Draft Regulatory Analysis

Heavy-Duty Diesel Particulate Regulations

Environmental Protection Agency
Office of Air, Noise, and Radiation
Mobile Source Air Pollution Control

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Approved by:

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NOTE

This document has been prepared in satisfaction of the Regulatory Analysis and the Urban and Community Impact Analysis required by Executive Order 12044 and the Economic Impact Assessment required by Section 317 of the amended Clean Air Act. This document also contains an Environmental Impact Statement for the proposed Rulemaking Action.

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CHAPTER I

SUMMARY

A. Background

Heavy-duty vehicles powered by diesel engines are a significant source of particulate emissions, especially in urban areas. Currently, diesel engines power a third of the heavy-duty vehicles sold in this country. By 1995, though, it is projected that diesels will comprise about two-thirds of heavy-duty vehicle sales. Over a third of these emissions will occur in urban areas, where the total suspended particulate problems are most acute.

Based on the above and the fact that Congress has required the control of particulate emissions from these vehicles through the 1977 Amendments to the Clean Air Act, EPA is proposing emission standards to control particulate emissions from heavy-duty vehicles powered by diesel engines. Also included are changes in the test equipment and procedures currently used to measure gaseous emissions from these vehicles. These changes will allow the measurement of particulate emissions concurrently with the measurement of the currently regulated gaseous emissions without affecting the stringency of current gaseous emission standards.

B. Proposed Rulemaking

Section 202(a)(3)(A)(iii) of the Clean Air Act, as amended, requires the Administrator to prescribe particulate emission standards by the 1981 model year. It is under this authority that EPA is now proposing a Federal heavy-duty diesel particulate emission standard for 1986 and later model year vehicles. The standard was delayed until 1986 due primarily to the lack of an adequate test procedure. Also, the existing hydrocarbon and smoke standards appeared capable of holding current particulate levels in reasonable check in the absence of strong forces in the opposite direction.

The proposed changes to the existing regulations include:

1. The addition of a dilution tunnel and other equipment to measure particulate emissions, and

2. The implementation of an exhaust emission standard for particulate matter from diesel-powered heavy-duty vehicles of 0.25 gram per brake horsepower-hour (0.093 gram per megajoule) beginning with the 1986 model year.

C. Heavy-Duty Diesel Characterization and Industry Description

The particulate regulations being proposed apply to diesel-

Note: All references referred to in these chapters are shown as _/.

powered heavy-duty vehicles. The heavy-duty vehicle class consists of vehicles rated at more than 8,500 pounds (3,546 kg) gross vehicle weight rating (GVWR). This vehicle class would also include those vehicles under 8,500 pounds (3,546 kg) GVWR which have a total frontal cross section of more than 46 square feet (4.3 square meters).

Currently, about one-third of the heavy-duty vehicles sold in the U.S. are powered by diesel engines. The engines are made primarily by five U.S. manufacturers whose sales comprise 97 percent of domestic sales; Cummins, Detroit Diesel (GMC), Caterpillar, Mack, and International Harvester. The remaining three percent are produced by a number of foreign manufacturers.

Due primarily to the rising cost of fuel, the percentage of heavy-duty vehicles sold with diesel engines is projected to increase dramatically over the next 15 years. By 1995, EPA projects that diesels will power nearly two-thirds of all heavy-duty vehicles sold in the U.S. This, coupled with general growth, is expected to increase sales of heavy-duty diesels by 166 percent between 1980 and 1995.

D. Standards and Technology

The Clean Air Act, as amended in August 1977, requires heavy-duty diesel particulate emission control based upon control technology which the Administrator determines will be available for the model year to which such standards apply. Due consideration must also be given to cost, energy, leadtime and safety. The 0.25 gram per brake horsepower-hour (g/BHP-hr) (0.093 gram per megajoule (g/MJ)) proposed standard fulfills these requirements.

The level of this proposed standard was based on:

1. An engine-out particulate emission level of 0.41 g/BHP-hr (0.153 g/MJ);

2. A 60 percent reduction in engine-out particulate emissions from the application of trap-oxidizers;

3. Over the full useful life, an increase in particulate emissions of up to 20 percent due to engine and trap-oxidizer deterioration; and

4. A 12 percent variability in the particulate emissions of production engines (used to determine the effect of a Selective Enforcement Audit having a 10 percent acceptable quality limit). These 4 points are discussed below.

The 0.41 g/BHP-hr level represents the level of particulate emissions determined to be technologically feasible by 1986 without the use of aftertreatment devices (i.e., trap-oxidizers). Practically, it is the average of the set of engines made up of each manufacturer's lowest particulate emitting model tested by EPA on No. 2 diesel fuel. This approach was chosen from among several alternatives because it complies most closely with the Clean Air Act requirements that the standard "reflect the greatest degree of emission reduction achievable . . . giving appropriate consideration to the cost . . . and to noise, energy, and safety factors associated . . . ."

Three other approaches to determining the technologically achievable level of engine-out particulate emissions were considered. They were: 1) the worst baseline engine (highest particulate emission level), 2) the lowest particulate emission level among the tested engines, and 3) the highest emission level among each manufacturer's best engines.

The reasons why these alternatives were rejected are presented in detail in Chapter IV. Briefly, the major fault with options 1 and 3 is that they would ignore the emission reduction potential of engine modifications already incorporated on many current production-line engines. Option 2 was rejected because it would lead to a standard beyond the technological limits of most engines. Implicit in this option (2) is the judgment that all engines, regardless of size or application, have exactly the same potential for achieving low particulate emissions as the best engine. EPA has not been able to absolutely make this determinination.

The option chosen, which based the feasible level of engine-out particulate emissions on the average of the emission levels of the lowest-emitting engine from each of the five major manufacturers, appears to best solve the problems present in each of the previous three options and comply with the applicable congressional mandate. The level of 0.41 g/BHP-hr (0.15 g/MJ) is a stringent level, requiring the higher-polluting engines to incorporate, to a great degree, the demonstrated technology of the best engines; yet it recognizes some level of difference between manufacturer's designs and avoids the problems associated with focusing on the single best engine (Option 2).

Up until this point, the discussion of engine-related technology was restricted to that already present on existing engines and avoided discussing additional engine modifications which could also reduce particulate emissions. The reason for this is the additional Congressional mandate related to heavy-duty diesel emissions which requires that emissions of nitrogen oxides (NOx) be reduced by 75 percent from a pre-controlled gasoline engine baseline (to be proposed for the 1986 model year). While the mandate referring to particulate emissions calls for the greatest reductions achievable considering cost, leadtime, safety and energy, the mandate referring to NOx emissions is more specific, calling for a set reduction from a certain baseline level. In the case of heavy-duty diesels, it is often possible to reduce emissions of both pollutants at the same time. However, there are also those control techniques which reduce the emissions of one pollutant while raising the other. To date the data available have not shown that the NOx standard can be met using NOx control techniques which do not also increase particulate emissions. Thus, it is possible that some NOx control techniques which increase particulate emissions (e.g., exhaust gas recirculation and retarded timing) may be necessary to attain the NOx standard. Given the specificity of the NOx mandate and its stringency, it would not therefore be reasonable to rely on particulate control techniques which would also increase NOx emissions. Thus, no such techniques have been included in the determination of a technologically feasible level of engine-out particulate emissions.

Particulate reductions from engine modifications not yet used on current engines and not adversely affecting NOx emissions were not included in determining the technologically feasible level of engine-out particulate emissions. Instead, these reductions were reserved to mitigate increases due to NOx control. The forthcoming NOx rulemaking will take this into account and propose a standard which will be attainable by heavy-duty diesels which are also complying with the proposed particulate standard. This allowance should make this proposed particulate standard a reasonable standard in light of the NOx mandate.

In addition to reducing particulate emissions formed in the combustion process, additional reductions are available from the application of aftertreatment devices, particularly trap-oxidizers. A trap-oxidizer basically consists of a high-temperature trapping material housed in a stainless steel shell. Placed in the exhaust, it collects particulate and periodically (or continually) incinerates (oxidizes) it. The incineration process usually requires a minimum exhaust temperature of 450-500°C to begin. Because such temperatures may not normally occur in heavy-duty diesel exhaust, exhaust temperatures may need to be artificially raised to the necessary level when regeneration (i.e., incineration) is desired.

The particulate collection efficiencies of many trap materials are already very good. Many materials, such as alumina-coated wire mesh and metal wool, have shown efficiencies of up to 65 percent. Slightly-modified ceramic monolithic substrates (similar to those used in automotive catalysts) have shown collection efficiencies of up to 84 percent. In determining the technologically-achievable level of particulate emissions with aftertreatment, 60 percent initial collection efficiency was used. This is the same efficiency which was determined to be achievable in light-duty applications (See 45 FR 14496).

Several trap-oxidizer regeneration approaches have been investigated. The simplest solution would be to continuously (or near-continuously) oxidize the particulate, in which case the trap-oxidizer would function much like a diesel catalytic converter. The problem with diesel converters is simply in maintaining the high-temperature conditions that ensure continual oxidation. Much effort is being expended on producing converters which would function on diesels, and designs have been tested that are close to what is needed. An alternative is to oxidize the particulate only occasionally, when enough organic material has been collected by the trap to aid the process and when the exhaust temperature is high enough to initiate oxidation. Many approaches have been suggested to initiate the oxidation process, but the most promising is the addition of an inlet air throttle, which would limit the intake air into the combustion chambers, thus raising the temperature of the exhaust. The throttling would be periodic, and could be actuated by a combination of the odometer reading and rack position, or might have to be linked to a controller unit coordinating several parameters such as rack position, backpressure, exhaust gas recirculation, etc. In a study using light-duty diesels, GM reported that over a 1,000-mile series of load-up and regeneration tests, utilizing throttling to initiate oxidation, the trap collection efficiency actually increased slightly. There appear to be no technical problems with utilizing throttling to initiate oxidation, and there is evidence that throttling may possibly reduce engine-out particulate and NOx emissions slightly.

Collection efficiencies and regeneration techniques have progressed to the point where the most critical issue is whether the efficiency and regeneration mechanism can be maintained over the useful life of the vehicle. At this time, EPA has limited trap-oxidizer durability data, as researchers have been reluctant to fund durability testing until other, more basic questions were solved. The problems of durability are problems which lend themselves to engineering solutions; no major new technology is required. We are confident that the durability questions will be resolved in the near future.

EPA is very confident that trap-oxidizers will be available to permit compliance with the 1986 standard. As discussed above, the basic concept of the trap-oxidizer is well understood. The improvements that are necessary are engineering problems, and are more a function of the resources allocated to the problem than any scientific or technical breakthrough. In the leadtime analysis in the light-duty diesel situation (45 FR 14496), it was determined that trap-oxidizers would likely be available for the 1984 model year. However, to ensure their availability, the more stringent light-duty standard was postponed until 1985. The delay of an additional year should be sufficient for the application of these devices to heavy-duty diesels. All of the information gained from the study of trap-oxidizers on light-duty diesels to this date should be equally applicable to heavy-duty diesels. However, unique heavy-duty diesel design and operational characteristics (such as long idling periods which could inhibit regeneration) indicate that more time is needed in order to optimize their use on heavy-duty diesels. The fact that trap-oxidizers are not currently available to permit compliance with the proposed 1986 heavy-duty diesel standard is recognized, but given sufficient good faith effort by the manufacturers, 60 percent efficient trap-oxidizers should be available in time to be incorporated on the 1986 model year fleet. While the necessary particulate collection efficiencies have been achieved, improvements in the areas of durability, backpressure build-up and on-board incineration are still needed.

Left to the marketplace, it is extremely unlikely that sufficient pressure would be brought to bear on the industry to aggressively pursue trap-oxidizer development. Experience has shown the greatest emission control development work to have taken place when direct regulatory incentives were in place. Perhaps the best example of this was the general reluctance by the light-duty industry to pursue catalyst technology before Congress mandated control of gaseous emissions from those vehicles. Since final trap-oxidizer designs are not now available to successfully comply with the 1986 standard, to the extent that the standard motivates the industry to aggressively pursue research and development it, is a "technology-forcing" standard. The term "technology-forcing" often implies that the sought-after technology is completely unknown or unforeseeable, but such is not the case here. The basic concept of the trap-oxidizer is very well understood, and, as explained above, much development has already occurred. Thus, this rulemaking is technology-forcing only in the respect that it will encourage a feasible control strategy that might otherwise be ignored.

The third factor used to determine the level of control relates to emissions deterioration. Data indicating the degree of deterioration of heavy-duty diesel engines, with regard to particulate emission over their useful lives, are not available. However, EPA tests of in-use light-duty diesels having accumulated an average 48,000 miles (77,250 kilometers) indicate that little if any increase in engine-out particulate emissions occurs. With the stability of heavy-duty diesel emissions of other pollutants and the similarity of the general emissions stability of light- and heavy-duty diesels, it is reasonable to project that the engine-out particulate emissions of heavy-duty diesels will deteriorate very little. Information on the deterioration of trap-oxidizer efficiency is even more scarce, as none are currently commercially available and durability tests of available prototypes have been waiting until after collection and burn-off techniques were perfected. For the purposes of this proposed rulemaking, the combined engine and trap-oxidizer deterioration was estimated to be no more than 20 percent.

In addition to complying with EPA's certification process for new engines, heavy-duty diesel manufacturers are also subject to a Selective Enforcement Audit (SEA) of their production engines, the fourth point mentioned above. As is the case for other regulated pollutants, at least 90 percent of the production engine must meet the proposed particulate standard. This forces manufacturers to design their emission control systems to reach levels below the standard on the average. Otherwise, if the control system were designed to just meet the standard, only about half the engines would pass instead of the required 90 percent.

To determine how far a manufacturer must design below the standard, two factors must be taken into account: 1) the variability of the particulate emissions of the production engines of a given engine family, and 2) the small number of prototypes upon which the design decision is made. Overall, it is estimated that the 10 percent acceptable quality level could force manufacturers to design their engines to meet a particulate level 22 percent lower than the standard (0.25 g/BHP-hr) divided by the deterioration factor (1.2), or 0.16 g/BHP-hr (0.060 g/MJ) if they were unable to reduce production line variability. Actual data on the particulate emission variability of production engines is not available. However, this variability was assumed to be similar to that for gaseous emissions, or 12 percent of mean emissions.

E. Environmental Impact

Despite significant gains made in the control of particulate emissions from stationary sources, there are many air quality regions which are not able to meet the primary National Ambient Air Quality Standard (NAAQS) for total suspended particulate matter (TSP) of 75 micrograms per cubic meter (annual mean). As diesel vehicles assume an increasing portion of the heavy-duty vehicle market, their contribution to ambient TSP levels will increase because diesel engines emit approximately 40 times the amount of particulate that is emitted by gasoline-fueled engines equipped with catalytic converters.

If the diesel fraction of heavy-duty vehicle market sales is assumed to be 57-69 percent by 1995, this standard will reduce particulate emissions from heavy-duty diesels by 64 percent in 1995 with respect to what would be expected without regulation. National particulate emissions in 1995 from heavy-duty diesels will be reduced from approximately 218,000-266,000 metric tons per year to 78,000-95,000 metric tons per year. Urban particulate emissions from these vehicles will also decrease 64.3 percent in 1995 from 79,000-97,000 metric tons per year to 28,000-35,000 metric tons per year. This emission reduction will reduce ambient heavy-duty diesel particulate levels in large cities (e.g., New York, Chicago, Los Angeles) from 1.7-7.2 to 0.6-2.6 micrograms per cubic meter. Heavy-duty diesel particulate levels in smaller cities (e.g., St. Louis, Pittsburgh, Phoenix) will also decrease from 1.6-4.9 to 0.6-1.8 micrograms per cubic meter. Localized levels which occur over and above these larger-scale impacts will also decrease from 4.9-6.0 micrograms per cubic meter to 1.6-2.0 micrograms per cubic meter. These latter impacts could occur as far as 90 meters from very busy roadways.

The above impacts clearly show the significant ambient particulate emission level reductions that are expected from these regulations. But not all types of particulate matter have the same level of impact on human health. Small particles, which are much more likely to be deposited in the alveolar region and which require much longer periods of time to be cleared from the respiratory tract, are believed to be much more deleterious to human health on an equal mass basis than larger particles. Thus, control of diesel particulate (100 percent is less than 15 micrometers in diameter and approximately 97 percent is less than 2.5 micrometers in diameter) is especially important with respect to human health. There is also particular concern over the chemical composition of diesel particulate emissions, as the extractable organic fraction of diesel particulate has been shown to be mutagenic in short-term bioassays. EPA is currently performing a health assessment to determine the carcinogenic risk (if any) to human health. This uncertainty is another factor which necessitates priority control of diesel particulate emissions.

F. Economic Impact

The retail price of heavy-duty diesel vehicles is expected to increase by approximately $527-650 in 1986 due to the engine and vehicle modifications necessitated by this regulation. (All costs are in terms of 1980 dollars.) The retail price increase of a new vehicle mentioned above is about 0.5-3 percent of the total cost of a new heavy-duty diesel vehicle. The range of costs is due to possible differences in trap-oxidizer systems which may be used on different models. The trap-oxidizer system is also expected to require maintenance costing about $30 when it is five years old. However, the vehicle modifications involved in adding the trap-oxidizer will eliminate the need to replace the exhaust pipe and muffler throughout the vehicle's life. This will save about $409 in maintenance costs (undiscounted) during the vehicle's life. In all, vehicle maintenance costs should decrease by $197 due to the 1986 standard (discounted to year of vehicle purchase). Overall, then, this regulation will cost $349-472 per vehicle. All of these estimates include profit at both the manufacturer and dealer level. Overall, the increased cost of owning and operating a heavy-duty diesel due to this regulation will be about 0.06 percent.

Due to past and future increases in the price of gasoline-fueled vehicles due to emission controls and the negligible impact of this regulation on the cost of transporting goods via heavy-duty diesels, EPA expects no decrease in diesel sales relative to the sales of gasoline-fueled vehicles due to aggregate environmental regulation. The aggregate cost of this proposed particulate standard over five years (1986-1990) will be $249-413 million (present value in 1980) or $442-731 million (present value in 1986). Two present value reference points are given because two different conventions have been used in the past; the present (1980) and the year the standard is to be implemented (1986).

G. Cost Effectiveness

The overall and marginal cost effectiveness of the proposed 1986 heavy-duty diesel particulate standard is $1070-1410 per metric ton of particulate controlled. (All costs are in terms of 1980 dollars.) However, the traditional measure of cost effectiveness (dollars per metric ton of particulate controlled) can be made more relevant to health improvements by considering only the inhalable or fine particulate that is controlled. Based on available data, the inhalable and, especially, the fine fractions of suspended particulate may have the greatest potential adverse health impact. When this is done, the marginal cost effectiveness for the 1986 standard is $1070-1410 per metric ton of inhalable particulate and $1070-1550 per metric ton of fine particulate. Using any of these three bases the cost effectiveness of the 1986 diesel standard is consistent with that of stationary source and other mobile source control strategies which have been adopted in the past.

There is another step which can be taken to improve the measure of cost effectiveness and that is to relate it to reductions in ambient pollutant concentrations instead of emission reductions. People's exposure to pollutants is directly related to the ambient pollutant concentration of the air they breathe, but only indirectly related to the emissions from various sources. However, the data necessary to perform such an analysis are difficult to obtain and not generally available. Still, to indicate the potential effects such factors can have on a cost-effectiveness analysis, some rough calculations were performed. Using some rough indicators of a source's impact on air quality relative to its emissions, it was found that diesels produce between 45 and 188 times the ambient pollutant concentration as the largest power plants (2,920 megawatt heat input) based on equivalent emission rates. Similarly, diesels produce between 1.1 and 4.7 times the ambient pollutant concentration as smaller power plants (73 megawatt heat input), based on equivalent emission rates. Only large-scale impacts were examined. Had localized impacts been included, the results could have been different. Similarly, a comparison of a different stationary source to diesels could have a much different result. One can imagine the potential effects of adding five to ten such factors to the cost-effectiveness analysis. The results of the previous paragraph could be made meaningless. Thus, while the cost-effectiveness of heavy-duty diesel control appears to be consistent with that of past EPA actions, the use of cost-effectiveness to compare different source strategies should be taken very cautiously. The type of factors which need to be included are simply not available and could drastically affect the results. The size of these factors also shows the need to further develop the methodology used to determine particulate cost effectiveness before it can really be used to identify strategies which should be implemented from those which should not.

The marginal cost effectiveness of the 1986 standard could only be compared with those from a few other strategies. Because the use of a marginal cost effectiveness is relatively new, these values are not readily available for most existing control strategies. Similarly, it was available for only one future control strategy, the control of emissions from mid-sized steam generators (3-73 megawatt heat input). However, more future control will be needed than the heavy-duty diesel and the mid-sized steam generator regulations if the nation is to meet the national ambient air quality standard for suspended particulate. Thus, the cost effectiveness of the 1986 standard should really be compared to those strategies which will be needed in the future, which haven't yet been developed and implemented. These strategies will likely be more costly than those of the past, since EPA has been attempting to implement the most cost effective strategies first. This being the case, the cost effectiveness of the 1986 standard would appear even more cost effective than it did against the past strategies. This is all the more reason why the 1986 standard appears to be a reasonable control strategy.

H. Alternative Actions Considered

Control of particulate emissions from heavy-duty vehicles is required by the Clean Air Act. Thus, EPA does not have the authority to forego control of heavy-duty diesel particulate emissions in favor of other particulate control strategies. However, to demonstrate that this action is consistent with EPA's overall strategy for controlling particulate emissions, other control strategies were examined in the course of this rulemaking. They included further control of stationary source and other mobile sources of particulate emissions. Per engine emission standards for heavy-duty diesels of varying stringency were also considered as alternatives.

Averaging concepts are not being considered in this heavy-duty diesel rulemaking. This decision is based primarily on the findings of the Regulatory Analysis for Light-Duty Diesel Particulate Regulations. However, EPA is planning a detailed examination of averaging concepts for the mobile source area in a future rulemaking. Any decisions for averaging will in part arise out of that analysis.

The alternative of further controlling stationary sources of particulate emissions as a substitute for these regulations was rejected for two reasons. First, while stationary source controls can mitigate the effects of future growth, they cannot be expected to reduce TSP concentrations in urban areas. Secondly, further control of stationary sources would not diminish the high levels of diesel particulate near roadways where significant adverse impacts occur.

The control of other mobile sources was also considered as an alternative to these regulations. By 1986, the only class of new vehicles emitting significant amounts of particulate matter will be light-duty diesels. Since these vehicles have already been controlled to the furthest extent possible, further control is not a viable alternative to these heavy-duty diesel regulations.

The alternatives remaining concern both the level and timing of an individual engine particulate standard. The Clean Air Act requires this individual engine standard to "reflect the greatest degree of emission control achievable through the application of technology which the Administrator determines will be available for the model year to which such standards apply." EPA must also give due consideration to cost, energy, and safety. The main goal of our analysis of alternative levels and dates, then, was to determine the level(s) and timing of the standard which best complied with the requirements of the Act.

First, the implementation of a one-step or a two-step standard was considered. The prime advantage of the one-step standard was that the final level of technology (trap-oxidizers) would be available in the same year (1986) as the revised NOx standards for heavy-duty diesels. This would allow manufacturers to design their engines to meet both standards simultaneously. An interim standard earlier than 1985 would have to use the 13-mode test procedure, which would not be as representative of in-use particulate emissions as the transient cycle (heavy-duty engines must certify under the transient test procedure beginning in 1985). An interim standard in 1985 would only hold the line against increases in particulate emissions at a time when no such increases would be expected and divert valuable Agency and industry resources from implementing and meeting the 1986 standards (NOx and particulate) and shifting them toward a less effective interim particulate standard. In 1986 with the coming of the revised NOx standard, a particulate standard will be needed to prevent potential increases in particulate emissions. However, by then the final standard based on trap-oxidizers could be implemented and no interim standard would be needed.

To insure that this was the case, the alternative of a two-step standard with the first step occurring in 1986 was considered in detail. Under this scenario, the 1986 standard would be based on improved engine design, while the later standard (in this case, 1988) would be based on the use of trap-oxidizers. This alternative would have the advantage of allowing the manufacturers more time to develop trap-oxidizers and also separate this work from the engine-related work. Its disadvantages were the added cost of recertifying all engines in 1988 and delaying air quality improvements for two more years. The effect of delay on capital and trap-oxidizer costs was examined, but no major effects were found in either direction. In all, the advantages did not outweigh the disadvantages and this alternative was rejected. Thus, a one step standard was chosen for 1986.

Second, the possible choices for the level of this standard were considered. These alternative levels have already been discussed in the section on technology and will not be repeated here. In summary, EPA examined the various levels in light of their ability to comply with the primary Clean Air Act requirement that the standard reflect the greatest reduction potential achievable given the leadtime available. Standards less stringent than the proposed standard were not able to fulfill this requirement. Standards significantly more stringent than the proposed standard carried the risk that a large number of diesels would not be able to meet the standard and the cost of compliance (and non-compliance penalties) could have been excessive. EPA did find the proposed standard to be reasonable with respect to cost, energy, and safety and to comply with those requirements of Section 202(a)(3)(A)(iii) of the Clean Air Act. Thus, the level of 0.25 gram per brake horsepower-hour in 1986 was chosen to be proposed.

CHAPTER II

INTRODUCTION

A. Background of Heavy-Duty Diesel Particulate Emission Regulation

The regulations examined in this document are intended to limit the emission of particulate matter from heavy-duty diesels. The regulations were mandated by Congress via the 1977 Amendments to the Clean Air Act and apply to diesel-powered heavy-duty vehicles hereafter designated heavy-duty diesels. Section 202(a)(3)-(A)(iii) of the Act as amended states:

> The Administrator shall prescribe regulations under paragraph (1) of this subsection applicable to emissions of particulate matter from classes or categories of vehicles manufactured during and after model year 1981 (or during any earlier model year, if practicable). Such regulations shall contain standards which reflect the greatest degree of emission reduction achievable through the application of technology which the Administrator determines will be available for the model year to which such standards apply, giving appropriate consideration to the cost of applying such technology within the period of time available to manufacturers and to noise, energy, and safety factors associated with the application of such technology. Such standards shall be promulgated and shall take effect as expeditiously as practicable taking into account the period necessary for compliance.

These regulations were necessitated because of the current national urban particulate problem.1/,2/ With current projections showing a doubling of the penetration of diesels into the heavy-duty market by the early 1990's, particulate emissions from these diesel-powered vehicles will become even more of a significant source of particulate emissions in urban areas and a major source in areas immediately nearby busy roadways.

While the Clean Air Act required this standard for the 1981 model year, a number of factors have caused EPA to postpone the implementation date until 1986. First and foremost was the absence of a transient test for heavy-duty diesels, which is necessary to accurately simulate in-use particulate emissions. This test procedure has just been developed and will be available for all 1985 diesel emissions testing.3/ Second, the leadtime available for earlier implementation dates would not have allowed any substantial reduction from uncontrolled levels. Third, until 1986 and the required revision of the emission standard for nitrogen oxides, there were no outside forces tending to increase particulate emissions. With the existing hydrocarbon and smoke standards, there was little reason to expect that particulate emissions would increase if left uncontrolled.

B. Description of Particulate Emission Control from Heavy-Duty Diesels

1. Test Procedure and Instrumentation

The test procedure under which particulate emissions will be determined is essentially the same test procedure currently used to determine gaseous exhaust emissions. The test for particulate emissions will be performed simultaneously with the test for gaseous pollutants. Thus, the driving cycles, weighting procedure, etc., will remain the same as currently set forth in the current Federal Test Procedure. The changes required include the need for additional equipment and instrumentation to allow for the determination of the amount of particulate matter being emitted.

One significant change in the test equipment will be the substitution of a dilution tunnel for the current baffle box. The baffle box causes a measurable decrease in particulate emissions from diesels due to particle deposition on the baffles.4/ Also, the baffle box does not provide the amount of residence time necessary for the organic compounds in the exhaust to come to equilibrium with the particulate before sampling. The dilution tunnel will allow the diesel exhaust to be diluted with ambient air with a minimum of particle deposition and allow reactions between the gaseous and particulate phase to occur before sampling as they would in real life.

The other significant change depends upon which of two particulate sample systems is used. If a single dilution system is used, then larger volumetric sampling systems will be required to lower the exhaust temperature below the required 125°F (52°C). If a double dilution system (two-stage dilution) is used, then the existing sampler will provide sufficient flow for the first stage of dilution and only a small second stage dilution system will have to be added. A heat exchanger will be required with either sampling system to ensure that the mass flow rate of the exhaust sample being filtered is always a constant proportion of the mass flow rate of the total diluted exhaust. Otherwise, the particulate sampling system would overweight certain portions of the test cycle and underweight others. Existing gaseous emission regulations already require the systems used to measure gaseous emissions to be proportional.

