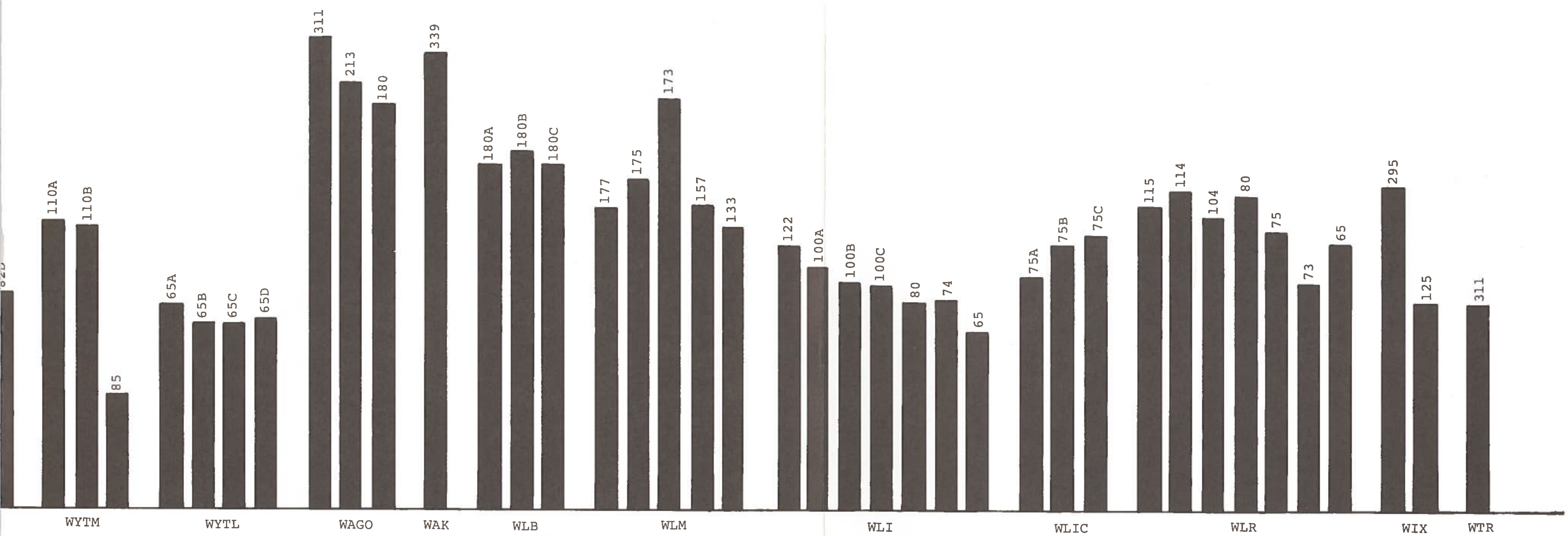
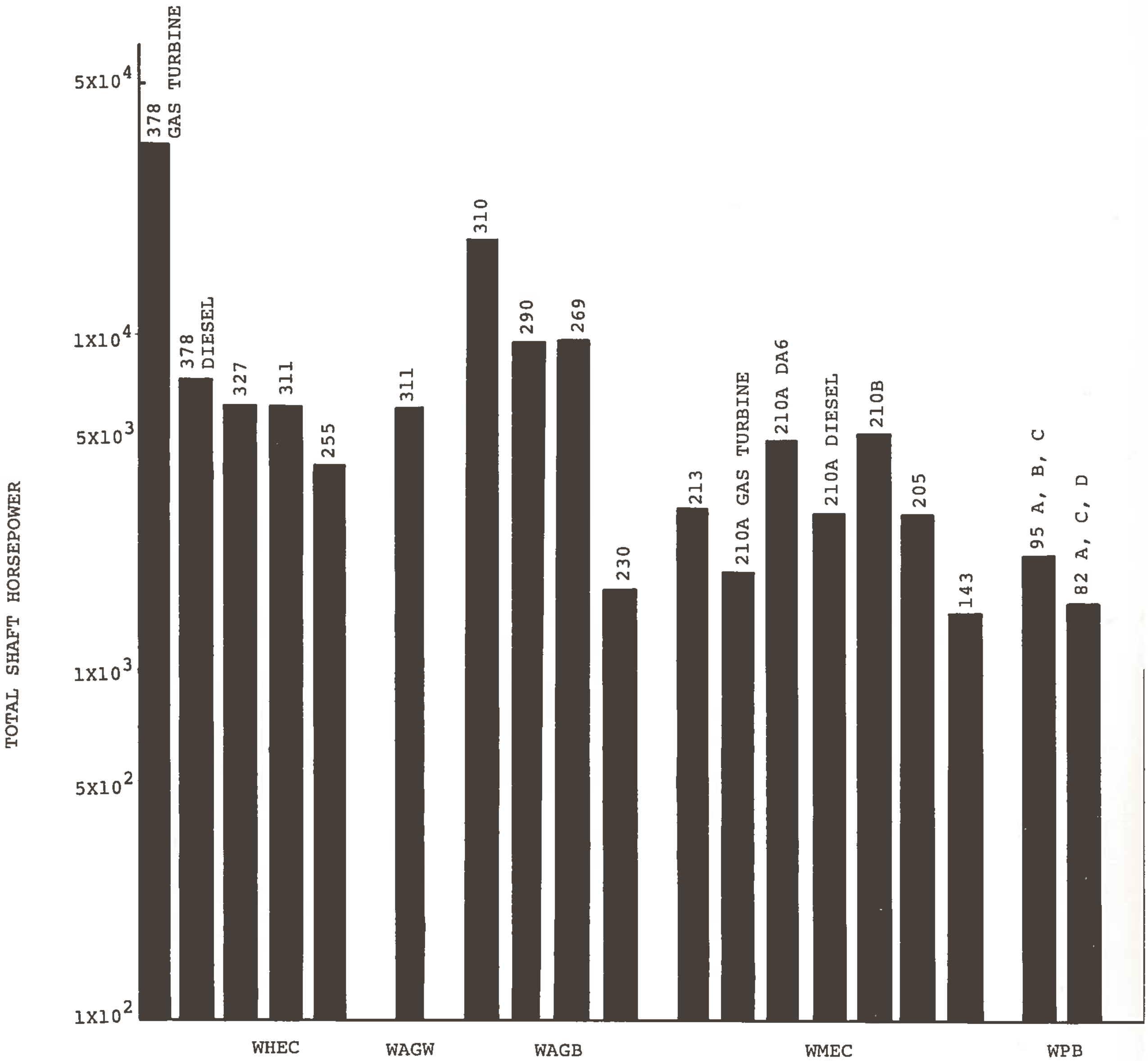


Figure 7. Average Yearly Fuel Consumption by Class (Five Year Average



TOTAL SHAFT HORSEPOWER
5X10^4
1X10^4
5X10^3
1X10^3
5X10^2
1X10^2
378 GAS TURBINE
378 DIESEL
327
311
255
311
310
290
269
230
213
210A GAS TURBINE
210A DA6
210A DIESEL
210B
205
143
95 A, B, C
82 A, C, D
WHEC
WAGW
WAGB
WMEC
WPB

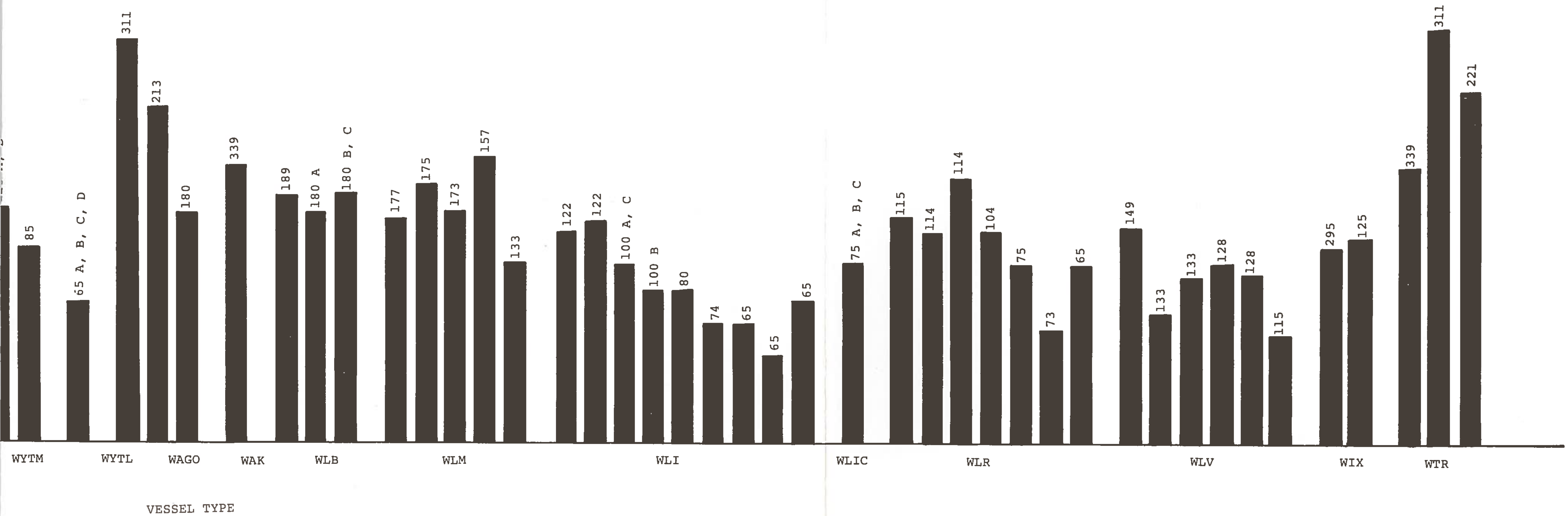


Figure 8. Total Shaft Horse-power by Class

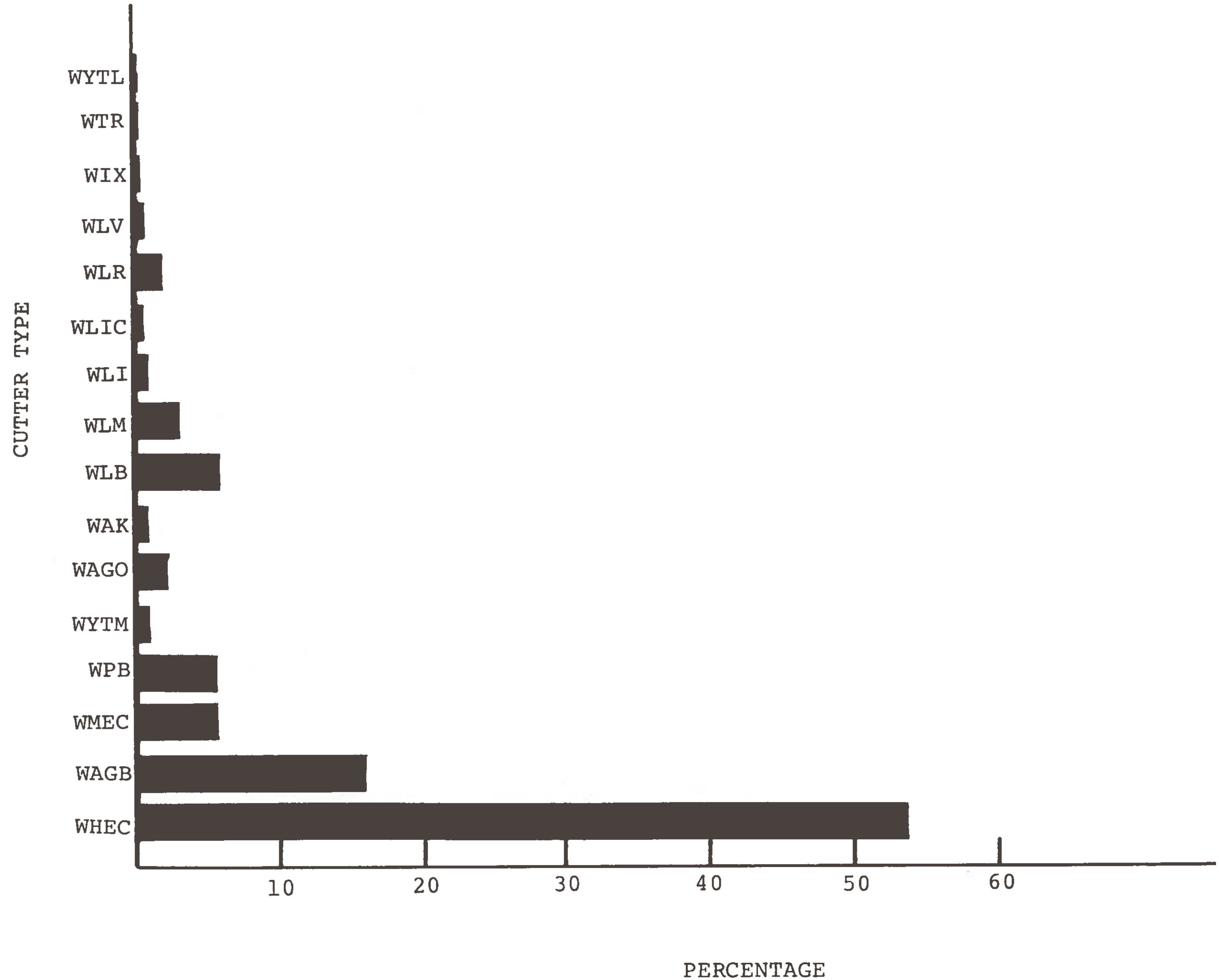


Figure 9. Percentage of Total Yearly Fuel Usage by Cutter Type

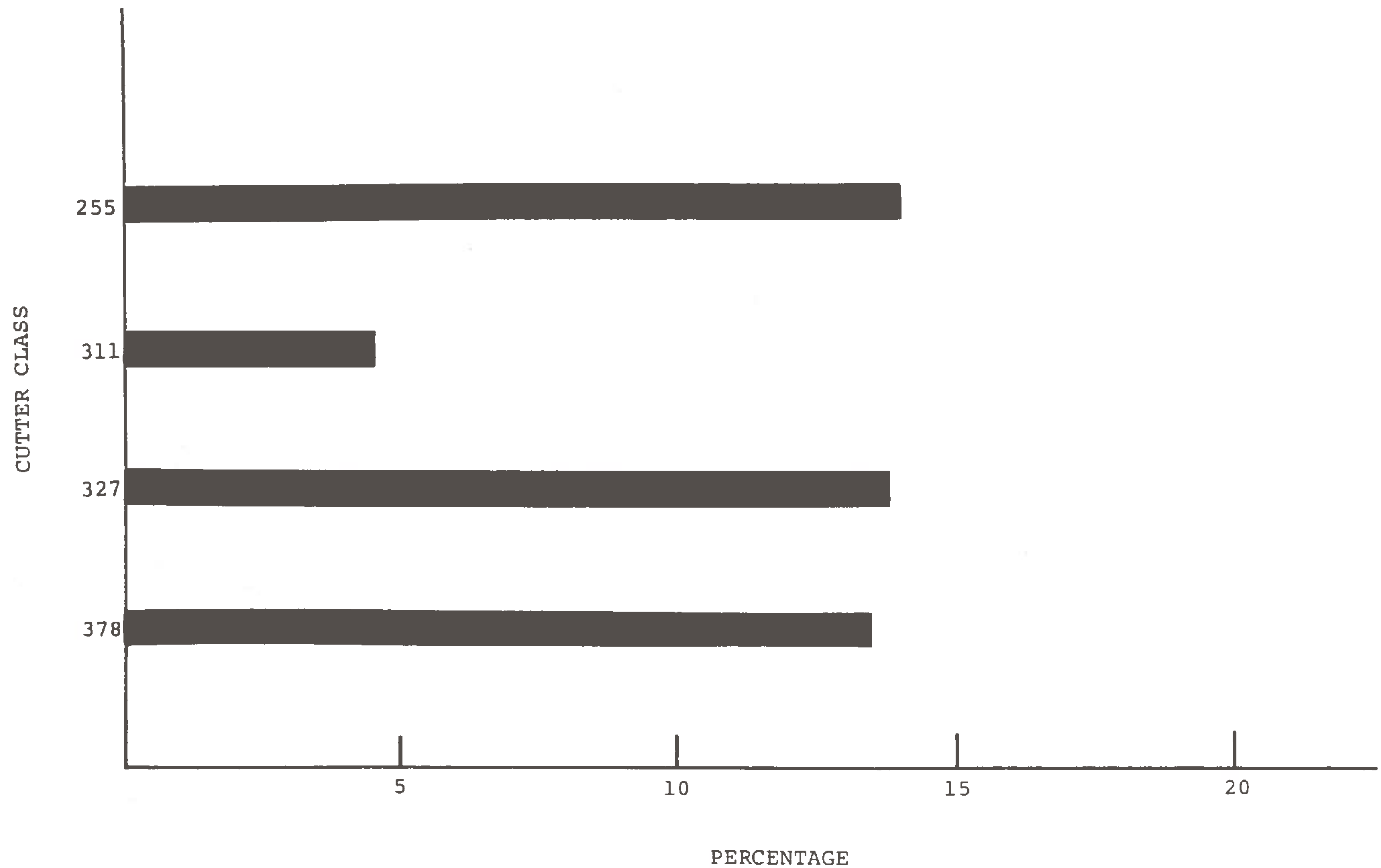


Figure 10A. Percentage of Yearly Fuel Usage by WHEC Class

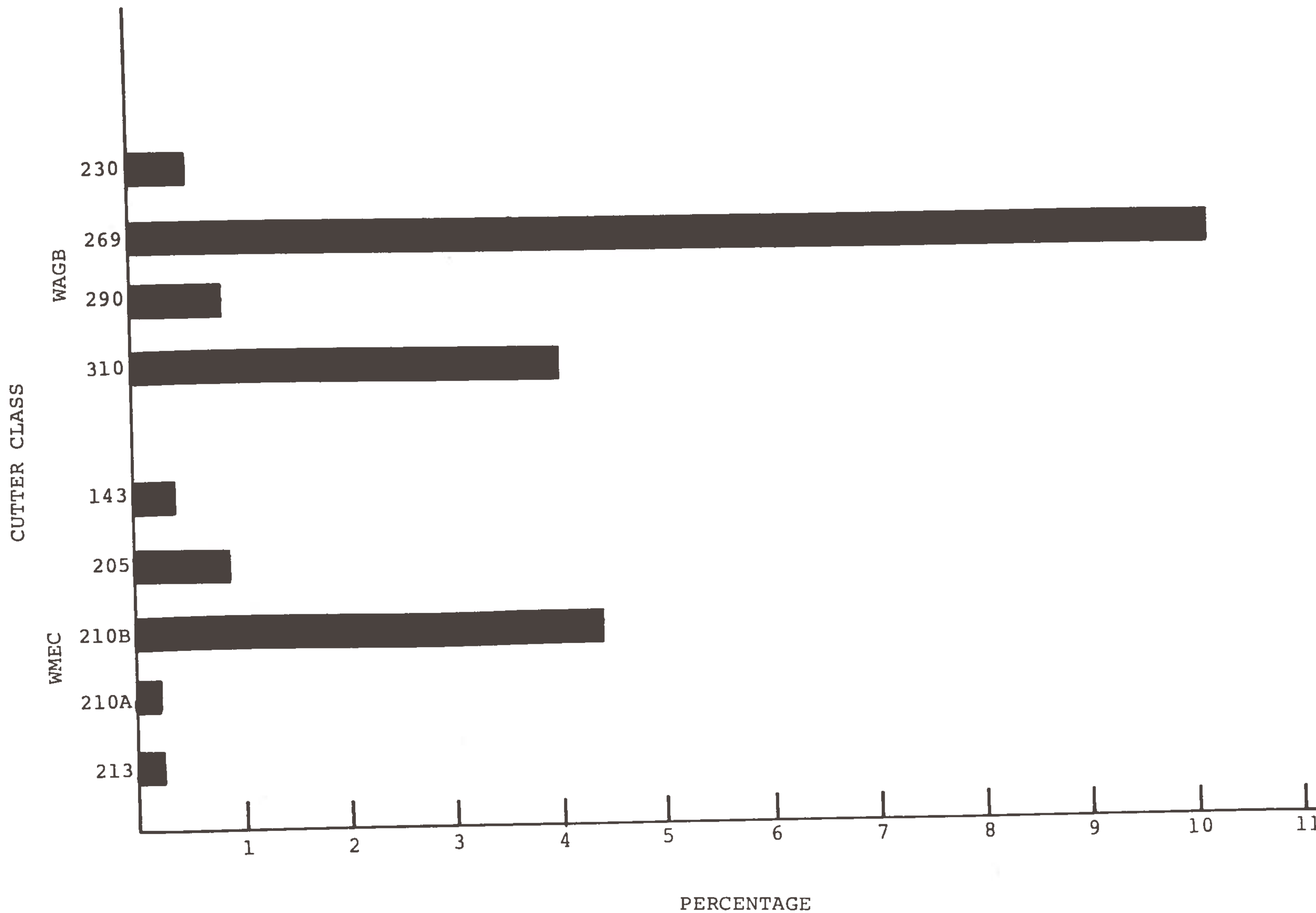


Figure 10B. Percentage of Yearly Fuel Usage by WAGB & WMEC Class account for the large variations in "underway" fuel usage for the 378 class. A smaller deviation from the average is seen in station keeping fuel usage of the 378 class, perhaps as a result of the limited turbine operation. The gas turbine is inherently "clean" in operation and, with usage limited to the 378 WHEC and 210A WMEC, the impact of these total emissions is minimal. The variation, by a factor of two, in fuel usage of the 327 class while station keeping is a result of keeping either one or two boilers "on-line" while on station. However it is felt that the large variations in fuel usage for the WHEC cannot be adequately explained at this time. It will be necessary to delve into this point further in Phase Two of the project and, possibly, resolve the differences by measurement of engine emissions.

TABLE 18. DISTRIBUTION OF WHEC'S BY DISTRICT

USCG District	# WHEC	% Total WHEC
1st	8	37 %
3rd	5	16.6%
5th	5	16.6%
7th	2	6.6%
11th	3	10.0%
12th	1	3.3%
13th	3	10.0%
14th	3	10.0%
Total	30	100 %

"In-port" fuel usage accounts for between 5% and 20% of the total fuel usage among WHEC, with the 327 class showing the highest proportion. As would be expected, seasonal and climatic variations are evident in the in-port fuel usage. For instance, among the 378 class, the CGC Chase, in Boston, had a 5 year average of in-port fuel usage of 80,828 gal, while the CGC Mellon, in Honolulu, consumed an average of 38,000 gal. in-port. It is expected that in-port fuel usage for the fleet as a whole will decrease as the older steam powered ships are phased out, more ports provide commercial power to the ship, and ships are equipped with electrically heated boilers.

Regarding the remainder of the fleet, it is interesting to note that 12% of the fuel usage is by the sea-going buoy tenders

(WLB) and patrol craft (WPB). Although this is substantially less than the WHEC fuel consumption, the potential impact of these types, with their inherently close-to-shore operation, cannot be ignored. In contrast, the icebreakers (WAGB) are responsible for 10% of the fuel usage, but their operation is primarily in the Artic Regions and their emission impact is minimal. (There are plans to shift WAGB operations to domestic icebreaking, rather than extensive Artic missions, which could alter this situation somewhat.) The other types that should be noted are the medium endurance cutters (WMEC) and the oceanographic cutters (WAGO). Although the WMEC 210A has an inherently high fuel consumption, due to its "DAG" power plant (simultaneous operation of diesel and gas turbines), the 210B has a higher potential impact due to the larger number of vessels in this class. The majority of the "underway" operation of these vessels, however is seen outside the continental limit on SAR and fishing fleet surveillance missions. The fuel usage of WAGO and subsequent emission potential must be evaluated on a mission by mission basis. Although most of the WAGO operation is on the open seas, missions do arise that constitute close-to-shore operation. For instance, in 1970 the Evergreen assisted NOAA in an evaluation of pollution in New York harbor for an extended period and was, therefore, operating close to shore.

3.3.2 BOAT FUEL USAGE DATA

Figures 11A and 11B show the average fuel usage, in gallons per hour, and the average annual engine operating time for the boat types in the Coast Guard fleet (excluding outboard engines). Data were gathered on approximately 160 boats from all districts. The fuel consumption by all boats in the Coast Guard fleet is 1.6×10^6 gallons per year. This is 3.4% of the fuel used by the cutter fleet. Figure 12 shows the proportion of yearly fuel usage by boat type. As would be expected, the highest fuel consumption is seen by the "work horses" of the fleet: the 44', 40', and the 30' boats.

Analysis of fuel data indicates that four boat types are responsible for 86% of the boat fuel usage: the 44' lifeboat (MLB), the 40' utility boat (UTB), the 30' medium utility boat (UTM), and buoy boats. The relatively high fuel usage by these boat types is simply a result of the large number of boats involved and their frequent use in SAR missions. In the case of the buoy boats, high fuel usage results from their closely scheduled, almost daily, operation. Any fuel analysis and measurement programs should be weighted by the following factors pertinent to boats:

1. Fuel usage is, in most cases, limited to the main engines, with little heating or power requirements.

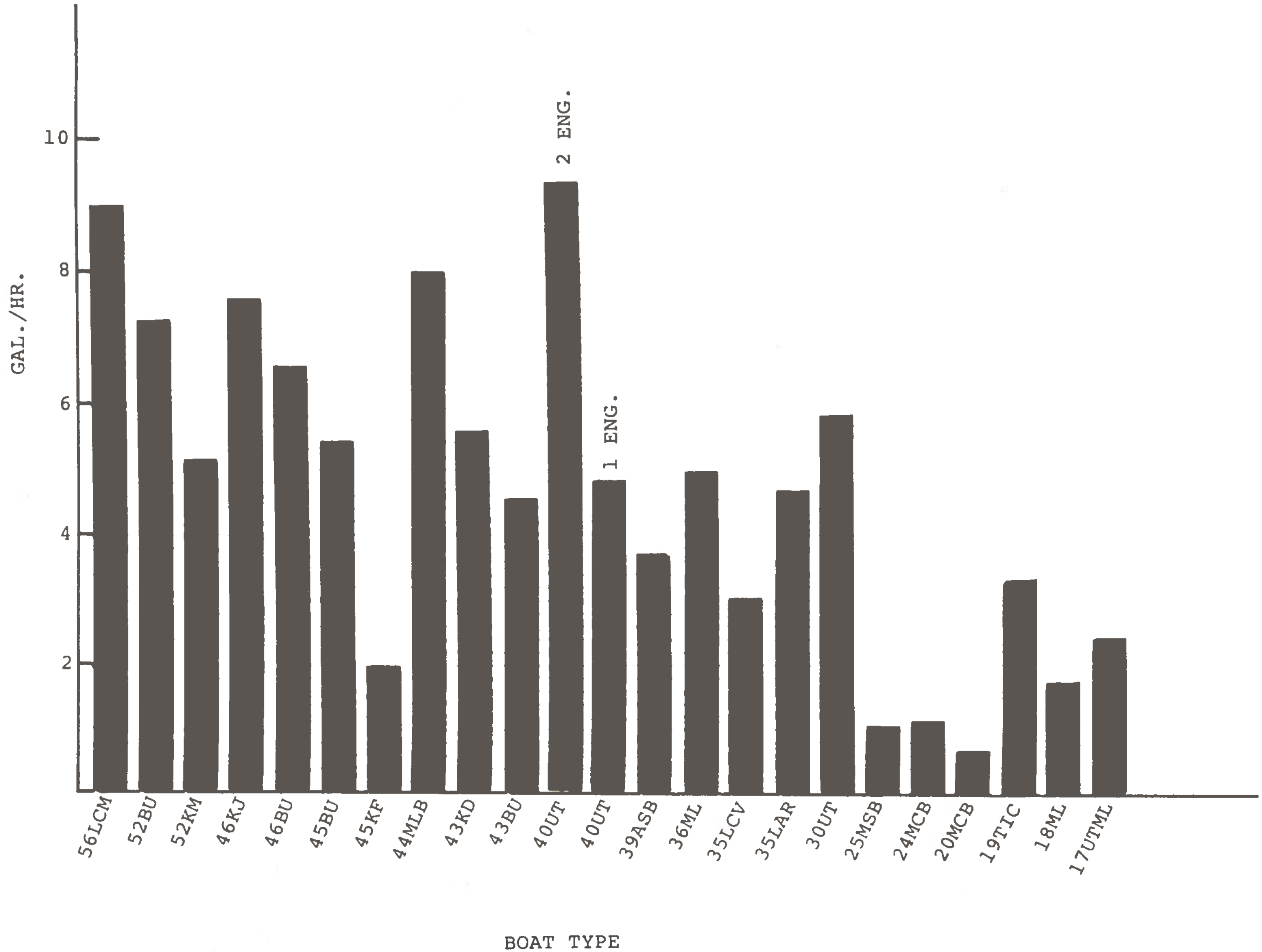


Figure 11A. Average Boat Fuel Usage

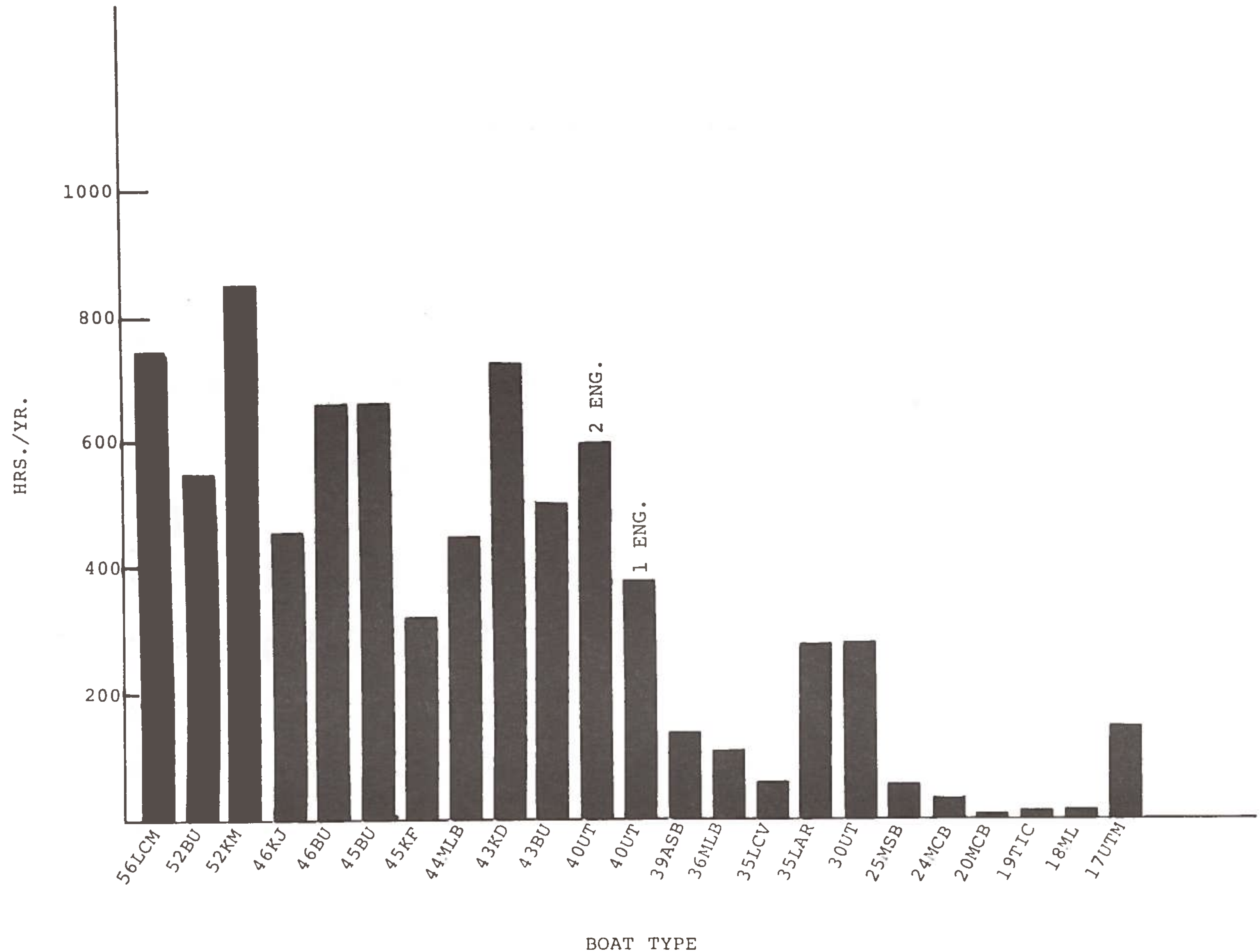


Figure 11B. Average Boat Engine Hours Per Year

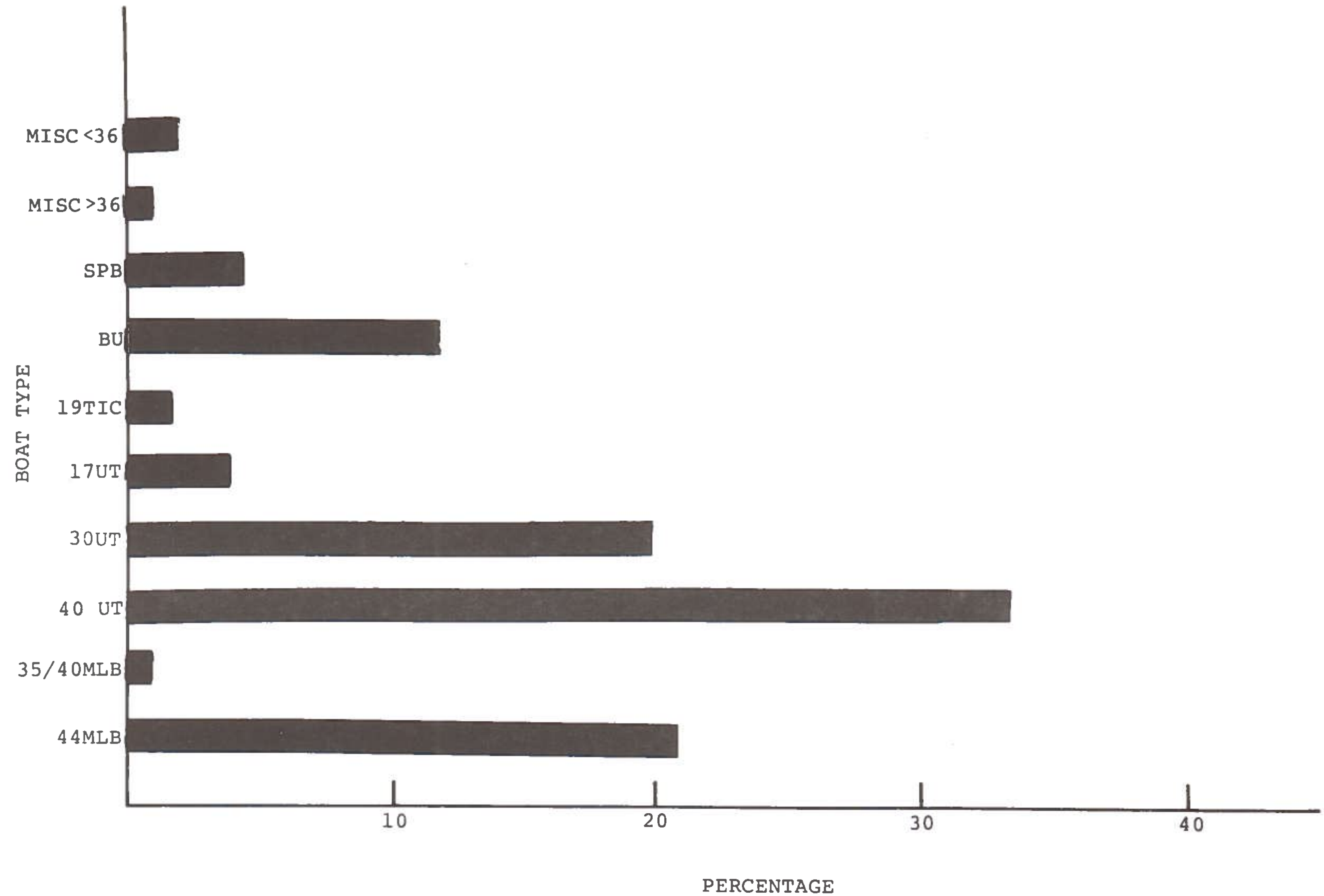


Figure 12. Percentage of Yearly Fuel Usage by Boat Type

2. Many of the engines in the boat fleet are quite modern and technical data in some cases, including emission factors, are available.

It should be stressed that the preceeding analysis did not include outboards, as no reliable emission data are presently available on these engines and any fuel use analysis would be premature. However, a wide variety of engines exists in the Coast Guard outboard fleet, with the typical engine being approximately 30 horsepower. This correlates rather well with the data discussed in Section 3.2.4.

3.3.3 Merchant Fleet Fuel Usage Data

Table 19 gives typical fuel usage, in gallons per mile, for various design types of over 1000 gross tons in the Merchant Marine Fleet. Figure 13 shows typical fuel usage per year per vessel for various design types. This fuel usage is based on private communications with Merchant Fleet operators, who indicated that the typical vessel engaged in foreign trade steams 100,000 miles per year. Passenger vessels are not included in the preceeding discussion. (Although there are 14 passenger vessels listed in the Merchant Fleet, they are currently in an "idle" status.)

Figure 14 illustrates the proportion of total average yearly fuel consumed by individual design type. The total annual fuel usage by this fleet is calculated to be 2.7×10^9 gallons.[17] This indicates that 90% of the residual fuel is used by the 636 ships of the Merchant Marine.

The remainder of the residual fuel (3×10^8 gal), all of the distillate fuel (6.7×10^8 gallons), and 2×10^8 gallons of gasoline are used by the remainder of the Merchant Vessels. This includes all documented power vessels over 5 tons, which amount to about 25,000 units, including pleasure craft.

All the U.S. Merchant Vessels use 3.9×10^9 gallons of fuel annually. This is a factor of 100 higher than the fuel consumed by the Coast Guard fleet. It is interesting to note that the current trend is towards larger vessels with subsequent higher emission levels per ship. New construction in the U.S. includes 27 dry cargo vessels, with an average horsepower of 31,000; 21 tankers, with an average horsepower of 24,400; and two 15,000 hp Chemical Carriers. Two of these vessels use engines of 50,000 shaft horsepower. All of the vessels are steam turbine powered, with the exception of four 16,500 hp diesels.

In 1968, only 13.5% of all the tonnage in the U.S. ports was carried on U.S. vessels. It is anticipated that this figure will increase to 25% in the next few years. Although it

TABLE 19. FUEL USAGE OF TYPICAL MERCHANT MARINE VESSELS

Design	C_1 & C_2 & Misc. Fuel Cap. Gal ($\times 10^5$)	Range Mi ($\times 10^3$)	Gal/Mi
C_2A	4.88	18	27
C_2A5	6.03	22	27.4
C_2	4.79	16	29.9
SC_2	5.46	17	32.1
C_1A	3.96	21	18.9
C_1A	4.01	17	23.6
C_1B	3.47	16	21.7
V_2	8.07	24	33.6
V_3	8.07	21	38.4
EC2	3.17	9	35.1
C_1M	1.02	10	10.2
RsA	4.23	7	60.4
R_2B	4.79	16	29.9
C_2S1	5.67	23	24.6
R_1D	3.37	11	30.6
R_1	1.02	10	10.2
C_1M	1.02	10	10.2
		AVG	27.3

Design	Cargo C_3 Fuel Cap. Gal ($\times 10^5$)	Range Mi ($\times 10^3$)	Gal/Mi
$C_3 33$	6.5	14	46.4
$C_3 37$	7.9	17	46.4
$C_3 37$	7.9	18	43.8
$C_3 37$	5.6	15	37.3
$C_3 38$	6.24	13	48
$C_3 43$	6.18	13	47.5
$C_3 76$	6.09	-	-
C_3	4.5	12	37.5
SC_3	5.69	16	35.5
$C_3 4$	4.45	12	37.0
$C_3 5$	4.21	13	32.3
$C_3 BH$	5.56	15	37.0
$C_3 B2$	8.54	14	61.0
$C_3 46$	5.73	13	44.1
		AVG	42.6

Design	Cargo C_4 & C_5 Fuel Cap. Gal ($\times 10^5$)	Range Mi ($\times 10^3$)	Gal/Mi
$C_4 57$	7.1	12	59.2
$C_4 58$	8.1	16	50.6
$C_4 60$	7.2	14	51.4
$C_4 64$	9.46	19	49.7
$C_4 65$	6.5	12	54.2
$C_4 66$	5.9	12	49.2
$C_4 41a$	7.4	12	61.7
$C_4 41u$	9.4	14	67.1
$C_4 A4$	5.8	11	52.7
C_4	5.7	11	51.8
C_5	5.7	11	51.8
		AVG	54.5

Design	Comb. Pass & Tankers Fuel Cap. Gal ($\times 10^5$)	Range Mi ($\times 10^3$)	Gal/Mi
$C_4 49$	4.35	-	-
$C_3 P$	6.21	14	44.4
T_5	12.4	18	68.8
T_3	4.82	14	34.4
ST2E	4.11	10	41.1
T_2E	4.16	13	32.0
T_1	.16	4	4.0
T_1B_2	.43	6	7.1
		AVG	33.1

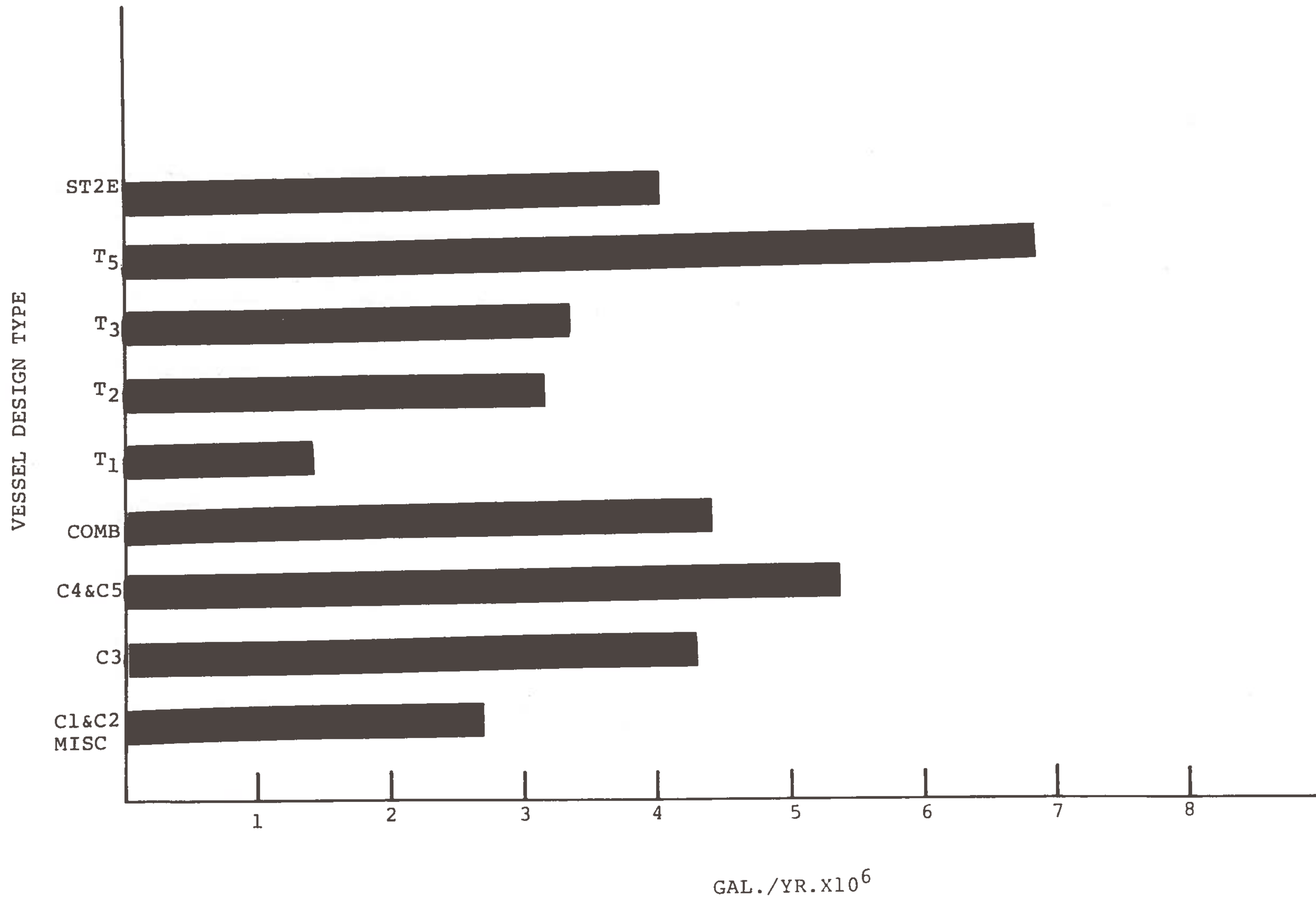


Figure 13. Typical Fuel Usage Per Year of Merchant Marine Vessels

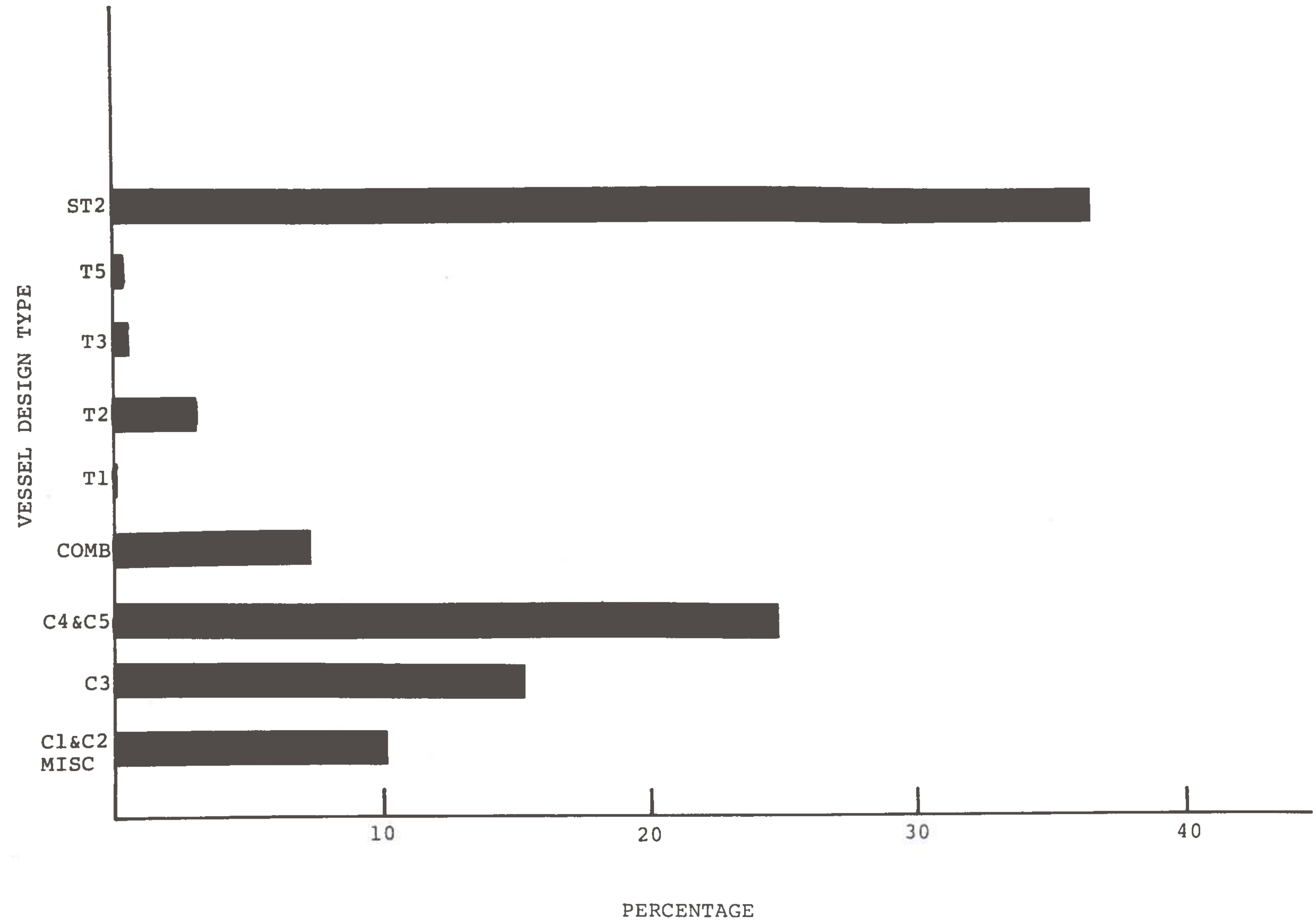


Figure 14. Percentage of Yearly Total Fuel Usage by Merchant Marine Design Type

makes little difference whether the pollutants are generated by U.S. or foreign fleets, emission control and especially, Federal enforcement of regulations is complicated by the presence of foreign flag ships.