2. Emission Standards

Heavy-duty vehicles are currently required to meet emission standards for hydrocarbons, carbon monoxide, oxides of nitrogen and smoke (diesels only), but no standards exist for particulate emissions. The current and future standards for the gaseous pollutants are shown in Table II-1. The proposed standard for particulate emissions from heavy-duty diesels is 0.25 gram per brake horsepower-hour (g/BHP-hr)(0.093 gram per megajoule (g/MJ))

Table II-1

Heavy-Duty Engine Exhaust Emission Standards

	Federal					California				
Year	Option	HC	CO	NOx	HC+NOx	Option	HC	CO	NOx	HC+NOx
1969 1/		NR	NR	NR	NR		275	1.5	NR	NR
1970-71 1/		275	1.5	NR	NR		275	1.5	NR	NR
1972 1/		275	1.5	NR	NR		180	1.0	NR	NR
1973		275 1/	1.5 1/	NR	NR		--	40 2/	--	16 2/
1974 2/		--	40	--	16		--	40	--	16
1975-76		--	40	--	16		--	30	--	10
1977-78		--	40	--	16	A	--	25	--	5
						B	1.0	25	7.5	--
1979	A	1.5 3/	25	--	10 3/	A	1.5 3/	25	7.5	--
	B	--	25	--	5	B	--	25	--	5
1980-83	A	1.5 3/	25	--	10 3/	A	1.0	25	--	6
	B	--	25	--	5	B	--	25	--	5
1984	A 4/	1.3	15.5	10.7	--		0.5	25	--	4.5
	B 5/	0.5	15.5	9.0	--					
1986 4/		1.3	15.5	75% 6/	--					

1/ HC = parts per million; CO = % mole volume. Used for Federal Standards 1970-73 and California Standards 1969-72.

2/ Grams per brake horsepower-hour hereafter.

3/ Measured on 1979 test procedure (HFID for HC). Reduced 0.5 g/BHP-hr when 1978 procedure is used (NDIR for HC). NDIR is allowed in 1979 for all manufacturers, beyond 1980 only for low volume manufacturers seeking Federal certification.

4/ As measured on transient test procedure.

5/ Option only available for diesels. 1979 test procedure.

beginning with the 1986 model year. This level of control is expected to require the use of trap-oxidizers on most vehicles.

With a market penetration for diesels of 57-69 percent by 1995, these standards will result in a 64 percent reduction in particulate emissions from heavy-duty diesels in 1995 with respect to what would be expected without these regulations. National particulate emissions in 1995 from heavy-duty diesels will be reduced from approximately 218,000-266,000 metric tons per year to 78,000-95,000 metric tons per year. Urban emissions from these vehicles will also decrease 64 percent in 1995 from 79,000-97,000 metric tons per year to 28,000-35,000 metric tons per year. This emission reduction will reduce heavy-duty ambient diesel particulate levels in large cities (e.g., New York, Chicago, Dallas) from 1.7-7.2 to 0.6-2.6 micrograms per cubic meter. Heavy-duty diesel particulate levels in smaller cities (e.g., St. Louis, Phoenix) will also decrease from 1.6-4.9 to 0.6-0.8 micrograms per cubic meter. Localized levels which occur over and above these larger-scale impacts will also decrease from 4.9-6.0 to 1.6-2.0 micrograms per cubic meter. These latter impacts could occur as far as 90 meters away from very busy roadways. The primary national ambient air quality standard (NAAQS) for TSP is 75 micrograms per cubic meter.

While these standards are projected to reduce particulate emissions from heavy-duty diesels by 64 percent, particulate emissions from these vehicles will still be about 15 times greater than the particulate emissions from a typical catalyst-equipped vehicle powered by a gasoline engine. Thus, while the standards call for significant control, they do not call for control to a level attainable by an alternative type of motor vehicle.

No standards are being promulgated at this time to control any other aspects of diesel particulate besides its total weight. While EPA health effects studies performed thus far indicate that certain organic materials present on the filter used to determine diesel particulate mass emissions may present a greater health hazard than the particulate's effect on ambient TSP levels, there is currently not enough data available on which to base special control of these substances. It is possible, though, that additional standards will be promulgated in the future to control the emission of any particularly dangerous compounds as more becomes known about their unique effect on health.

The new standard for particulate emissions could affect the ability of heavy-duty diesels to meet the revised standard for nitrogen oxide emissions to be proposed for 1986. To prevent the situation from occurring where two standards must be met, each being feasible alone but together infeasible, the influence of conflicting control technologies has been taken into account in determining the level of the proposed particulate standard.

The accompanying changes in the test equipment are not expected to affect the stringency of gaseous emission standards.

The dilution tunnel should be equally effective as the baffle box in mixing the exhaust with the dilution air and the additional dilution air should not affect the measurement of gaseous emissions.

C. Organization of the Statement

This statement presents an assessment of the environmental and economic impacts of the particulate emission regulations for heavy-duty diesels which EPA is proposing. It also provides a description of the information and analyses used to review all reasonable alternative actions which were available.

The remainder of this statement is divided into six major sections. Chapter III presents a brief description of the manufacturers of heavy-duty diesel engines and vehicles and the market in which they compete.

An analysis of available particulate control technology is presented in Chapter IV. Potential emission standards and their timing are also discussed in detail.

An assessment of the primary and secondary environmental impacts attributed to these particulate regulations is given in Chapter V. The degree of control reflected by the standards is described and a projection of nationwide and urban particulate emissions from heavy-duty diesels in 1995 is presented. The impacts of these regulations on urban and roadside air quality are also presented. Secondary effects on other air pollutant emissions, water pollution and noise are also discussed in this section.

An examination of the cost of complying with the new regulations is presented in Chapter VI. These costs include those incurred to install emission control equipment on vehicles and trucks, costs required to purchase new emission testing equipment, and the costs to certify new engines for sale, as well as any increased vehicle operating costs which might occur. Analysis is made to determine aggregate cost for the 1986-1990 time frame. Finally, the impact that this regulation will have on industry and consumers will be reviewed.

Chapter VII will present a cost effectiveness analysis of this action and compare the results of this analysis with those performed on other mobile source and stationary source control strategies.

Chapter VIII will examine alternative mobile source control options including alternative per engine emission standards. It also will explain why the alternatives of achieving additional reduction of emissions from other mobile sources or stationary sources were not considered to be acceptable substitute actions for these regulations.

References

1/ "National Air Quality and Emissions Trends Report, 1976," OAQPS, OAWM, EPA, December 1977, EPA-450/1-77-002.

2/ "National Assessment of the Urban Particulate Problem, Volume I: National Assessment," OAQPS, OAWM, EPA, July 1976, EPA-450/3-76-024.

3/ "Gaseous Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines," Federal Register, Vol. 45, No. 14, Monday, January 21, 1980, pp. 4136-4227.

4/ Black, Frank, "Comments on Recommended Practice for Measurement of Gaseous and Particulate Emissions from Light-Duty Diesel Vehicles," ORD, EPA, April 13, 1978.

Chapter III

DESCRIPTION OF THE PRODUCT AND THE INDUSTRY

A. Heavy-Duty Diesel Vehicles

The Clean Air Act defines the term "heavy-duty vehicle" as ". . .a truck, bus, or other vehicle manufacturered primarily for use on the public streets, roads, and highways (not including any vehicle operated exclusively on a rail or rails) which has a gross vehicle weight (as determined under regulations promulgated by the Administrator) in excess of six thousand pounds. Such term includes any such vehicle which has special features enabling off-street or off-highway operation and use."1/

For the purposes of this regulation, however, heavy-duty vehicles are those vehicles which fulfill the above description and which have a gross vehicle weight (GVW) in excess of 8500 pounds. Vehicles with a gross vehicle weight greater than 6000 pounds but less than 8500 pounds are termed light-duty trucks and have been considered under separate regulations. This treatment is in harmony with the Clean Air Act which states that with regards to particulate emissions regulations, "the Administrator may base such classes or categories" of vehicles to be regulated "on gross vehicle weight, horsepower, or such other factors as may be appropriate."2/

Heavy-duty vehicles are powered by two types of engines - gasoline (spark ignition) and diesel (compression ignition). Generally both type of engines are treated equally by EPA regulations. In this instance it has been determined that heavy-duty gasoline engines are not significant particulate emitters and that, under the authority of Section 202 (a)(3)(A)(iv) of the Clean Air Act cited above, they would not be required to certify under the proposed standards. Thus the proposed regulations apply to heavy-duty diesel engines only.

Traditionally the industry uses GVW as a basis for reporting production and sales data. The standard categories are:

Class	GVW (pounds)
I	0 - 6,000
II	6,001 - 10,000
III	10,001 - 14,000
IV	14,001 - 16,000
V	16,001 - 19,500
VI	19,501 - 26,000
VII	26,001 - 33,000
VIII	33,001 and greater

Thus the proposed regulations would apply to part of Class II diesel vehicles (those with gross vehicle weights between 8,500 and 10,000 pounds) and all of the diesel vehicles in Classes III through VIII.

Table III-1 gives the total heavy-duty vehicle (gasoline and diesel) sales in the United States during the years 1972 through 1978. These data include vehicles imported from Canada sold in this country and excludes vehicles built here but sold elsewhere. As mentioned earlier there is a discrepency in that while the break point for the proposed regulations is at 8,500 pounds the industry only reports sales for 6,000 to 10,000 pound class. A study based on 1973 production data found that 5.0 percent of all trucks of 10,000 pounds GVW or less were in the 8,500 to 10,000 pound GVW range. A similar study based on 1977 production data found this figure to be 5.8 percent. As it is not known whether or not this change between 1973 and 1977 is a trend or a more random variation, an intermediate value of 5.5 percent was used to develop the sales split shown in Table III-1.

Table III-2 lists the total heavy-duty diesel vehicle (HDV-D) sales in the United States for the years 1972 through 1978 and Table III-3 lists the diesel percentages of the heavy-duty vehicle market. Clearly diesels have dominated the very heavy truck market for years, but have played no role in the 8,500 to 19,500 GVW classes. The basic tradeoff involved is the higher initial cost of the diesel engine versus its lower operating costs, in terms of better fuel economy and less frequent major maintenance. For example, a diesel engine that could be used in a 27,000 GVW vehicle would cost anywhere from $6,000 to $10,000, about three times the cost of a gasoline engine for the same vehicle ($2,000 to $3,500). But the diesel would yield anywhere from 25 to 50 percent lower fuel consumption (on a work output basis) and would require overhauling only about half as often. In the past this tradeoff favored the diesel only in the very largest and most heavily used trucks. As Tables III-2 and III-3 show, however, diesels now comprise the majority of new vehicles in the 26,001 to 33,000 pound GVW class and are beginning to make up a significant percentage of the 19,501 to 26,000 pound GVW class. Overall, diesels comprised 33 percent of the new heavy-duty vehicle fleet in 1978, up from 30 percent in 1978. As fuel economy becomes more and more important it is expected that diesels will continue to make up a larger portion of the heavy-duty vehicle market. The introduction of the diesel into the light-duty truck market indicates that diesels will begin to be used in the lower heavy-duty weight classes.

B. Heavy-Duty Diesel Engines

A heavy-duty diesel engine is simply a diesel engine which powers a heavy-duty vehicle as defined in the previous section. Diesel engines are reciprocating internal combustion engines which produce power by confining a combustible mixture in a small volume

Table III-1

U.S. Sales of Trucks and Buses by GVWR (pounds)
(U.S. Domestic Factory Sales plus Imports from Canada)

Year	0-* 8,500	8,501- 10,000	10,001- 14,000	14,001- 16,000	16,001- 19,500	19,501- 26,000	26,001- 33,000	33,000 and over	Yearly Totals
1978	3,218,772	187,336	34,014	5,959	3,982	157,168	41,516	163,836	3,812,583
1977	2,972,752	173,017	30,064	3,231	4,989	160,396	32,249	148,728	3,525,426
1976	2,525,755	147,002	43,411	67	8,920	149,293	22,918	103,098	3,000,466
1975	1,790,355	104,201	19,497	6,508	13,916	152,070	24,698	74,896	2,186,141
1974	2,088,200	121,535	8,916	8,120	24,366	215,221	32,364	160,465	2,659,187
1973	2,370,208	137,949	52,558	8,744	37,043	199,481	40,816	155,814	3,002,613
1972	1,929,883	112,321	57,803	10,353	37,492	177,723	40,150	130,328	2,496,054

* The MVMA does not split sales at 8,500 pounds GVWR, but rather publishes sales for the 0-6,000 and the 6,001-10,000 pound classes. The split in the table represents EPA's best estimate.

Total Vehicles Subject to HD Regulations

1978	593,811
1977	552,674
1976	474,709
1975	395,786
1974	570,987
1973	632,405
1972	566,170

Source: FS-3, MVMA data.

Table III-2
Total U.S. Heavy-Duty Diesel Vehicle Sales*

Year	8,500-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001 and over	Yearly Totals
1978	0	0	0	0	*13,148	*25,464	*155,890	*194,502
1977	0	0	0	0	11,142	17,997	141,294	170,433
1976	0	0	0	0	6,216	10,053	93,714	111,481
1975	0	0	0	159	4,803	10,320	62,016	77,298
1974	0	0	0	41	3,360	11,700	137,908	153,009
1973	0	0	296	6	3,740	16,018	137,147	157,207
1972	0	0	215	5	3,704	12,450	116,473	132,847

Source: MVMA

* Includes 1978 diesel bus production data but not previous years bus data. Includes Canadian imports but excludes all other imports.

Table III-3
Diesels as a Percentage of Heavy-Duty Market

Year	8,500-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001 and over	All HD Vehicles
1978	0	0	0	0	8%	61%	95%	33%
1977	0	0	0	0	7%	56%	95%	31%
1976	0	0	0	0	4%	44%	91%	23%
1975	0	0	0	1%	3%	42%	83%	20%
1974	0	0	0	0	2%	36%	86%	27%
1973	0	0	3%	0	2%	39%	88%	25%
1972	0	0	2%	0	2%	31%	89%	23%

between the head of a piston and its surrounding cylinder, causing the mixture to burn, and allowing the resulting high-pressure products of combustion gases to push the piston. This force can then be used as a source of power. Diesel engines are differentiated from gasoline engines in the way in which ignition is instigated. In the gasoline engine a metered mixture of gasoline and air is ignited by the spark of an electrical discharge (thus gasoline engines are also called spark ignition engines). In the diesel engine only air is compressed and heated in the cylinder such that when diesel fuel is injected near-spontaneous ignition occurs. Diesel engines are also known as compression ignition engines.

Diesel engine design is a very large complex field. The rest of this section will attempt to explain, as simply as possible, some basic diesel engine design parameters, especially those which may be discussed later in this analysis.

One basic engine parameter is the number of piston strokes per combustion cycle. The four-stroke cycle involves 1) an intake stroke in which the fresh air charge is drawn into the combustion cylinder followed by 2) a compression stroke in which the air is compressed to a temperature suitable for combustion. Late in the compression stroke the diesel fuel is injected into the cylinder. Combustion transpires producing 3) the expansion stroke as the high pressure gases force the piston downward transferring energy to the crankshaft. During 4) the exhaust stroke the exhaust gases are rejected from the cylinder due to the upward movement of the piston. This one four-stroke cycle necessitates two revolutions of the crankshaft.

In a two-stroke engine the power cycle is completed in just one revolution of the crankshaft. The basic concept involves avoiding complete piston strokes for intake and exhaust purposes. As the piston moves to the top of the cylinder, air is compressed for ignition. The fuel is injected initiating combustion and the piston delivers power during the expansion stroke. Near the end of the expansion stroke the exhaust ports open and exhaust gases begin to be purged. Also the intake ports are opened allowing fresh air to be blown into the cylinder. Soon after the piston begins the following compression stroke the exhaust and intake ports are all closed.

The primary advantage of the two-stroke engine is its greater horsepower to weight ratio since it has twice as many powerstrokes per unit time as the four-stroke engine. Its poorer scavenging and volumetric efficiencies are its primary drawbacks.

A second parameter of interest is injection timing. This refers to the time at which the diesel fuel begins to be injected into the combustion cylinder. Ideally it would be preferable to inject the fuel instantaneously when the piston is at top dead center (TDC) of the cylinder since at that time the air is compressed to its maximum extent and combustion conditions are most optimum. But because it takes finite amounts of time for the physical processes of injection and ignition to take place, injection is always initiated before the piston reaches TDC. The point where injection begins is usually expressed in terms of degrees of crankshaft rotation before TDC.

Also of interest is whether the engine utilizes direct or indirect fuel injection. With direct injection the diesel fuel is introduced directly into the cylinder head initiating combustion there. With indirect injection the fuel is introduced, and combustion is initiated in a small fuel-rich antechamber before expanding into the rest of the cylinder. Indirect injection engines are also referred to as precombustion chamber engines or prechamber engines. Indirect injection has several advantages but has not been utilized often in the heavy-duty industry due to a slight fuel economy penalty associated with its use.

Another important parameter is the method of introducing air into the combustion cylinder. In a naturally aspirated engine the vacuum created behind the moving piston is utilized to draw in the fresh air charge. Since a greater power output per unit volume of the cylinder is possible with greater masses of air and fuel involved in the combustion process, many engines pressurize the intake air which allows a similar increase in the amount of fuel which can be effectively burned. A turbocharger combines a turbine, driven by engine exhaust gases, with a compressor which increases the air flow into the cylinder. Cooling the presssurized air before it entered the cylinder, called aftercooling or intercooling, also increases the mass that can be accommodated and thus the power output. Both two-stroke and four-stroke engines can be either naturally aspirated or turbocharged. All naturally-aspirated two-stroke engines utilize low-pressure blowers to aid in the expulsion of exhaust gases and intake of fresh air. However, these blowers are only used to remove exhaust gases and do not pressurize the chamber. These engines are called blower-scavenged engines. The primary tradeoff involved in all of the options is the cost of the system versus the increase in power.

A final parameter of interest, though more accurately termed an emission control technique rather than simply an engine parameter, is exhaust gas recirculation (EGR). This involves the recirculation of exhaust gases directly into the intake manifold. The exhaust then makes up part of the "fresh" aircharge to the cylinders. The purpose of EGR is to reduce peak temperatures in the cylinders by providing a mass which can absorb some of the heat released during combustion. The lower peak temperatures result in lower emissions of oxides of nitrogen (NOx). EGR has become a principal NOx control strategy. The major disadvantage of EGR is that the addition of the residual gases often necessitates a slightly richer mixture, resulting in slightly greater fuel consumption.

Two additional characteristics of heavy-duty diesel engines will be used for classification purposes: engine displacement and maximum power. Engine displacement is simply the volume of each cylinder that is swept out by each piston during combustion, i.e., from bottom dead center of the cylinder to top dead center, multiplied by the number of cylinders in the engine. Maximum power is the power delivered by the engine shaft at the output end when the engine is operated at the optimum speed for power. The two are related in that generally the maximum power increases as the displacement increases.

C. Structure of the Heavy-Duty Diesel Industry

Unlike the light-duty vehicle industry where the engine and vehicle manufacturers are typically one and the same, heavy-duty diesel vehicles and the diesel engines used in them are often manufactured by independent companies. The engine/vehicle interconnections are so marked, in fact, that three of the major heavy-duty diesel engine manufacturers sell engines to every major heavy-duty diesel vehicle manufacturer. Because of this characteristic, as well as because of the logic of basing heavy-duty emissions on a useful engine work basis, EPA requires heavy-duty engine certification rather than vehicle certification. This has facilitated the performance of certification requirements by the engine manufacturer and avoided the situation where many vehicle manufacturers might certify the very same engine resulting in a duplication of effort.

The difficulty posed by the engine manufacturer/vehicle manufacturer matrix is that it makes any analysis of the heavy-duty diesel industry that much more complicated. However, because it is the engine manufacturer who bears the financial burden both for any design changes necessary to meet emissions standards and for the facilities and personnel required for certification testing, it has been concluded that the primary economic impact of emission regulations would affect the engine manufacturers rather than the vehicle manufacturers. Thus this chapter will place somewhat more emphasis on engine manufacturers.

1. Heavy-Duty Diesel Engine Manufacturers

The U.S. heavy-duty diesel engine market can be handily divided into two groups of manufacturers with distinctive characteristics. One group is composed of the five large, domestic manufacturers which seem to have a fairly permanent hold on the market: Cummins, General Motors (Detroit Diesel Allison division), Caterpillar, Mack, and International Harvester. The manufacture and marketing of heavy-duty diesel engines in the U.S. is a significant concern of each of these companies. Together these five firms accounted for 97.2 percent of all heavy-duty diesel engine sales in the U.S. in 1978 (see Table III-4).

The second group generally includes large foreign manufacturers which sell a very small fraction of their total production in the U.S. The composition of this group is thus much more likely to be variable as the decision of whether a particular manufacturer will export a small number of already-built engines or vehicles can be reversed in a relatively short period of time. As Table III-4 shows, this group accounted for approximately 2.8 percent of 1978 U.S. diesel engine sales and was composed of Mercedes-Benz, IVECO, Volvo, and Deutz Diesel. It is rather difficult to predict the composition of this second group in future years, but this limitation will be considered later in this analysis.

The leading heavy-duty diesel engine manufacturer is Cummins Engine Company. They constituted 36.9 percent of the 1978 market. Unlike many of their competitors, Cummins does not manufacture gasoline engines nor diesel vehicle chassis. Cummins makes exclusively four-stroke, direct injection engines with approximately 90 percent of those eventually powering heavy-duty vehicles having a displacement of 855 cubic inches. Their horsepower output ranges from approximately 250 to 400 horsepower which makes them among the most powerful truck engines produced. Cummins makes widespread use of turbocharging for additional power (approximately 95 percent) and uses intercoolers on about half of its models. Approximately two-thirds of Cummins' total sales result from their NTC-290 and NTC-350 models. Cummins' engines are utilized by every major heavy-duty diesel vehicle manufacturer, with International Harvester its biggest customer, and power many of the very heaviest diesel freight trucks.

Detroit Diesel Allison is a division of General Motors Corporation (GMC) which is primarily involved in manufacturing the engines used in GMC heavy-duty diesel vehicles. Detroit Diesel, which constituted almost one-quarter of the market in 1978, manufactures two-stroke, direct injection engines exclusively and is the only maker of two-stroke diesel truck engines. It is believed that Detroit Diesel may soon market a four-stroke engine. Detroit Diesel has a very broad range of displacements (212 to 736 cubic inches) and power settings (170 to 430 horsepower), thus, their engines are used in both lighter and heavier heavy-duty vehicles. About 30 percent of these engines are blower-scavenged (naturally aspirated) with the remaining turbocharged. Most of the turbocharged engines also include an intercooler. Although approximately one-third of all Detroit Diesel engines are used in GMC trucks, every major heavy-duty diesel vehicle manufacturer is a customer of Detroit Diesel. Top models include the 6V-92TA, 8V-92TA, and 6L-71N models.

Table III-4

1978 U.S. Heavy-Duty Diesel Engine Sales by Manufacturer

Manufacturer	Number	Percentage of Market
Cummins	73,872	36.9%
Detroit Diesel	47,737	23.9%
Caterpillar	30,576	15.3%
Mack	27,504	13.7%
International	14,813	7.4%
Mercedes	2,607	1.3%
IVECO	2,397	1.2%
Volvo	360	0.2%
Deutz	180	0.1%
TOTAL	200,046	100.0%

The Caterpillar Tractor Company, for years the leading manufacturer of heavy construction machinery,* has a 15.3 percent share of the 1978 heavy-duty diesel engine market. Caterpillar is the only major manufacturer which produces indirect injection engines, although approximately five-sixths of its fleet utilizes direct injection. All Caterpillar engines are four-stroke engines. Only about one-fifth of these engines are turbocharged, with most of these also using an intercooler. As of the 1978 model year, Caterpillar was also the only company marketing a heavy-duty diesel engine with exhaust gas recirculation (EGR). The majority of Caterpillar's engines are in the 636 to 638 cubic inch size range, though they do make some larger engines. Caterpillar sells a majority of its engines to the Ford Motor Company but also sells its engines to every other major diesel vehicle manufacturer. Its most popular model is its standard 3208 engine, accounting for approximately 70 percent of its total sales.

The fourth largest heavy-duty diesel engine manufacturer is Mack Trucks, Incorporated with 13.7 percent of the 1978 U.S. market. All Mack engines are four-stroke, direct injection engines with over 95 percent of them having a displacement of 672 cubic inches and utilizing a turbocharger. Half of its engines are intercooled as well. Two models, the ENDT(B)676 and the ENDT (B)675, epitomize the entire Mack fleet and themselves account for over 80 percent of the total sales. All Mack engines are assembled into Mack heavy-duty vehicles.

The International Harvester Company, which is a major manufacturer of gasoline engines, and diesel and gasoline heavy-duty vehicles as well, had a 7.4 percent share of the heavy-duty diesel engine market in 1978. One of its engines, the DT-466B, accounted for almost 90 percent of its sales in 1978 and thus, well represents its entire fleet. It is a four-stroke, direct injection, turbocharged engine with a displacement of 466 cubic inches and about 200 horsepower output and is used in some of the lighter heavy-duty diesel vehicles. All International engines are used in International vehicles.

2. Heavy-Duty Diesel Vehicle Manufacturers

The U.S. heavy-duty diesel vehicle market is split among more than fifteen vehicle manufacturers. However, like the heavy-duty diesel engine market, most of the vehicle market is concentrated among a few large manufacturers. Nearly 70 percent of the market belongs to the four largest vehicle manufacturers: IHC, Ford, Mack and GMC. The seven largest manufacturers hold nearly 90 percent of the market. The actual breakdown of U.S. sales in 1978 is shown in Table III-5, along with a breakdown of manufacturers providing

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* This analysis ignores all diesel engines used in off-road vehicles.

Table III-5

U.S. Sales of Heavy-Duty Diesel Vehicles - 1978

	Engine Manufacturer						
Vehicle Manufacturer	Cummins	Detroit Diesel	Caterpillar	Mack	IHC	Others	Total
IHC	22,331	8,304	2,587	-	14,813	-	48,035
Ford	10,108	6,930	18,964	-	-	-	36,002
Mack	2,057	356	202	27,504*	-	-	30,119
GMC	4,667	16,226	1,330	-	-	-	22,223
White	9,840	3,794	965	-	-	-	14,599
Kenworth	8,987	2,833	2,309	-	-	-	14,129
Freightliner	9,155	2,119	709	-	-	-	11,983
Peterbilt	5,410	1,502	2,027	-	-	-	8,939
Chevrolet	605	3,749	1,071	-	-	-	5,425
Others	712	1,924	412	-	-	5,544	8,592
Total	73,872	47,737	30,576	27,504	14,813	5,544	200,046

Source: MVMA, FS-5. Corrected for imports, buses, and exports.

* Includes 596 engines produced by Scania Vabis.

engines for the vehicles being produced. As can be seen, every vehicle manufacturer buys engines from a number of engine manufacturers. Only two vehicle manufacturers, GMC (including Chevrolet) and Mack, also produce a majority of the engines which are used in their vehicles.

D. Future Sales of Heavy-Duty Diesels

There are many factors which could affect future sales of heavy-duty diesels. Soaring energy costs are likely to be a major factor. Federal deregulation of the trucking industry and changing state weight and length limitations could also affect future sales. When these factors are coupled with general uncertainties about the nation's economic growth in the 1980's, it becomes obvious that predicting future sales of heavy-duty diesels is a very difficult task. Any such prediction is going to be tenuous, being based on a number of questionable assumptions. Rather than try to develop a scenario that is based on an assumption concerning each one of these factors, each assumption being quite questionable, here we will simply try to predict the effect of energy costs on the gasoline-diesel engine split. The other factors mentioned above will be essentially ignored at this time due to the uncertainty of their effects. This exclusion is in itself an assumption concerning the cumulative effects of these factors (that of no effect). Given the available information, this assumption is probably as good as any other.

The actual projection of future sales will be performed in two steps. First, a projection of total heavy-duty vehicle sales will be made. Second, a projection of the split between gasoline and diesel engines will be made. These two projections will then be combined to yield a scenario of future sales of heavy-duty diesels.

As mentioned earlier, this study will not attempt to account for many of the factors which could affect heavy-duty vehicle sales in future years. Instead, the historical growth rate from 1967 will be projected to continue in the future. This should not be too inaccurate since the time period being examined includes both periods of real growth in the early years and then a period of retrenchment due to the 1973 oil embargo and the continuing rise of fuel prices. It is reasonable to expect some growth in the 1980's and early 1990's, though it is similarly reasonable to expect this growth to be tempered by other factors, energy prices being one of them.

A compilation of annual domestic sales of heavy-duty vehicles from U.S. plants between 1967 and 1978 is shown in Table III-6. A linear regression of this data shows that sales have grown on the average of 10,904 vehicles per year, with 1978 sales (taken from the least-squares line) being 510,174 vehicles. However, imports (all from Canada) have averaged about 10% of these figures during

Table III-6

Domestic Sales of Heavy-Duty Vehicles from U.S. Plants - 1967-1978

Year	Sales
1978	555,902
1977	505,293
1976	419,368
1975	348,438
1974	513,572
1973	563,348
1972	509,503
1971	413,750
1970	366,622
1969	428,362
1968	408,820
1967	369,471

Results of Linear Regression:

$S = -340307 + 10903.6Y$ where;

S = Annual sales in a given year

Y = Last two digits in year

this period. Thus, modifying the regression results accordingly, the annual growth rate would be 11,994 vehicles per year and the regression yields 561,191 vehicles for 1978 sales. It will be assumed that growth continues to be linear through 1995 at 11,994 vehicles per year starting with 561,191 vehicles in 1978. The resultant sales for future years can be found in Table III-7.

To apportion these total sales projections among the various weight classes, historical data was used again. The breakdown by class between 1974 and 1978 was compiled and averaged and the following breakdown resulted.

Class IIB	8,501 - 10,000#	28.3%
Class III	10,001 - 14,000#	5.3%
Class IV	14,001 - 16,000#	0.9%
Class V	16,001 - 19,500#	2.2%
Class VI	19,501 - 26,000#	32.2%
Class VII	26,001 - 33,000#	5.9%
Class VIII	33,001 and over	25.2%

This breakdown was assumed to stay constant through 1995 and was used to allocate the projections of total sales among the various classes. These projected sales within each class are also shown in Table III-7.