SECTION 4. ENGINE EMISSIONS

4.1 THE NATURE OF ENGINE EXHAUST EMISSIONS - GENERAL

Having documented the types of power plants employed in vessels and boats, and estimated the fuel used by typical craft, we consider in this section the composition of air pollutant emissions present in engine exhaust gases. The deleterious emissions from diesel engines, gas turbine engines, spark-ignited gasoline 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 the 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 at levels greater than 300 ppm for as low as one hour exposures. 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 complex which results in eye and membrane irritation.

Carbon monoxide effects 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 the 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, a major irritant. The effects of sulfuric acid on humans are dependent on droplet size of the mist (respirable size range). It has been noted that SO_2 in concentrations above 5 ppm can adversely affect bronchial passages.

Particulate matter may produce toxic effects by intrinsic toxicity of the material (i.e. beryllium), respiratory interference or by causing absorption of toxic substances in the lungs. It is evident that particle size and mass are significant in assessing potential toxicity. It is not practical, then, except in the case of intrinsic toxicity, to arrive at specific concentrations that produce toxic effects in humans.

4.2 EMISSIONS FROM DIFFERENT ENGINE TYPES

Diesel - The diesel engine is, if properly maintained, relatively "clean" compared to a gasoline engine. It is operated fuel lean with excess air available for more complete combustion. Hydrocarbons emitted from diesel engines are the products of incomplete combustion and the cracking of fuel. Although the overall average engine air to fuel ratio is high, there exist, in any compression ignition engine, pockets of varying air to fuel ratios in the cylinder charge which contribute to incomplete combustion and result in hydrocarbon production. Recent work by General Motors[19] has indicated that a large percentage of the hydrocarbons is produced by residual raw fuel from the fuel injector tip that enters the combustion chamber too late to be completely burned.

Oxides of nitrogen (NO_x) are formed by the oxidation of atmospheric nitrogen at high temperatures in the combustion process. NO_x concentrations tend to increase with increasing peak flame temperatures, load and decreasing fuel to air ratio, and are relatively high in diesel engine exhausts.

Carbon monoxide levels are controlled, in part, by the air to fuel ratio. As a diesel engine approaches full load conditions, CO emissions increase dramatically because of incomplete combustion as available oxygen is depleted. Generally, compared to gasoline engines, the diesel engine shows relatively low CO output.

The SO_2 emitted by a diesel is directly related to the sulphur 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 sulphur content of #2 distillate fuel, the commonly used fuel in the Coast Guard, is limited to 1% by weight, which would correspond to 400 ppm SO_2 in the exhaust at 0.04 fuel/air ratio and 100% combustion.

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

Although no effort is planned in this program toward defining and controlling odors from diesels it should be recognized that this is a problem deserving further attention. In this regard, considerable effort has been directed toward defining the sources of odors from diesel exhaust by others.[27] Table 20 is a compendium of measured concentrations of pollutants from diesel engines reported by various sources. Both two-stroke and four-stroke engine data are presented. It is obvious that measured emissions vary by factors of at least two or three and it is important to keep in mind the following facts

TABLE 20. MEASURED EMISSIONS FROM DIESEL ENGINES

ALL EMISSIONS AT FULL POWER IN PPM CORRECTED FOR EXCESS AIR EXCEPT WHERE NOTED

Source	HC	CO	NO_x	PART	COMMENTS
Stern	1148	0.25%	1530	-	2 cycle [2]
GE (Train)	18	200-350	1500-2500	-	not corrected 4 cycle TC [28]
GM (6-71)	300	1000	1600	-	2 cycle [19]
Int. Hur.	100	950	1950	-	4 cycle [27]
Int. Hur.	40	1600	1450	-	2 cycle [29]
MAN	-	100	800	-	not corrected 2 cycle Marine
MAN	-	200	600	-	not corrected 4 cycle Marine
Cater	50-150	300-400	700-900		2 cycle TC PC [30]
Cater	170	400	1200		2 cycle TC [30]
Cater	720	900	1500	0.1gm/lb	2 cycle [30]

TC - Turbocharged
PC - Pre-Combustion Chamber
PART - Particulates

concerning diesel emissions:

- Diesel engine emissions vary considerably with engine design, i.e. whether the engine is of two- or four-stroke cycle operation, has pre-combustion chambers or employs direct injection, is turbocharged or naturally aspirated.

- Emission levels are a function of engine timing.

- Emissions are a function of fuel/air ratio. Unlike gasoline engines, which are always intended to operate at near stoichiometric conditions, the diesel air to fuel ratio varies with engine operating conditions. (The diesel is not, generally, a choked engine.)

- Emissions vary considerably with engine age and, especially, quality of maintenance.

Gas Turbine - Emissions from gas turbine engines are of generally the same nature as those from diesels. The gas turbine is an inherently efficient engine. It is sufficient to point out that pollutants from the gas turbine result from many of the same conditions discussed above. 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 0.1μ in diameter formed, it is thought, at least in part by quenching of the 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 21 gives the emission estimates for jet engines in marine use. Of particular importance is the FT4 engine, adapted for marine use on the WHEC 378 class. Also included are data obtained from the manufacturer of the Solar Saturn turbine, used on the WMEC 210A class. No further consideration will be given the gas turbine in this report as it warrants no place in a measurement program due to its low emission levels, low use factor and the availability of reliable data on its exhaust emission levels.

Oil-Fired Boilers - 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 generally burned, fly ash (particulates) and oxides of sulphur 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 surface quenching of the flame, fuel-rich operation, poor maintenance procedures, etc.

TABLE 21. ESTIMATED EMISSIONS FROM GAS TURBINES

		Emissions (in lbs/1000 lbs fuel consumed)	
		NO LOAD	FULL LOAD
FT4 Propulsion Engine:[31]			
	CO	45	2
	HC	47	<.1
	NO_x	2	9
Solar Saturn Generator:[29]			
	CO	70	25
	HC	.75	.25
	NO_x	4.5	4

Oxides of nitrogen are present in much lower concentrations than evidenced in diesels and gas turbines due to the boiler's lower combustion temperature.

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 insufficient oxygen is present in the flame region. This usually results from poor air/fuel mixing and is more prevalent in older, poorly maintained units.

The emission from oil fired boilers of SO_2 is, again, directly a function of the sulphur content of the fuel. Coast Guard cutters presently burn Navy Special Fuel Oil, which is a blend of heavy and light fuels. The sulphur content can vary, but is generally from 1% to 3% depending on the source of the heavy oil. There is no specified limit on the sulphur content of residual oils.

Particulate emissions, in this case, primarily consist of fly ash, a coke dust produced from dispersions of high molecular weight solids in the oil medium. Ideally, these particles would be burned off if given sufficient residence time at high temperatures. In practice, enough quenching takes place to produce considerable quantities of fly ash, depending on the conditions of the boiler and the ash content of the fuel.

Table 22 gives measured emission levels in exhaust gases of various boiler types, both stationary and marine, using #2 fuel oil and heavy fuel oil. The emissions are obviously not scalable, and 200 hp is the largest marine boiler shown. These data are more closely related to heating boilers used on Coast Guard vessels; no data were found on large power boilers used in ships.

TABLE 22. EMISSIONS FROM VARIOUS INDUSTRIAL AND COMMERCIAL OIL-FIRED EQUIPMENT

Equipment	Rated Size (hp)	Oil rate (ghp)	Oil properties: API Gravity	Oil properties: S (%)	Oil properties: Ash (%)	Excess air (%)	Sulfur Dioxide: Measured ppm	Sulfur Dioxide: Measured lb/hour	Sulfur Dioxide: Calculated lb/hour	SO_2 (ppm)	CO (%)	Aldehydes (as formaldehyde) (ppm)	Nitrogen oxide (as NO_2) (ppm)	Particulates (grains SCF at 12% CO_2)	Particulates (mg/m^3 at 12% CO_2)
							Number 2 Fuel Oil								
Firetube	60	9	31	1.05	0.02	65	355	1.4	1.37	1.6	0.01	9	47	0.069	158
boiler	300	39.6	35	0.29	0.01	220	7	2.2	-	0	0	6	14	0.142	325
Scotch	200	21.0	34	0.97	0	210	11	2.3	-	5.6	0.02	52	21	0.14	320
marine	350	85.3	33	0.42	0	94	17	7.2	-	0	0	3	72	0.014	32
boilers															
Water tube	100	6.1	29	0.71	0	290	98	0.5	0.64	1.4	0	5	36	0.071	163
boiler	200	9.7	35	0.55	0	370	trace	-	-	0	0.002	8	55	0.10	229
	245	23.1	33	0.21	0.07	115	102	1.3	-	0.5	0.002	7	63	0.041	94
Oil heater	-	5.2	34	0.80	0	120	138	0.4	-	2.8	0.002	11	34	0.073	167
							Number 1 Fuel Oil								
Scotch marine boiler	150	15.3	40	0.09	0	150	28	0.5	0.19	1.7	0.001	5	20	0.038	87
Ceramic	-	10.0	45	trace	0	21	0	0	-	0	0.04	3	27	0.004	9
kiln	-	20.0	45	trace	0	373	trace	-	-	0	0	3	20	0.038	87
							Heavy Fuel Oil								
Firetube boiler	120	36.3	16	1.0	0	68	414	7.5	5.3	4.7	0.003	7	368	0.074	169
Scotch marine boiler	125	23.1	11	1.78	0.18	180	264	5.0	7.4	3.2	0	9	128	0.11	252
Water tube	245	99.4	11	0.44	0.13	43	397	17.3	-	0.4	0	8	387	0.064	146
boiler	425	160.0	8	3.06	0	110	700	75.0	83.0	6.7	0.001	4	275	0.28	640
	460	80.5	12	0.78	0.12	107	362	17.6	10.4	2.2	0	7	199	0.039	89
	500	248.0	15	1.39	0.04	92	594	79.0	55.5	3.6	0	17	256	0.045	103
	580	57.5	13	1.30	0.03	95	640	21.0	12.2	2.2	0	8	206	0.060	137
	670	168.0	9	1.94	0.03	73	344	27.2	55.2	1.2	0	48	256	0.096	220

SECTION 5 AN ESTIMATE OF VESSEL EXHAUST EMISSION LEVELS

5.1 GENERAL

This section presents preliminary estimates of the amount of pollutant emissions resulting from the operation of vessels and boats. As such, it constitutes an "emission inventory" of these sources. The estimates are based on fuel use data presented in Section 3.0 and emission estimates available in the literature. The emission indices are given in the form of lbs of pollutant per 1000 lbs of fuel used by a vessel. This was required for the following reasons:

1. Since all fuel on a ship is drawn from a single tank, it is impossible at this stage of the program to evaluate the emission contributions of each engine on a multi-engined ship on an individual basis.

2. Considering diesel engines, it is generally assumed that emission measurements are "scalable", i.e. measurements made on small engines can be directly scaled to larger engines. Based on this assumption, it is of little concern whether the pollutants originate in the main or auxiliary engines.

3. Estimates of the potential impact of pollutants can then be based on a mission profile of each class, and emission indices scaled accordingly.

4. It is possible, using this approach, to make use of available fuel consumption data. It should be stressed that an emission measurements program is a necessity in order to evaluate the individual contributions of each engine and arrive at a more meaningful emission index (gms/bhp-hr) for Coast Guard use.

5.2 A PRELIMINARY INVENTORY OF EMISSIONS

Diesel Engine Emission Indices - The only manufacturers' data available on emissions from marine diesels per se were obtained from MAN Corp. (Table 20). These measurements were made with Drager length-of-stain tubes and are accurate at best to ±20%. No reliable data are available on emissions from other diesel engines specifically configured for marine use.

The emission estimates for diesel engines given in this report are based on recent published data obtained from General

Motors. These data were used because:

1. There were recently obtained using SAE techniques approved for compliance testing of 1973 diesel emission standards.

2. It pertains to the GM 6-71 engine, one version of a common engine in the Coast Guard fleet.

The emission index for particulate matter is taken from data published by HEW.[20] For diesel engines, the following indices were used based on fuel consumed:

HC - 3.3 lbs/1000 lbs of fuel
NO - 50 lbs/1000 lbs
CO - 20 lbs/1000 lbs
SO_x - 7 lbs/1000 lbs (Based on 0.25% Sulphur fuel)
Part - 15.8 lbs/1000 lbs

Emission Indices for Oil Fired Steam Boilers - For oil fired steam boilers, the emission indices are in agreement with a report of the San Francisco Bay Area APCD.[32] It should be stressed that this estimate is based on the use of Bunker C fuel. The indices are as follows based on fuel consumed:

HC - 1.8 lbs/1000 lbs of fuel
NO_x - 11 lbs/1000 lbs
CO - 21 lbs/1000 lbs
SO_x - 21 lbs/1000 lbs
Part - 3.2 lbs/1000 lbs

Emissions Attributed to the Cutter Fleet - Table 23 shows average yearly emissions for a typical vessel in each class. Figure 15 depicts the amount of pollutants emitted each year, by cutter type. Using these figures a total pollutant output by the cutter fleet is given in Table 24.