The last step remaining is to estimate the breakdown between diesel and gasoline engines. This is a more difficult area to predict due to the nation's current energy problems. Due to the wide range of vehicle types which fall into the category of heavy-duty vehicles, separate projections of gas-diesel split will be made for most classes. The need for this is shown in Table III-3, which shows the historical gas-diesel split for each class. As can be seen, there are large differences between classes, with the heavier weight classes showing the higher percentage of diesels. This is primarily true because it is these heavier vehicles which are used in line-haul operation and have the highest annual mileage. Since the primary advantage of the diesel is in fuel economy, these are the vehicles where the diesel shows the greatest advantage. The actual projections of gas-diesel split follow, beginning with the heaviest classes (VIII) and moving to the lightest.

Class VIII (greater than 33,000 pounds GVWR) has traditionally been the class where diesels have had the greatest penetration, as shown by the figures in Table III-3. The fraction of diesels in this class has been steadily increasing over the past seven years and it is safe to assume that this should continue. It will be assumed that this class will be entirely diesel by 1984, with the diesel fraction increasing linearly from 0.95 in 1979. These projections are shown in Table III-8.

Table III-7
Estimated HDV Sales for
1979 through 1995 by GVWR (pounds)

Year	8,500-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001 and over	All HD Vehicles
1995	216,520	40,550	6,855	16,832	246,359	45,140	192,803	765,089
1994	213,126	39,914	6,777	16,568	242,497	44,433	189,780	753,095
1993	209,731	39,278	6,670	16,304	238,635	43,725	186,758	741,101
1992	206,337	38,643	6,562	16,040	234,772	43,018	183,735	729,107
1991	202,943	38,007	6,454	15,776	230,910	42,310	180,713	717,113
1990	199,549	37,371	6,346	15,512	227,048	41,602	177,691	705,119
1989	196,154	36,736	6,238	15,248	223,186	40,895	174,668	693,125
1988	192,760	36,100	6,130	14,985	219,324	40,187	171,645	681,131
1987	189,366	35,464	6,022	14,721	215,462	39,479	168,623	669,137
1986	185,971	34,829	5,915	14,457	211,600	38,771	165,600	657,142
1985	182,577	34,193	5,806	14,193	207,738	38,064	162,578	645,149
1984	179,183	33,557	5,698	13,929	203,876	37,356	159,555	633,154
1983	175,788	32,921	5,590	13,666	200,014	36,648	156,533	621,160
1982	172,394	32,286	5,482	13,402	196,151	35,941	153,510	609,166
1981	169,000	31,650	5,375	13,138	192,289	35,233	150,487	597,172
1980	165,605	31,014	5,267	12,874	188,427	34,526	147,465	585,178
1979	162,211	30,379	5,159	12,610	184,565	33,818	144,442	573,184

Table III-8

Projected Future Diesel Sales as a Fraction of Heavy-Duty Sales for 1979 through 1995 by GVWR (pounds)

Year	8,500-19,500	19,501-26,000 1/	19,501-26,000 2/	26,001-33,000	33,001 and over	All HD Vehicles
1995	0.30	0.15	0.71	1.00	1.00	0.63
1994	0.28	0.14	0.67	1.00	1.00	0.61
1993	0.26	0.13	0.64	1.00	1.00	0.59
1992	0.24	0.12	0.60	1.00	1.00	0.57
1991	0.22	0.11	0.56	1.00	1.00	0.56
1990	0.20	0.10	0.53	1.00	1.00	0.54
1989	0.18	0.09	0.49	1.00	1.00	0.52
1988	0.16	0.08	0.46	1.00	1.00	0.50
1987	0.14	0.07	0.42	0.96	1.00	0.48
1986	0.12	0.06	0.39	0.92	1.00	0.46
1985	0.10	0.05	0.35	0.89	1.00	0.44
1984	0.08	0.04	0.31	0.85	1.00	0.42
1983	0.06	0.03	0.28	0.81	0.99	0.40
1982	0.04	0.02	0.24	0.77	0.98	0.37
1981	0.02	0.01	0.21	0.73	0.97	0.35
1980	0.00	0.00	0.17	0.69	0.96	0.34
1979	0.00	0.00	0.14	0.65	0.95	0.33

1/ School buses

2/ Trucks

As can be seen, with the current diesel fraction of class VIII so near one, the actual year in which the fraction becomes one has little effect on the projected number of diesel Class VIII sales. This is convenient, as will become more evident later, because 1) most of total diesel sales will come from this class and 2) an even greater percent of diesel vehicle-miles-travelled will come from this class. While many of the following projections of diesel-gasoline splits are very tenuous, their effect on the overall results are much smaller than the impact of Class VIII. Because of this, the accuracy of the overall sales projection will be much greater than it might appear on the surface.

Vehicles sold in Class VII (26,001-33,000 pounds) have also been increasingly equipped with diesel engines. Between 1972 and 1978, diesel usage increased from 31 percent to 61 percent of the vehicles. Due to both the relatively low sales of this class (40,000 vehicles per year) and the push toward greater fuel economy, the dieselization of this class is expected to continue at its current pace, reaching 100 percent in 1988. The actual gasoline-diesel split up to 1988 is shown in Table III-8.

So far, Class VII and VIII vehicles have been projected to switch completely to the diesel by the mid to late 1980's. This projection is in accordance with many other projections made elsewhere.3/,4/,5/ However, these past studies have also projected similar levels of dieselization for the lighter classes of heavy-duty vehicles (Class VI and below). There are a number of reasons why this is probably not going to be the case. One reason is simply economics. The diesel's primary advantage lies in fuel economy, and its primary disadvantage lies in initial cost. The annual mileage of these lighter vehicles is far below that of the Class VII and VIII vehicles, so the advantage of the diesel is much less, though the disadvantage is the same.

A second reason is primarily social. Diesels were tried in the 1960's in these classes and were not very successful.6/ Poor designs and inappropriate use caused a host of mechanical problems. While the quality of future mid-size diesels should be vastly improved over those used in the 1960's, it may take time to change prejudices from the past.

The third reason for lower diesel sales in these classes is primarily practical. First, diesels do not provide the same ability to accelerate as their gasoline counterparts. Second they are harder to start in the cold. Third, an established service industry does not exist to service a completely diesel heavy-duty fleet. Last, the shortage of diesel fuel last summer is still in people's minds. These practical considerations will all cause a hesistancy to dieselize, even though in the long run (20-30 years) their effect may be minimal.

A few manufacturers have predicted that Class VI sales will be 35-50 percent by 1985.6/ Given 1) the considerations mentioned above, 2) the fact that the 50 percent estimate came from two diesel manufacturers and the 35 percent estimate came from a manufacturer of both gasoline and diesel engines, and 3) the usual optimism of industry projections, the lower figure has been chosen as the best estimate of the gasoline-diesel split for Class VI trucks in 1985.

About 18 percent of 1978 Class VI sales were school buses. Due to their suspected lower annual mileage, these vehicles are not expected to dieselize nearly as much as the trucks of this class. A projection of 10 percent will be used for the diesel fraction of school bus sales in 1990. In 1978, about 10 percent of class VI trucks were diesel and no school buses were diesel. The dieselization rate for trucks is projected to be linearly between 10 percent in 1978 and 35 percent in 1985. The rate for school buses is also projected to be linearly starting with zero percent in 1980 growing to 10 percent in 1990. The resulting gasoline-diesel splits for 1979 to 1995 for both of these sub-classes are shown in Table III-8. Also, due to the nationwide trend toward fewer school children, total sales of school buses were assumed to remain constant at 1978 levels. All growth in Class VI sales was assumed to be trucks.

For the remaining classes (II-V), the rate of dieselization should be less than that of Class VI. As the exact difference is difficult to determine, it will be assumed that the diesel fraction of 1990 sales for these classes will be about the same as that projected for light-duty vehicles, 20 percent.7/ It will simply be projected that this growth occurs linearly from zero in 1980 and continues at least until 1995 (30 percent). These fractions for the various years are also shown in Table III-8.

The diesel fractions of sales by class (Table III-8) can now be coupled with the projections of total heavy-duty sales (Table III-7) to yield the overall diesel fraction of sales each year (shown in Table III-8) and the total sales of heavy-duty diesels each year by class (Table III-9). As can be seen, the diesel fraction of heavy-duty sales increases from 33 percent in 1979 to 63 percent in 1995. Total heavy-duty diesel sales increase from 181,080 vehicles in 1979 to 481,120 vehicles in 1995.

Table III-9

Estimated Diesel Usage in Heavy-Duty Vehicles for 1979 through 1995 by GVWR (pounds)

Year	8,500-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001 and over	All HD Vehicles
1995	64,956	12,165	2,065	5,050	158,941	45,140	192,803	481,120
1994	59,675	11,176	1,898	4,639	148,233	44,433	189,780	459,824
1993	54,530	10,212	1,734	4,239	137,784	43,725	186,758	438,982
1992	49,521	9,274	1,575	3,850	127,621	43,018	183,735	418,594
1991	44,647	8,362	1,420	3,471	117,737	42,310	180,713	398,660
1990	39,910	7,474	1,269	3,102	108,132	41,602	177,691	379,181
1989	35,308	6,612	1,123	2,745	98,804	40,895	174,668	360,155
1988	30,841	5,776	981	2,398	89,755	40,187	171,645	341,583
1987	26,511	4,965	843	2,061	80,984	37,979	168,623	321,966
1986	22,316	4,179	710	1,735	72,490	35,824	165,600	302,854
1985	18,258	3,419	581	1,419	64,275	33,725	162,578	284,255
1984	14,335	2,685	456	1,114	56,338	31,678	159,555	266,161
1983	10,547	1,975	335	820	48,931	29,685	154,968	247,261
1982	6,896	1,291	219	536	40,852	27,675	150,440	227,909
1981	3,380	633	108	263	34,723	25,720	145,972	210,799
1980	0	0	0	0	27,223	23,823	141,566	192,612
1979	0	0	0	0	21,878	21,982	137,220	181,080

References

1. Clean Air Act as amended in August, 1977, Section 202(b) (3)(c).

2. Clean Air Act as amended in August, 1977, Section 202(a) (3)(A)(iii).

3. "The Impact of Future Diesel Emissions on the Air Quality of Large Cities," PEDCo Environmental, Inc. for EPA, February 1979, EPA.

4. "Air Quality Assessment of Particulate Emissions from Diesel Powered Vehicles," PEDCo Environmental, Inc. for EPA, March 1978, EPA-450/3-78-038.

5. "Assessment of Environmental Impacts of Light-Duty Vehicle Dieselization (Draft)," Aerospace Corp. for DOT, March 1979.

6. Szigetly, William, "Will Diesels Dominate?," Fleet Specialist, Chilton, May/June, 1979.

7. Summary and Analysis of Comments on the Notice of Proposed Rulemaking for the Control of Light-Duty Diesel Particulate Emissions from 1981 and Later Model Year Vehicles, MSAPC, EPA, October 1979.

Chapter IV

STANDARDS AND TECHNOLOGY

A. Introduction

The statutory authority for proposal of this heavy-duty diesel particulate regulation is Section 202(a)(3)(A)(iii) of the Clean Air Act as amended in August 1977. It requires that "The Administrator shall prescribe regulations...applicable to emissions of particulate matter from classes or categories of vehicles manufactured during or after model year 1981 (or during any earlier model year if practicable). Such regulations shall contain standards which reflect the greatest degree of emission reduction achievable through the application of technology which the Administrator determines will be available for the model year to which such standards apply, giving appropriate considerations to the cost of applying such technology with the period of time available to manufacturers and to noise, energy, and safety factors associated with the application of such technology. Such standards shall be promulgated and shall take effect as expeditiously as practicable taking into account the period necessary for compliance." Based on the above edict, a standard of 0.25 grams of particulate per brake horsepower-hour (g/BHP-hr) (0.093 grams per megajoule (g/MJ)) is being proposed for heavy-duty diesels beginning with the 1986 model year.

In order to determine typical particulate emission levels from existing and future heavy-duty diesels, a test program is being conducted by EPA at the Southwest Research Institute. Table IV-1 lists the 23 engines included in this program and Table IV-2 shows findings from the heavy-duty transient cycle tests conducted to date. Although the test program is not complete at this time, EPA believes a sufficient number of engines have been tested to establish a representative range of heavy-duty diesel particulate emissions.

In this chapter, several means of achieving reduced particulate emissions (engine modifications and after-treatment devices) from heavy-duty diesels are discussed followed by a section explaining the rationale behind the proposed level of control. Much impetus is placed on trap-oxidizer technology since it is currently viewed as the most promising means of obtaining substantial particulate control and a technique applicable to all engines. Collection efficiencies of up to 84 percent have been reported for prototype trap designs and research is well under way by several firms to refine trap-oxidizers for heavy-duty diesel applications. 2/3/

B. Trap-Oxidizers

Several approaches to diesel exhaust particulate control exist today. In addition to engine modifications, to be discussed later,

Table IV-1

Heavy-Duty Diesel Test Program Engines

Caterpillar -	1978 3208 Dina Family 3
	1979 3208 Dina Family 3
	1979 3208 EGR Family 13
	1979 3406 DITA Family 16
	1979 3406 PLTA Family 10
Cummins -	1976 NTC-350
	1979 NTCC-350
	1979 VTB-903 Coach
	1979 BIG CAM NTC-350
	1979 NTC-290
	1979 NH-250
Detroit Diesel - Allison	1978 6V-92T*
	1978 8V-71N Coach*
	1979 6V-92TA 10g
	1979 6L-71T
	1979 6V-92TA 6g
	1979 8V-71TA
	1979 V8-8.2
Deutz -	1979 F5L-912
International - Harvester	1979 DTI-466B
	1979 DT-466
Mack -	1979 ETAZ(B) 673A
	1980 ETSX 676-01

* These engines are scheduled to be discontinued by 1982.1/

Table IV-2

Heavy-Duty Diesel Test Program Results - Transient Cycle

Engine*	Emissions: Particulate g/BHP-hr	Emissions: NOx g/BHP-hr	Number of tests
1) 1978 Caterpillar 3208**	0.79	5.84	7
2) 1979 Caterpillar 3406 (Family 10)	0.37	5.40	2
3) 1979 Caterpillar 3406 (Family 16)	0.52	8.41	2
4) 1976 Cummins NTC-350**	0.60	8.51	4
5) 1979 Cummins NTC-350 "Big Cam"	0.40	7.43	2
6) 1979 Cummins NTCC-350**	0.39	4.91	2
7) 1979 Cummins NTC-290	0.58	8.28	2
8) 1979 Cummins VTB-903			
#1 Fuel**	0.31	5.58	2
#2 Fuel	0.37	6.33	3
9) 1978 DDA 6V-92T**	0.54	7.12	2
10) 1978 DDA 8V-71N**			
#1 Fuel	0.69	5.33	2
#2 Fuel	0.79	5.69	2
11) 1979 DDA 6V-92TA 6 g.**			
#1 Fuel	0.48	5.82	2
#2 Fuel***	0.55	5.83	3
12) 1979 DDA 6V-92TA 10 g.	0.54	8.69	2
13) 1979 DDA 8V-71TA	0.38	7.32	2
14) 1979 IHC DTI-466B**	0.36	5.56	2
15) 1979 IHC DT-466	0.53	5.90	2
16) 1979 Mack ETAZ(B)673A	0.58	6.73	2
17) 1980 Mack ETSX-676	0.63	5.15	2

* Engines operated on #2 fuel except where noted.
** Bagged NOx.
*** Particulate mean based on 2 tests.

research has also focused on add-on particulate collection devices. General Motors and others, in their effort to develop a particulate control strategy for light-duty diesel engines, have investigated the feasibility of several such devices.4/ These include disposable traps with paper filters, traps requiring owner servicing, and traps with regenerative capabilities. Although each warrants further investigation, the regenerating traps (trap-oxidizers) are currently the most promising and will be the only design discussed here.

A trap-oxidizer basically consists of a trapping substrate (such as a metal or fiber mesh or a ceramic monolith) housed in a stainless steel shell designed to last throughout the vehicle's lifetime. Placed in the exhaust line, a trap-oxidizer collects particulate and incinerates it on-board, eliminating disposal problems. Significant backpressure build-up, due to the collected particles clogging the substrate's air passageways, should be avoided if incineration occurs prior to substantial particulate accumulation. The general consensus is that the minimum temperature required for combustion of the particulate is approximately 450-500°C. Because such high temperatures are not always found in heavy-duty diesel exhaust, research has been initiated to both periodically raise the exhaust gas temperature and lower the particulate oxidation temperature. In addition to these measures, the use of exhaust insulating features, such as port liners and insulated manifolds will reduce heat loss at all times, effectively raising the exhaust gas temperature.

Current trap-oxidizer research centers on both continual and periodic oxidation designs. Efforts to develop a continually-oxidizing trap have often involved the application of catalysts to the trapping media in order to lower the particulate oxidation temperature. Periodic oxidation involves routinely regenerating the trap by artificially raising the exhaust temperature periodically to levels that foster particulate combustion.

General Motors has suggested two means to elevate exhaust temperatures: air intake throttling and the use of an external heat supply.4/ Throttling increases exhaust temperatures by restricting the air intake, thus increasing the fuel-air ratio and reducing the dilution air available in the engine. GM reported that the collection efficiency actually increased slightly over a 1,000-mile load-up and incineration test when throttling was used to initiate incineration every 100 miles.4/

An electrical heating element is also a potential source of the additional heat needed to incinerate the collected particulate. Such a technique could employ a dual path trap with dual heating elements and a flip valve which would route a small fraction of the exhaust flow to the side being incinerated and the rest to the side currently trapping.4/ The dual path design has the advantage of only requiring a small amount of energy to heat the exhaust, since only a small fraction of the exhaust is actually being heated. Its disadvantage is high trap cost, since two full traps are essentially needed.

Traps using periodic regeneration would probably require a control unit with a number of sensors monitoring various engine parameters in order to regulate the regeneration process. The control unit would detect backpressure build-up or mileage since the last burn-up and trigger the incineration process at desired times. The control unit could be very similar to those currently used for feedback carburetion control on gasoline engines or could possibly be much simpler in design.

A trap-oxidizer system, of either the continual or periodic regeneration designs, would necessitate durable exhaust piping from the engine to the trap capable of lasting throughout the vehicle's useful life, estimated to be 475,000 miles or 9 years.5/ This is necessary to ensure that all the exhaust is being routed through the trap and not escaping through holes and cracks in the system. If piping upstream of the trap were made of materials unable to last throughout the vehicle's (and the trap's) lifetime, the opportunity to remove the trap-oxidizer during exhaust system servicing would become more of a possibility. Stainless steel is the usual candidate for such applications and experience with catalyst-equipped light-duty vehicles has shown that it will last the life of the vehicle.

Thus, a possible trap-oxidizer system would consist of stainless steel exhaust piping upstream of the trap, port liners and insulated exhaust manifolds, the trap itself with stainless steel shell and trapping media, and an auxilliary heat supply or air intake throttle with the appropriate control logic and sensors. As mentioned above a catalyzing material could potentially provide continual particulate incineration. Such a system conceivably would not require the control device associated with periodically regenerating traps.

As was the case with light-duty diesels,6/ the trap-oxidizer system should be able to function properly throughout the vehicle's life. It is acknowledged that the Class VII and VIII diesels travel more miles over their life (475,000) than the lighter heavy-duty classes and light-duty diesels (120,000 and 100,000 respectively).5/6/ However, the usage characteristics, such as longer trips, steadier operation, etc., of these largest diesels should be much less stressing on the trap-oxidizer on a per mile basis than those associated with lighter class diesel operation. These advantageous usage patterns coupled with the stainless steel construction of trap-oxidizers should make them capable of filtering exhaust particulate efficiently throughout the vehicle's life.

Among the corporations actively pursuing trap-oxidizer development are Corning, Texaco, Engelhard, Matthey-Bishop, and Imperial Chemical Industries Limited (ICI). Table IV-3 provides an overview of initial collection efficiencies reported for their

Table IV-3

Trap-Oxidizer Test Results*

Trap	Effect on Brake-Specific Emissions(%) Particulate	NOx	HC	CO
Texaco A-IR 1/	-59	0	-60	-4
Englehard CST-1 coating on Texaco trap 1/	-49	-1	-92	-99
ICI-Saffil 2/	-32	9	2	-11
Corning Ex-20 2/	-84	-4	-48	-17
Matthey-Bishop** 7/	-58	-	-90	-
Matthey-Bishop*** 8/	-61	-8	-90	-94

* Tests were conducted on light-duty diesel vehicles over the FTP cycle, except where indicated.

** This Matthey-Bishop trap-oxidizer was tested by Matthey-Bishop on a taxi for 2,000 miles; its efficiency was tested at 600-mile intervals. All tests of other traps were conducted by EPA and reflect zero-mile collection efficiencies.

*** After 600 miles, particulate emissions increased by approximately 200 percent of baseline levels.

respective designs. Nearly all of the research performed so far on the use of trap-oxidizers on light-duty diesels should be applicable to heavy-duty diesels. However, heavy-duty diesels typically are subjected to different operating conditions than light-duty diesels. Heavy-duty diesels, for example, are often left running for several hours while the operator rests or eats a meal. These long periods would not be conducive to trap-oxidizer regeneration since the exhaust temperature is very low during idling. Also, the effect of frequent high-load operation which is characteristic of heavy-duty diesel operation could require improvements over the light-duty design. Thus, some additional leadtime beyond 1985 appears appropriate for heavy-duty trap development. One extra year plus the leadtime remaining after promulgation of the heavy-duty diesel particulate standard should be sufficient to optimize trap designs for the larger diesels.

C. Engine Modifications

A large number of engine design and operating variables could conceivably affect particulate emission levels. Among these are timing, load, speed, combustion chamber design, fuel injector design and orientation, injection pressure, and turbocharging. In a report prepared by Southwest Research Institute (SwRI) for EPA, the effect of several of these variables on heavy-duty diesel particulate emissions was investigated.9/ Table IV-4 shows the effect of timing, EGR, and indirect versus direct injection on the particulate and NOx emissions of a Caterpillar 3406 engine described in Table IV-5. Noteworthy particulate reductions of 23 percent due to a 5 degree timing advance and 21 percent by indirect injection were found. Although these tests were run on the 13-mode cycle and not over the more representative transient cycle, they indicate the potential impact of such parameters.

In order to evaluate the effect of turbocharging on diesel particulate emissions, Southwest chose a Daimler-Benz OM-352 naturally-aspirated and an OM-352A turbocharged engine. As can be seen from Table IV-5, these engines are quite comparable except for the turbocharging. The OM-352 emitted 0.991g/BHP-hr (0.369 g/MJ) of particulate over two tests while the turbocharged OM-352A emitted an average of 0.562 g/BHP-hr (0.209 g/MJ).9/ Thus, the turbocharged version emitted 43 percent less particulate. It should be noted that there is no way to evaluate the effect that turbocharging alone had on this emission reduction since the addition of a turbocharger also required related engine modifications and adjustments to optimize performance. For example, injection pump recalibration and timing adjustments, two modifications deemed necessary when converting a naturally-respirated to a turbocharged engine,10/ will themselves affect emissions. The 43 percent reduction should, therefore, be interpreted as the net effect of turbocharging and associated adjustments. However, as these modifications always accompany turbocharging, the reduction can be said to be essentially due to turbocharging. Since turbochargers are in wide use on today's heavy-duty fleet, minimal

Table IV-4

Summary of Emission Reduction Potential of
Selected Engine Modifications (Based on 13-Mode Cycle) 9/

Modification	Effect on Brake-Specific Emissions (%)	
	Particulate	NOx
5° timing advance	-23	42
10° timing retard	191	-46
EGR	166	-44
Indirect injection	-21	-47

Table IV-5

Description of Heavy-Duty Diesel
Engines Used to Evaluate Engine Modifications 9/

Engine Make	Mack	Caterpillar	Daimler-Benz	Daimler-Benz
Engine Model	ETAY(B)673A	3406 c/	OM-352	OM-352A
Engine Serial No.	6F4310	IA5484	936-10-125488	935-10-01-9653
Strokes/Cycle	4	4	4	4
Cylinder Arrangement	I-6	I-6	I-6	I-6
Displacement (Liter)	11.01	14.63	5.67	5.67
Compression Ratio	14.99:1	14.5:1 (16:1)	17.0:1	16.0:1
Type Aspiration	TC a/	TC a/	NA a/	TC a/
Rated Speed (rpm)	1900	2100	2800	2800
Power at Rated Speed (kw)	235	242	96	108
Peak Torque Speed (rpm)	1450	1200 (1400)	2000	1800
Peak Torque (N-M)	1423.8	1375 (1319)	361	415
Typical Application	IC b/	IC b/	U b/	U b/
Typical Fuel Type	DF-2	DF-2	DF-2	DF-2

a/ TC-Turbocharged, NA-Naturally Aspirated.
b/ IC-Intercity Truck, Tractor, U-Urban Truck and Truck-Tractor.
c/ Items in ( ) are for indirect injection configuration.

research should be involved for those manufacturers choosing this method to reduce particulate emissions. However, it is also only available to those vehicles without turbochargers. While the leadtime necessary to turbocharge a given naturally-aspirated engine can be a number of years, many manufacturers may already have investigated the turbocharging of their naturally-aspirated engines and there may be time available before 1986 for manufacturers to use this control strategy if they so desire.

Southwest Reseach also investigated the reduction potential of a new high-pressure injection system being developed by American Bosch. 11/ The test engine was a Mack ETAY(B) 673A, which is described in Table IV-5. Particulate emissions were obtained from a standard Mack engine which had been run for 1,000 hours, the same engine with a new standard injection system, and the same engine with a new high-pressure injection system. As was the case with turbocharging, engine adjustments and modifications were needed to optimize high-pressure injection performance. However, since again these adjustments would always accompany high-pressure injection, any effect can be attributed to high-pressure injection itself. The results outlined in Table IV-6 lead to several conclusions. First and foremost are the 50 percent particulate emission reduction by the high-pressure system compared to the 1,000-hour old standard pump and the 55 percent reduction of this system versus a new standard pump. Second, these results were accompanied by increased fuel economy, 3.7 percent relative to the 1,000-hour standard pump and 1.1 percent relative to a new standard pump. A third result is the demonstrated lack of deterioration in the particulate emission rate due to injection system deterioration. The experimental high pressure injection system also caused a 34 percent increase in NOx emissions.

There is also evidence that basic engine modifications, often made for reasons other than particulate control, can in fact have a beneficial effect on particulate emissions. Two examples involve Cummins and Caterpillar engines. First, two improved versions of a 1976 Cummins NTC-350 engine were tested at SwRI, along with the older version. One of the newer engines was the California version (NTCC-350) and the other was the 49-state version (NTC-350). The emission results of all three engines are shown in Table IV-2. As can be seen, both newer engines showed marked reductions in particulate emissions, 35 and 33 percent, respectively; NOx emissions of these newer engines decreased at the same time by 42 and 13 percent respectively. It is also important to point out that fuel consumption of the newer versions decreased by 7.9 and 4.2 percent respectively.12/ This is an indication that engine modification can be optimized to simultaneously reduce particulate and NOx (a point which will become more readily important in later portions of this chapter), without adversely affecting fuel economy.

Second, Caterpillar has submitted data on a 3406 engine which was redesigned for NOx control.13/ There were a number of improvements made to the engine, but the most notable were separate

Table IV-6

Effect of High-Pressure Injection on Emission and Fuel Consumption (2-test averages, based on 13-mode cycle) 9/

Engine Configurations	Particulate g/BHP-hr	NOx g/BHP-hr	Fuel Consumption kg/BHP-hr
High pressure A. Bosch pump (10° BTC)	0.30	9.0	.181
Standard pump - 1000 hours (21° BTC)	0.61	6.61	.175
Standard pump - new (21° BTC)	0.67	-	.179

* NOx as NO_2 by non-dispersive infrared.

circuit aftercooling, high pressure injection, and a small degree of retarded timing. While NOx emissions were reduced 20 percent, particulate emissions (as estimated by smoke) were reduced 50 percent. While smoke measurements do not always correlate with particulate emissions, there are two factors in this case which would support the smoke reduction as a reasonable indication of a particulate reduction. First, only one engine was involved and a correlation of smoke and particulate was already available for that engine. Second, the instantaneous volumetric flow rate was coupled with the smoke reading (which is a form of concentration measurement) to give the overall smoke measurement more of a mass emission orientation. Thus, while these data cannot be used to strictly state that particulate emissions were reduced 50 percent, it can be said that particulate emissions decreased and very likely by a large amount. One of the more notable aspects of these data is that the unmodified Caterpillar 3406 is already one of the cleaner engines tested by SwRI (see Table IV-2). These data are evidence, then, that reductions via engine modifications can be made even beyond the lowest values shown in Table IV-2.

The leadtime necessary to make such modifications would vary from engine to engine. In the two examples cited above, the modifications were occurring for reasons other than particulate control and will be implemented by 1986 with or without the promulgation of a particulate standard. This may not be the case with other engines and those design features beneficial to particulate control will have to be incorporated specifically for that reason. However, it should be true that most if not all heavy-duty diesel engines will be undergoing some degree of redesign in the next five years. The drive for fuel economy is forcing improvements in existing engines as well as opening up new markets for on-road diesel engines. The latter should result in new families of diesels being designed, as well as the modification of old designs, to power vehicles traditionally equipped with gasoline engines. Due to this degree of redesign already occurring, it should be much easier to incorporate the necessary design changes for particulate control than it would be if existing designs were not changing over the next 5-10 years. Thus, it can be expected that most engines will be able to incorporate the necessary changes by 1986.

In summary, several engine modifications have been shown to reduce particulate emissions by varying degrees. Advanced timing reduced particulate emissions by 23 percent, indirect injection by 21 percent, turbocharging by 43 percent and high-pressure injection by 50 percent. The leadtime necessary to incorporate timing changes and turbochargers should be available before 1986 since the former is a relatively simple adjustment and the latter involves technology which is readily available. The Bosch high-pressure injection system is still in the developmental stages and will require more time to refine. Nevertheless, such a system should be available as a particulate control device for use by the 1986 model year fleet. Indirect injection would require redesign of the engine, implying significant effort in order to implement. As can be seen from Table IV-4, indirect injection not only reduces particulate emissions but NOx emissions as well. These reductions, however, are usually associated with a fuel economy penalty; 7.5 percent in this test case.9/

Engine modifications incorporated on newer production engines and from prototypes also indicate that particulate emissions can be reduced without raising NOx emissions. These are probably the most promising modifications as they have already been practically demonstrated and have occurred for reasons other than particulate control. The latter factor would imply that these design modifications would have other benefits connected with them besides particulate reduction. With the large amount of redesign occurring in the industry at this time, these types of modifications should be able to be incorporated by 1986 on most, if not all, engines.

D. Particulate-NOx Relationship

Section 202(a)(3)(A)(ii) of the Clean Air Act calls for a 75 percent reduction in NOx emissions for heavy-duty vehicles (based on uncontrolled gasoline engines). This requirement is relevant to particulate control since, as discussed in the previous section, certain engine modifications which reduce particulate emissions also increase NOx emissions and vice versa. Also evident from the preceding section is the fact that not all engine modifications improving particulate emissions have a deleterious effect on NOx. Figure IV-1 demonstrates that engines can be built which emit relatively low amounts of both NOx and particulate. As can be seen, at least four engines produced by three different manufacturers have both very low NOx and particulate emissions.

Since EPA is required to regulate both particulate and NOx emissions from heavy-duty diesels, and as mentioned above certain control techniques which lower particulate also raise NOx emissions, the method used to set the particulate standard should be designed to affect the achievability of the mandated NOx reduction as little as possible. In this way, manufacturers will not be placed in the unfair position of complying with two Congressional mandates, which separately may be achievable but together are not. Thus, in arriving at the level of the particulate standard (a discussion of this topic follows this section) EPA will not consider the potential particulate emission reduction of those engine modifications which could have an adverse impact on NOx emissions. It should be pointed out at this time that trap-oxidizers do not adversely affect NOx emissions and are affected by the above-mentioned restriction.

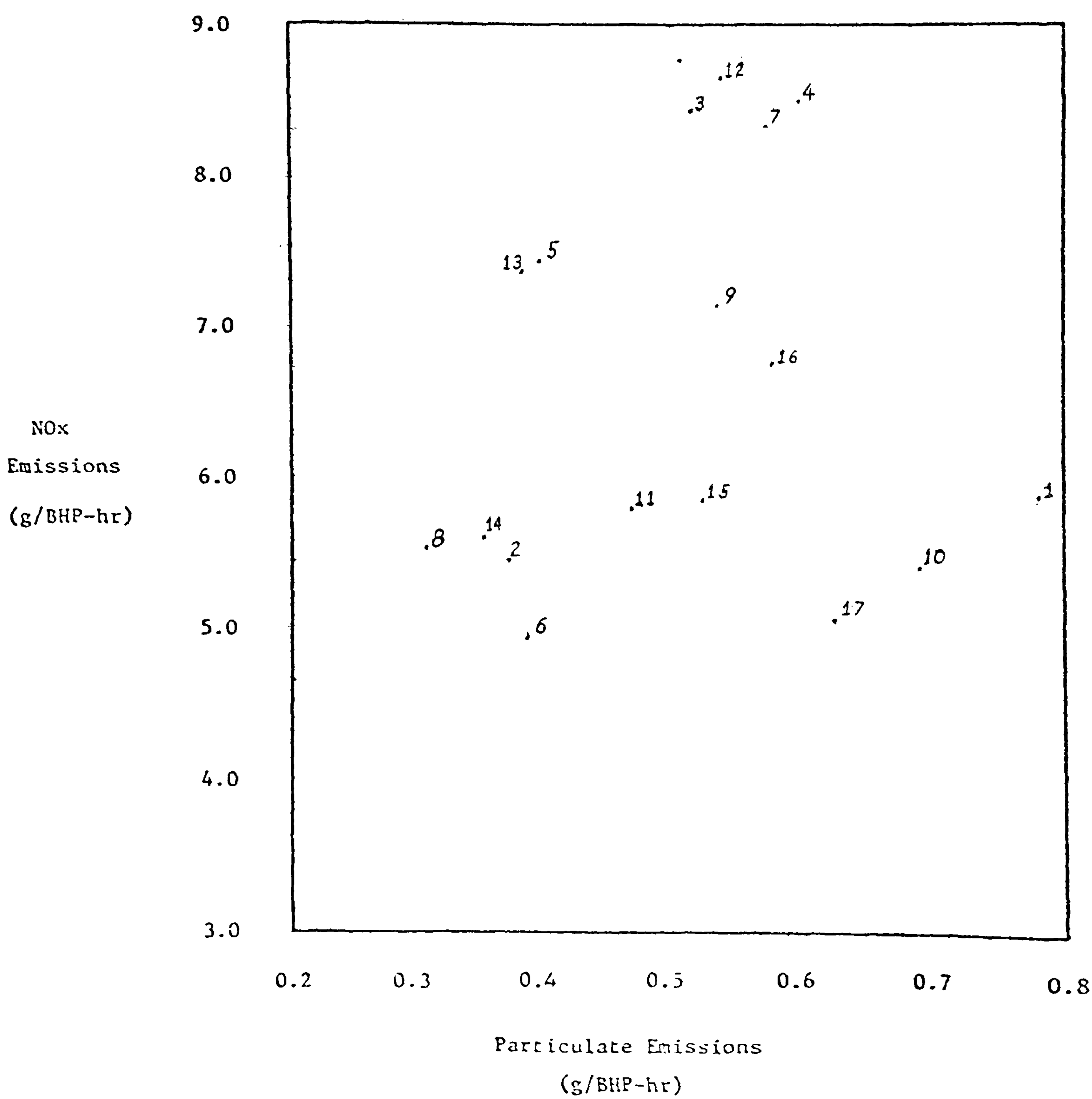
E. Rationale for Level of Control

When determining the level of control, several factors must be considered. These include 1) the degree of reductions achievable from existing levels; 2) emission deterioration over the vehicle's useful life; and 3) the 10 percent Acceptable Quality Level

Figure IV-1

NOx vs. Particulate Emissions

from Table IV-2 Engines



(AQL) of Selective Enforcement Auditing (SEA), which includes the effect of production line variability.

Before these factors can be applied, however, a decision must be made as to the baseline emission level from which the reductions should be taken. This topic is dealt with in the following subsection and the 3 points listed above are discussed in the subsection which follows it.

1. Baseline Level

Section 202(a)(3)(A)(iii) requires the Administrator of EPA to set a particulate standard for heavy-duty diesels which reflects "the greatest degree of emission reduction achievable through the application of technology which the Administrator determines will be available . . . ." Several options have been considered with regards to this edict, any one of which could conceivably provide a baseline from which to set the standard. They include: 1) the worst engine (highest particulate emission level from the Southwest test program); 2) the lowest particulate emission level of the tested engines; 3) the highest emission level among each manufacturer's best engines; or 4) the average emission level of the set of engines which includes each manufacturer's best engine.

As can be seen from the above options, a wide range of levels could conceivably be chosen as the baseline from which to take reductions. An examination of the options and the data in Table IV-2 reveals that Option 1 would result in the highest baseline level, 0.79 g/BHP-hr (0.29 g/MJ), and Option 2 would result in the lowest level, 0.31 g/BHP-hr (0.12 g/MJ). The extent of this range makes it clear that the determination of the proper "baseline" level from the test data contained in Table IV-2 also includes an evaluation of the control technology inherently present in each of the engines shown in Table IV-2. As such, the question of which option best conforms with the requirements of the Clean Air Act includes more than that of the typical baseline, but includes discussion of control technology as well. This control technology can be distinguished from that to be discussed later, when further reductions are taken from the baseline, by the fact that it is already present on existing engines. The control technology to be discussed later will consist of new devices and techniques, both engine-related and exhaust-related, which are not generally in use today. Thus, when determining this "baseline" level, the mandate of the Act to achieve the greatest reduction that is technologically feasible is just as applicable as when determining the reduction potential of trap-oxidizers and the like. With this in mind, a discussion of the four options will be presented below.

Referring to Table IV-2, a standard based on Option 1 would reflect the reductions achievable from the relatively small 1978 Caterpillar 3208's level of 0.79 g/BHP hr (0.29 g/MJ). This particular engine emits by far more particulate than its counterparts (14 percent more than the second highest engine). Any standard based on this level could still reflect the greatest degree of control available from new technology, but would ignore the demonstrated potential of other existing engine designs to reduce particulate emissions by more than 50 percent. It seems clear from the wording of the Act, that this demonstrated technology is to be included in determining the level of the particulate standard. This would require the rejection of 0.79 g/BHP-hr (0.29 g/MJ) as a viable baseline level.

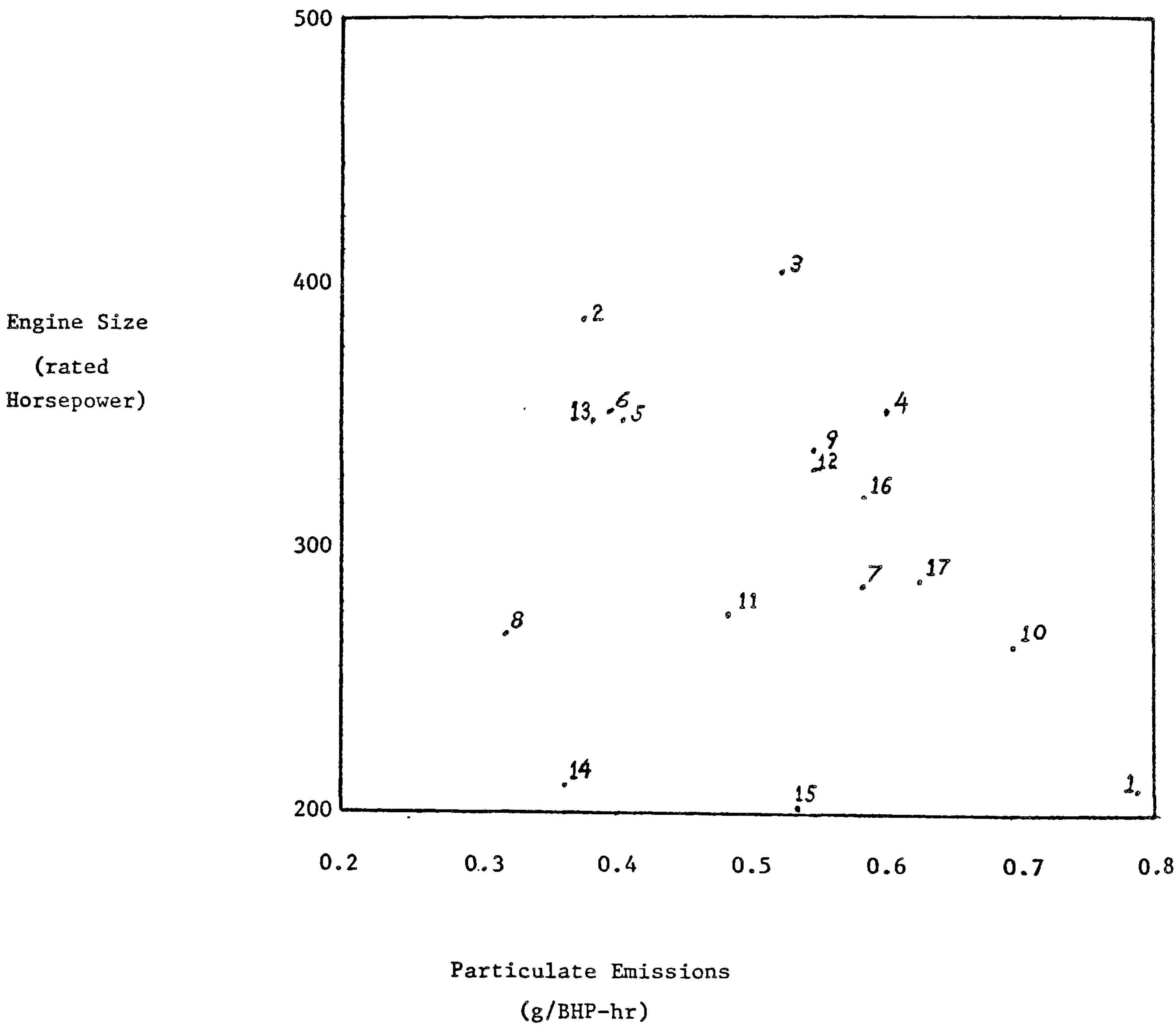
It is possible that not all heavy-duty diesel engines would have the same inherent potential for low particulate emissions. If a certain type of engine (e.g., a bus engine) or a certain size engine (e.g., relatively low power) had inherently higher particulate emissions than the others and this type or size of engine was necessary to the market, then some allowance may be in order. Certainly, this is the case with use of No. 1 diesel fuel. As indicated in Table IV-2 and supported by past literature, use of No. 1 diesel fuel, as opposed to use of No. 2 diesel fuel, will reduce particulate emissions 10-20 percent. Thus, it would be inappropriate to use test results on No. 1 fuel to demonstrate feasibility for another engine required to use No. 2 fuel. And while this particular problem does not apply to the Caterpillar 3208, this particular engine is a relatively small engine with respect to power (210 hp) and it could be possible that small engines have inherently higher emissions than larger, more powerful engines. To evaluate this possibility, the particulate emissions of those engines shown in Table IV-2 were plotted against their maximum power outputs in Figure IV-2. As can be seen, particulate emissions appear to have no correlation at all with engine size and all sizes would appear to have nearly the same potential for low particulate emissions. Thus, no allowance appears necessary for engine size.

It could also be possible that the particular design of the 3208 may lead to higher particulate emissions and some significant changes in its design would be necessary to reach the lower particulate levels of other engines. The requirements of Section 202(a) of the Act would still require a standard based on the lower levels of demonstrated technology. However, the provisions of Section 206(g) of the Act, providing non-conformance penalties for engines of this class, would apply very appropriately in this case. Under these provisions, engines not meeting an emission standard could still be sold if a pre-determined fee were paid for each engine sold. The fee schedule would be designed to encourage manufacturers to meet the standard as soon as possible. Thus, even in this case, Option 1 should be rejected.

The logic of the above argument could be applied to the second highest emitting engine, the third highest, etc. until the only engine left would be the best engine tested so far, the Cummins VTB-903 at 0.31 g/BHP-hr (0.12 g/MJ). This is essentially Option 2. A problem arises with this particular engine because it was

Figure IV-2

Engine Size vs. Particulate Emissions
(Numbers beside points refer to engine listing order from Table IV-2)



tested using No. 1 fuel. As discussed earlier, this particular datum should not be used in setting the baseline. Instead, an engine tested on No. 2 fuel should be used and this could easily be done. However, the arguments that would apply for or against that engine also apply to the VTB-903 and for simplicity it will be used as the example.

In order for Option 2 to be acceptable, the determination would have to be made that all engines (or nearly all engines when nonconformance penalties are considered) could incorporate all of the pertinent design features of the best engine. Absolutely no allowances would be made for engine type, size or manufacturer differences. One might say that the only guaranteed way to ensure reaching that level would be to copy the best engine. While Figure IV-2 shows no real relationship between particulate emissions and engine size and Table IV-2 shows no discernable difference between truck and bus engine emissions, the data are simply not strong enough to demonstrate that there is absolutely no effect in this area. This option would also leave no room for differences between manufacturers, even if their effect on particulate emissions were quite small. From all this it would appear that Option 2 would go beyond the mandate of the Act and set a standard that may not be achievable by a sizeable portion of the industry. Therefore, it should be rejected.

One solution to the problems of Option 2 would be to include manufacturer differences into the methodology. In the extreme, rather than a baseline set by the best engine of those tested, the baseline would be set by the highest-emitting engine from among the best of each manufacturer. This is Option 3 and would base the standard on Mack's 1979 ETAZ(B)673A which emitted 0.58 g/BHP-hr particulate. Upon examining Table IV-2, it is apparent that this engine's particulate emission level is well above that of the other manufacturers' best engines' (57 percent higher than the average of the other low-emitting engines). Indeed, 12 of the 17 engines on Table IV-2 are already at or below this level. While this option attempts to take manufacturer differences into account, it would appear to go too far and ignore the possibility that the manufacturers of the higher-emitting diesels could produce engines like those of their competitors. It would seem impossible to argue that this level represented the lowest achievable level when two-thirds of the existing engines could do better, particularly with the possibility of nonconformance penalties being available. Thus, Option 3 should be rejected.

The last option listed, which would average the best engines of each manufacturer, appears to be the most appropriate as it avoids the problems associated with the other options. One, it avoids basing the standard on a single engine design. Two, it still appears to comply with the "greatest degree of emission reduction" requirement of the Clean Air Act. Following this procedure, the standard would be based on further emission reductions achievable from a 0.41 g/BHP-hr level.* This is a stringent level, currently achieved by only six of the seventeen engines tested so far and only 14 percent higher than the lowest-emitting engine (on No. 2 fuel). Three, it does take into account manufacturer differences by basing the level on an average (four of the five manufacturers' engines are below the average). And four, engines of different size and type are included in the average. This should allow for any slight differences in inherent emission levels due to these factors. A closer examination of each manufacturer indicates the feasibility of the 0.41 g/BHP-hr level.

Caterpillar's 1979 3406 Family 10 is already below this level. Their 3406 Family 16 is slightly above, but should be able to incorporate features of the Family 10 and also be able to comply with the proposed standard. While the 3208 model listed is well above 0.41 g/BHP-hr (tests indicate 0.78 g/BHP-hr) the particular engine tested was a relatively old 1978 model. It should also be pointed out that another manufacturer's engine with the same rated horsepower as the 3208's has been tested and found to emit less than half as much particulate over the transient cycle: the International Harvester DTI-466B. Therefore, there should be no inherent reason why an engine of that size cannot reach the 0.41 g/BHP-hr level. As can be seen from Figure IV-2, there is no discernable link between engine size and particulate emission level.

Three Cummins engines tested are below the 0.41 g/BHP-hr level. Newer versions of the 1976 NTC-350, which was found to emit 0.60 g/BHP-hr, were among those meeting the 0.41 g/BHP-hr requirement. The Cummins engines listed on Table IV-2 further indicate that lower particulate emissions can indeed be achieved through basic engine modifications.

Of the Detroit Diesel Allison (DDA) engines listed in Table IV-2, the 8V-71TA is already below 0.41 g/BHP-hr, a second is close at 0.48 g/BHP-hr (the 6V-92TA 6g), and two of those listed (the 6V-92T and 8V-71N) are 1978 models scheduled to be discontinued by 1982.1/ EPA believes technology already proven on the relatively new 8V-71TA should enhance the ability of other DDA engines to reach the 0.41 g/BHP-hr level.

Neither of the two Mack engines tested emit less than 0.41 g/BHP-hr particulate; their levels were 0.58 and 0.63 g/BHP-hr. One of the Mack engines, however, has the second lowest NOx emissions of the engines tested. This should aid them in complying with any future NOx standard (mandated by the Clean Air Act). Since as mentioned earlier, some engine modifications which reduce NOx also increase particulate, e.g., retarded timing, Mack may not need to rely on such techniques to the same extent as other

* This value reflects the average of those best engines tested on No. 2 diesel fuel only, since as mentioned earlier, only bus engines can certify using the lower particulate emitting No. 1 diesel fuel.

manufacturers. Thus when the potential adverse effect on particulate emissions of NOx control is considered, Mack's engines may be ultimately in a more advantageous position than is now apparent.

If after a good faith effort, their engines (or those of any other manufacturers) are not able to comply with an emission standard, nonconformance could be made available, as mentioned above.

To summarize Option 4, it would base the level of the proposed standard on an average taken from each manufacturer's lowest particulate emitting engine. By requiring dirtier engines to become more like the cleaner ones before reductions from add-on devices (trap-oxidizers) are considered, this methodology complies with requirements of the Clean Air Act that the standard reflect the "greatest degree of emission reduction achievable . . . ." The 0.41 g/BHP-hr level is not excessively stringent since control technology exists today whereby several engines have already reached this level (refer to Table IV-2). By averaging the particulate emission levels of the best engines, Option 4 reflects a more representative range of performance capabilities than other options based on the performance of single engines while still resulting in a stringent standard. All manufacturers listed in Table IV-2 have at least 1 engine which is below the 0.41 g/BHP-hr level except Mack. In Mack's case, the fact that four other manufacturers, each within their own design constraints, have met this level should be sufficient evidence that the ability to meet this level is not connected to some unique design feature, but indeed can be attained by all manufacturers.

2. Choice of Standard

Now that the basic engine-out particulate emission level (0.41 g/BHP-hr) has been established, the process of choosing a standard can continue. The next step is to determine the greatest degree of reductions achievable on prototype engines by applying control technology not commonly found on current engines. These techniques fall into two categories, engine modifications and exhaust aftertreatment (trap-oxidizers). As mentioned earlier, reductions achievable from engine modifications which adversely affect NOx emissions have been excluded from the determination of a technologically achievable particulate standard. This was done in order to affect the achievability of the mandated NOx standard as little as possible (refer to the discussion of the particulate-NOx relationship earlier in this chapter). In addition to foregoing this type of control technique, other engine modifications not commonly found in current engines which do not adversely affect NOx (e.g., indirect injection) have also been excluded from the methodology used to set the particulate standard. The forthcoming NOx rulemaking will consider the potential of such techniques and propose a NOx standard which heavy-duty diesels can meet while at the same time complying with a 0.25 g/BHP-hr particulate standard. Thus, the emission reduction potential of engine modifications not commonly found on today's engines have not been applied to the basic engine-out particulate emission level of 0.41 g/BHP-hr. The second category of control techniques not commonly found on current engines is exhaust aftertreatment (trap-oxidizers). Particulate reductions from this strategy have been included in the methodology used to set the level of the standard.

Based on results from prototype trap-oxidizers, EPA believes 60 percent efficient trap-oxidizers will be available for application on the 1986 model year heavy-duty diesel fleet (see Section B and Table IV-3). This level of efficiency is the same as that determined to be feasible for light-duty diesel applications for the 1985 model year fleet.6/ By mathematically applying such a device to the 0.41 g/BHP-hr baseline, an emission level of 0.16 g/BHP-hr is obtained. This value represents the lowest mean particulate emission level a manufacturer could achieve on new prototype engines.

In order to estimate the production line mean from this sample (prototype) mean when the standard deviation of the population is known, the z distribution can be used. In equation form, this is represented by:

$$P[\mu \leq \bar{x} + z_{\alpha}\frac{\sigma}{\sqrt{n}}] = 1 - \alpha$$

Where:

- P = probability
- μ = population (production line) mean
- $\bar{x}$ = sample (prototype) mean
- α = degree of confidence
- z_{α} = z statistic
- σ = standard deviation of population
- n = sample size

Several of these factors deserve clarification. The sample prototype mean is 0.16 g/BHP-hr, as determined earlier. The degree of confidence that the equation within the brackets in the above equation is true is represented by α. A 90 percent confidence level has been chosen for this application. This level is believed to be reasonable since not all engine families are audited and a greater degree of certainty would likely be cost prohibitive. Based on this 90 percent degree of confidence, the z statistic can be obtained from statistical tables such as Table A-1 of reference 14; and is 1.28. No data are available which indicate the standard deviation of production line particulate emissions (σ) so EPA has assumed it to be 12 percent of the population mean, as is the case with regards to gaseous emissions from heavy-duty diesels.15/ Last, for the purposes of this study, a sample size of 3 was chosen. This value represents the number of prototypes a manufacturer might develop on a certain project. Of course the number of prototypes to be developed is at the manufacturer's discretion. It should be pointed out, however, that as n increases, z decreases; this has the effect of enhancing the likelihood that the prototypes are indicative of potential production-line performance. Incorporating the above values, a production line mean based on a prototype mean of 0.16 g/BHP-hr would be approximately 0.18 g/BHP-hr.

The remaining factors to be considered in the standard development process deal with deterioration (both engine and trap-oxidizer) and Selective Enforcement Auditing (SEA). A 20 percent increase in particulate emissions over a vehicle's useful life due to deterioration in trap-oxidizer collection efficiency and engine wear has been assumed. In-use data on General Motors light-duty diesels show negligible increase in particulate emissions with an average 48,000 miles accumulated.16/ If this were also indicative of heavy-duty engines, it would essentially leave the full 20 percent factor for trap deterioration alone. Production line engines emitting a mean 0.18 g/BHP-hr would thus, at the end of their useful lives, emit approximately 0.22 g/BHP-hr.

To assure that 90 percent of his vehicles pass SEA, a manufacturer must allow a margin of 1.28 σ from the mean production-line emission level, where σ is defined as above. Thus, a manufacturer would design his vehicles so that the mean production line particulate emission level is 0.03 g/BHP-hr below the standard. Applying this factor to the deterioration corrected production line mean, a standard of 0.25 g/BHP-hr is determined.

Engines operating on No. 1 fuel (bus engines) may have an advantage with regards to a margin for NOx reductions since use of this fuel usually results in lower particulate and NOx emissions but these engines are only required to meet a particulate standard based on emission results using No. 2 fuel. This effectively gives them an additional control technique not available to all engines (refer to earlier discussions of this topic in this chapter). Other methods which could be employed to reduce particulate without adversely affecting NOx include a tighter control of production line variability, technologically improving the durability of trap-oxidizer and/or engine components, the development of more efficient trap-oxidizers, and by relying on a less than 90 percent confidence that a particular engine family will pass SEA. This latter point is important since, if after a good faith effort a manufacturer's engines are slightly above the 0.41 g/BHP-hr pre-trap-oxidizer level, there can still be a good chance of passing SEA, only not with a 90 percent confidence.

As mentioned earlier, the Agency is in the process of developing a standard to limit the emissions of NOx from heavy-duty engines and light-duty trucks. Since certain control techniques which lower NOx also raise particulate emissions and vice versa, the possibility exists whereby heavy-duty diesels could be required to meet NOx and particulate standards which alone would be technologically feasible, but taken together, infeasible. To avoid this situation no particulate control techniques which also cause a rise in NOx emissions were relied upon in this proposal to determine the technologically achievable level of particulate control. Similarly, the forthcoming NOx proposal will demonstrate that a 0.25 g/BHP-hr particulate standard can be achieved while at the same time complying with the proposed NOx level of control.

Given the data available, the proposed 0.25 g/BHP-hr (0.093 g/MJ) particulate standard complies with the requirements of the Clean Air Act as delineated in Section 202(a)(3)(A)(iii).

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CHAPTER V

ENVIRONMENTAL IMPACT

A. Health Effects of Particulate Matter

Suspended particulate matter has long been recognized as a major pollutant of our nation's air. Of the greatest concern is the effect of particulate matter (PM) on human health. Research has shown that exposure to PM is associated with respiratory and pulmonary functions, and that effects of high PM levels range from increased discomfort to healthy persons and aggravation of cardio-respiratory symptoms in elderly persons, to increased susceptibility to bronchitis, asthma, and pneumonia, to increased mortality. Based on such research, when the Clean Air Act Amendments of 1970 mandated the establishment of National Ambient Air Quality Standards (NAAQS), PM expressed in terms of levels of total suspended particulates (TSP), was among the first six pollutants for which a standard was promulgated. The primary NAAQS for TSP, which are intended to provide protection to the public health, are 75 micrograms per cubic meter (annual geometric mean) and 260 micrograms per cubic meter (maximum 24-hour concentration, may be exceeded once per year). The secondary NAAQS for TSP, which is intended to protect the public welfare, is 150 micrograms per cubic meter (24-hour average to be exceeded only once per year).

Since promulgation of the NAAQS for TSP, numerous reviews have appeared evaluating the scientific literature bearing on the scientific basis for the standards. For example, the National Academy of Sciences has extensively reviewed all aspects of PM, and the reader is referred to the NAS document on Airborne Particles for a detailed treatment of the health and welfare effects of PM.1/ Also, EPA is currently conducting a review of the criteria and standards for particulate matter. The scientific consensus that particle levels impact on human health will be taken as given here. The emphasis of this section will be on the contribution of heavy-duty diesel particulate emissions to ambient PM levels, and to any special health impacts that might result from diesel particulate matter.

B. Health Effects of Diesel Particulate

This section will highlight only those aspects of the health effects of diesel particulate which differ from those of TSP in general. Much has been learned in the years since the NAAQS (based on total mass of particulate) was promulgated, and it is now accepted by most scientists that some particulate emissions are more deleterious than others, and that some sources necessitate priority control over others. There are two characteristics of diesel particulate matter which place it among the most harmful types of particulate matter. The first is size and the second is chemical composition. These will be discussed below.

1. Size-Related Effects

It is now generally accepted that size is one of the most critical characteristics of particulate matter. The size of a particle primarily affects three parameters which, in turn, help determine the health effect of that particle: total deposition, or how efficiently the particles are deposited in the respiratory tract; regional deposition, or where the particle is deposited in the respiratory tract; and clearance time, or how long it takes to remove the particle from the respiratory tract. When examining data presented, it will be important to note the differences in deposition between nose and mouth breathers. As the nasal passages are more efficient in capturing large particles than the mouth, the sizes of particles reaching various sections of the respiratory tract depend on how the air is being inhaled.

Total deposition by particle size for a mouth breather is shown in Figure V-1. As can be seen, the fraction decreases with particle diameter, until about 0.5-0.7 micrometers when the trend begins to reverse.