TABLE 23. TYPICAL AVG. YEARLY EMISSIONS PER VESSEL OF CG DIESEL CUTTERS FULL USAGE IN 1000 GALLONS AND 1000 LBS

Class	Fuel $galX10^{-3}$ Usage $lbsX10^{-3}$	HC	NO	CO	SO_x	Part
		EMISSION RATES FOR DIESEL FUEL				
		$\frac{3.3\ lbs}{1000\ lbs}$	$\frac{50\ lbs}{1000\ lbs}$	$\frac{20\ lbs}{1000\ lbs}$	$\frac{7\ lbs}{1000\ lbs}$	$\frac{15.8\ lbs}{1000\ lbs}$
		Emissions lbs/year				
WHEC 378	$9.5X10^2-7X10^3$	$2.3X10^4$	$3.5X10^5$	$1.4X10^5$	$4.9X10^4$	$1.1X10^5$
311	$5.2X10^2-3.6X10^3$	$1.1X10^4$	$1.8X10^5$	$7.2X10^4$	$2.5X10^4$	$5.7X10^4$
WAGB 310	$1.9X10^3-1.33X10^4$	$4.4X10^4$	$6.6X10^5$	$2.7X10^5$	$9.3X10^4$	$2.1X10^5$
290	$4.2X10^2-2.9X10^3$	$9.6X10^3$	$1.45X10^5$	$5.8X10^4$	$2.3X10^4$	$4.5X10^4$
269	$7.8X10^2-5.5X10^3$	$1.8X10^4$	$2.75X10^5$	$1.1X10^5$	$3.85X10^4$	$8.7X10^4$
230	$2.9X10^2-2.03X10^3$	$6.7X10^3$	$1.0X10^5$	$4.1X10^4$	$1.4X10^4$	$3.2X10^4$
WMEC 213	$1.7X10^2-1.2X10^3$	$4.0X10^3$	$6X10^4$	$2.4X10^4$	$8.4X10^3$	$1.9X10^4$
210A	$2.9X10^2-2.0X10^3$	$6.6X10^3$	$1.0X10^5$	$4X10^4$	$1.4X10^4$	$3.2X10^4$
210B	$1.9X10^2-1.33X10^3$	$4.4X10^3$	$6.6X10^4$	$2.6X10^4$	$9.3X10^3$	$2.1X10^4$
205	$1.5X10^2-1.05X10^3$	$3.4X10^3$	$5.25X10^4$	$2.1X10^4$	$7.35X10^3$	$1.7X10^4$
143	$1.05X10^2-7.35X10^2$	$2.4X10^3$	$3.7X10^4$	$1.5X10^4$	$5.1X10^3$	$1.2X10^4$
WPB 95A	$4X10^1-2.8X10^2$	$9.2X10^2$	$1.4X10^4$	$5.6X10^3$	$1.9X10^3$	$4.9X10^3$
95B	$3.7X10^1-2.6X10^2$	$8.6X10^2$	$1.3X10^4$	$5.2X10^3$	$1.8X10^3$	$4.1X10^3$
95C	$3.5X10^1-2.45X10^2$	$8.1X10^2$	$1.2X10^4$	$4.9X10^3$	$1.7X10^3$	$3.9X10^3$

TABLE 23. TYPICAL AVG. YEARLY EMISSIONS PER VESSEL OF CG DIESEL CUTTER (CONT)

Class	Fuel Usage galX10^{-3} lbsX10^{-3}	HC	NO_x	CO	SO_x	Part
82A	$3X10^{1}-2.1X10^{2}$	$6.9X10^{2}$	$1.05X10^{4}$	$4.2X10^{3}$	$1.5X10^{3}$	3.3X10
82C	$2.4X10^{1}-1.68X10^{2}$	$5.5X10^{2}$	$8.4X10^{3}$	$3.4X10^{3}$	$1.2X10^{3}$	$2.6X10^{3}$
82D	$1.8X10^{1}-1.3X10^{2}$	$4.3X10^{2}$	$6.5X10^{3}$	$2.6X10^{3}$	$9.1X10^{2}$	$2.0X10^{3}$
WYTM 110A	$4.2X10^{1}-2.9X10^{2}$	$9.6X10^{2}$	$1.45X10^{4}$	$5.8X10^{3}$	$2.0X10^{3}$	$4.6X10^{3}$
110B	$4X10^{1}-2.8X10^{2}$	$9.2X10^{2}$	$1.4X10^{4}$	$5.6X10^{3}$	$1.96X10^{3}$	$4.4X10^{3}$
85	4 $-2.8X10^{1}$	$9.2X10^{1}$	$1.4X10^{3}$	$5.6X10^{2}$	$1.96X10^{2}$	$4.4X10^{2}$
65A	$1.4X10^{1}-9.8X10^{1}$	$3.2X10^{2}$	$4.9X10^{3}$	$1.96X10^{3}$	$6.9X10^{2}$	$3.5X10^{3}$
65B	$1.06X10^{1}-7.4X10^{1}$	$2.4X10^{2}$	$3.7X10^{3}$	$1.5X10^{3}$	$5.2X10^{2}$	$1.2X10^{3}$
65C	$1.1X10^{1}-7.7X10^{2}$	$2.5X10^{2}$	$3.8X10^{3}$	$1.5X10^{3}$	$5.4X10^{2}$	$1.2X10^{3}$
65D	$1.15X10^{1}-8.0X10^{2}$	$2.6X10^{2}$	$4X10^{3}$	$1.6X10^{3}$	$5.6X10^{2}$	$1.3X10^{3}$
WAGO 311	$5X10^{2}$ $-3.5X10^{3}$	$1.1X10^{4}$	$1.7X10^{5}$	$7X10^{4}$	$2.4X10^{4}$	$5.5X10^{4}$
213	$2.6X10^{2}-1.8X10^{3}$	$5.9X10^{3}$	$9X10^{4}$	$3.6X10^{4}$	$1.3X10^{4}$	$2.8X10^{4}$
180	$2.2X10^{2}-1.54X10^{3}$	$5.1X10^{3}$	$7.7X10^{4}$	$3.1X10^{4}$	$1.1X10^{4}$	$2.4X10^{4}$
WAK 339	$4.1X10^{2}-2.9X10^{3}$	$9.6X10^{3}$	$1.45X10^{5}$	$5.8X10^{4}$	$2.0X10^{4}$	$4.6X10^{4}$
WLB 180A	$1.1X10^{2}-7.7X10^{2}$	$2.5X10^{3}$	$3.8X10^{4}$	$1.5X10^{4}$	$5.4X10^{3}$	$1.2X10^{4}$
180B	$1.2X10^{2}-8.4X10^{2}$	$2.7X10^{3}$	$4.2X10^{4}$	$1.7X10^{4}$	$5.9X10^{3}$	$1.3X10^{4}$
180C	$1X10^{2}$ $-7X10^{2}$	$2.3X10^{3}$	$3.5X10^{4}$	$1.4X10^{4}$	$4.9X10^{3}$	$1.2X10^{4}$

TABLE 23. TYPICAL AVG. YEARLY EMISSIONS PER VESSEL OF CG DIESEL CUTTER (CONT)

Class	Fuel Usage gal$\times10^{-3}$ lbs$\times10^{-3}$	HC	NO_x	CO	SO_x	Part
WLM 177	$5.2\times10^{1}-3.6\times10^{2}$	1.2×10^{3}	1.8×10^{4}	7.2×10^{3}	2.5×10^{3}	5.7×10^{3}
175	$7.8\times10^{1}-5.5\times10^{2}$	1.8×10^{3}	2.75×10^{4}	1.1×10^{4}	3.85×10^{3}	8.7×10^{4}
157	$5\times10^{1}-3.5\times10^{2}$	1.15×10^{3}	1.75×10^{4}	7.0×10^{3}	2.45×10^{3}	5.5×10^{3}
133	$3.9\times10^{1}-2.7\times10^{2}$	8.9×10^{2}	1.3×10^{4}	5.4×10^{3}	1.9×10^{3}	4.3×10^{3}
WLI 122	$3.2\times10^{1}-2.2\times10^{2}$	7.3×10^{2}	1.1×10^{4}	4.4×10^{3}	1.5×10^{3}	3.5×10^{3}
100A	$2.4\times10^{1}-1.7\times10^{2}$	5.6×10^{2}	8.5×10^{3}	3.4×10^{3}	1.2×10^{3}	2.7×10^{3}
100B	$1.9\times10^{1}-1.3\times10^{2}$	4.4×10^{2}	6.6×10^{3}	2.6×10^{3}	9.3×10^{2}	2.1×10^{3}
80	$1.5\times10^{1}-1.05\times10^{2}$	3.5×10^{2}	5.2×10^{3}	2.1×10^{3}	7.35×10^{2}	1.66×10^{3}
74	$1.6\times10^{1}-1.1\times10^{2}$	3.6×10^{2}	5.5×10^{3}	2.2×10^{3}	7.7×10^{2}	1.7×10^{3}
65302, 65303, 65400	$9.5-6.65\times10^{1}$	2.2×10^{2}	3.3×10^{3}	1.3×10^{3}	4.6×10^{2}	1.05×10^{3}
WLIC 75A	$2.1\times10^{1}-1.5\times10^{2}$	4.9×10^{2}	7.5×10^{3}	3.0×10^{3}	1.05×10^{3}	2.4×10^{3}
75'B	$3.1\times10^{1}-2.2\times10^{2}$	7.3×10^{2}	1.1×10^{4}	4.4×10^{3}	1.5×10^{3}	3.5×10^{3}

TABLE 23. TYPICAL AVG. YEARLY EMISSIONS PER VESSEL OF CG DIESEL CUTTER (CONT)

Class	Fuel gal$X10^{-3}$	Usage lbs$X10^{-3}$	HC	NO_x	CO	SO_x	Part
WLIC 75D	$3.6X10^{1}$	$2.5X10^{2}$	$8.25X10^{2}$	$1.25X10^{4}$	$5.0X10^{3}$	$1.75X10^{3}$	$3.9X10^{3}$
WLR 115	$5.4X10^{1}$	$3.8X10^{2}$	$1.25X10^{3}$	$1.9X10^{4}$	$7.6X10^{3}$	$2.7X10^{3}$	$6X10^{3}$
114	$6.7X10^{1}$	$4.7X10^{2}$	$1.5X10^{3}$	$2.3X10^{4}$	$9.4X10^{3}$	$3.3X10^{3}$	$7.4X10^{3}$
104	$4.7X10^{1}$	$3.3X10^{2}$	$1.1X10^{3}$	$1.65X10^{4}$	$6.6X10^{3}$	$2.3X10^{3}$	$5.2X10^{3}$
80	$6.5X10^{1}$	$4.5X10^{2}$	$1.5X10^{3}$	$2.25X10^{4}$	$9.0X10^{3}$	$3.15X10^{3}$	$7.1X10^{3}$
75	$4X10^{1}$	$2.8X10^{2}$	$9.2X10^{2}$	$1.4X10^{4}$	$5.6X10^{3}$	$1.96X10^{3}$	$4.4X10^{3}$
73	$1.8X10^{1}$	$1.26X10^{2}$	$4.2X10^{2}$	$6.3X10^{3}$	$2.5X10^{3}$	$1.1X10^{3}$	$2.0X10^{3}$
65	$3.1X10^{1}$	$2.2X10^{2}$	$7.3X10^{2}$	$1.1X10^{4}$	$4.4X10^{3}$	$1.5X10^{3}$	$3.5X10^{3}$
WLV 149	$4.8X10^{1}$	$3.4X10^{2}$	$1.1X10^{3}$	$2.4X10^{4}$	$9.6X10^{3}$	$3.4X10^{3}$	$7.6X10^{3}$
133	$4.2X10^{1}$	$2.9X10^{2}$	$9.6X10^{2}$	$1.45X10^{4}$	$5.8X10^{3}$	$2.0X10^{3}$	$4.6X10^{3}$
128	$3.6X10^{1}$	$2.5X10^{2}$	$8.25X10^{2}$	$1.25X10^{4}$	$5.0X10^{3}$	$1.75X10^{3}$	$3.7X10^{3}$
115	$2.6X10^{1}$	$1.8X10^{2}$	$5.9X10^{2}$	$9X10^{3}$	$3.6X10^{3}$	$1.3X10^{3}$	$2.8X10^{3}$
WIX 295	$7X10^{1}$	$4.9X10^{2}$	$1.6X10^{3}$	$2.45X10^{4}$	$9.8X10^{3}$	$3.4X10^{3}$	$7.7X10^{3}$
125	$4.5X10^{1}$	$3.15X10^{2}$	$1.0X10^{3}$	$1.6X10^{4}$	$6.3X10^{3}$	$2.2X10^{3}$	$5.0X10^{3}$
WTR 311	$4.2X10^{2}$	$2.9X10^{3}$	$9.6X10^{3}$	$1.45X10^{5}$	$5.8X10^{4}$	$2.0X10^{4}$	$4.6X10^{4}$

TABLE 23. TYPICAL AVG. YEARLY EMISSION PER VESSEL OF CG STEAM SHIP (CONT)

			Emission Rates for Residual Oil				
Class	Fuel gal	Usage lbs	HC	NO_x	CO	SO_x	Part
			9.8 lbs / 1000 lbs	11 lbs / 1000 lbs	2 lbs / 1000 lbs	21 lbs / 1000 lbs	3.2 lbs / 1000 lbs
				Emission lbs/year			
WHEC 327	$9.7X10^2$	$7.8X10^3$	$1.4X10^4$	$8.6X10^4$	$1.5X10^4$	$1.6X10^5$	$2.5X10^4$
311	$5.2X10^2$	$4.2X10^3$	$7.5X10^3$	$4.6X10^4$	$8.4X10^3$	$8.8X10^4$	$1.3X10^4$
WLM 173	$2.3X10^2$	$2.3X10^3$	$4.1X10^3$	$2.5X10^4$	$4.6X10^3$	$4.8X10^4$	$7.4X10^3$

TABLE 24. TOTAL USCG CUTTER ANNUAL EMISSIONS

HC - 1.08 x 10^6 lbs/year
NO_x - 1.45 x 10^7 lbs/year
CO - 5.5 x 10^6 lbs/year
SO_x - 4.2 x 10^6 lbs/year
Part. - 4.6 x 10^6 lbs/year

Fuel usage by heating boilers was not treated separately in the previous estimates. Comparisons with in-port fuel use data indicate that heating boiler consumption amounted to generally less than 10% of the total fuel used. Any error arising from this factor should, therefore, be insignificant.

50% of all the emissions by the Coast Guard cutter fleet are due to the WHEC. Approximately 80% of these pollutants are emitted on the open sea; their impact on air quality is insignificant. Of more concern is the effect of close-to-shore and in-port emissions on the local environment. This will be covered below in more detail.

Emissions from Coast Guard Boats - Boat fuel usage comprises only 3.4% of the total fuel used by the Coast Guard fleet, and no effort was made to evaluate the resultant emissions on a "type" basis. Obviously, the emissions as a function of boat type are directly related to the rate of fuel consumption. In this regard, 86% of the emissions arise from the 44 MLB, the 40 UTB, the 30 UTM and the Buoy boats. Table 25 lists the annual emissions from all boats in the Coast Guard fleet, using the emission indices for diesel engines established earlier.

TABLE 25 EMISSIONS FROM COAST GUARD BOATS

FUEL USAGE		EMISSION LBS PER YEAR				
galx10^{-3}	(lbsx10^{-3})	HC	NO_x	CO	SO_x	PART.
1.6x10^3	(1.1x10^3)	3.6x10^4	5.5x10^5	2.2x10^5	7.7x10^4	1.7x10^5

Emissions from the Merchant Fleet - Using the fuel data from Section 3 for all vessels, Table 26 tabulates the annual emissions arising from all vessels in the merchant fleet.