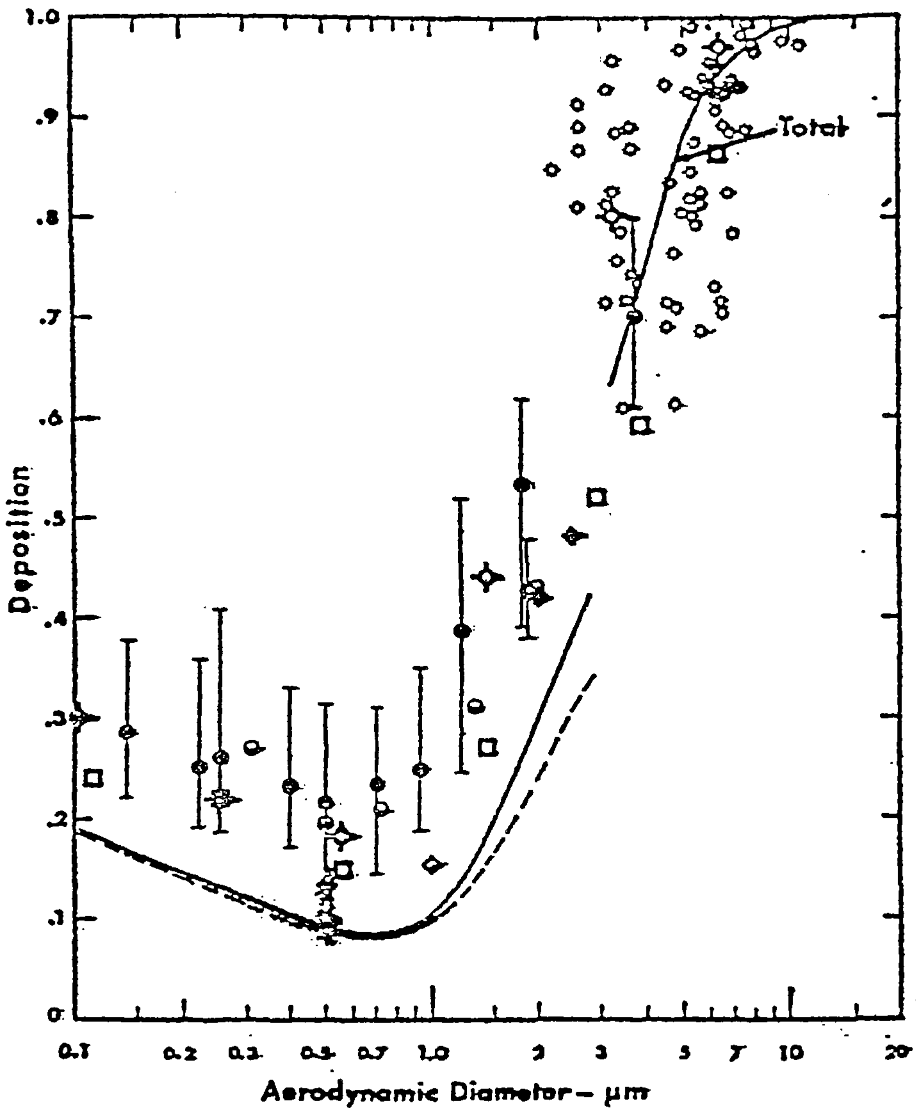
More important than total deposition, however, is the deposition occurring in selected regions of the respiratory tract, because the health effect of a particle is dependent on the region in which it is deposited. Deposition in three regions will be discussed: the head, the tracheo-bronchial zone and conducting airways, and the alveolar zone. These regions are depicted in Figure V-2.2/

Deposition in the head (for nose breathers) is highest for large particles and negligible for very small particles. Deposition is close to 100 percent for coarse mode particles between ten and fifteen micrometers and higher in size, while deposition is less than 10 percent for fine mode particles below one to two micrometers.1/ It is clear that far less deposition in the nasal passages and greater respiratory tract penetration occur for both fine and coarse mode particles during mouth breathing than during nasal breathing.

Deposition in the tracheo-bronchial region is very similar to that in the head(for both nose and mouth breathers), if deposition is determined as a fraction, or percent, of particles entering the tracheo-bronchial region. Deposition approaches 100 percent around eight to fifteen micrometers and approaches 10 percent around one to two micrometers.

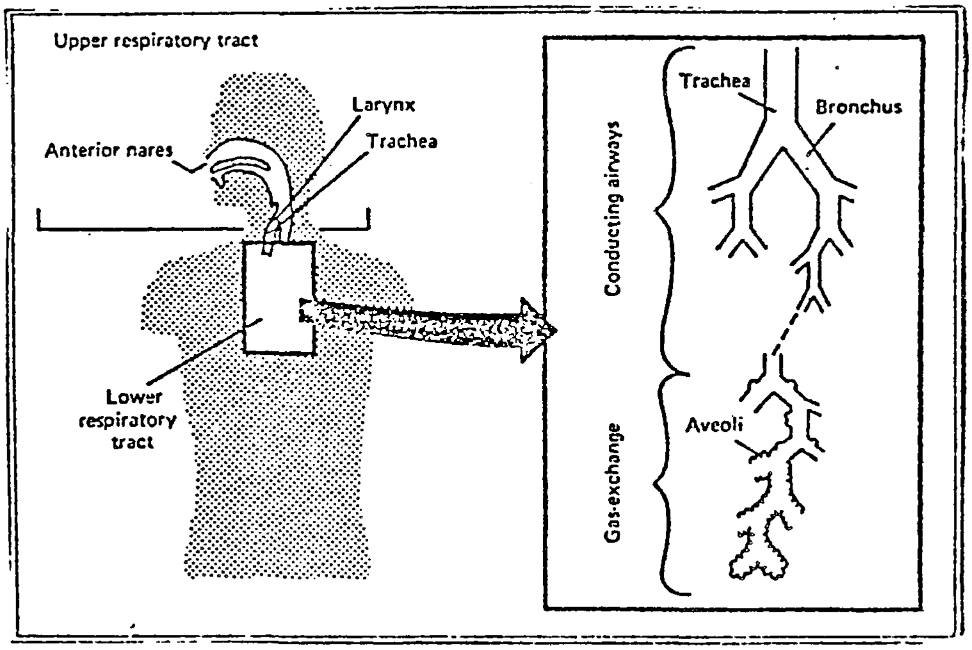
Deposition in the alveolar region is shown in Figure V-3, based on the total number of particles entering the mouth or nose, not on the number of particles entering the alveolar region.1/ Deposition in this region is low above five to seven micrometers because the larger particles have already been captured by the

Figure V-1 1/



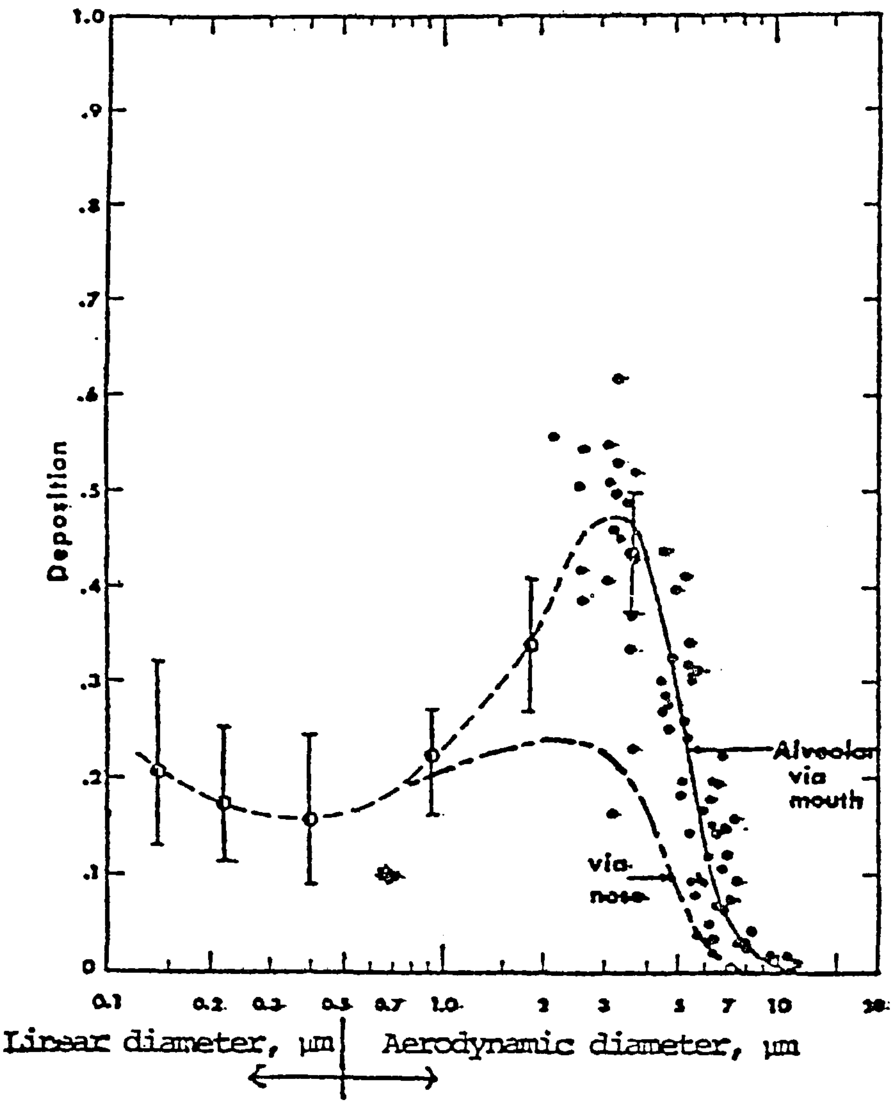
Total respiratory tract deposition during mouthpiece inhalations as a function of D (aerodynamic diameter in µm) except below 0.5 µm, where deposition is plotted vs linear diameter.

Figure V-2 2/



Diagrammatic representation of the human upper and lower respiratory tract.

Figure V-3 1/



Deposition in the nonciliated alveolar region, by percent of aerosol entering the mouthpiece, as a function of diameter.

nasal passages and the tracheo-bronchial region. Deposition reaches a relative peak around two to five micrometers. The level of the peak depends on whether the person is breathing through the mouth, when deposition reaches 40-50 percent, or the nose, 20 percent.

Depending on chemical composition, particles deposited in any region of the respiratory tract can affect health. Of particular concern are those particles that reach the lung (tracheo-bronchial region, conducting airways and the alveoli). The alveolar region (where gas-exchange takes place) is the most sensitive region of the respiratory tract. Moreover, a significantly longer clearance time is required for particles in the alveolar region. Clearance time is the time it typically takes for a particle to be removed from the region in question. In healthy individuals, the clearance of particles deposited in the nasal passages and the tracheo-bronchial region is usually completed in less than one day.1/ Clearance can take somewhat longer for those people with respiratory ailments. In the alveolar region, clearance is measured in weeks unless the particle is very soluble in body fluid, which diesel particulate is not. While the results of studies on humans are variable, it appears that a half-time clearance for relatively insoluble particles is on the order of five to nine weeks.1/

As a result of a review of the available information on the effects of particle size on deposition and health, EPA has recommended that future health effects research be conducted on two size-specific fractions of PM.2/ One fraction is labeled inhalable particulate (i.e., particles having a diameter equal to or less than fifteen micrometers). This fraction includes those particles which primarily deposit in the conducting airways and the gas-exchange portions of the respiratory tract. The second fraction is the fine particulate (i.e., particles having a diameter equal to or less than 2.5 micrometers). This second cutoff was chosen for two reasons; 1) this fraction includes those particles which primarily deposit in the gas exchange portion of the lung (alveolar), and 2) due to the breakdown of ambient particulate by size and chemical composition, there is a natural break between fine and coarse (diameter larger than 2.5 micrometers) particles at this size.

Diesel particulate is very small in size. Its mass mean diameter varies between 0.05 and 0.2 micrometers.3/4/ Essentially all diesel particles fall into the inhalable range and between 94% and 100% can be characterized as fine particulate.3/4/5/ Because of its small size, diesel particulate belongs to that category of particulate which is most likely to deposit in the alveolar region, thus remaining in contact with the most sensitive areas of the respiratory tract for comparatively long periods of time. Clearly, diesel particulate is of more concern than larger particles which deposit in the head or tracheo-bronchial regions and which have much shorter clearance times. Because of this, the control of diesel particulate and other fine and inhalable particulate is of high priority.

2. Chemical Composition-Related Effects

In addition to particle size, chemical composition is an important factor in determining the health effect of a particle. There are a wide variety of chemicals of particular concern, such as fibers (e.g., asbestos), toxic elements (e.g., Be, Cd, Pb), organic matter (e.g., benzo(a)pyrene), carbon, and sulfuric acid.

Diesel particulate is primarily carbonaceous, with between 10 and 50 percent of the particulate by weight being extractable organic matter.4/5/6/7/ This organic matter is definitely mutagenic in short-term bioassays,7/ and EPA is currently performing a health assessment to determine the carcinogenic risk of diesel particulate to humans.8/ Known or suspected human carcinogens are present in diesel particulate, such as benzo(a)pyrene, which comprises about 0.0001 to 0.007 percent by weight of diesel particulate.5/6/ However, most of the mutagenic response is being caused by substituted polycyclic organic matter, which does not require metabolic activation.7/ At this time, no definitive statement can be made concerning the complete effect of diesel particulate on human health. However, the data available is serious enough to merit caution and diesel particulate should definitely be numbered among those chemical types of particulate which require priority control.

C. Visibility

Visibility degradation is perhaps the most noticeable effect of air pollution on today's society. In addition to the adverse health effects previously delineated, diesel particulate also plays a significant role in light extinction; which is defined, for the purposes of this study, as the process whereby the illuminance of light is reduced while propagating through a medium (such as air).9/

The typical observer can detect an object with 2 percent contrast against the background.9/ Expressed mathematically the distance, Lv, at which a black object is just visible is given by:

$$Lv = \frac{3.92}{b_{ext}}$$

Where, 3.92 = -ln 0.02 and b_{ext} refers to the sum of the collective extinction coefficients of the four processes responsible for light attenuation.9/ These processes are:

1) Scattering by gas molecules, responsible for the sky's blue color;

2) Absorption by gas molecules;

3) Scattering by small particles; and,

4) Absorption by particles.

Since diesel particulate impacts directly on two of these four mechanisms, the latter two, its potential effect on visibility is of some concern. In order to gain insight into the relative role of diesel particulate in light attenuation, each of the four components of the extinction coefficient should be examined.

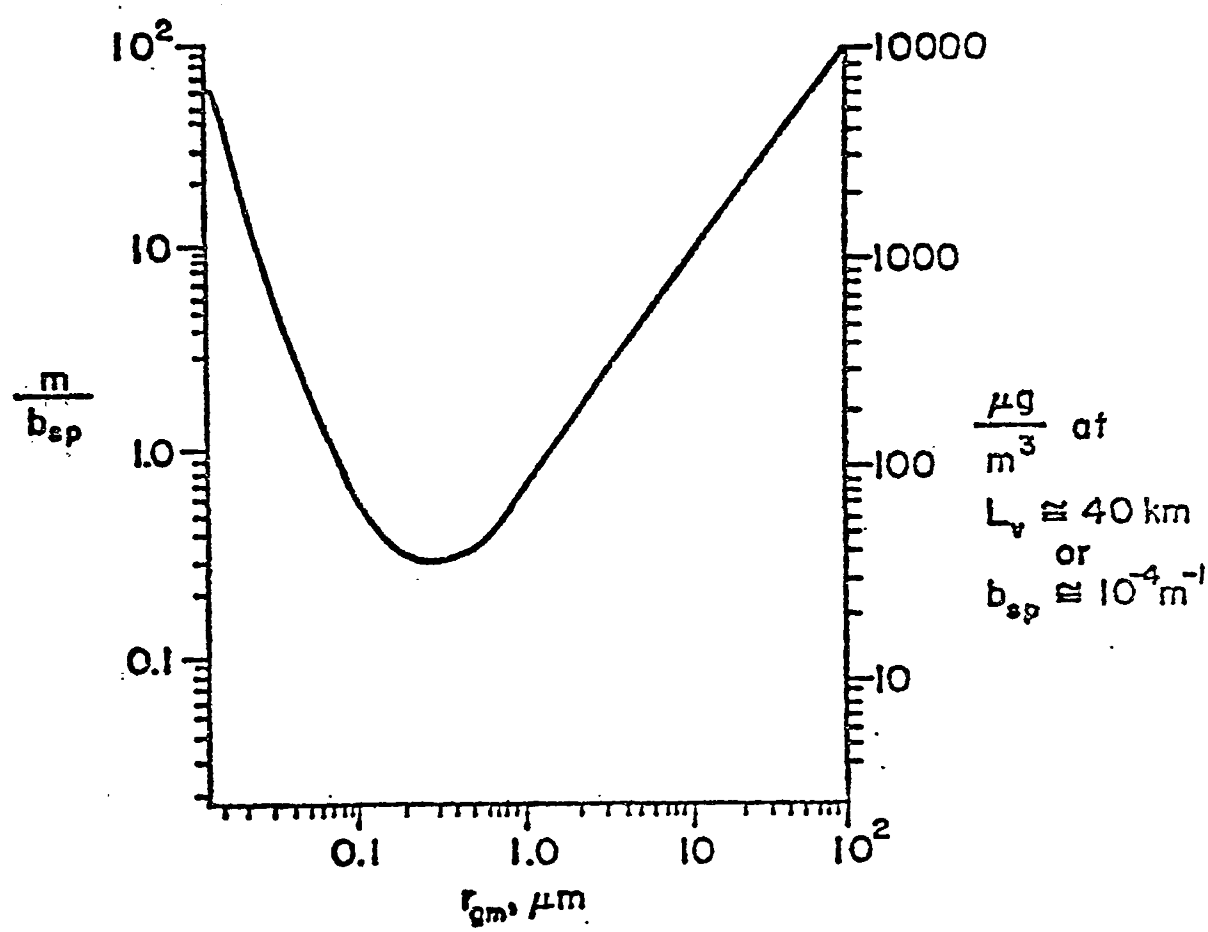
The extinction coefficient due to scattering by gas molecules in the free atmosphere at sea level is roughly 1.5 x 10^{-5} meters^{-1} (for light at a wavelength of 0.52 micrometers (green)); values of the extinction coefficient within a few percent of this have actually been measured.9/ If light degradation were due solely to gas molecule scattering, then the visibility would be approximately 260 kilometers, by the aforementioned formula. Thus, scattering by gas molecules does not play a major role in visibility degradation.

Of the many gaseous species present in the atmosphere, only nitrogen dioxide (NO_2) is present in high enough concentrations to have a significant light absorption impact.9/ Nitrogen dioxide is a strong absorber of blue light and can cause the atmosphere to have a reddish-brown haze. At a NO_2 concentration of 0.05 parts per million, the National Ambient Air Quality Standard for nitrogen dioxide, the extinction coefficient due to NO_2 absorption would be approximately 8.1 x 10^{-5} meters^{-1} (based on 0.40 micrometer wavelength light (blue)).10/ In a homogeneous atmosphere with 0.05 parts per million NO_2 visibility would be roughly 41 kilometers due to the combined effect of NO_2 absorption and gas molecule scattering. An important caveat to consider is that the aforementioned extinction coefficient was based on blue light only; the visual spectrum, of course, consists of other colors as well, colors which are not as affected by NO_2 absorption. For example, light with a wavelength of 0.70 micrometers (red) would yield an extinction coefficient of 8.1 x 10^{-7} meters^{-1} at a NO_2 concentration of 0.05 parts per million; less sensitive than blue light by a factor of 100.

The scattering of light by particulate is generally attributed to particles whose size corresponds to the wavelength of incident light; that is, sub-micron particles. Figure V-4 shows the ratio of mass to scatter coefficient as a function of particle radius. From this figure, it follows that particles whose radii lie in the 0.1 to 1.0 micrometer range are the most efficient at scattering. Some typical particles in this size range (and up to 2.0 micrometers in diameter) include sulfates and organic compounds such as condensed hydrocarbons and oxidized organic matter.1/ By contrast such particles as soil and tire dust, road debris, fly ash, and airborne products of rock-crushing have little influence on scattering (except in the case of rare dust storms).1/

In addition to particle size (and, of course, concentration), atmospheric water vapor plays an important interactive role in light scattering by particles. Relative humidity in the 30-60

Figure V-4 9/



Calculated scattering efficiency for a log normal aerosol size distribution, geometric standard deviation equal to 2, as a function of geometric mass mean radius. M is the fine particle mass concentration, b_{sp} is the scattering coefficient, and r_{gm} is the geometric mass mean radius. For reference, the right hand axis is the mass concentration required to give a visual range of 40 km.

percent range has little effect on visibility. However, at 80 percent relative humidity, the light scattering potential of aerosols is twice that at the 30 percent level.11/ As relative humidity approaches 88 percent, the light scattering ability of typical aerosols is about four times that for the same aerosol concentration at 30 percent relative humidity.11/ This effect is due to the hygroscopic nature of the particles. As the air's water vapor content increases, particles pick up water and, thereby, increase in size. Their potential to scatter light is maximized as their size approaches the wavelengths of visible light and as they ultimately become fog droplets. Of course, the effect of relative humidity varies depending on the composition of the aerosol.

For particles with a diameter from 0.05 to 0.2 micrometers, typical for diesel particulate, the scattering extinction coefficient at a concentration of 5 micrograms per cubic meter ranges from 8.3×10^{-6} to 5.0×10^{-7} $meters^{-1}$.9/ Maximum scattering occurs from particles whose diameter is approximately 0.6 micrometers.

Absorption of light by particles is approximately 10 percent of the particle scattering attenuation in clean areas and up to 50 percent in urban areas, with the most important contributor being graphite carbon.9/ Thus, any sub-micron particles with a high carbon content will have a significant impact on visibility. Heavy-duty diesel particulate, with its 50 to 90 percent carbon content, falls into this category.5/6/7/ The absorption to mass ratio for carbon is approximately 7 $meters^2$ per gram.12/ Actual measurements of the absorption to mass ratio of diesel particulate approach this value, verifying the high carbon content and implying that gaseous hydrocarbons bound to the surface of diesel particulate play an inconsequential role in light absorption.12/ Thus, at a concentration of 5 micrograms per cubic meter the light absorption coefficient of carbon in diesel particulate is roughly 1.8×10^{-5} to 3.2×10^{-5} $meters^{-1}$.12/

Since diesel particulate affects visibility through both the scattering and absorbing phenomena, the extinction coefficients of each of these processes should be combined when evaluating the net visibility impact of diesel particulate. Thus, the visibility in an atmosphere permeated with 5 micrograms per cubic meter of diesel particulate would be 71-117 kilometers when the scattering effect of ubiquitous gas molecules is included. Although this scenario is admittedly ideal, due to such assumptions as a fixed 5 microgram per cubic meter heavy-duty diesel particulate level extending throughout a hypothetical 71-117 kilometer line of sight, it does indicate the potential visibility impact of diesel particulate. Indeed, such an impact may already exist, as suggested in a recent study of Denver's "Brown Cloud."13/

Another approach to assessing the visibility impact of diesel particulate is to quantify attenuation on a per kilometer basis. This can be done through the following relationship:

$$I = I_o e^{-b_{ext} X}$$

Where:

I = Intensity of light after attenuation;

I_o = initial intensity;

b_{ext} = extinction coefficient;

X = distance from observer to object.9/

Using the values of the extinction coefficient previously determined, one finds that an atmosphere permeated with 5 micrograms per cubic meter attenuates 3.3 to 5.4 percent of incident light per kilometer of propagation. Were that same atmosphere void of diesel particulate, then only 1.5 percent of incident light would be attenuated due to inherent gas molecule scattering.

In conclusion, of the four primary mechanisms of light attenuation in the atmosphere, heavy-duty diesel particulate directly impacts two: particle scattering and absorption. In an atmosphere void of NO_2 and sub-micron particulate, the hypothetical visual range is approximately 260 kilometers. With 5 micrograms per cubic meter homogeneously distributed throughout the same pristine atmosphere, the visibility is reduced to 71-117 kilometers, a reduction of 55-73 percent. These figures reflect the maximum distance at which an object could be discerned. Impairment can occur at substantially smaller distances. On a per kilometer basis, for instance, 3.3-5.4 percent of the incident light is attenuated in an atmosphere with a heavy-duty diesel particulate concentration of 5 micrograms per cubic meter.

D. Current Ambient Levels of TSP

The primary NAAQS for TSP of 75 micrograms per cubic meter (annual geometric mean) is currently being exceeded in many areas of the country. While relatively large reductions in ambient TSP levels occurred between 1971 and 1975,14/ (particularly at those sites which showed high levels of TSP), the next two years have shown more of a holding pattern than a continued downward trend.15/ Figure V-5 shows the nationwide averages of ambient TSP levels from 1972 through 1977. The ambient TSP level exceeded by 25 percent of the sites decreased from 78 to 71 micrograms per cubic meter between 1971 and 1975, while in 1977 it was still 71 micrograms per cubic meter. The TSP level exceeded by the worst 10 percent of the sites still managed to improve, however, through 1977. This level decreased from 97 to 88 micrograms per cubic meter between 1972 and 1975 and then decreased to 84 micrograms per cubic meter in 1977.

The high ambient levels of 1976 and 1977 were due at least partially to very dry weather.15/16/ In 1977, some sites recorded levels of 1000 micrograms per cubic meter for a day or two and this

Figure V-5 15/

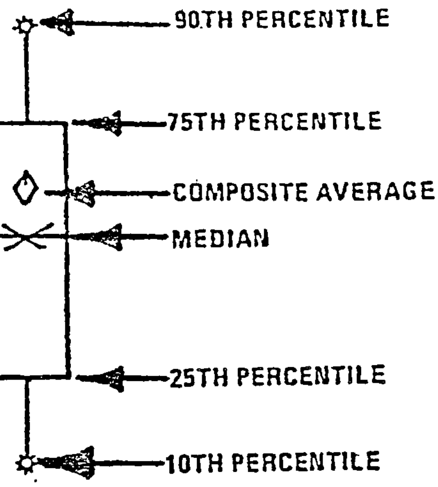
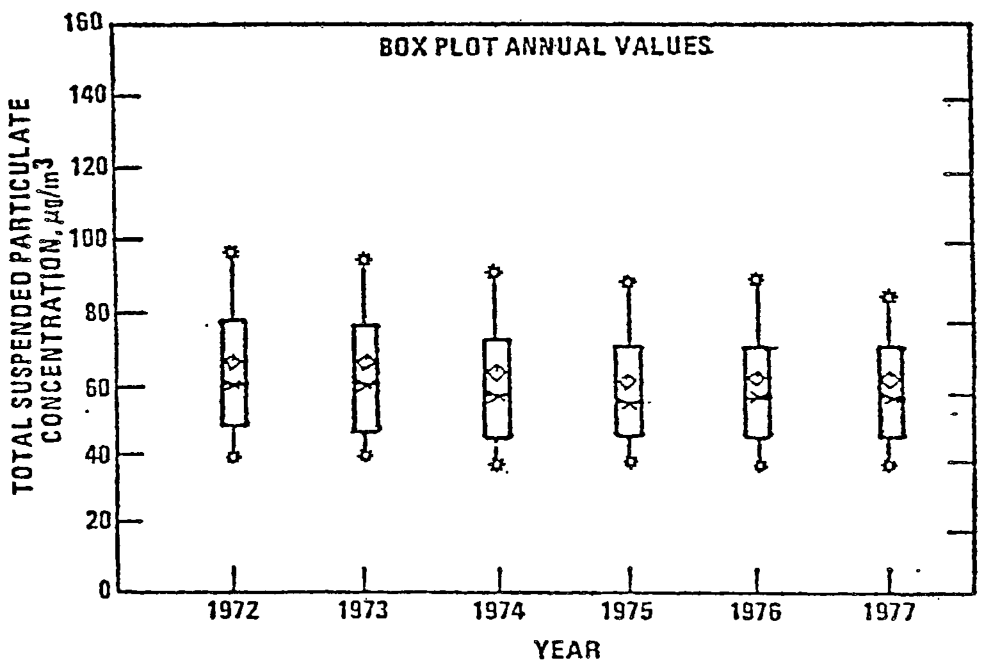


Figure 3-1. Sample illustration of plotting conventions for box plots.



Nationwide trends in annual mean total suspended particulate concentrations from 1972 to 1977 at 2,707 sampling sites.

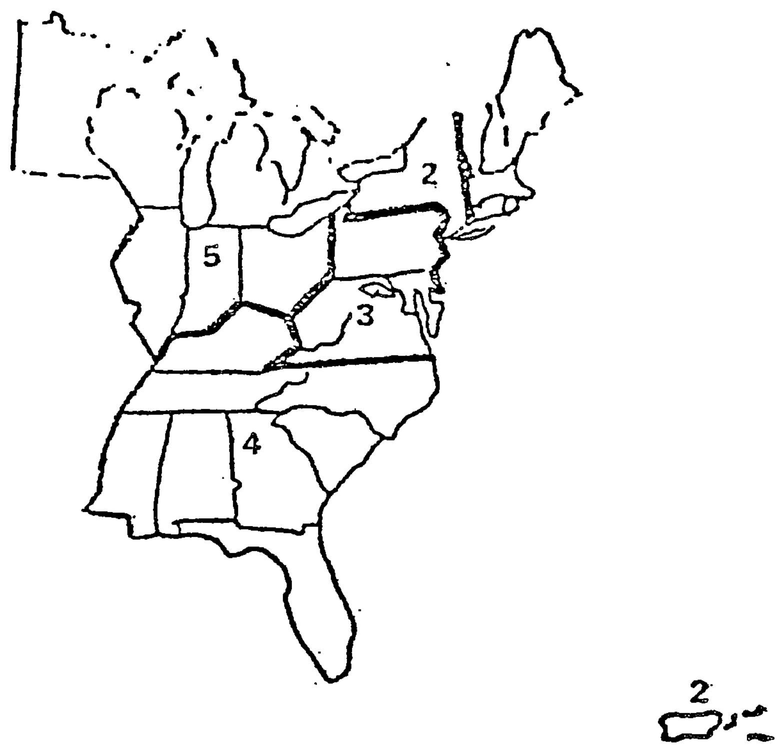
alone can cause the annual mean to increase 10 percent.15/ Figures V-6 and V-7 show the ambient TSP trends by region for 1972 through 1977. The dust storms of 1976 were primarily located in Regions 8, 9, and 10, while those of 1977 were primarily located in Region 6.