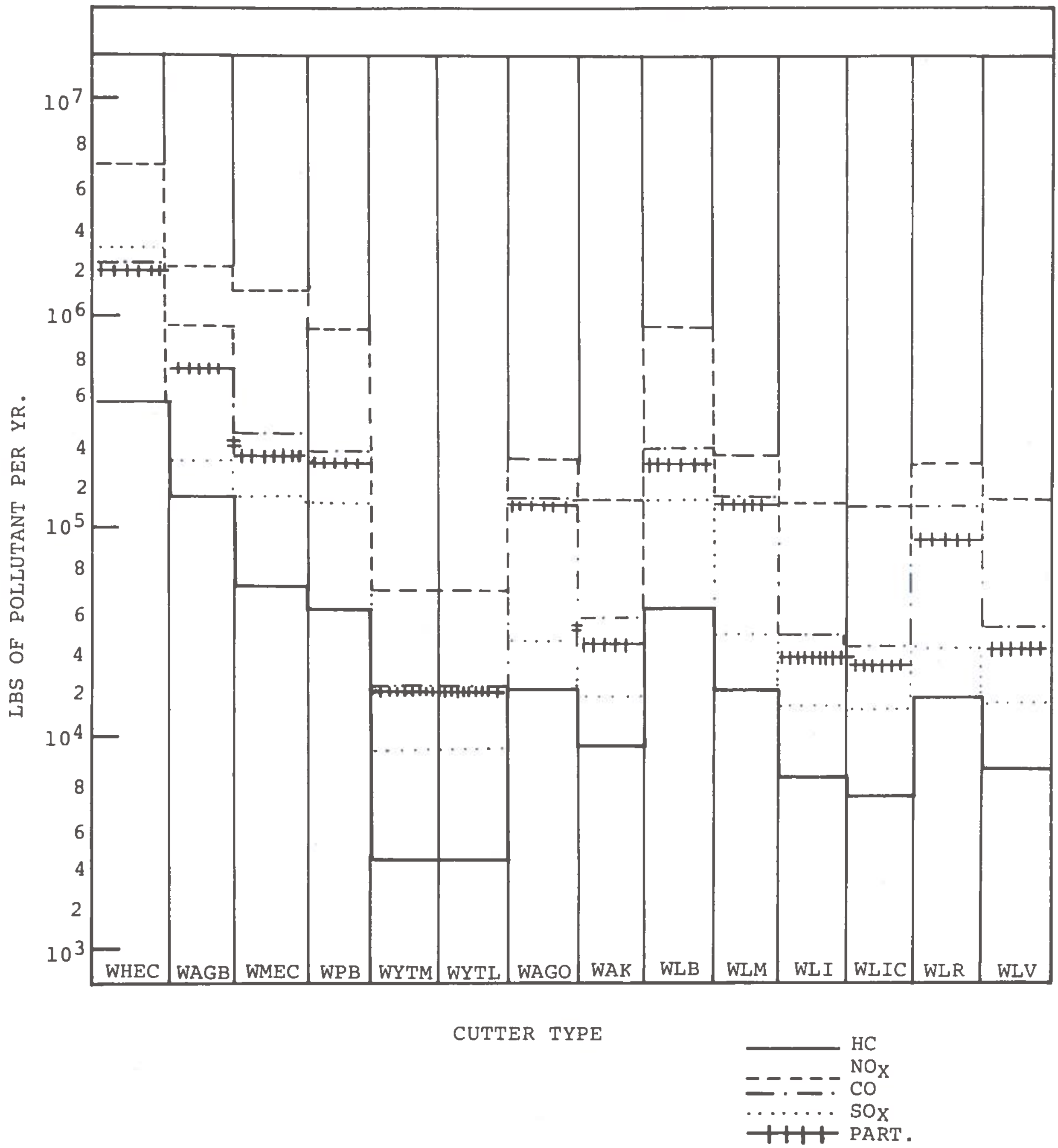


Figure 15. Yearly Emissions By Cutter Type

TABLE 26 EMISSIONS FROM MERCHANT VESSELS

FUEL TYPE	FUEL USAGE	EMISSIONS LBS/YEAR				
Vessel	$LBSX10^{-3}$	HC	NO_x	CO	SO_x	PART.
Bunker C, Vessels Over 1000 tons	$2.2X10^7$	$4X10^7$	$2.4X10^8$	$4.4X10^7$	$4.6X10^8$	$7x10^7$
Bunker C, Vessels Less than 1000 tons	$2.4X10^6$	$4.3X10^6$	$2.6X10^7$	$4.8X10^6$	$5X10^7$	$7.7X10^6$
Distillate, Vessels Less than 1000 tons	$4.7X10^6$	$1.5X10^7$	$2.3X10^8$	$9.4X10^7$	$3.3X10^7$	$7.4X10^6$

For vessels over 1000 tons, the emission levels for each design type directly follow the fraction of the total fuel used by these vessels, as given in Table 19.

5.3 EMISSION IMPACT

Table 27 indicates that slightly less than 3% of the emissions from all U.S. vessels (excluding outboards) can be attributed to the United States Coast Guard. It should be noted that this estimate does not include the 3000 ships of the U.S. Navy. Inclusion of these ships would substantially lower the relative contribution of Coast Guard vessels. On a nationwide basis all vessels contribute less than 1% of the total pollutants from all modes of transportation (according to a 1968 emission inventory performed by HEW). The national picture does not present a true indication of emission impact. This can best be accomplished by consideration of the Coast Guard Fleet emissions on a local basis.

The First Coast Guard District, and the Boston area in particular, were chosen for this impact assessment since data was readily available and 23% of all the fuel used by the Coast Guard fleet occurs in the 1st District. This would represent the worst possible case of adverse emission impact.

Table 28 is taken from a report for the Massachusetts State Department of Health[33] describing the annual fuel usage in the Boston Metropolitan Air Pollution Control District (MAPCD) (Fig. 16). Using this data, an emission inventory of all sources in the MAPCD is given in Table 29. The emission indices used are taken from HEW [16, 20, 21, 22, 23]. In order to assess the contribution of the CG fleet to pollution within the MAPCD, a survey of emissions from the Boston group (only) of the 1st District was undertaken. Table 30 presents the results of that survey, made with the following assumptions:

TABLE 27 EMISSION IMPACT OF CG VESSELS

Source	lbs of Pollutants per year	Percent of Pollutants per year
USCG Cutters	$3X10^7$	2.2
USCG Boats	$1X10^6$	0.074
Merchant Marine (>1000 tons)	$8.5X10^8$	63
Merchant Vessels	$4.7X10^8$	34.8
Total All Vessels $1.35X10^9$ lbs of Pollutants per year		
Total - All Transportation In U.S. 1.5X10"		
(Vessels Comprise ∿ 1% of All Transportation Sources Of Emissions)		

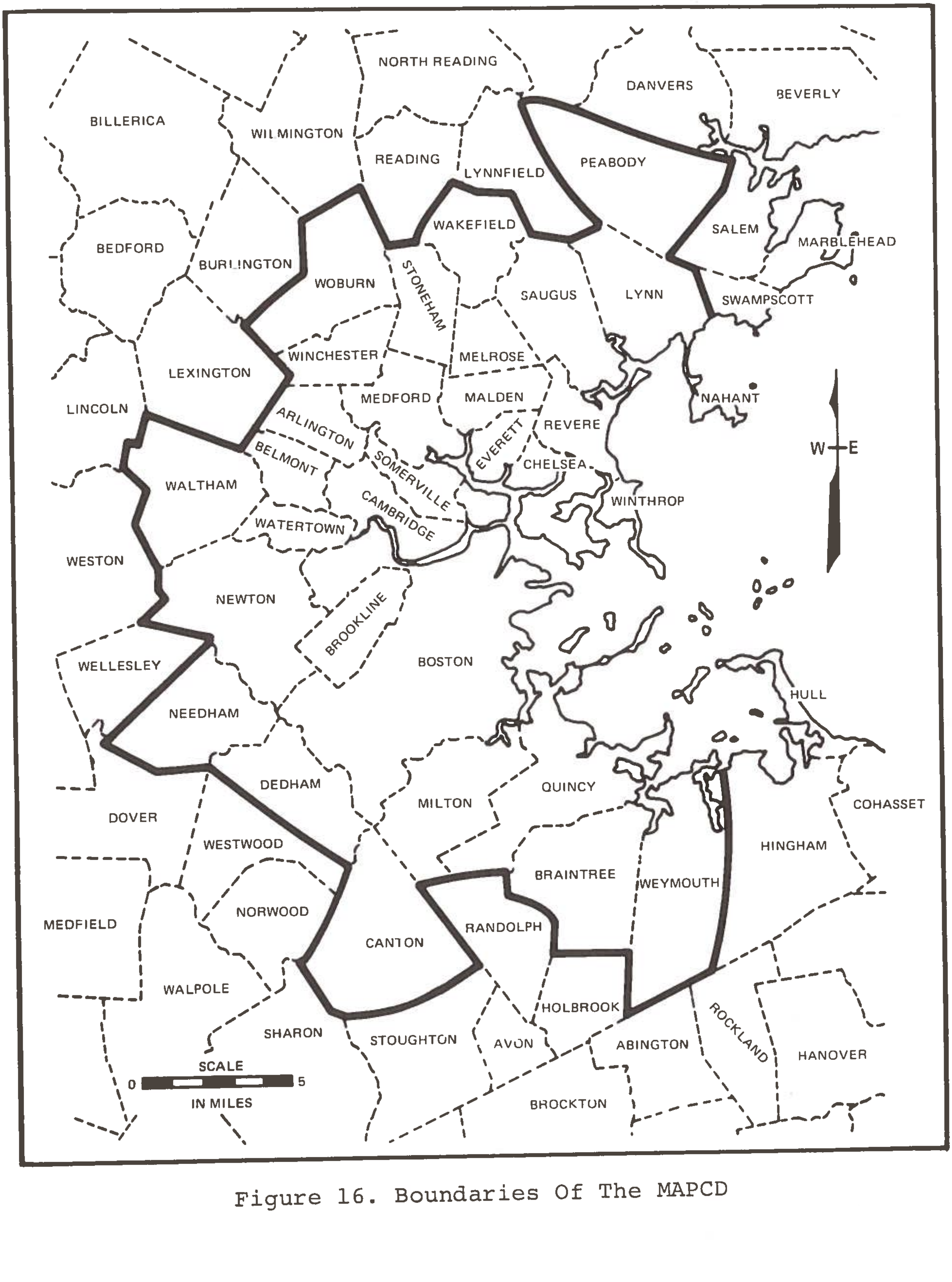


Figure 16. Boundaries Of The MAPCD

TABLE 28. SUMMARY OF ANNUAL (1966) FUEL USE IN BOSTON MAPCD

CATEGORY	COAL (tons)	COKE (tons)	RESIDUAL OIL ($x10^{-6}$ gal)	DISTILLATE OIL ($x10^{-6}$ gal)	NATURAL GAS ($x10^{-9}$cu ft)
Residential Heating	171,712	0	0	750.93	12.863
Commercial					
Area sources	58,565	0	417.18	134.83	11.501
Point sources	8,000	0	19.37	0.02	0.207
Manufacturing					
Area sources	85,650	4361	132.08	31.57	3.349
Point sources	260	0	64.03	1.03	0.118
Steam-electric Utilities	22,340	0	730.48	0	4.099
Transportation Facilities					
Rapid transit	0	0	21.90	0	0
Airport	0	0	1.26	0	0
Railroads	32,350	0	0.08	0	0
TOTALS	378,877	4361	1386.38	918.38	32.200
Automotive	QUANTITY ($x10^{-6}$ gal)				
Gasoline	492.66				
Diesel	14.78				

TABLE 29. EMISSION INVENTORY FOR BOSTON MAPCD BASED ON 1966 FUEL USAGES

		Emission Index					Emissions				
Fuel	Usage	lbs/10³ lbs					lbs/yr				
Type	lbs/yr	HC	NO_x	CO	SO_x	Part	HC	NO_x	CO	SO_x	Part.
Coal	$7.6X10^8$	.5	10	1.5	19	8	$3.8X10^5$	$7.6X10^6$	$1.1X10^6$	$1.4X10^7$	$6.1X10^6$
Coke	$8.8X10^6$	.5	10	1.5	19	8	$4.4X10^4$	$8.8X10^5$	$1.3X10^5$	$1.7X10^6$	$7X10^5$
Res Oil	$1.1X10^{10}$	.3	13	.3	29(1%)	1.4	$3X10^6$	$1.4X10^8$	$3X10^6$	$3.2X10^8$	$1.5X10^7$
Dis Oil	$5.7X10^9$	.3	10.5	.3	14.5(5%)	1.1	$1.7X10^6$	$6X10^7$	$1.7X10^6$	$8X10^7$	$6.3X10^6$
		Emission Index					Emissions				
Fuel	Usage	lbs/10⁶ft³					lbs/yr				
	ft³/yr		NO_x	CO	SO_x	Part	HC	NO_x	CO	SO_x	Part.
Nat Gas	$3.2X10^{10}$		214	.4	.4	15		$6.8X10^6$	$1.3X10^4$	$1.3X10^4$	$4.8X10^5$
		Stationary Totals					$5.1X10^6$	$2.1X10^8$	$5.9X10^6$	$4.2X10^8$	$2.9X10^7$
Mobile		Emission Index					Emissions				
Fuel	Usage	lbs/10³lbs					lbs/yr				
Type	lbs/yr	HC	NO_x	CO	SO_x	Part	HC	NO_x	CO	SO_x	Part
Gasoline	$3.35X10^9$	56	23.5	264	1.3	1.8*	$1.9X10^8$	$7.9X10^7$	$8.8X10^8$	$4.3X10^6$	$6X10^6$
Diesel	$1X10^8$	3.3	50	20	7	15.8	$3.3X10^5$	$5X10^6$	$2X10^6$	$7X10^5$	$1.6X10^6$
				Mobile Totals			$1.9X10^8$	$8.4X10^7$	$8.8X10^8$	$5X10^6$	$7.6X10^6$
				Total All Sources			$2.0X10^8$	$2.9X10^8$	$8.9X10^8$	$4.25X10^8$	$3.7X10^7$

*Based On 1970 Avg. Car Driven In Urban Traffic

TABLE 30 EMISSION INVENTORY OF BOSTON CG FLEET IN BOSTON MAPCD

(PRELIMINARY ESTIMATE)

Type	Fuel Usage	Fuel Usage	Fuel Usage	Emissions				
	Port	Other	Total			lbs/yr		
	gal/yr	gal/yr	lbs/yr	HC	NO_x	CO	SO_x	Part
WHEC-D	$2.95X10^5$	-	$2.1X10^6$	$6X10^2$	$2.2X10^4$	$6X10^2$	$3X10^4$	$2.3X10^3$
WHEC-S	$5.4X10^5$ (NS)	-	$4.3X10^6$	$7.7X10^3$	$4.7X10^4$	$8.6X10^3$	$9X10^4$	$1.4X10^4$
WAGB	$1.25X10^5$	-	$8.7X10^5$	$2.8X10^2$	$9X10^3$	$2.8X10^2$	$1.3X10^4$	$9.6X10^2$
WAGO	$2.2X10^4$	-	$1.5X10^5$	$4.5X10^1$	$1.6X10^3$	$4.5X10^1$	$2.2X10^3$	$1.65X10^2$
WLB	$2.2X10^4$	$4.6X10^4$ (1)	$4.76X10^5$	$1.05X10^3$	$1.8X10^4$	$6.5X10^3$	$4.4X10^3$	$5.3X10^3$
WLM	$1.6X10^4$	$1.0X10^4$ (1)	$1.8X10^5$	$2.6X10^2$	$4.7X10^3$	$1.4X10^3$	$2.1X10^3$	$2.2X10^3$
WYTL	$2.2X10^3$	$7.1X10^3$ (2)	$6.5X10^4$	$1.65X10^2$	$2.6X10^3$	$9.85X10^2$	$5.6X10^2$	$7.9X10^2$
WLV	$1.1X10^4$	$2.8X10^4$ (3)	$2.7X10^5$	$6.4X10^2$	$1X10^4$	$3.8X10^3$	$2.4X10^3$	$3.1X10^3$
Boats (4)	-	$4X10^4$ (4)	$2.8X10^5$	$2.8X10^3$	$1.4X10^4$	$5.6X10^3$	$2.0X10^3$	$4.4X10^3$
Totals	$1.03X10^6$	$1.3X10^5$	$8.7X10^6$	$1.3X10^4$	$1.3X10^5$	$2.8X10^4$	$1.4X10^5$	$3.3X10^4$

D - Diesel
S - Steam
NS - Navy Special Fuel

(1) Assume 50% of underway fuel usage in BMAPCD
(2) 100% of underway fuel usage in BMAPCD
(3) 100% station fuel WLV 539
10% station fuel WLV 613
(4) 100% fuel usage of 54 boats assigned Boston Group

1. All in-port fuel used by cutters is burned in hotel service boilers;

2. 50% of the underway fuel usage by sea-going and coastal buoy tenders is within the MAPCD;

3. All the fuel used by harbor tugs is burned within the MAPCD;

4. All the fuel usage of the Boston Light Ship and 10% of that of the Relief Light Ship contribute emissions to the MAPCD;

5. All the fuel used by the 54 boats assigned to the Boston Group is consumed within the MAPCD.

Analysis of fuel records and operational status of Boston vessels, along with consideration of the Boston climate and topology, indicate that this emission inventory might bias the data on high side - i.e. project more emissions than actually exist. In all cases, the contribution of the Coast Guard fleet amounts to less than .1 to .01% of the total emission of each pollutant within the MAPCD.