The fraction of the nation's population which is exposed to TSP levels exceeding the primary NAAQS is shown in Figure V-8.16/ While the number of people exposed to such levels dropped 9 percent between 1972 and 1975, this downward trend stopped in 1976 and 1977 when the number of people exposed remained constant at about 22 percent of the nation's population. An identical trend is present for the nation's metropolitan population. For the last three years (1975-1977), 27 percent of the nation's metropolitan population has been exposed to ambient TSP levels exceeding the primary NAAQS. These people are living in areas where the quality of the air they breathe could be harmful to their health.

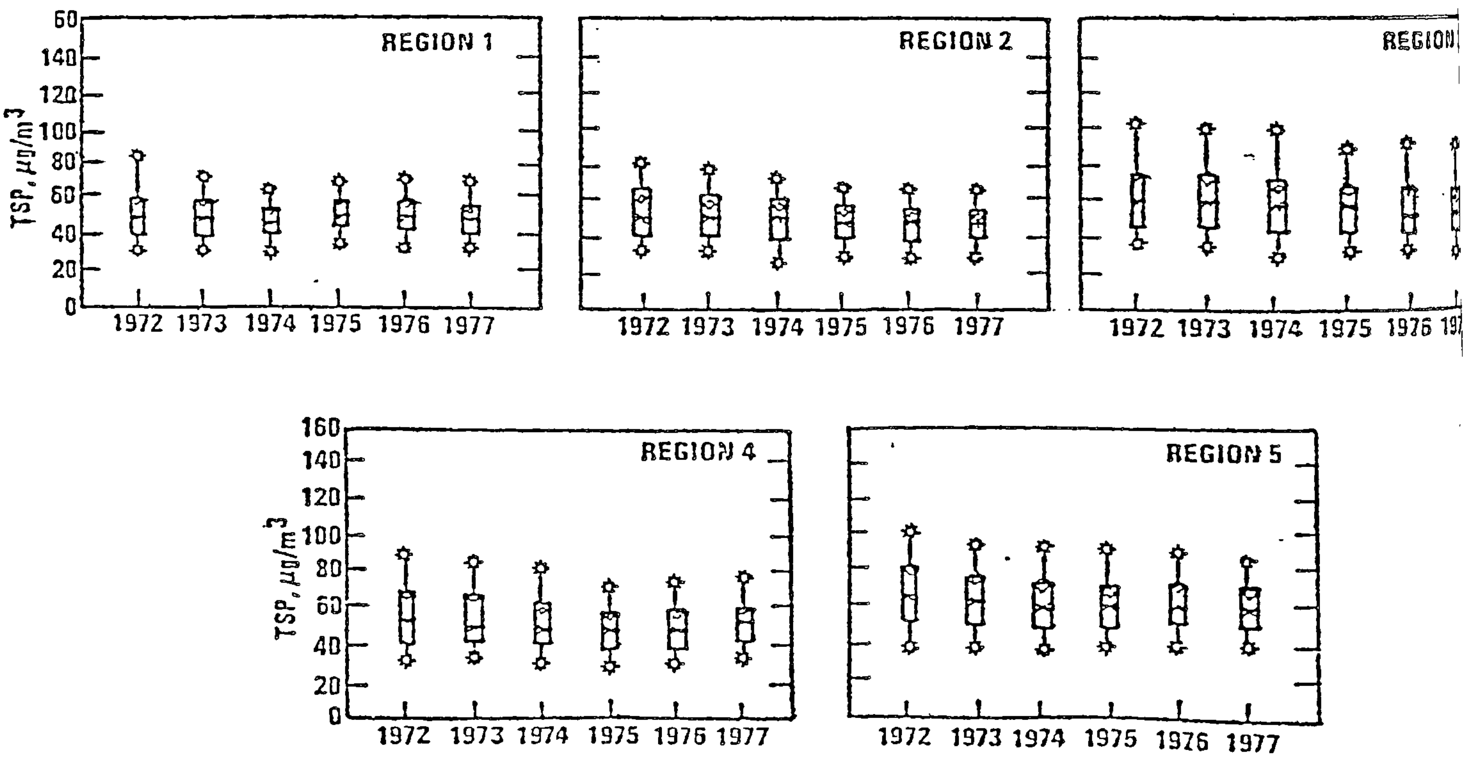
An even greater percentage of people are living in areas exceeding the secondary NAAQS for TSP. For example, in 1975 when 49 million people were living in areas exceeding the primary NAAQS, 89 million people were living in areas exceeding the secondary NAAQS. These people are living in areas where the air quality could be a hazard to their welfare (i.e., visibility, corrosion of materials, vegetation, etc.).

To examine the TSP problem in greater detail, ambient TSP trends are available for five large metropolitan areas.15/16/ These five cities, New York, Chicago, Denver, Cleveland, and St. Louis, were largely unaffected by the dry weather of 1976 and 1977 (except possibly St. Louis), so this bias should not be present. The populations exposed to TSP levels exceeding the primary NAAQS in these five metropolitan areas are shown in Table V-1. The most significant improvements occurred in the New York metropolitan area.16/ In 1970, 11.2 million people in metropolitan New York lived in areas where the annual primary NAAQS was being exceeded. By 1976, all TSP monitors had registered annual means below this level. Thus, no one was living in areas exceeding the primary NAAQS. The average TSP concentration in metropolitan New York dropped from 78 micrograms per cubic meter in 1970 to 55 micrograms per cubic meter in 1976.

The results for the other four cities were somewhat different. Improvements in the number of people exposed to ambient TSP levels in excess of the primary NAAQS have been made, but significant numbers are still exposed. Denver is probably in the worst situation.16/ While the percentage of people exposed to TSP levels exceeding the NAAQS has decreased 9 percent, a full three-fourths of the population are still exposed to these excessive levels. Likewise, for Chicago, 64 percent of the population are still living in areas where the TSP levels violate the primary NAAQS.16/ Cleveland has experienced a steady decrease in population exposure to excessive TSP levels since 1972, though 27 percent of the people in the air quality control region are still exposed.15/

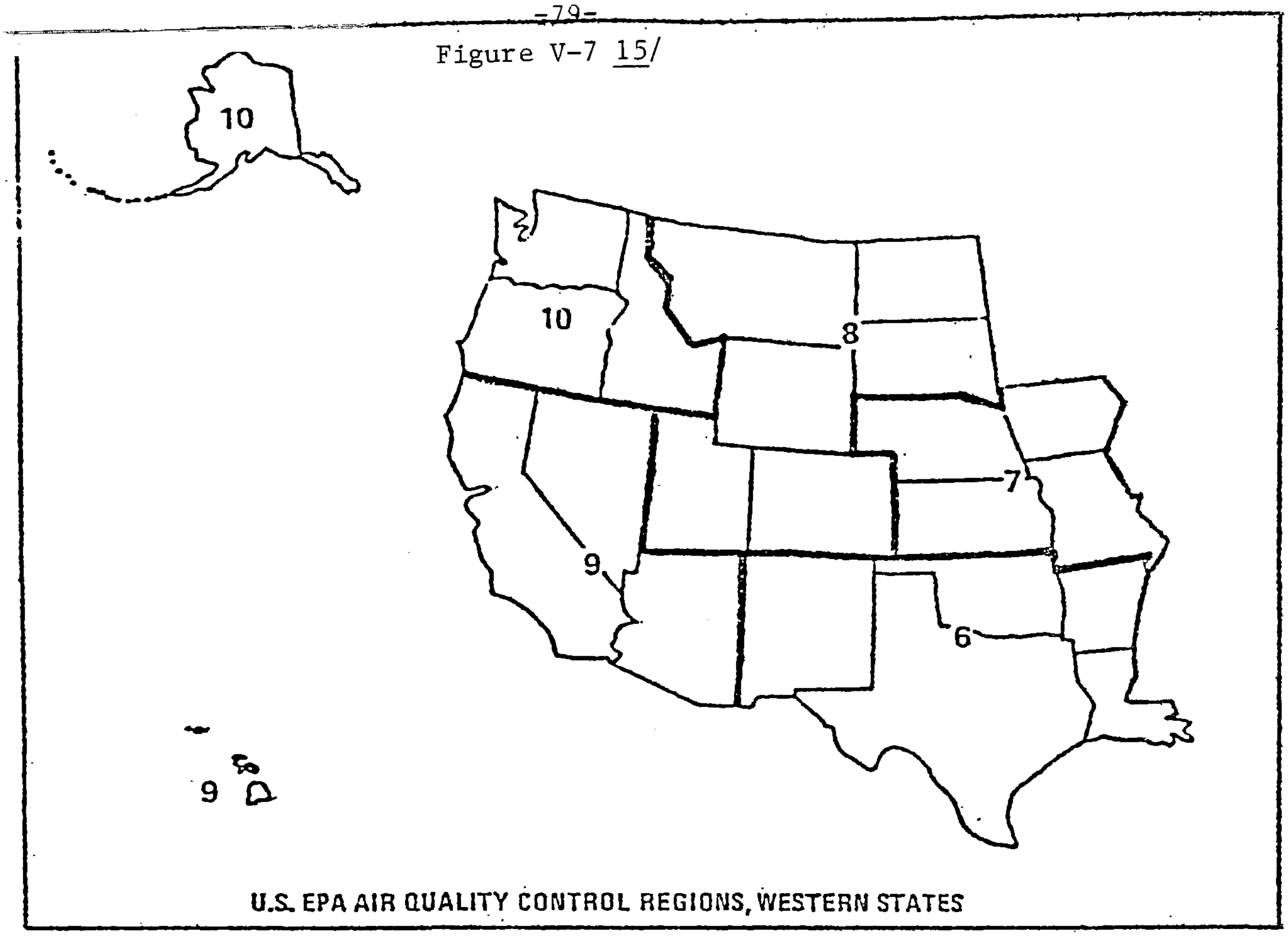


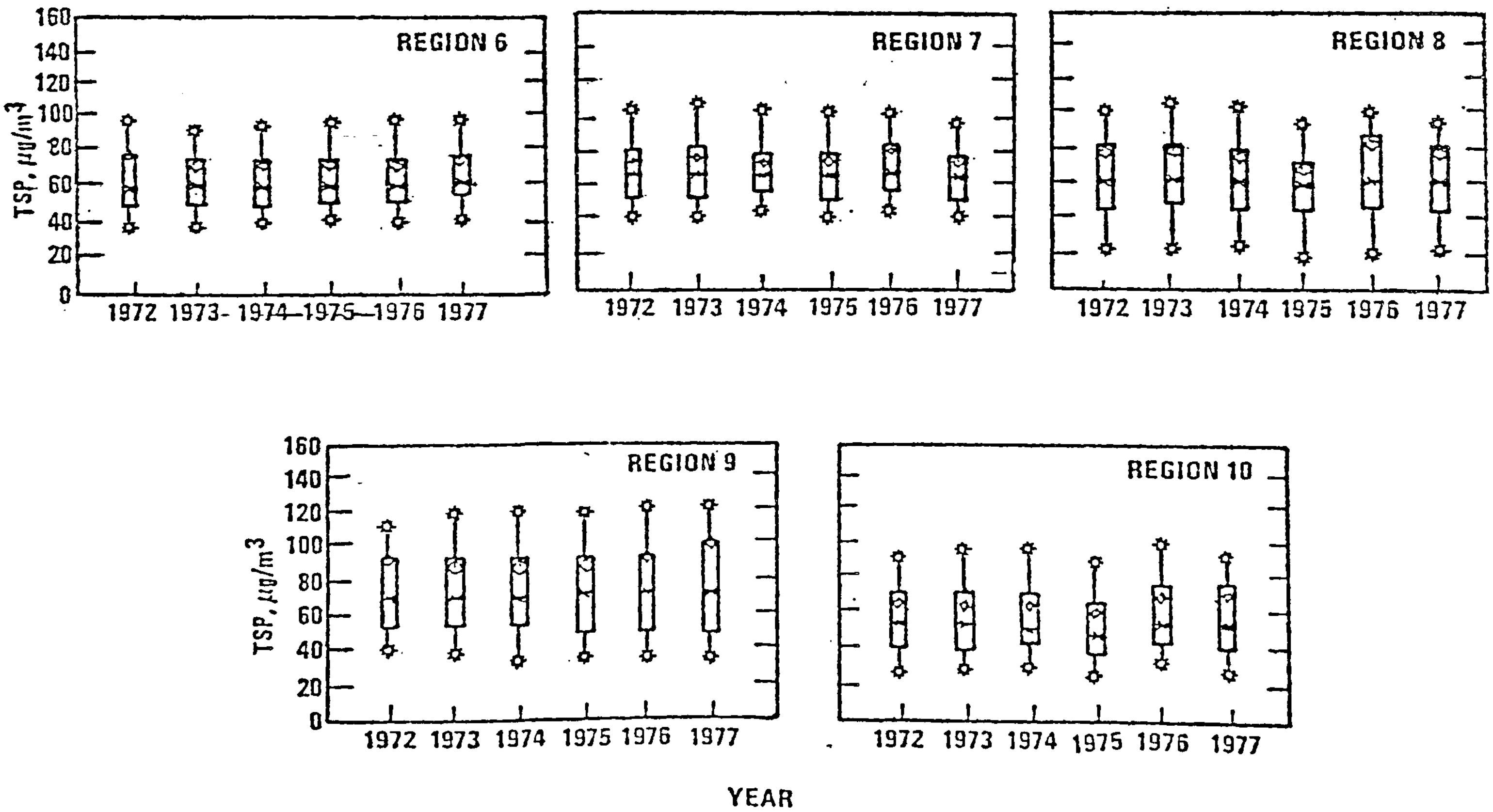
U.S. EPA AIR QUALITY CONTROL REGIONS, EASTERN STATES



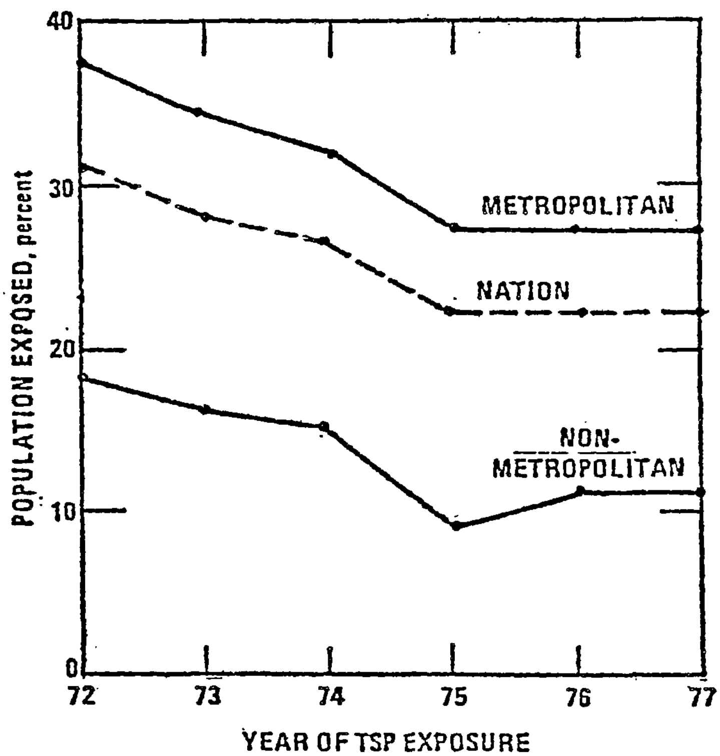
Regional trends of annual mean total suspended particulate concentrations, 1972 - 1977.

Figure V-7 15/





Regional trends of annual mean total suspended particulate concentrations, 1972 - 1977.



Population exposure to annual mean TSP in excess of NAAQS (75 μg/m^3).

Table V-1

Population Exposure to TSP Levels in Violation of the Primary NAAQS 15/16/

	New York	Chicago	Denver	Cleveland	St. Louis
Population (millions)*	17	3.4	1.1	3.4	1.9
	Percentage of Population Exposed to Levels Exceeding NAAQS				
1970	60%	100%	83%		
1972				60%	69%
1973	12%			50%	46%
1974				37%	48%
1975			75%	44%	43%
1976	0%	64%		29%	60%
1977				27%	62%

* 1970 Census data for the area studied, usually comprising the Air Quality Control Region.

St. Louis is the most interesting case. The population exposed to excessive TSP levels decreased steadily from 69 percent to 43 percent between 1972 and 1975. After that the exposed population increased back to nearly the 1972 level. Part of the reason for this increase, which first occurred in 1976, may have been the dry weather of that year. The precipitation around St. Louis was "slightly below normal" for 1976.16/ However, nothing is mentioned concerning the weather of 1977 and Region 7 (which includes St. Louis) in general showed no signs of exceptionally dry weather in 1977 (see Figure V-7). Thus, it would appear that at least some and perhaps most of the increase of 1977 is due to factors other than dry weather.

There are two primary reasons why ambient TSP levels have dropped significantly between 1971 and 1975. Both reasons concern stationary source particulate emissions. The first reason is the application of particulate control technology to the stationary sources of particulate emissions. Since 1970, many of the largest polluting industries have been required to control particulate emissions. This has occurred nationwide through attempts by states and localities to comply with the NAAQS for TSP (e.g., through equipping existing plants with particulate control devices as deemed necessary by local TSP levels). The second reason is that many combustion sources have switched to cleaner fuels which result in lower particulate emissions. The combustion of coal produces much more particulate emissions than the combustion of oil, and the combustion of natural gas produces even less particulate emissions than the combustion of oil. Thus, many sources in the early 1970's switched to oil and gas to reduce particulate emissions, as well as sulfur dioxide emissions.

While these methods have decreased ambient TSP levels over the last seven to eight years, there are some inherent problems associated with both of them which limit future reductions. First, most of the large reductions in particulate emissions possible from stationary sources have already been made.14/ The majority of the largest polluting plants have already come under state and federal standards, or are under compliance schedules soon to be completed. The potential for continued emission reductions has diminished, and future reductions will be even more costly. Since current NSPS are based on the best system of emission reduction which has been adequately demonstrated, (while taking into account the cost of such a system), the advent of even greater control of currently controlled industries will not be widespread, barring major technological breakthroughs.

Second, the trend toward switching to oil and natural gas from coal has already stopped and even reversed itself due to the shortage of domestic oil and natural gas. Thus, any gains made in the past from switching to cleaner fuels will eventually disappear, and likely reverse themselves as coal usage becomes more and more prominent.

Finally, growth in production will enter into the situation. In any industry where emission standards stay at current levels, every new plant not replacing an obsolete plant will add to the overall emissions inventory. The ability of the air to clean itself does not increase with the nation's productive capabilities, so the end result is dirtier air.

In conclusion, while significant progress was made in the early 1970's in reducing ambient TSP levels, 22 percent of the national population is still exposed to ambient TSP levels in excess of the primary NAAQS of 75 micrograms per cubic meter (annual geometric mean). And the two strategies which contributed most to the TSP reductions of the early 1970's, application of emission controls to the stationary sources with the largest potential reductions and fuel-switching from coal to oil and natural gas, clearly will not be able to provide significant new reductions, especially since the fuel-switching process will likely reverse itself and continued economic growth is expected to provide new sources of particulate matter. Therefore, heretofore uncontrolled particulate sources and new major particulate sources will need to be regulated if further TSP reductions are to be achieved. The next section will show the environmental benefits to be gained from the control of light-duty diesel particulate emissions.

E. Impact of Diesel Particulate Emissions

Three different aspects of the diesel's environmental impact will be examined here. First, the amount of particulate emitted to the atmosphere will be determined. Second, the diesel's impact on large-scale TSP levels will be examined. Finally, the diesel's impact in localized areas where particularly high concentrations could occur will be examined. All of these impacts will be determined for 1995, as by that time the environmental benefits of the 1986 standard will be nearly complete.

1. Emissions

In order to determine the particulate emissions from all heavy-duty diesel vehicles, two basic factors are needed: the amount of particulate emitted by each vehicle per unit distance traveled and the total distance traveled by all heavy-duty diesels. For the purpose of evaluating the future impact of heavy-duty diesels as a particulate source the year 1995 will be the focal point.

Historically, 2.0 grams per mile (g/mi)(1.24 grams per kilometer (g/km)) has been used as the heavy-duty diesel particulate emission factor.17/18/19/ Even though this factor was based on steady-state tests, as opposed to more representative transient tests, it is believed to be a good estimation of future heavy-duty diesel particulate emission levels. Transient cycle test results from the Southwest Research Institute program (refer to Chapter IV) indicate an average emission rate of approximately 1.5 g/mi for new engines. However, this simple average does not consider the caveat that larger diesel engines, which generally emit more particulate per unit distance traveled than smaller engines, will constitute the largest share of the heavy-duty diesel fleet. Also, as suggested in Chapter IV, the mandated control of heavy-duty diesel NOx emissions would likely increase particulate emissions if a particulate standard were not implemented. These two tenets together with some in use deterioration, support the use of the historical 2.0 g/mi(1.4 g/km) heavy-duty diesel particulate emission factor in this analysis.

PEDCo Environmental (based on DOT data) reported that in 1974, 1.286 trillion miles were traveled by all motor vehicles in this country; 8.8 percent of which were by heavy-duty vehicles nationwide and 3.4 percent by heavy-duty vehicles in urban areas.19/ A 1.5 percent per year growth rate in nationwide and urban vehicle miles traveled (VMT) has been used to extrapolate 1974 VMT to the 1995 scenario. These results appear in Table V-2.

In order to determine the fraction of future heavy-duty VMT attributable to diesels, several factors have been used. These include the sale projections outlined in Chapter III; the standard EPA breakdown of annual heavy-duty VMT by model year;20/ the fraction of total registration by model year;20/ and the urban/-rural VMT split by mobile source category.19/ The result is that 71-86 percent of nationwide heavy-duty VMT and 67-82 percent of urban heavy-duty VMT will be by diesels in 1995. Consult Appendix I for further details.

Combining the expected 1995 heavy-duty diesel VMT with the 2.0 g/mi (1.248 g/km) emission factor, 218,000-266,500 metric tons of heavy-duty diesel exhaust particulate will be emitted in 1995 nationwide if no control is implemented. In urban areas, 79,000-97,000 metric tons will be emitted in 1995. These values are shown in Table V-2. To put things into perspective, Table V-3 provides a comparison of current annual emissions from several major industrial source categories with estimates of uncontrolled diesel emissions in 1990. As can be seen, heavy-duty and light-duty diesels are projected to be significant sources of particulate emissions by 1990, if left uncontrolled.

It should be remembered that heavy-duty gasoline engines also emit particulate (mostly in the form of lead-salts). The recently promulgated 1984 hydrocarbon and carbon monoxide emission standards for all heavy-duty vehicles will result in the use of unleaded gasoline in this vehicle class; effectively phasing out lead-salt emissions from that source. Reductions in lead-salt emissions will also transpire in the 1980-1984 time frame due to the "capturing" of part of the heavy-duty gasoline market by heavy-duty diesels. EPA estimates that gasoline-fueled heavy-duty vehicles emitted approximately 30,000 metric tons of lead-salt in 1974; however, only 13,000 metric tons could be classified as suspendable (the

Table V-2

Traffic Characterization

	Nationwide	Urban
1974 Total VMT 19/	1.286 Trillion	0.694 Trillion
1995 Total VMT	1.758 Trillion	0.949 Trillion
VMT Growth Rate	1.5 % Per Year	1.5 % Per Year
Heavy-Duty VMT Fraction 19/	0.088	0.062
1995 Heavy-Duty VMT	154 Billion	58.8 Billion
1995 Heavy-Duty Diesel VMT	109-133 Billion	39.5-48.3 Billion
1995 Heavy-Duty Particulate Emission (Metric Tons)	218,000-266,500	79,000-97,000

Table V-3

1975 Emissions from Selected Major Stationary Source Categories and Projected 1990 Emissions from Diesel Vehicles

Stationary Sources	1975 Emissions* (tons per year)
Electric Generation Plants	3,000,000
Industrial Boilers	1,000,000
Iron and Steel Industry	
Coke Ovens	<100,000
Basic Oxygen Furnaces	100,000
Blast Furnaces	<100,000
Kraft Pulp Mills	200,000
Aluminum Industry	200,000

Mobile Source	1990 Emissions (tons per year)
Heavy-Duty Diesels	215,000-266,500

* Stationary source data extracted from National Emission Data System, 1975.

rest being too large to remain suspended in the atmosphere for extended periods of time). In urban areas approximately 13,000 metric tons of lead-salt were emitted in 1974 (5,600 metric tons suspendable). By 1995, nationwide lead-salt emission from heavy-duty gasoline-fueled vehicles are expected to decrease to 1,700-3,600 metric tons nationwide (700-1,500 metric tons suspendable). In urban areas, projected 1995 lead-salt emissions from heavy-duty gasoline vehicles are 600-1,300 metric tons (250-540 metric tons suspendable).

2. Regional Impact

The regional, or large-scale, impact of diesel particulate emissions is greatest in urban areas. This is no surprise since it is in urban areas where the greatest concentration of vehicles exist. As it is also in urban areas where most of the people of the nation live and where most of the violations of the NAAQS for TSP occur,15/ it is appropriate that this section concentrates primarily on the impact of diesel particulate emissions in urban areas.

Two studies have attempted to determine the impact of diesel particulate emissions on urban air. The first study was performed by PEDCo Environmental for EPA.21/ It used ambient lead concentrations coupled with lead emission factors to determine the relationship between emissions and air quality for mobile sources in New York, Chicago, and Los Angeles. Then, ambient concentrations of diesel particulate in those cities were calculated using this relationship and known diesel particulate emission factors. Ambient levels of diesel particulate were calculated at 15 actual TSP monitoring sites so the calculated levels could be directly compared to levels currently being measured at the same sites.

The second study was conducted by EPA and used a methodology similar to that used in the PEDCo report.22/ Ambient diesel particulate concentrations were estimated from ambient lead measurements taken in over 35 cities ranging in population from less than 100,000 to over 5,000,000. The study also includes similar estimates of ambient diesel particulate levels in Chicago and Toledo which were submitted by General Motors during the comment period following the proposal of the light-duty diesel particulate regulation.23/

Each study used a different set of input data for emission factors, VMT growth, diesel penetration, etc. In order to be comparable, each had to be adjusted to a common set of input factors. This has already been done under separate cover for convenience.22/ The common set of input factors used was described in the previous subsection on emissions from uncontrolled diesels. The only difference was that growth in VMT was only assumed to be one percent per year in the central city areas being examined by the two studies.

One additional adjustment was also made to the results of the

PEDCo study. From PEDCo's text, it seemed possible that an error was made concerning the automobile's contribution to ambient TSP levels in New York. An analysis of the references used by PEDCo revealed that an error was indeed made. A referenced study, which determined the auto's total contribution to ambient TSP levels included reentrained dust, but was taken to refer only to automobile exhaust emissions. This error caused the New York results to be overestimated by a factor of 2.66. Due to the fact that the Chicago results were partially based on this erroneous factor, they were overestimated by a factor of 1.62. Any use of the PEDCo results here will be adjusted by these factors and a detailed discussion of the adjustments can be found under separate cover.22/

The results of both studies are shown in Tables V-4, and V-5. The expected impacts in New York, Los Angeles and Chicago are about the same whether determined by EPA (Table V-5) or PEDCo (Table V-4). This finding is not surprising since both studies used ambient lead measurements as a basis, though slightly different methodologies were used to convert these ambient lead concentrations into diesel particulate concentrations. The level found at the first Chicago monitor modeled by PEDCo (Table V-4) appears quite out of line with all the others and will be excluded from further reference. It is known that PEDCo assumed that automotive exhaust particulate was a constant fraction of TSP throughout the city. If this particular monitor was in a heavily industrial area showing a very high TSP level due to industrial sources, of which Chicago has quite a few,16/ then the automotive portion could have been overestimated.

The studies indicate that the regional impact of uncontrolled heavy-duty diesel particulate emissions in 1995 would be 2-7 micrograms per cubic meter in the nation's three largest cities. The levels for other cities are somewhat lower and these levels tend to decrease with decreasing population, as shown in Table V-5. There are exceptions in each population category, such as Phoenix and Kansas City. The impact of heavy-duty diesel particulate emissions in Phoenix is projected to be 4.0-4.9 micrograms per cubic meter while that in Kansas City is only projected to be 1.4-1.7 micrograms per cubic meter. It should be noted that the regional impacts in Table V-5 are based on National Air Surveillance Network (NASN) data, which typically involve only one or two monitors per city. Certainly the small number of monitors might explain some of the variability between cities. However, being a part of the NASN system, these monitors have a much greater likelihood of representing areas at least as large as a neighborhood and not be overly influenced by nearby sources. National Aerometric Data Bank (NADB) data was not used because these monitors are more likely to be located near large sources of lead and may not represent larger-scale impacts. Thus, the presence of a large nearby source should not be the cause of this variability.

In summary, moderate increases in heavy-duty diesel particulate levels (2-7 micrograms per cubic meter) will add to already

Table V-4

Estimated 1995 Ambient Levels of Heavy-Duty Diesel Particulate at 15 TSP Monitoring Sites in Three Cities 22/

City	Height (meters)	Distance from Road (meters)	Average Daily Traffic	Diesel Particulate Levels (micrograms per cubic meter)
New York*	22.9	91.5	12,100	1.8-2.2
	22.9	30.5	16,500	1.9-2.3
	18.3	15.25	26,600	2.3-2.8
	13.7	30.5	17,900	1.7-2.1
	7.6	91.5	16,800	2.2-2.7
Los Angeles	1.2	N/A	15,000	4.7-5.7
	7.6	1.8	15,000	4.9-6.0
	27.4	5.0	13,500	5.9-7.2
	5.5	17.0	18,000	5.0-6.1
	18.3	N/A	N/A	5.4-6.6
Chicago*	9.5	24.4	N/A	8.5-10.4
	4.6	30.5	4,700	4.2-5.1
	4.9	21.3	9,400	4.5-5.5
	39.9	9.15	11,600	4.3-5.3
	19.2	3.6	25,100	3.6-4.4

* The levels shown include a reduction by a factor of 2.66 (New York) and 1.62 (Chicago) to account for an error in the original PEDCo analysis. See text for further description.

Table V-5

Estimated 1995 Regional Ambient Levels of Heavy-Duty Diesel Particulate in 39 Cities in 1990 22/*

Population Category	City	Particulate Level (micrograms per cubic meter)
Over 1 million	Chicago	2.7-3.4
		5.8-7.0
	Detroit	1.9-2.3
	Houston	4.0-4.9
	Los Angeles	5.2-6.4
	New York	2.0-2.5
		2.6-3.1
	Philadelphia	2.4-2.9
	Average	3.3-4.0
500,000 to 1,000,000	Boston	1.7-2.1
	Dallas	5.8-7.2
	Denver	1.8-2.2
	Kansas City, MO	1.4-1.7
	New Orleans	2.0-2.5
	Phoenix	4.0-4.9
	Pittsburgh	1.6-2.0
	San Diego	2.2-2.7
	St. Louis	2.3-2.8
	Average	2.6-3.1
250,000 to 500,000	Atlanta	2.0-2.5
	Birmingham, AL	2.4-2.9
	Cincinnati	1.6-1.9
	Jersey City	2.0-2.5
	Louisville	1.8-2.2
	Oklahoma City	3.2-3.9
		1.9-2.3
	Portland	1.6-1.9
	Sacramento	2.0-2.5
	Tucson	1.5-1.8
	Yonkers, NY	2.2-2.7
	Average	2.0-2.5
100,000 to 250,000	Baton Rouge	1.8-2.2
	Jackson, MS	1.6-1.9
	Kansas City, KA	0.8-1.0
		1.2-1.5
	Mobile, AL	1.8-2.2
	New Haven	2.2-2.7
	Salt Lake City	1.9-2.3
	Spokane	1.1-1.3
	Torrance, CA	4.6-5.6
	Trenton, NJ	1.7-2.1
	Waterbury, CT	3.5-4.2
	Average	2.0-2.5
Under 100,000	Anchorage	1.9-2.3
	Helena, MN	0.5-0.7
	Jackson Co., MS	0.8-1.0
	Average	1.1-1.3

* Based on data from National Air Monitoring System (NAMS)

excessive regional levels of TSP and increase the difficulty of complying with the primary NAAQS for TSP for practically all of the regions which have the very worst TSP violations. As discussed in the section on health effects, all of this additional particulate burden will involve particles which are inhalable, and nearly all will involve particles with diameters less than 2.5 micrometers, which are thought to have the greatest potential for affecting human health.

3. Localized Levels

Approximately six studies are available which examine the localized air quality impact of diesel particulate emissions. Here localized is defined to include areas on an expressway, beside an expressway at distances up to approximately 91 meters from its edge, and in a street canyon. These scenarios represent exposure to: people while commuting to and from work; persons employed by roadside businesses such as gasoline stations; families residing near major thoroughfares; pedestrians on busy streets; and occupants of offices, apartments, etc. which flank busy streets. As a survey and analysis of these studies has already been performed, only the pertinent results along with short descriptions shall be discussed here.24/

Since each study utilized different diesel penetration rates and emission factors, these variables were factored from their respective results and replaced by the standard set of conditions, described earlier, in order to be comparable. For heavy-duty vehicles, the diesel emission factor is 2.0 grams/mile. The low and high diesel penetration estimates are 67 percent and 82 percent of urban miles traveled by heavy-duty vehicles in 1995, respectively. An analysis of urban traffic characteristics reveals that 93.8 percent of accumulated miles are from light-duty vehicles and trucks. The remainder are, for the purposes of this study, attributable to heavy-duty vehicles (based on DOT data, PEDCo19/).

A Southwest Research Institute study evaluated the on-expressway scenario.17/ Positive aspects of this report include: the choice of dispersion model, GM's line source model,25/ which yielded good correlation with tracer gas experiments;26/ the study site, a portion of I-45 at Joplin (Houston), where the wind is oriented roughly parallel to the roadway approximately 15 percent of the time (from 2.75°-25.25° relative to the road at 2.06-8.3 meters/second); and the traffic count was well documented at 1494 vehicles/hour for each of 6 lanes. The results, modified to comply with the aforementioned standard emission factors and dieselization rates, can be found in Table V-6.

From this study it can be seen that commuters on an expressway with a traffic volume of approximately 9000 vehicles per hour may expect exposure to heavy-duty diesel particulate at concentrations above regional levels of diesel particulate ranging from

Table V-6

Expected 1995 On-Expressway Heavy-Duty Diesel Particulate Concentrations (micrograms per cubic meter)

2.06 m/sec at 2.75°*	2.06 m/sec at 25.25°	8.3 m/sec at 2.75°	8.3 m/sec at 25.25°
31.9 - 39.1	20.2 - 24.7	23.0 - 28.2	6.7 - 8.2

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* Wind speed and orientation with road.

Table V-7

Expected 1995 Off-Expressway Heavy-Duty Diesel Particulate Concentrations (micrograms per cubic meter)

	24-Hour Max	Annual Geo. Mean
30 Meters from Road	21.0 - 25.8	7.0 - 8.6
91 Meters from Road	13.7 - 16.8	4.6 - 5.6

Table V-8

Expected Street Canyon Concentrations (micrograms per cubic meter)

	24-hour Max	Annual Geo. Mean
1.8 Meters Above Street	15.0 - 18.4	5.0 - 6.1
9.1 Meters Above Street	12.1 - 14.8	4.0 - 4.9
27.4 Meters Above Street	7.2 - 8.8	2.4 - 3.0

6.7-31.9 micrograms per cubic meter. These values reflect the low estimate of dieselization. The high estimate of dieselization yields concentrations ranging from 8.2-39.1 micrograms per cubic meter. The wide range in expected levels reflects the important role of the wind. Higher on-expressway concentrations result when lower velocity wind approaches a trajectory parallel to the road. This condition allows cumulative dispersion towards receptors (people in cars) rather than away from them as would be the case for steeper road-wind angles.

To characterize the off-expressway impact, the Aerospace Corporation utilized a number of studies which used monitors to construct roadside spatial distributions of carbon monoxide and tracer gases.18/ Carbon monoxide is an especially good surrogate for ambient diesel particulate level projections, since motor vehicles are the predominant contributors to ambient CO levels and diesel particulate disperses more like a gas than a typical large particle. Their approach involved developing a pollutant concentration index by subtracting background concentration from measured roadside values and dividing the resulting difference by the appropriate source term. This process was repeated for various distances from the roadway. A roadside diesel particulate concentration profile was developed by multiplying the index values for specific locations by the desired particulate source term. The 7850 vehicle per hour traffic count was based on a 24-hour integration of actual traffic flow on an 8 lane urban freeway in Los Angeles.

This approach should be superior to mathematical modeling efforts because it is based on measured trends and characteristics while avoiding such assumptions as constant wind speed and atmospheric stability. The results, found in Table V-7, are given in terms of a 24-hour maximum concentration during one year and the corresponding annual geometric mean. In order to obtain 24-hour maximums, Aerospace chose values of the concentration index which corresponded to the 99.73 percentile ((1 - 1/365) x 100%). Annual geometric means were then calculated by dividing the 24-hour maximum values by 3.

To confirm this relationship between the two sampling times, the carbon monoxide records of the 8 cities listed in Table 6-1 of Air Quality Criteria for Carbon Monoxide were examined.27/ A slightly different divisor of 3.16 was obtained when the geometric mean of the ratio of 24-hour maximums to annual geometric means was calculated. Since the range of individual ratios is 2.44 (Chicago) to 5.0 (Washington D.C.), it is concluded that the factor used by Aerospace is reasonable and well within the scatter of the data.

Following this methodology, persons approximately 30 meters from a roadway carrying 7850 vehicles per hour could be exposed to annual mean diesel particulate concentrations of 7.0-8.6 micrograms per cubic meter from both light and heavy-duty vehicles. Similarly, concentrations at a distance of about 91 meters from the roadway fall in the 4.6-5.6 microgram per cubic meter range. As mentioned above, annual geometric mean values are roughly one-third of the 24-hour maximum values.

It is important to remember that all these local impacts consider only one source. The total concentration that people would be exposed to would, therefore, be the predicted localized value plus the regional or background value coming from other roadways nearby which was discussed in the previous section. It is also important to note that the 91 meter distance used above to characterize a localized effect is further from the road than many of the 'regional' monitors used to develop the regional impacts shown in Tables V-4 and V-5. This does not mean that the regional impacts described in Tables V-7 and V-8 are instead localized impacts. The regional monitors are located near roadways, but most are elevated and the roads are not heavily travelled relative to the expressway examined above. Rather, the large distances (91 meters) at which one can still find single source effects (busy expressway) is simply an example of the extent of potential localized effects.

Aerospace used the same methodology employed in the off-expressway study to characterize the street canyon impact.18/ Data collected from carbon monoxide monitors at various heights above the street were used to determine the pollutant concentration indices. Although it is recognized that mathematical models are valuable tools when trying to analyze pollutant dispersion, the Aerospace approach is more appropriate when trying to study general trends and situations. By not relying on such assumptions as constant building height and wind velocity this study relates more directly to everyday conditions. Their results, modified to reflect the standardizing assumptions mentioned earlier, are in Table V-8. The traffic count for the street canyon scenario was 936 vehicles per hour.

When determining the potential impact of a particular concentration, it is important to consider the length of time people will be exposed to that level of pollutant. People who live and work in downtown areas (characterized by the 9.1 and 27.4 meter receptor heights) will be exposed for longer periods of time than those who are merely shopping (pedestrians). The impact to those living and working in the downtown area is, therefore, greater than the pedestrian impact under the conditions of this study.

In assessing the localized impact from diesels, it is beneficial to compare predicted concentrations to the National Ambient Air Quality Standards for particulate. The primary standards are 75 micrograms per cubic meter for an annual geometric mean and 260 micrograms per cubic meter for a maximum 24-hour concentration not to be exceeded more than once a year.

Due to the highly-specialized nature of the on-expressway study (designed to represent a worst case meteorology), no comparisons of its maximum 31.9-39.1 microgram per cubic meter diesel particulate levels to the standards will be made. Conditions favorable for such levels will occur less than 15 percent of the time. However, it would be useful to note that commuters could be exposed to these levels up to 2 hours per day.

Approximately 30 meters from the roadway, heavy-duty diesel particulate will constitute 8.1-9.9 percent of the 24-hour standard and 9.3-17.5 percent of the annual standard. At the 91 meter distance, diesel contributions represent 5.3-6.5 percent of the 24-hour standard and 6.1-7.5 percent of the annual standard. It is important to remember that these numbers reflect the contribution from a single roadway and, therefore, do not consider background levels from other nearby streets and highways.

In the street canyon, at the 1.8 meter height, diesels are responsible for 5.8-7.1 percent of the 24-hour maximum and 6.7-8.1 percent of the annual standard. At a height of 9.1 meters the percentages are 4.7-5.7 percent for the 24-hour case and 5.3-6.5 percent for the annual case.

These analyses clearly indicate that uncontrolled heavy-duty diesel particulate emission levels would have significant air quality impacts on areas surrounding busy streets and expressways. These localized impacts would be in addition to the regional impacts analyzed in the previous section and would make it extremely difficult for some areas to comply with the NAAQS standards for TSP. The health effects consequences on persons who live, work, and travel in such areas would be even greater than those expected based on TSP impacts, since the small size of diesel particulate makes it especially hazardous to human health.

F. Air Quality Impact of Regulation

Beginning in 1986, emissions from new heavy-duty diesels will be reduced 67 percent from uncontrolled levels (as per Chapter IV). The full impact of this regulation on air quality will not be realized, however, until older uncontrolled trucks (pre-1986) are replaced. By 1995 particulate emissions from combined pre- and post-control heavy-duty diesels will be reduced 64.3 percent from 218,000-266,500 metric tons per year to 77,800-95,100 metric tons per year nationwide. Urban emissions will similarly be reduced 64.3 percent from 79,000-97,000 metric tons per year to 28,200-34,600 metric tons per year.

Table V-9 shows the ambient levels both before and after regulation of 15 cities having a population over 500,000 people. The data have been taken from Tables V-4 and V-5 and the full range has been used when more than one estimate was available. These impacts should be indicative of neighborhood or larger scale impacts in the cities mentioned. Any monitors modeled by PEDCo (Table V-4) which did not meet EPA's criteria for the minimum

Table V-9

Large-Scale Air Quality Impact on Regulation of Heavy-Duty Diesel Particulate Emissions - 1995

Population Category	City	Heavy-Duty Diesel Ambient Particulate Level micrograms per cubic meter Uncontrolled	Regulated
Over 1 Million	New York	1.7 - 3.1	0.6 - 1.1
	Los Angeles	4.7 - 7.2	1.7 - 2.6
	Chicago	2.7 - 7.0	1.0 - 2.5
	Philadelphia	2.4 - 2.9	0.9 - 1.0
	Houston	4.0 - 4.9	1.4 - 1.7
	Detroit	1.9 - 2.3	0.7 - 0.8
500,000 to 1,000,000	Dallas	5.8 - 7.2	2.1 - 2.6
	New Orleans	2.0 - 2.5	0.7 - 0.9
	Boston	1.7 - 2.1	0.6 - 0.7
	Denver	1.8 - 2.2	0.6 - 0.8
	Pittsburgh	1.6 - 2.0	0.6 - 0.7
	San Diego	2.2 - 2.7	0.8 - 1.0
	Phoenix	4.0 - 4.9	1.4 - 1.8
	St. Louis	2.3 - 2.8	0.8 - 1.0
	Kansas City, MO	1.4 - 1.7	0.5 - 0.6

distance from the roadway were excluded from Table V-9. As can be seen, ambient heavy-duty diesel particulate levels will be reduced by 3.0-4.6 micrograms per cubic meter in Los Angeles and 2.4-3.2 micrograms per cubic meter in Houston due to this regulation.

The impact of this regulation on particulate levels in localized areas of particularly high concentrations is also significant. Table V-10 presents an overview of this impact. (All concentrations refer to heavy-duty diesel contributions only.) On the expressway the diesel particulate level will drop from 31.9-39.1 micrograms per cubic meter to 11.4-14.0 micrograms per cubic meter for the 2.06 meters per second wind speed -2.75° worst case scenario. At a distance of approximately 30 meters from the roadway, the maximum 24-hour particulate levels are reduced from 21.0-25.8 to 7.5-9.2 micrograms per cubic meter. This reduction in the heavy-duty diesel particulate levels will benefit such people as service station operators who spend large amounts of time near roadways. Similarly, the maximum 24-hour particulate exposure level to people residing approximately 91 meters from the roadway is reduced from 13.7-18.8 to 4.9-6.0 micrograms per cubic meter.

Although heavy-duty trucks may constitute a smaller fraction of the central business district VMT when compared to urbanwide VMT, other heavy-duty diesel vehicles, such as buses and garbage trucks, are in wide use there. Thus, people residing in downtown areas are exposed to heavy-duty diesel particulate as well. Without control in 1995 maximum 24-hour heavy-duty levels will be 12.1-14.8 micrograms per cubic meter at a height of 9 meters above the street. These levels will be reduced to 4.3-5.3 micrograms per cubic meter if this proposed rulemaking is promulgated.

As was mentioned earlier, uncontrolled heavy-duty diesels are projected to be a significant source of particulate emissions by 1995. In terms of projected reduction potential, however, heavy-duty diesel may be even more significant. The annual particulate emission reductions available from heavy-duty diesels are actually close to the total annual emissions from some entire industries, such as the iron and steel industry (see Table V-3). Also, while further reductions in stationary source emissions can be expected to mitigate future increases in emissions due to industrial growth, they cannot be expected to significantly reduce total emissions from current levels, making reductions from heavy-duty diesels even more necessary.

G. Secondary Environmental Impacts of Regulation

Five potential secondary areas of impact will be discussed: energy, noise, safety, waste, and water pollution. No significant impact is expected in any of these areas.

The control technology expected to be used to meet the 1986 standard does not appear to affect fuel economy, either positively or negatively. Thus, there should be no impact on the

Table V-10

Heavy-Duty Diesel Particulate Levels With and Without Regulation (micrograms per cubic meter) - 1995

On-Expressway

	2.06 m/sec wind speed at 2.75°*	2.06 m/sec at 25.25°	8.3 m/sec at 2.75°	8.3 m/sec at 25.25°
Without Control	31.9 - 39.1	20.2 - 24.7	23.0 - 28.2	6.7 - 8.2
With Control	11.4 - 14.0	7.2 - 8.8	8.2 - 10.1	2.4 - 2.9

Off-Expressway

	30 Meters from Road		91 Meters from Road	
	24-Hour Max.	Annual Geo. Mean	24-Hour Max.	Annual Geo. Mean
Without Control	21.0 - 25.8	7.0 - 8.6	13.7 - 16.8	4.6 - 5.6
With Control	7.5 - 9.2	2.5 - 3.1	4.9 - 6.0	1.6 - 2.0

Street Canyon

	1-8 Meters Above Street		9.1 Meters Above Street		27.4 Meters Above Street	
	24-Hour Max.	Annual Geo. Mean	24-Hour Max.	Annual Geo. Mean	24-Hour Max.	Annual Geo. Mean
Without Control	15.0 - 18.4	5.0 - 6.1	12.1 - 14.8	4.0 - 4.9	7.2 - 8.8	2.4 - 3.0
With Control	5.4 - 6.6	1.8 - 2.2	4.3 - 5.3	1.4 - 1.7	2.6 - 3.1	0.9 - 1.1

* Wind road angle.

nation's energy resources. Similarly, this control technology should not significantly affect engine noise.

There are potential safety implications connected with the use of a trap-oxidizer. It is possible that the trap-oxidizer could be damaged by extreme temperatures if too much particulate were captured before burn off. These higher than normal temperatures could also represent a fire hazard if combustible material (such as leaves) were in close proximity to the malfunctioning trap-oxidizer. This scenario, however, is considered unlikely since heavy-duty diesels typically operate on paved roadways which are essentially free of such debris. To the extent that vehicle manufacturers mount trap-oxidizers on the vehicles' side, as is the current practice for most heavy-duty diesel mufflers, this risk should be further minimized as this location would be away from the ground where combustible materials might be.

Of course, any design of a device like this will need to adequately ensure that accidental occurrence such as those depicted would not affect vehicle safety.

It is also possible that these regulations could have an impact on solid waste and water pollution. While disposable traps are not envisioned as a likely control technology, if they were used to collect the particulate emissions, these traps would need to be discarded into the garbage, or burned. If discarded into the garbage and used as land fill, some of the chemical compounds present in diesel particulate could leach into the ground and pollute the ground water. However, this should not be more difficult to solve than the current problem of disposing of used engine lubricating oil. Assuming a typical heavy-duty diesel engine oil replacement period of 10,000 miles, (6214 km), a 26.5 liter engine capacity and an oil having a specific gravity of 0.9, 23.9 kilograms (kg) of oil must be disposed of every 10,000 miles. If a trap collected 1.3 g/mi (0.81 g/km), this would produce 13 kg of particulate plus the trap every 10,000 miles. Since the engine oil actually contains some particulate from the cylinder and is essentially all organic matter, while the majority of the particulate matter is carbon, the traps should be less of an environmental problem than the existing oil disposal problem.

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CHAPTER VI

ECONOMIC IMPACT

There is associated with nearly all emission standards a cost of compliance. In this chapter, the costs necessary for compliance with these regulations are examined and analyzed. The primary cost involves the development and installation of emission control technology and hardware on the diesel vehicles. Lesser costs are incurred by the emissions testing required for EPA certification, which include the purchase of new instrumentation and equipment required for the measurement of particulate emissions. All of these costs are borne by the manufacturer, who, in turn, passes them on to the consumer. The manufacturer will also attempt to make a profit on his investment and this will also be passed on to the consumer. A return on the manufacturer's investment is necessary, even if the investment is for pollution control equipment. Finally, the consumer also must bear any additional operating costs that may result from the proposed standards. All costs presented in the following sections will be in terms of 1980 dollars. The economic impact of alternate approaches can be found in Chapter VIII, Alternative Actions.

A. Costs to Vehicle Manufacturers

1. Emission Control System Costs

The technology necessary to meet the 1986 particulate emission standard was discussed in Chapter IV. Heavy-duty engines are expected to be able to meet the 1986 standard with trap-oxidizers along with incorporating the design features of those current engines with low particulate emissions. The trap-oxidizer represents additional equipment and will increase the cost of the engine (and vehicle). The design modifications, however, should not raise production costs, except through the amortization of new tooling and engineering costs. These design features of the lower particulate emitting diesels are present on these engines at no apparent price differential and should be similarly available to others. It is possible that some of these heavy-duty vehicles will be able to use other techniques to meet the standard, but to be conservative, this economic analysis will assume that all vehicles will require trap-oxidizers.

In summary, EPA estimates the average first price increase of a trap-oxidizer system for heavy-duty vehicles to be $521-$632 (1980 dollars). The cost of the trap itself represents about 80 percent of this total. Necessary modifications to the engine and exhaust system represent 10 percent of the total cost. The remaining costs are associated with the control system used to initiate oxidation of the trapped particulate. The use of the trap-oxidizer system as described in this section should also reduce maintenance costs by $197 (1980 dollars, discounted back to year of vehicle purchase) due to reduced exhaust system maintenance. A detailed discussion of the cost estimates for components comprising a trap-oxidizer system is contained in Appendix II of this document. It is suggested that Appendix II be read to understand the details of the methodology behind the cost estimates. This section (Section VI-A1) will only present the costs estimated for the whole trap-oxidizer system (as determined from Appendix II) and outline some of the methodology followed.*

The cost analysis covered the first five years following implementation of the regulation, 1986-1990. It was assumed that the trap-oxidizer and other components would be produced by three outside suppliers, each having a third of the heavy-duty diesel engine sales market. For purposes of this analysis, a 12 percent learning curve was used, which means that the cost of a trap-oxidizer system will increase 12 percent each time the accumulated production is halved.

The costs of the trap-oxidizer systems are shown in Table VI-1, where it can be seen that costs appear for four groups of vehicle classes. The first group consists of Classes IIB, III, and IV. The costs estimated for this group corresponds to the average size of trap-oxidizer systems fitted to the three vehicle classes. The remaining groups consists of Classes V, VI, VII, and VIII. The trap-oxidizer system for these groups were sized with a trap to fit a Class VIII vehicle, and it was assumed that a Class VIII trap would be used for Classes V, VI, and VII vehicles as well. Originally, it was assumed that different sizes of traps would be used for Class V-VI, Class VII, and Class VIII vehicles. However, the low production volumes involved with the Class V-VI and Class VII traps caused these traps to be more expensive than the larger Class VIII traps, even when the effect of trap size on costs was taken into account. Thus, it was assumed that the industry would follow the least-cost approach and equip the smaller vehicles with the larger traps.

A range of costs are shown for each of the two groups in Table VI-1. This is due to possible variations in the trap-oxidizer systems that could be used. For example, the cheapest system could consist of a trap, stainless steel exhaust pipe, electronic control unit, sensors, and a throttle body and switch. The next higher costing system could be the same as the previous system without the electronic control unit and sensor, and with the addition of port liners, insulated exhaust manifold, and mechanical control. The most expensive system could include the combined components of the first two systems. This range of costs will decrease in later years because of an increase in cumulative production from 1986 to 1990. The fleetwide-average cost for each year is then a sales-weighted average (based on the sales scenario in Table A-II-1 of

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* Costing methodology was based on a study by LeRoy Lindgren, "Cost Estimations for Emission Control Related Components/Systems and Cost Methodology Description" EPA-460/3-78-002. See Appendix II for a more detailed discussion.

Table VI-1

Estimated Costs of Trap-Oxidizer Systems
At Predicted Production Volumes (1980 dollars)

	Vehicle Class	Vehicle Class Average
1986	IIB, III, IV	551-644
	V, VI	611-688
	VII	652-805
	VIII	642-789
Sales Weighted:		629-756
1987	IIB, III, IV	480-562
	V, VI	540-632
	VII	574-709
	VIII	564-695
Sales Weighted:		552-670
1988	IIB, III, IV	438-513
	V, VI	497-584
	VII	530-649
	VIII	520-643
Sales Weighted:		508-618
1989	IIB, III, IV	410-480
	V, VI	472-553
	VII	502-622
	VIII	495-612
Sales Weighted:		482-586
1990	IIB, III, IV	384-451
	V, VI	449-527
	VII	480-596
	VIII	472-588
Sales Weighted:		458-559

Appendix II) of costs for the two basic vehicle groups. The fleetwide average cost in 1986 is then $629-$756 and should decrease to $458-$559 in 1990.

Sensitivity analyses were performed to examine the effects of the two assumptions made above; 1) that three outside suppliers would produce the trap-oxidizers and 2) that a 12 percent learning curve would apply (see Appendix II-Section C). To examine the effect of the first assumption, a new assumption was made, that each manufacturer would produce his own trap-oxidizers. This is a worst case assumption since the production volumes involved are as small as practically possible. Also, from catalyst production experience, it is highly unlikely that each manufacturer would attempt to produce his own traps, due precisely to the small production volumes involved. The analysis showed that trap-oxidizer costs were not highly sensitive to the number of supplies. Under the worst possible situation, industry-wide costs would only increase 5 percent and the cost to the smallest manufacturer would only be 23 percent higher than the industry average. The 12 percent learning curve was again used to adjust for changes in production volume.

To examine the effect of the 12 percent learning curve, it was assumed that there was no learning curve and that costs would be the same at any production volume. This change did affect cost significantly, particularly in the early years. In 1986, trap-oxidizer costs were about 37-62 percent lower than those shown in Table VI-1. However, by 1990, the difference had narrowed to 15-40 percent. The examination of a flat learning curve in this analysis stems from the judgment that, if the 12 percent learning curve is in error, then it errs by being too steep. Thus, the percent cost analysis is conservative in this respect. If additional data becomes available during the comment period with respect to the level of learning curve operating in this area, the analysis will be adjusted accordingly. However, at this time, 12 percent is the best estimate available.

2. Certification Costs

Certification is the process in which EPA determines whether a manufacturer's engines conform to applicable regulations. The engine manufacturer must prove to EPA that its engines are designed and will be built such that they are capable of complying with the emission standards over their full useful life. Certification begins by a manufacturer submitting an application for certification to EPA and is followed by a 2-step process which determines the emissions of the engine over its useful life.

The first step involves the determination of preliminary deterioration factors for the regulated pollutants. These deterioration factors must be multiplicative in nature. The engine manufacturer may determine these preliminary deterioration factors in any manner it deems necessary to ensure that the preliminary deterioration factors it submits to EPA for certification purposes are accurate for the full useful life. Manufacturers must state that their procedures follow sound engineering practices and specifically account for the deterioration of EGR, air pumps, and catalysts as well as other critical deterioration processes which the manufacturer may identify. In addition, when applicable, the manufacturers must state that the allowable maintenance intervals were followed in determining the preliminary deterioration factors. The manufacturers would submit preliminary deterioration factors, based on the definition of useful life, in each case where current certification procedures require testing of a durability-data engine. Beyond these requirements, EPA would not approve or disapprove the durability test procedures used by the manufacturers.

Step two involves emission-data engines. One to two diesel engines will be chosen for each engine family. These engines would be operated for 125 hours in a procedure designed by the manufacturers before the emission test. The preliminary deterioration factor will be multipled by the 125-hour emission test results to predict whether the emission data engines would meet the standards for their full useful life. If the emission-data engines are predicted to pass the standards over the full useful life, then the engine family is granted certification. The number of engines expected to undergo both types of testing is shown in Table VI-2.1/

For the purpose of this cost analysis, the following assumptions are reasonable based on past practice. Manufacturers will certify one emission control system per engine family resulting in the need for one set of preliminary deterioration factors per family. EPA will select two emission-data engines for each diesel family,1/ since each manufacturer will develop its own preliminary deterioration factors. As a base estimate, EPA has assumed that a manufacturer will follow the former EPA durability procedure.2/ For a diesel engine, this procedure covers 1,000 hours with an emissions test each 125 hours plus tests associated with scheduled maintenance.

In order to estimate certification costs, unit costs must be known for each of the following: 1) an emission data engine test with and without particulate testing, including the required 125 hours of service accumulation plus the prototype engine and, 2) preliminary deterioration factor assessment with and without particulate testing, which EPA believes will be conducted in a manner similar to the former pre-production durability testing procedure. All certification test costs include transient and smoke testing for diesel engines.