SECTION 6 INSTRUMENTATION AND MEASUREMENT TECHNIQUES

6.1 BACKGROUND

Measurements of Coast Guard vessel exhaust emissions are an essential requirement in compliance with Presidential Executive Orders to evaluate pollution stemming from Federal government activities. Exhaust emission rates from large and small vessels are undefined at the present time. Hence, it is difficult to quantitatively assess the impact of these emissions on the local environment, whether the emissions originate from a small pleasure craft or a large ocean going vessel. It is even more difficult to estimate the impact of vessel exhaust emissions on the global environment.

Vessels currently in use do not generally employ control devices to reduce emissions. Thus, a measurement program at this time is needed to produce base line data on "uncontrolled" vessel exhaust emissions and determine the need for control of the emissions.

The emission rates from vessels obtained from a field measurement program will be directly usable in local and global air pollution inventories. These measured emissions will define the contribution to air pollution arising from the Coast Guard fleet in particular and provide a sound basis for estimating total vessel exhaust pollution. If these emissions are considered excessive, the measurements will serve as guidelines for the enactment of vessel powerplant source performance standards. Also the measured emission rates will be utilized as basic design criteria in the formulation of an effective emission control strategy. These data are expected to be utilized in the design of new vessels and the definitation of new or improved mission profiles.

6.2 EXHAUST EMISSIONS TO BE CONSIDERED

Air pollutants known to be emitted from combustion of fossil fuel are carbon monoxide, hydrocarbons, nitrogen oxides, sulfur oxides, and particulates. "Smoke" is the visual effect of large concentrations of particulate matter. These air pollutants are all present, to some degree, in the Coast Guard fleet's exhaust.

Certain emissions from fossil fuel combustion are not, at present, the subject of source performance or ambient air quality standards. These pollutants are currently under study in an attempt to assess their potential or real health hazard, and possible control methods. Emissions from Coast Guard vessels that may be termed "undefined" air pollutants include polycylic aromatic hydrocarbons (PAH), submicron diameter particulate matter, odorous compounds, and reactive organic compounds. Benzo - α - pyrene is a PAH and is also a carcinogen. This compound and its close relatives have been identified in soot, smoke and fuel combustion products of diesel and gasoline engines, and many other substances.[34] Submicron particles are known to penetrate and be deposited in the pulmonary structure of the respiratory tract.[15] The effect of this deposition is not fully understood at this time, but it may contribute to respiratory disease. Odorous compounds are pollutants that elicit unwanted physical and mental responses. Reactive organics are of interest for their role in atmospheric photochemical reactions (the smog forming reactions).

It is expected that some efforts will be directed toward characterizing, within the Coast Guard fleet, sources of "undefined" air pollutants in addition to "defined" pollutants.

6.3 GENERAL EXPERIMENTAL CONSIDERATIONS

Vessel Exhaust Properties - Consideration must be given to the physical and chemical composition of the exhaust stream. Factors such as gas temperature, pressure, volumetric flow, and concentrations of water vapor, oxygen, and pollutant dictate sampling conditions and the type of instruments that can be used for performing the required measurements. Measurement of the concentrations of water, oxygen, carbon dioxide and pollutant, in addition to fuel flow, are essential to the determination of the power plant's air to fuel ratio and hence volumetric flow rate.

Fuel - The properties of the fuel burned by an engine or boiler are factors in determining the exhaust emissions. An ASTM fuel analysis will be performed on each fuel batch to ascertain the combustion properties, the sulfur and ash content, the percent of olefinic and aromatic content, and the stoichiometric combustion relationship. The fuel consumption of the power plant under investigation will be obtained by direct measurement.

Specific Vessel - The vessel design and mission dictate the duty cycle of the engines and boilers. Thus, representative test cycles will be defined for each class of Coast Guard vessel by examining data from ships' logs. A principal objective of using the test cycle is to obtain emission measurements during conditions simulating all phases of actual vessel operation.

Instrument Mounting - The marine environment requires special attention in selecting and packaging the measurement equipment. Consideration must be given to the temperature, humidity, moisture, corrosion, shock and vibration that may be encountered in the shipboard environment.

The exact physical dimensions of the instrument package cannot be specified at this writing. It is anticipated that six to eight continuous monitoring instruments will be employed, along with a central data recorder. The basic packaging design will center upon weatherproofed modular cases for each instrument. The individual instruments will be shock mounted in their respective cases. The cases will have provisions for mounting on a base plate that is fixed to the deck of the vessel, and for stack mounting one case upon another. The modular cases will provide the flexibility required for employing the instrument package on all classes of vessels by only changing the base plate configuration.

It is anticipated that all instruments will use 115 volt AC single phase power. Some instruments will require calibration gases stored in compressed gas cylinders. Provisions will be made for the shipboard stowage of these cylinders.

An important portion of the monitoring package is the sample probe and transport line. This equipment will be designed to minimize sampling bias, and losses due to coagulation, condensation, and diffusion.

6.4 MEASUREMENT METHODS

6.4.1 Sampling Methods

Exhaust gas streams can be sampled by three basic techniques.[35] The first is the "grab" sample technique, which utilizes a plastic bag or other container to retain a specific volume of exhaust sample. The sample is then analyzed by auxiliary equipment which may consist of glassware, for a wet chemical analysis, or some automatic instrument. The surface to volume ratio of the bag and the duration of sample containment before analysis are important factors in determining the accuracy of the analysis. Clearly, the number of data points obtainable in a given period of time is limited.

The time average collection method is another sampling technique. This method is characterized by collecting a particular pollutant from the exhaust stream over a finite period of time and then performing analysis similar to grab sample technique. The average concentration of the pollutant over the sampling period is thus obtained. Time averaged collection is frequently used for the determination of atmospheric particle and sulfur dioxide concentrations.[36]

The third sampling technique involves the use of continuous monitoring instruments. The data obtained are essentially continuous in nature with good (a few seconds) time resolution. This method is generally used for the characterization of short duration phenomena and transients. It is difficult, if not impossible, to obtain peak concentrations of pollutants without employing continuous monitors. As expected, continuous monitors may require a larger capital investment than the grab or time average collection methods.

For this measurement program, it is anticipated that the majority of instruments will be continuous monitors, though some analysis of exhaust constituents of secondary interest will be done by grab sampling.

6.4.2 Instrument Parameters

In emission monitoring, it is desirable to employ standardized instruments and methods whenever possible. In selecting the detection principle, and hence the sampling technique, careful attention must be given to individual instrument parameters. Factors that must be considered include:

- Specificity - The method must respond only to the pollutant of interest in the presence of other substances likely to be encountered in the exhaust.

- Sensitivity and Range - The method must be sensitive to the expected pollutant and the anticipated range of concentrations.

- Stability - If the sample is to be collected, it must remain unaltered during the sampling interval and during the subsequent storage period.

- Precision and Accuracy - The results must be reproducible and represent the true pollutant concentration.

- Sample Averaging Time - The method must meet the above stated requirement for sample stability.

- Reliability and Feasibility - Instrument maintenance cost, analytical time and manpower requirements must be consistent with needs and resources.

  Continuous automatic instruments must fulfill the following additional requirements:

- Zero Drift and Calibration - Instrument drift over an operation period must be low enough to ensure reliability of the data. Calibration must be simple and straightforward, and ideally, automatic.

- Response, Lag, Rise, and Fall Time - The instrument must function rapidly enough to record accurately changes in pollutant concentration that occur over a period of a few seconds.

- Ambient Environment - The instrument must not be affected by the ambient environment or changes in such.

- Maintenance Requirements - The instrument must operate continuously over long periods with minimum "down time," maintenance time and maintenance cost.

- Data Output - The instrument must produce data in a recordable format and with minimum necessity for use of correction factors or human interruption.

6.4.3 Available Monitoring Techniques

Several methods are available for the measurement of the "defined" air pollutants. These pollutants may be measured by approved reference methods that have been tested by EPA's Air Pollution Control Office and accepted as industry standards. Below is a list of representative techniques available for the determination of a variety of pollutants, sampling methods and comments.

Sulfur dioxide

SO_2 Detection Principle	Sampling Method	Comments
Colorimeter-West Gaeke*	Grab or Time Average	Manual, wet chemical, one datum point per sample
Colorimetric	Continuous	$2-5K
Coulometric	Continuous	$2-5K
Flame Photometric	Continuous	$2-5K
Electrochemical	Continuous	$2-5K
Conductimetric	Continuous	$2-5K
Spectrophotometric	Continuous	$2-8K

*Accepted APCO Reference Method

Carbon monoxide is usually measured by non-dispersive infrared spectrometry (NDIR). Water vapor may interfere with the measurement and therefore must be removed in the sampling system.

CO Detection Principle	Sampling Method	Comments
NDIR*	Continuous	$2.5-5K
H_g Replacement	Continuous	$3K
Gas Chromatograph	Grab	$2-10K
Orsat	Grab	Wet chemical, Manual

*Accepted APCO Reference Method

Oxides of nitrogen measurement methods are nearly as numerous as those for sulfur dioxide.

NO_x Detection Principle	Sampling Method	Comments
Colorimetric*	Grab, Time Average	Wet Chemistry, Manual
Colorimetric	Continuous	$2-5K
Coulometric	Continuous	$2-5K
Electrochemical	Continuous	$2-5K
Chemiluminescent	Continuous	$2-6K

*Accepted APCO Reference Method

Total hydrocarbons have traditionally been measured with hydrogen flame ionization detectors (FID) similar to those used on gas chromatograph. As the name implies, hydrogen gas must be available for the operation of this instrument.

HC Detection Principles	Sampling Method	Comments
FID*	Grab, Continuous	$1-10K
Spectrophotometer	Grab, Continuous	$2-10K

Instruments for the determination of reactive organics in exhaust gases are not available in field models at this time.

Reactive Organics Detection Principle		
Chromatograph	Grab	Variable**

*Accepted APCO Reference Method
**Field instrument unavailable off the shelf.

Particulates frequently present several measurement problems, since the measurement techniques used determine the size range and composition that are measured. This arises from the fact that the diameters of particulate matter that exist in exhaust gases may span several orders of magnitude (10^{-7} to 10^{-2}cm). Measurement techniques available are compiled below:

Particulate Detection Principle	Sampling Method	Comments
Gravimetric-Filter*	Time Average	Manual
Gravimetric-Impingers	Time Average	Manual
Gravimetric-Crystal Oscillator	Time Average/Continuous	$5K
Light Scattering	Continuous	$3-8K
Electrostatic Precipitator	Continuous	$18-20K
Condensation-Light Scattering	Continuous	$7K
Electronic Mobility	Continuous, Grab	$4K-10K
Beta Absorption	Continuous	Unknown**
Opacity/Light Scattering*	Continuous	$1-2K

*Accepted APCO Reference Method
**Field unit unavailable off the shelf

In the definition of the air to fuel ratio of the power plant, the oxygen, carbon dioxide and water content of the exhaust must be determined. The techniques available are outlined below.

CO_2 Detection Principle	Sampling Method	Comments
NDIR	Continuous	$2.5-6K
Electrochemical	Continuous	$2-5K
Orsat	Grab	Manual, Wet Chemical

O_2 Detection Principle	Sampling Method	Comments
Paramagnetic	Continuous	$1-4K
Electrochemical	Continuous	$2-5K
Orsat	Grab	Manual, Wet Chemical

H_2O Detection Principle	Sampling Method	Comments
Dew Point	Continuous	$1/2-3K
Condensation-Gravimetric	Grab	Manual

The selection of specific instruments for the field monitoring package will be based upon the criteria previously mentioned, the cost, and the ease of integrating the entire package. This will be accomplished in the next phase of this project.

SECTION 7 EMISSION CONTROL TECHNOLOGY

7.1 GENERAL REMARKS

We are concerned with four basic types of power generation equipment: the diesel engine, the gas turbine engine, the steam engine and spark-ignited gasoline engines (both two and four stroke cycle). Sections 4 and 5 show quite clearly that, to a crude, first approximation, the amount of pollution which may be attributed to a single vessel or boat is directly proportional to the size of its engine(s). This statement, of course, neglects the contribution of hotel service equipment (heating, etc.) and auxiliary power generators but it is accurate enough for the preliminary considerations of this section. A good rule of thumb is that, for a displacement vessel (the usual case in the Coast Guard fleet), the power required by the vessel is governed by the following relationship:[37]

required power = (constant) $(\text{speed})^3$ (displacement).

For a small pleasure craft with a planing hull, the required power is approximately proportional to $(\text{speed})^{2.5}$.[38]

These two relationships must play an important role in the design of any cost-effective pollution control program. The efficiency (or utility, in a sense) of a merchant vessel is directly proportional to the product of its displacement and speed, and increased efficiency is best obtained by increasing the displacement of a vessel. This approach is preferable because increased displacement is only directly proportional to increased pollution, but additional speed causes a far greater increase in pollution, since: pollution $\sim (\text{speed})^3$, all other things being equal. The same is true of a typical pleasure craft equipped with an outboard motor, where, however, pollution $\sim (\text{speed})^{2.5}$.

7.2 CONTROL TECHNOLOGY - GENERAL

Man-made sources of emissions that cause or contribute to air pollution can be regulated by law. Legislation regarding emissions for these sources is formulated in order to require a reduction in emissions to a level that will not endanger public health or welfare. The reduction in emissions may be accomplished by establishing legal maximum emission rates, termed source performance standards. These standards, in conjunction with a knowledge of the uncontrolled emission rates, would serve as principal design criteria in the selection of source emission control methods and equipment.

Most air pollution emission control problems can be solved in several ways. In order to select the best method of reducing pollutant emissions to acceptable levels, each solution must be thoroughly evaluated. Factors that must be considered for each control method include: 1) capital investment, 2) maintenance cost, 3) operating expenses, 4) installation expense, 5) depreciation, 6) cost and method of waste disposal, and 7) customer acceptance. These factors, when evaluated with regard to the expected decrease in emission levels, determine the overall cost-effectiveness of the control method.

The properties of the gas stream to be treated must be also considered in selecting the proper control method and equipment. Temperature, moisture and volume flow rate are physical characteristics of the gas stream; pollutant characteristics such as composition, particle size distribution, concentration, corrosiveness, flammability and toxicity must also be considered. The environment in which the control device must operate is a further consideration. Clearly, each source must be considered on an individual basis when selecting the best control method and equipment.

Air pollutants related to vessels and boats are emitted from the combustion of fossil fuel. These emissions are associated with all fossil fuel combustion equipment such as forced or neutral draft boilers, gas turbines, gasoline and diesel engines.[16, 21, 22, 23] The power plants of the Coast Guard fleet are similar to many of the stationary or mobile sources that exist in large quantities in any industrial nation. Table 31 is a listing of the power plants used by the Coast Guard fleet with cross-reference to similar power plants which might be more familiar. Also listed are the pollutants emitted and control methods currently employed for non-marine sources. It is anticipated that most of these control techniques could, with proper emphasis being placed on the harsh operating environment, be adapted for marine service. The two-stroke cycle outboard motor is the only power plant in the fleet which is lacking in basic emission data and exhaust emission control technology.

7.3 EMISSION CONTROL BY SOURCE MODIFICATION

Modification of the combustion process may be the most direct, and desirable, yet expensive and time consuming method of reducing engine emissions. Nitrogen oxide formation can be inhibited by controlling peak flame temperatures and time temperature profiles in the combustion chamber.[39,40] This may be accomplished in a steam boiler by proper design of the fuel atomizer and by the choice of a fuel that is compatible with the atomizer. Correct maintenance of an optimum air to fuel ratio will minimize carbon monoxide, hydrocarbon, and particulate emissions.[41,42] These operating procedures are employed in large stationary steam boilers to minimize emissions and are directly applicable to some of the Coast Guard fleet.

TABLE 31. COAST GUARD POWER PLANTS AND SIMILAR NON-MARINE PLANTS

Power Plant		Emissions	Control Methods
Marine	Non-Marine	HC, CO, NO_x	Fuel and combustion modifications, scrubbers, electro-static precipitators
Large Steam	Stationary Steam	SO_x, Particulates	
Diesel			
2 cycle, small	Trucks	HC, CO, NO_x	Fuel and combustion modifications, air to fuel ratio, loading of engine
2 cycle, large	(locomotives)	SO_x, Particulates	
4 cycle,	Trucks + Locomotives		
Gas Turbine	Jet Aircraft	HC, CO, NO_x Particulates	Fuel and combustion modifications
Gasoline			
2 cycle	Outboard Pleasure Craft	HC, CO, Particulates Raw Fuel	Combustion and Fuel modifications (needs additional study)
4 cycle	Automobiles + Trucks	HC, CO, NO_x	Combustion and Fuel modifications, air to fuel ratio, possibility catalytic converters

Fuel injector design affects the hydrocarbon, carbon monoxide and particulate emissions from diesel engines. Most diesel injectors currently in use are designed with a small volume or "sac" at the injector top. Residual fuel remains in this volume after injection and is only partially oxidized. This partially oxidized fuel is exhausted and contributes significantly to the total hydrocarbon and particulate emissions of the engine. A low sac volume injector, which minimizes the fuel retained in the tip, is currently being marketed by at least one manufacturer.[19]

The air to fuel ratio and the load placed on a diesel engine are two important factors which help determine exhaust emission levels. Excess fuel yields increased hydrocarbon, carbon monoxide, and particulate emissions with a decrease in nitrogen oxide. This effect is readily apparent when the throttle of a turbocharged diesel is rapidly opened; a puff of smoke results from the momentary excess fuel mixture. This momentary decrease in air to fuel ratio is a result of the time required by the turbocharger to get up to speed and provide the additional air required at increased speed.

Increased load on a diesel engine may produce an air to fuel ratio that does not minimize pollutant emissions. This situation may be rectified by decreasing the load or by increasing the engine size.

The speed (rpm) at which an engine is operated and the timing in the fuel injection system determine the maximum burning time of the fuel-air mixture. Short combustion periods may increase hydrocarbon, carbon monoxide, and particulate emissions while reducing nitrogen oxide emissions. By increasing the combustion period, the inverse is true; nitrogen oxides are increased while the other emissions are reduced.[19]

Nitrogen oxide formation is at least partly a function of the peak flame temperature in the combustion chamber. These peak temperatures can be reduced by modifications of injector design, combustion chamber design and fuel properties. Precombustion chambers have been introduced by some diesel manufacturers to reduce pollutant emissions. This method allows a fuel rich mixture to partially burn before the mixture enters the combustion chamber. Peak flame temperatures are lowered, inhibiting nitrogen oxide formation. The flame temperatures are still high enough in the fuel deficient combustion chamber to consume most of the particulates, hydrocarbons, and carbon monoxide formed in the precombustion chamber.[30]

It is the opinion of diesel manufacturers that current and future emission standards can be met by modification of the combustion process and by reducing the maximum power output of a given size engine.[43]

Gas turbines used by the Coast Guard are similar to units used for aircraft and electrical power generators. Major exhaust pollutants emitted from gas turbines are particulates, hydrocarbons, oxides of nitrogen and carbon monoxide; to a much lesser extent sulfur dioxide.[44] Current and future control methods emphasize combustion modification. Again, by reducing peak flame temperatures, nitrogen oxides can be reduced and by increased mixing of the fuel and air, other pollutants can be reduced. Any emission reduction required on the Coast Guard's turbines can be accomplished by implementing the control techniques employed by the aircraft industry. The marine environment requires that special attention be given the actual hardware employed.

The Coast Guard employs both two-and four-stroke cycle gasoline engines in their boat fleet. Four-stroke cycle engines emit air pollutants similar to automobiles and here the basic control measures are conceptually similar. Current control methods used by the auto industry include air to fuel ratio adjustment, timing, compression ratio changes and use of lower octane fuel. Future auto emission control will probably include exhaust recirculation and catalytic converters.[43]

Two cycle outboard motors are specialized power plants for marine service. The Coast Guard boat fleet utilizes motors that are identical in design to the pleasure craft fleet. Exhaust emissions are rich in hydrocarbons, carbon monoxide and particulates. The hydrocarbon emissions consist of raw and partially oxidized fuel.[45] A new engine design incorporates a recycling system to prevent the venting to the environment of condensed fuel from the crankcase. This modification is expected to substantially reduce hydrocarbon emissions. Likewise, new engine designs permit a decrease in the oil to fuel ratio, which decreases hydrocarbon and particulate emissions. Other control methods for two-stroke cycle outboards are undefined at this time, and require further work on emission characterization.

Fuel properties and composition are factors that relate to exhaust emissions. Physical properties determine the compatibility of a fuel with a particular atomizer or injector. The sulfur content of the fuel is directly related to the concentration of sulfur dioxide in the exhaust. This pollutant is probably the simplest to control, e.g., by substitution, for a high sulfur fuel, of a fuel of low sulfur content (less than 1/2%). The nitrogen content of the fuel is likewise important since this nitrogen is converted to the oxide during the combustion process. Fuel nitrogen is more reactive than atmospheric nitrogen; minimizing the peak flame temperature in the combustion chamber will only inhibit the reactions of atmospheric nitrogen. Inorganic compounds in the fuel will form ash that affects the heat transfer process in a steam boiler or may be emitted as particulate matter. Normally, the ash formed is a mixture of inorganic compounds and carbon particles.

The use of organo-metallic compounds as fuel additives to reduce smoke emissions has been reported.[46, 47, 48] Little emphasis has been placed on this method due to the uncertainty of the effect the metals, usually barium, may have on the environment.

One method of emission control often overlooked is a reduction in power consumption which represents a reduction in fuel usage at a modest loss in utility or speed. This method of emission control may not be generally applicable to the Coast Guard, since it would impair the performance of the fleet in its mission.

7.4 EMISSION CONTROL BY ADDITION OF PROCESS EQUIPMENT

The addition of process equipment for emission control is not as desirable for exhaust emission reduction when compared with fuel or combustion modifications. The use of process equipment implies the addition of a secondary device to clean the exhaust gas stream of contaminants. These devices always require space and frequently can adversely affect efficient operation of the main power plant. Normally, a waste product is collected that must be disposed of in a careful manner, unless the purpose of the control device is to be defeated.

Control technology for reducing particulate emissions has progressed in the last fifty years to a level where 99.5% of the particulate mass can be removed from fossil fuel steam generating plants.[42, 49]

Wet and dry "scrubbers" have been employed by many industries for emission reduction.[50, 51] These methods are not particularly attractive for exhaust cleaning. The wet scrubber may only result in a phase transfer of the problem: air pollution converted to water pollution.

Few chemical reactions other than catalytic reactions are useful in exhaust emission control. Currently, the use of catalytic beds for the reduction of nitrogen oxides in automobile exhaust is quite promising.[42] The current state of the art here rests in laboratory demostration equipment, whereas catalytic reduction of carbon monoxide and hydrocarbons is an established means of control.

Afterburners have been utilized to eliminate large hydrocarbon emissions from chemical plants and oil refineries.[52] Here, the characteristics of the exhaust and concentration of pollutants indicate that this method of emission control is unattractive for use by the Coast Guard.

SECTION 8 OUTLINE OF FUTURE WORK

8.1 GENERAL DISCUSSION

As conceived, this project consisted of four phases: a background study, field measurements, development of in-stack monitoring equipment (as required) and development of shipboard control equipment (as required). The work performed to date, most of which is documented in this report, has uncovered no data which would dictate a fundamental change in this structure. We have shown, however, that hard data are needed in the area of outboard motor (two-stroke cycle gasoline engine) emissions. The next phase of this program will be concentrated on producing data from emission measurements of a cross-section of the Coast Guard fleet. In addition, some measurements of other commercial outboard motor emissions will be made in order to fully assess the present and potential impact of small (pleasure) craft on air quality.

In addition to providing data on propulsion systems (i.e., prime movers), this (second) phase of the program will provide data on the relative contribution of hotel services and auxiliary power units to vessel emissions. Such data are not presently available and such emission sources have, therefore, been virtually ignored for the purposes of this report. The following sections will discuss the two measurement programs (i.e., Coast Guard vessels and boats, and outboard engines) in more detail.

It should be noted, at this point, that the program outlined below will be closely coordinated with other programs of a similar nature being conducted elswhere. These programs include:

1. A jointly funded EPA (Water Quality Office)- Boating Industries Association study of the effects of outboard engine exhaust on warm and cold lake water quality;

2. The completed (but not yet documented) study of the effect of pleasure craft exhaust on water quality performed at RPI in Troy, New York, under sponsorship of EPA;

3. A study of the effects of outboard exhaust on water quality, in progress at the University of Massachusetts (Amherst);

4. A characterization of off-road vehicle emissions being conducted for EPA (Emission Characterization Branch) by Southwest Research Institute.

8.2 COAST GUARD VESSEL AND BOAT MEASUREMENTS

The next phase of this project is intended to provide the data base for an up-to-date emissions inventory of the U.S. Coast Guard fleet. Such an inventory is needed in order to accurately assess the need for additional shipboard control of air pollutant emissions, in compliance with the national policy of minimizing air pollution by federal facilities. This section of the report will only briefly review the plans for this effort, as they have been well documented in the project plan agreement which initiated this project.

The vessel and boat measurements will be carried out on a representative cross-section of the Coast Guard fleet sufficient to provide confidence in the emissions inventory. Since most of the engines are similar in design (i.e., diesel), it is felt that a thorough documentation of a relatively small number of vessels will be adequate to provide these data. The work will be divided into tasks of (1) program definition, (2) procedure documentation and (3) field data taking. The first, which will be documented for review and approval by the sponsor, will include specification and procurement of any required measuring and exhaust handling equipment, and selection of specific vessels to be surveyed. Equipment will be selected from the candidates presented in Section 6 of this report; the classification of vessels and boats discussed in Section 3 will guide selection of the measurement subjects. In addition, during performance of the first task in Phase 2 of this work, we will begin documentation of actual operating cycles of the subject vessels and boats. This documentation will provide the basis for judging the fraction of vessel emissions which contribute to the metropolitan air pollution. (Emissions on the high seas are not, in general, a contributor to air pollution as usually defined).

This work will also include documentation of specific procedures to be followed in the field measurements, and calibration and testing of the specialized measurement systems. It is anticipated that at least two different concepts will be required for the design of sample handling equipment; those vessels which employ vertical stack exhaust discharge are more readily monitored than vessels with exhaust discharge at the waterline.

Lastly, the next phase of this project will constitute the actual measurement and data reduction efforts. It is anticipated that this work will be completed by late 1972.

8.3 SMALL DIESEL ENGINE AND OUTBOARD MOTOR EMISSIONS

In parallel with the work described in Section 8.2, characterization of outboard motor emissions will be accomplished.

Using the outboard engine population data outlined in Section 3.2.4, along with data on horsepower and years of significant engineering changes available from manufacturers, a tentative selection of 53 motors for emission testing has been made and is given in Table 32.

A test facility composed of an engine test stand and power absorbing dynamometers will be used to test the engines. A test cycle will be established based on further analysis of engine data and actual experience gained in running engines. As the engine is run through its test cycle, exhaust emissions will be monitored by instrumentation and techniques described in Section6. However two important aspects of a two cycle outboard with regard to its emissions are, the high hydrocarbon output (on the order of 1.0 to 4 per cent) and the water/exhaust mixing. The high hydrocarbon output may require dilution of the exhaust gases to maintain linearity in the measuring instrument (usually a flame ionization detector). The exhaust/water mixing is also of interest for various Coast Guard Vessels in which mixing takes place (WMEC 210, WPB 95 and 82, and some boats). It is anticipated that the effects of exhaust/water mixing will be studied in detail both from 2 cycle outboard and diesel engines. A detailed analysis of these test programs will be given in a future report.

TABLE 32. SELECTION OF MOTORS FOR OUTBOARD MOTOR EMISSIONS TESTING

Model Year	% of '70 Pop. HP	OMC JOHNSON	EVINRUDE	KIEKHAEFER-MERCURY	CHRYSLER
'72 (compar-	B,E,F,G^1	B,E,F,G^1	B,E,F,G^1	B,E,F,G^1	A,E,F,G^1
71 ison of					
pre & post	7.5				
69*recycle)	17	B,E,F,G^1	B,E,F,G^1	B,E,F,G^1	A,E,F,G^1
68	27				
67	34				
66*	42	E,F,G^1		E,F,G^1	
65	48				
64*	54				
63	60				
62	66				
61 (Little yr.)	71				
60* (Big yr.)	76	E,F,G^1		E,F,G^1	E,F,G^1
59	82				
58*	86				
57	89				
56 (Big yr.)	92	B,E,F		B,E,F	

TOTAL 53 MOTORS

A=0-3.9 Horsepower
B=4-6.9
C=7-9.9
D=10-19.9
E=20-44.9
F=45-64.9 Horsepower
G=65-up
G1=largest
*=alleged change introduced

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APPENDIX A
PROPOSED
"OUTBOARD MOTOR POLLUTION CONTROL ACT OF 1971"

S. 2096

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Outboard Motor Pollution Control Act of 1971".

Sec. 2. The Federal Water Pollution Control Act is amended by redesignating sections 21 through 27 as sections 22 through 28 respectively, and by inserting after section 20 a new section as follows:

"REGULATION OF OUTBOARD MOTORS

"Sec. 21. (a) The Administrator of the Environmental Protection Agency, after consultation with the Secretary of the department in which the Coast Guard is operating, shall promulgate, not later than June 30, 1972, regulations requiring that two-cycle outboard motors used on vessels or any other water craft on the navigable waters of the United States be equipped or modified in such a manner as will use the latest available technology to prevent such motors from polluting such waters.

"(b)(1) After the effective date of such regulations it shall be unlawful to operate a two-cycle outboard motor on the navigable waters of the United States in violation of such regulations.

"(2) Any person who violates the provisions of this subsection shall be liable to a civil penalty of not more than $500 for each violation. Each violation shall be a separate offense. The Secretary of the department in which the Coast Guard is operating may assess any such penalty.

"(c) The provisions of this section and regulations established thereunder shall be enforced by the Secretary of the department in which the Coast Guard is operating and he may utilize by agreement, with or without reimbursement, law enforcement officers or other personnel and facilities of the Administrator, other Federal agencies, or the States in carrying out such provisions.

"(d) Anyone authorized by the Secretary of the department in which the Coast Guard is operating to enforce the provisions of this section, may except as to public vessels or watercraft, (1) board and inspect any vessel or other watercraft upon the navigable waters of the United States, and (2) execute any warrant or other process issued by an officer or court of competent jurisdiction."