The cost of both types of gaseous emission testing for diesels has already been determined1/ and is shown in Table VI-3 inflated to 1980 dollars. The additional cost of particulate testing will be estimated here. It is estimated that the additional requirement

Table VI-2

Heavy-Duty Diesel Certification
Costs Due to Particulate Regulations (1980 dollars)

1986

Manufacturer	Estimated Number of Durability Engines 12/	Estimated Number of Emission Data Engines 12/
GM	9	18
Cummins	19	38
Caterpillar	9	18
Mack	4	8
IHC	5	10
Deutz	-	2
Isuzu	-	2
Fiat	-	2
Mercedes	3	6
Mitsubishi	-	1
Scania-Vabis	-	1
Volvo	-	3
Hino	-	1
Total	48	110
1987-1990		
Total	5	11
Direct Cost per Engine Tested Due to Particulate Testing	$975	$100
Indirect cost per Engine Tested Due to Particulate Measurement	$145	$ 15

Total Certification Costs Due to Particulate Regulation

1986	$65,000
1987-1990	$ 7,000

Table VI-3

Unit Costs of Certification Tests (1980 dollars) 1/

Test	Gaseous Emissions	Gaseous and Particulate Emissions
1. Preliminary deterioration factor assessment.2/	$114,000	$114,975
2. 125-hour emission data engine.3/	$ 21,600	$ 21,700

1/ Includes transient and smoke emissions. Source: Ref. 12/
2/ Assumed manufacturers follow past EPA procedures, but this is not mandatory.
3/ The manner in which the 125-hour break-in period is carried out is at the manufacturers' discretion.

of particulate measurement will require one extra technician hour during testing (including weighing of particulate filter), and one extra technician hour for data processing. Filters are the only material that must be renewed for each particulate test. Assuming that technicians cost $30/hour, and filters cost about $3 per test, the total incremental cost is $63 per emissions test.

In addition to this direct cost, the measurement of particulate emissions could increase testing costs by affecting the void rate occurring with emission testing. Based on current EPA experience in testing light-duty diesels for gaseous emissions, a void rate of 20 percent on such tests is typical.3/ This rate is expected to decrease in the future as experience with the diesel procedure increases. When other disqualifiers are included (e.g., manufacturer and administrative errors, lack of correlation with previous tests, etc.), the current overall retest rate becomes about 50 percent.3/ The addition of a particulate measurement system is expected to increase this retest rate by 5 percent, to an overall rate of 55 percent.3/

The impact of both the direct and indirect costs of testing for particulate emissions depends on the number of tests involved. The direct cost of particulate testing is $63 per emissions test. In the course of determining a deterioration factor for a durability engine, about ten successful emission tests are required.4/ Using an overall void rate of 1.55, the direct cost of adding particulate testing to durability testing would be about $975 per durability engine (10 x 1.55 x 63). Only one emissions test is required for an emission data engine. Again using a void rate of 1.55, the direct cost of particulate testing per emission data engine is about $100 (1.55 x 63). Both of these costs are shown in Table VI-2.

The indirect costs of particulate testing can be determined similarly. The addition of particulate testing is expected to increase the overall void rate for emissions testing from 1.50 to 1.55, or 5 percent based on the number of successful tests. About 2.5 percent of the costs of testing a durability engine and 1.2 percent of the costs of testing an emission-data engine are due to emission testing.4/ The rest of the costs are associated with the cost of the engine and the cost of accumulating time on the dynamometer. Thus, the addition of particulate testing will increase the total cost of testing by 0.125 percent (0.025 x 0.05) for durability engines and 0.06 percent (0.05 x 0.012) for emission-data engines. Using the figures in Table VI-10, this translates into a cost of $145 per durability engine and $15 per emission-data engine. These costs are shown in the middle of Table VI-2.

All that now remains is to determine the number of engines being certified under these particulate regulations. The years 1986-1990 will be examined as these are the five years covered by the aggregate cost analysis which appears later in this chapter. Normally, the implementation of a new emission standard, such as the 1986 particulate standard, would require all manufacturers to recertify their engines. However, in this particular situation, there is one other action which will already require the recertification of all heavy-duty diesel engines in 1986. This is the 75 percent reduction NOx standard which Congress has mandated and which will also be implemented in 1986. This revised standard should require most if not all heavy-duty diesels to be recertified in 1986 with or without particulate regulations. The total number of engine families expected in this time frame has already been determined elsewhere1/ and are shown in Table VI-2.

In the years following 1986, far fewer engines should require certification. As emission standards are not expected to change between 1987 and 1990, the great majority of engines should be able to obtain carryover for these years. If it is assumed that a heavy-duty diesel engine is marketed about 10 years before major redesign, then about one-tenth of the engines certified in 1986 should require certification in each year following. This is also shown in Table VI-2.

The total certification costs in each year, 1986-1990, can now be calculated directly from the figures in Table VI-2. The certification costs due to these particulate regulations are $65,000 in 1985 and $7,000 per year from 1987 to 1990.

3. Costs of Selective Enforcement Auditing (SEA)

The addition of particulate standards is not expected to increase the number of Selective Enforcement Audit (SEA) tests performed on heavy-duty diesels. These engines would have had to be audited for compliance with gaseous emission standards in any event. There will be an increase in the cost of these tests, however, due to both an increase in the number of voided tests and an increase in the number of personnel needed to perform each test. The number of heavy-duty diesel engine families which could be audited each year is 21 for 1986 and 1987, and 22 for 1988, 1989 and 1990.1/ If it is assumed that all audits are passed, then an average of 12 engines will need to be tested in each audit.1/* The cost of testing an engine is about $1,900,1/ ($1,750 (1979 dollars) inflated to 1980 dollars) with about 33 percent of the costs being due to actual emission testing.4/ Using an overall void rate of 1.55, the total number of tests in each year would be as shown in Table VI-4. The direct cost of particulate testing is $63 per test, as discussed in the previous section. The indirect cost,

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* If an audit is failed, then the need to accurately determine the average emission level of that engine family could raise the total number of engines requiring testing to 55. This would increase the economic impact of the particulate standard by a factor of 4.6 for that particular audit. However, since failed audits are expected to be quite rare (much less than 5 percent), the additional impact of failed audits will be small (much less than 20 percent).

due to a higher void rate, is as follows. The third of the $1,963 per engine testing cost which is associated with emission testing is increased by 0.05 out of the former void rate of 1.50. (The overall void rate of 1.55 is used rather than 1.0 because the number of tests shown in Table VI-4 is the actual number of tests including voids.) This fraction comes to $21 per test. The total impact of particulate testing is the sum of the direct and indirect costs, which is about $85 per engine tested. Combining this cost with the estimated number of tests performed each year (Table VI-4) yields the overall cost of SEA testing each year due to this regulation. As can be seen from Table VI-4, the cost rises gradually from $33,000 per year in 1986 to $35,000 per year in 1990.

EPA also expects that all manufacturers will institute a manufacturer operated production line audit program to measure the effectiveness of the compliance efforts and provide themselves assurance of their ability to pass a formal EPA audit.1/ EPA believes that in the first two years of SEA, 1984 and 1985, the manufacturers may audit, on the average, as much as 0.6 percent of their production. However, as they gain greater confidence in their SEA compliance efforts and build engines to achieve the same emission standards for several years, this percentage will decline to about 0.4 percent by 1986 and remain there through 1990. The total cost of a production line audit for gaseous emissions is $1,380 per engine (inflated to 1980 dollars),1/ with 45 percent of this cost due to actual emission testing.4/

The presence of a particulate standard should not affect the number of engines tested, but could affect the cost of each test and the total number of tests performed. Again, the direct cost of particulate testing due to personnel and equipment needs is $63 per test (Section VI-A2). The indirect cost is again 3.3 percent (0.05/1.55) of 45 percent of $1,440 (1380 + 63), or $21 per test. Together the cost of particulate testing is about $85 per test.

When this cost, the projected production figures shown in Table A-II-1, the overall void rate (1.55) and the above-mentioned testing percentages (0.4 percent in 1986 and later years) are combined multiplicatively, the result is the annual cost for each manufacturer. These annual costs are shown in Table VI-5. As can be seen, the total cost for the entire industry is $103,000 in 1986 and slowly increasing to $129,000 in 1990. These costs should continue to increase slowly as total heavy-duty diesel production increases.

4. Test Facility Modifications

These heavy-duty diesel particulate regulations will require manufacturers to purchase new equipment to modify their emission test cells to allow for the measurement of particulate emissions. It will be assumed that heavy-duty diesel engine manufacturers will anticipate these particulate regulations at the time

Table VI-4

Increased Cost of SEA
Due to Particulate Regulation (1980 dollars)

Year	Number of of Audits	Number of Emission Tests	Increased Cost of SEA 1/
1986	21	391	$33,000
1987	21	391	$33,000
1988	22	409	$35,000
1989	22	409	$35,000
1990	22	409	$35,000

1/ Based on a total direct and indirect cost of $85 per emission test.

they purchase equipment for the new transient test procedure becoming effective in 1984-1985. In the preamble to the regulations implementing the transient test procedure,5/ EPA announced that these particulate regulations were being developed for the same timeframe and that the gaseous emission test procedure had been modified to allow for equipment needed in particulate testing which was also central to the measurement of gaseous emissions. In this way, heavy-duty diesel manufacturers could design their testing systems for particulate testing right from the start and no money would be wasted on modifying newly-installed test equipment before it had ever been used. Because of this, only that particulate-testing equipment which is needed in addition to the basic set-up required for gaseous emission testing will be taken to be additional requirements of this particulate regulation. This basic set-up for gaseous emission testing will include those particulate-oriented devices which are also central to gaseous emission testing and which essentially replace a similar device which would not be allowed when testing for particulate (e.g., dilution tunnel over mixing box).

Table VI-6 shows the costs of the additional test equipment needed to measure particulate emissions. The costs of two systems are shown; a single dilution system and a double dilution system. Both are allowed under the proposed test procedure. If a single dilution system is involved, the major additional expense is due to the larger volume sampling system (CFV or PDP) required. A major additional cost of a double dilution system is due to the secondary dilution tunnel and related measurement devices. The total cost of the double dilution system is $34,000 more than the cost of equipment required for gaseous emission testing, while the total cost of the single dilution system is $61,000 to $70,000 more than the cost of equipment required for gaseous emission testing. It will be assumed that manufacturers will install the double dilution system since it is the least expensive of the two systems shown in Table IV-14. The incremental cost of test equipment per modified cell due to this particulate regulation would then be $34,000. A filter weighing system for each test facility (with either type system) will cost an additional $33,000.

The expected number of test cells and facilities requiring modification is shown in Table VI-7 for each manufacturer.1/ Only those test cells designed for emission testing have been assumed to require modification and not those used for service accumulation.1/ Coupling these figures with the above costs yields the overall cost to each manufacturer, and these are shown in Table VI-5. The total cost to the industry will be $2,056,000 (1980 dollars). The estimated number of test cells and facilities includes those required for SEA testing.

B. Costs to Users of Heavy-Duty Diesels

Purchasers of heavy-duty diesels initially will have to pay for the costs of any emission control equipment used to meet the

Table VI-5

Cost of Self-Audit Programs Due to
Particulate Regulation (Thousands of 1980 Dollars)

Manufacturer	1986	1987	1988	1989	1990
Cummins	48	51	54	57	60
Detroit Diesel (GM)	40	42	45	47	50
Caterpillar	29	31	32	34	36
Mack	22	24	25	27	28
International	11	12	13	13	14
Deutz	1	1	1	2	2
Isuzu	1	1	1	1	1
Hino 1/	0	0	0	0	0
Fiat	1	1	1	2	1
Mercedes	3	3	3	3	4
Mitsubishi	0	0	0	0	0
Scania-Vabis	0	0	0	0	0
Volvo	1	1	1	1	1
Total	157	167	176	187	197

1/ Zeros signify less than $500.

Table VI-6

Cost of Modifying an Emission Test Cell
for the Measurement of Particulate Emissions (1980 dollars)

Cost Per Item In Test Cell	Single Dilution	Double Dilution
Constant Volume Sampler		
CFV-CVS 1/2/	31,000	$0
PDP-CVS 1/2/	40,000	$0
Heat Exchanger 3/	25,000	25,000
Secondary Dilution Tunnel	-	1,500
Sampling Equipment for Tunnel (Probes, Filter Holders, Flowmeters, etc.)	5,000	7,500
Total Cost per Cell		
CFV-CVS	61,000	34,000
PDP-CVS	70,000	34,000
Cost per Item at Test Facility		
Microgram Balance	11,000	11,000
Weighing Chamber	22,000	22,000
Additional Cost per Facility	33,000	33,000

1/ Costs which are incremental to the system specified in the 1984 heavy-duty gaseous emissions regulations.
2/ Size of single dilution tunnel system is 6000CFM. Size of double dilution tunnel system is that which is required by the 1984 heavy-duty gaseous emission regulations.
3/ Includes price of water conditioning features in heat exchanger jackets.

particulate emission standards plus the cost of certification and SEA which includes the cost of new particulate measurement equipment. The vehicle manufacturers pass on these costs to the purchaser by increasing the "first cost" or sticker price of the vehicle.

To calculate these costs, an estimate of the number of heavy-duty diesels which will be sold each year is needed. EPA's best estimate of diesel penetration can be found in Section III of this analysis. The estimates of total heavy-duty sales were determined from an analysis of 1967 to 1978 sales of heavy-duty vehicles. Projected sales of all heavy-duty vehicles for 1979 and beyond were based on a growth rate determined by a regression analysis of the 1967 to 1978 data. It was estimated that sales of Class IIB, III, and IV vehicles would be 20 percent diesel by 1990, sale of Class VI school buses would be 10 percent diesel by 1990, sales of Class VI trucks would be 35 percent diesel by 1985, sales of Class VII vehicles would be entirely diesel by 1988, and sales of Class VIII vehicles would be entirely diesel by 1984. These diesel penetration rates by class were then combined with the projections of overall sales to yield diesel sales by class, which are shown in Table III-9.

The costs of this regulation to users of heavy-duty diesels can now be calculated and are shown in Table VI-8. The cost of test equipment modifications were assumed to occur in 1985 and all certification costs were assumed to occur during the year prior to that model year. SEA costs were assumed to occur during the model year in question. A 10 percent discount rate was used to determine the present value of these sets of expenditures in 1985. These costs were then amortized over 1986-1990 diesel production to yield a constant cost per vehicle. These five years were chosen because they are the first five years that the standard is in effect and the five years over which the aggregate cost is determined. Expenditures were assumed to occur on January 1 of the year in question and revenues were assumed to occur on December 31. The resulting cost is $2 per vehicle.

The cost of emission control hardware are shown next in Table VI-8, (taken from Table VI-1). Engine modifications will cost $4-16 per vehicle throughout the 5-year period (see Section D.1.a of this chapter). Trap-oxidizer costs are highest in 1986 at $629-756 per vehicle and decrease to $458-559 per vehicle in 1990. Over the five-year period, the sales-weighted average is $521-632 per vehicle.

The users of heavy-duty diesels will also have to pay for any increases in the costs of maintenance or fuel that occur because of this regulation. No fuel penalty is expected from the use of a trap-oxidizer or from any engine modification necessitated by this regulation.

As the designs of trap-oxidizers are becoming better known, it seems reasonable to expect some maintenance to be required. The

Table VI-7

Certification and SEA Test-Equipment Modification Cost by Manufacturer (1980 dollars)

Manufacturer	Estimated Number of Modified Cells	Estimated Number of Facilities	Total Cost
GM	6	2	$270,000
Cummins	12	2	474,000
Caterpillar	7	2	304,000
Mack	4	2	202,000
IHC	4	2	202,000
Deutz	1	1	67,000
Isuzu	1	1	67,000
Fiat	1	1	67,000
Mercedes	2	1	101,000
Mitsubishi	1	1	67,000
Scania-Vabis	1	1	67,000
Volvo	2	1	101,000
Hino	1	1	67,000
		Total	$2,056,000
		With Cost of Capital*	$2,344,000

* One year at 14 percent interest.

Table VI-8

Cost to the Consumer of Heavy-Duty Diesel
Particulate Regulation (1986-1990) (1980 Dollars)

Test Equipment, Certification and SEA Costs

	Equipment	Certification	SEA and Self Audit
1985	2,056,000	65,000	-
1986	0	7,000	190,000
1987	0	7,000	200,000
1988	0	7,000	211,000
1989	0	7,000	222,000
1990	0	-	232,000

Total cost (present value in 1985)1/ - $2,725,000
Cost per vehicle (1986-1990 production)2/ - $2 per vehicle

Engine Modifications

1986-1990	$4-16 per vehicle

Control Hardware Costs

1986	629-756
1987	552-670
1988	508-618
1989	482-586
1990	458-559

Sales Weighted Average, 1986 - 1990 3/ $521-632

Operating Costs (1986 and on)

Maintenance increases (discounted to year of vehicle purchase)	$19
Maintenance reductions (discounted to year of vehicle purchase)	(-$197)

Net Cost to Consumer

1986 and on	$349-472

1/ Discount rate at 10 percent.
2/ Amortization weighted to result in an equal cost per vehicle over the years of production cited. Discount rate assumed to be 10 percent. Expenses are assumed to occur on January 1 of the given year and revenues are assumed to be recieved on December 31 of the given year.
3/ Based on total diesel sales projections for 1986-1990 shown in Table A-II-1.

trap itself should still be maintenance-free, but the oxidation control system may require periodic adjustment. It is also possible that a temperature sensor may also need replacement. It is estimated that this type of maintenance would require about one hour of labor and $10 worth of parts and occur once throughout the life of the vehicle. At a labor rate of $20 per hour, the total cost would be $30. This maintenance should occur halfway through the vehicle's life (approximately 9 years) and will be assumed to occur after 5 years of vehicle operation. Discounted back to year of vehicle purchase, this cost would be $19.

However, the addition of a trap-oxidizer system is also expected to reduce maintenance in two ways. One, the system will include a stainless steel exhaust pipe which will eliminate the normal need to replace it. Two, the presence of the trap itself should eliminate the need for the muffler,3/6/7/ which in turn eliminates the need to replace the muffler.

In order to calculate the savings resulting from the elimination of these two maintenance items, two pieces of data are needed for both muffler and exhaust pipe replacements; timing and costs. These two items are thoroughly examined in Appendix II of this document.

It was found that an average of 1.27 muffler replacements were necessary for each heavy-duty vehicle. Using a 10 percent discount rate, the replacement rate as outlined in Appendix II is equivalent to 0.61 replacements at the time of vehicle purchase, or to 0.98 replacements when the vehicle is five years old. As no similar data could be found which related specifically to exhaust pipe replacements, these findings will also be used for exhaust pipes as well as mufflers.

The aftermarket costs of mufflers were estimated to be $136, $161, $164, and $181 for Class IIB-IV, Class V and VI, Class VII, and Class VIII engines, respectively. The cost of labor and incidental parts was estimated to be 25 percent of the cost of the muffler (details in Appendix II), so that the total cost of a muffler replacement would be $170, $201, $205, and $211, respectively. Using the sales figures of Table A-II-1 of Appendix II, the sales-weighted average of these costs is $211 per muffler replacement. Undiscounted, 1.27 muffler replacements would amount to $268 per vehicle. Using the actual schedule of replacements described in Appendix II and a 10 percent discount rate, the savings from eliminating muffler replacements would be $129 per vehicle, discounted back to the year of vehicle purchase.

The total cost of exhaust pipe replacements with 25 percent for labor and incidental parts becomes $54, $85, $105, and $136 respectively. Again, using the sales figures of Table A-II-1, a sales-weighted average cost is $111 per replacement. Using 1.27 replacements per vehicle, the undiscounted savings becomes $141 per vehicle. Using the actual replacement schedule determined for mufflers above and a 10 percent discount rate, the savings resulted from eliminating exhaust pipe replacements is $68 per vehicle (discounted to year of vehicle purchase). Adding to this the savings determined for mufflers above, the total maintenance savings is $197 per vehicle (discounted to the year of vehicle purchase). This savings is shown in Table VI-8.

The total cost to the consumer can now be simply added up from the figures of Table VI-8. For the 1986 models, the cost of owning and using a heavy-duty diesel should increase $349-$472 per vehicle due to these regulations. The range of the cost is primarily due to the possibility of different trap-oxidizer systems being used on different models. The actual cost paid by consumers will fall somewhere between these two costs, depending on the complexity of the trap-oxidizer system used on a given model.

C. Aggregate Costs--1986-1990

The aggregate cost to the nation of complying with the 1986 heavy-duty diesel particulate standards consists of the sum of increased costs for new emission control devices, new test equipment, additional certification and SEA costs, and changes in vehicle maintenance requirements. The cost of the 1986 standard will be calculated over a period of five years, 1986-1990.

The aggregate cost to the nation is dependent on the number of heavy-duty diesels sold during these time periods. Any projection of this type will by nature be rough, due to the many social and economic factors involved. The sales projections used will be those shown in Table A-II-1, plus and minus 10 percent. The per vehicle cost of this regulation will be taken from Table VI-8.

The aggregate cost to the nation based on these sales projections and per vehicle costs is shown in Table VI-9. As can be seen, two aggregate costs are presented. Both are in terms of 1980 dollars, but the present value in each case was determined in different years, 1980 and 1986. Two different years were chosen because there appears to be two conventions which set the present value reference point for the aggregate cost. Some analyses have used one and some the other. One is the current year of analysis, or "the present." In our case this year is 1980. The other is the year the regulation becomes effective, which here is 1986. The two figures are exactly equivalent. They are related by the discount rate (10 percent per annum) to the sixth power (1986-1980 = 6). The present value of the five-year aggregate cost in 1980 is $249-413 million and relates most closely to the cost to society today. The present value of the five-year aggregate cost in 1986 is $442-731 million and relates most closely to the cost to society in the year the regulation becomes effective-1986.

Table VI-9

Aggregate Cost to the Nation of Heavy-Duty Diesel Particulate Regulations

	Per Vehicle Cost	Sales	Aggregate Costs (1980 Dollars) 1/
1986-1990 Model Years	$349-472	1.5-1.8 Million	$249-413 Million 2/
			$442-731 Million 3/

1/ Ten percent discount rate used.
2/ Present value in 1980.
3/ Present value in 1986.

D. Socio-Economic Impact

1. Impact on Heavy-Duty Engine Manufacturers

This regulation will affect diesel engine manufacturers in two ways. First, the engine manufacturers will be faced with capital expenditures for test equipment and certification, and also possibly for some engine redesign and trap-oxidizer production. Second, the cost of emission control systems could affect sales and in turn affect the profitability of the company and employment. These effects will be investigated below.

a. Capital Expenditures

Capital expenditure is money spent for replacing, expanding, and improving business facilities. Capital expenditures include the cost of machinery and equipment used in production, the cost of research and development, engineering and product launching, and the costs of certifying to EPA emission standards. Capital expenditures do not include operating costs or product material costs. The capital expenditures arising out of this particulate regulation fall into two categories. First, the engine manufacturers will need to modify their current test cells to allow for particulate measurements and to test their vehicles in 1986 for particulate emissions when they would have only had to test for gaseous emissions and smoke. Second, engine manufacturers or outside suppliers must pay for tooling, R&D, machinery, land, and other capital costs involved with producing aftertreatment devices and possibly in the partial redesign of engines.

Overall, diesel engine manufacturers will have to spend $2.3 million (1980 dollars) by 1986 to modify their emission test cells and certify 1986 model year engines, including the cost of one year's borrowing at 14 percent interest. These initial costs are small compared to the initial costs estimated for the heavy-duty gaseous emission regulations being implemented in 1984. Breakdown of the initial costs for both regulations are shown for each manufacturer in Table VI-10. (Taken from Tables VI-2 and VI-7 in this section and from Table V-DD in reference 1/). EPA has already determined that the five largest manufacturers (Cummins, GM, Caterpillar, Mack, and IHC) will be able to raise the capital involved for test facilities and certification costs of the 1984 gaseous emissions regulation.1/ Thus, the small additional cost of this particulate regulation (about 2.5-3.4 percent of the initial cost for the gaseous emission regulations) should not be troublesome for these manufacturers. While it is possible that the small additional initial capital requirements of this particulate regulation could be the proverbial "straw that broke the camel's back," this does not seem to be a likely possibility. The amounts of monies involved are simply very small, both absolute and relative to the 1984 requirements.

Small-volume manufacturers may experience a greater impact than the large manufacturers on a per vehicle (sold in the U.S.)

Table VI-10

Initial Investment Required by Heavy-Duty Diesel Engine Manufacturers for Diesel Particulate and Gaseous Emission Regulations (1980 dollars)

Manufacturer	Cost for Test Cell Modification and 1984 Certification due to Gaseous Regulation 1/	Cost for Test Cell Modification and 1986 Certification due to Particulate Regulation
Cummins	$17,477,000	$500,000
GM (Detroit Diesel)	$12,246,000	$282,000
Caterpillar	$12,537,000	$316,000
Mack	$ 6,908,000	$207,000
IHC	$ 6,744,000	$209,000
Deutz	$ 1,562,000	$ 67,000
Isuzu	$ 1,562,000	$ 67,000
Fiat	$ 1,562,000	$ 67,000
Mercedes	$ 3,429,000	$105,000
Mitsubishi	$ 1,065,000	$ 67,000
Scania Vabis	$ 1,065,000	$ 67,000
Volvo	$ 3,021,000	$101,000
Hino	$ 1,065,000	$ 67,000

1/ Costs are the sum of 1979 initial certification costs and 1979 test facility modification costs for certification and SEA, taken from Table V-DD (p. 117-118) of reference 1/. The costs as they appear in this table are inflated to 1980 dollars, using an 8 percent inflation rate.

basis, but on an absolute basis, these manufacturers should be able to raise the small amounts of capital involved (at most, $105,000). All the small volume diesel engine manufacturers are foreign-based with a small percentage of their sales exported to the United States. On a worldwide basis, their profits should be more than sufficient to cover the initial investments for 1986 certification and test facility modifications of this regulation.

Small volume truck and bus manufacturers should not experience any disadvantage, since they will only see an increase in engine prices as they purchase engines and this increase will not be significantly larger than the increase seen by large truck and bus manufacturers.

The second area of capital investments concerns those capital expenditures associated with production of aftertreatment devices or engine redesign. Looking at aftertreatment devices, the major capital expenditures involved are tooling, land and building, and research and development expense. These costs are contained in equation 5 of Appendix II for calculating the retail price equivalent. Tooling expenses consist of four major components: one year recurring tooling expenses (tool bits, disposable jigs and fixtures, etc.); three-year non-recurring tooling expenses (dies, etc.); twelve-year machinery and equipment expense; and twelve-year launching costs (machinery foundations and other incidental set-up costs) which was assumed to be 10 percent of the cost of machinery and equipment.1/ Land and buildings needed for new production facilities has also been included for calculating emission control hardware costs (see Appendix II), and their cost has been amortized over 40 years. In most cases, however, space in existing facilities was assumed to have been made available for production purposes and hence is covered in the overhead costs. Research and development (R&D) expenses associated with aftertreatment devices will include product development, engineering, and product launching. Tooling, land and building expenses will be referred to as simply tooling costs (unless otherwise stated), and these costs will be calculated separately from R&D expenses for the remainder of this section.

The tooling costs associated with the production of aftertreatment devices will be calculated first for the trap itself. The cost of a trap most closely represents the cost of a monolithic oxidation catalyst without the washcoat and noble metals and this was the basis of the trap costs determined in Appendix II. Lindgren has calculated the tooling costs for a 1.0 liter (63 cu. in.) monolithic oxidation catalyst (pp. 114-117).1/ Lindgren has also calculated the manufacturing costs for 1.0 to 6.5 liter (63 cu. in. to 400 cu. in.) monolithic catalysts (pp. 134, 359-360), and projects no change of capital costs with this increase in catalyst size. The size of a heavy-duty trap is still larger, between 10 and 12.8 liters, but the same assumption that capital costs do not increase will still be made. This projection appears reasonable as the cost of machinery and space for land and buildings should follow the function of the machine more closely than a simple doubling of the part size. To take this projection into account, however, a range will be placed around the calculated capital requirements to indicate that some variation is expected.

While the capital investment is not expected to change significantly with trap size, it would change with varying production volumes of traps. A manufacturer of traps could not increase his production capacity adequately without investing in additional tooling. However, tooling costs can be expected to decrease (or increase) at a slower rate than a decrease (or increase) in production volume. For purposes of this analysis, it will be assumed that tooling costs decrease by 30 percent when the production volume is halved. Knowing this, the tooling costs calculated at Lindgren's production volume monolithic oxidation catalyst (p. 115) can be modified to reflect the tooling costs of heavy-duty diesel traps at EPA's estimated production volume. Lindgren's annual production volume and tooling costs for each part of the trap are shown in Table VI-11. EPA's annual production volume of heavy-duty diesel traps can be estimated by looking at the average annual heavy-duty diesel sales figures of Table A-II-1. Assuming one trap for each Class IIB-IV vehicle and two traps for each Class V-VIII vehicle, the number of Class IIB-IV traps and Class V-VII traps sold from 1986-1990 would be about 162,000 and 2,897,000, respectively. The five year total is roughly 3 million, and an annual average would be about 600,000. It was assumed in Appendix II that a trap sized for a Class VIII vehicle would also be fitted to Class V, VI, and VII vehicles as well. Thus, there will be two types of traps, one to fit Class IIB-IV vehicles and one to fit Class V-VIII vehicles. The total capital costs for trap production is the sum of capital costs calculated for producing traps for Class IIB-IV vehicles at an annual production of 30,000, and for producing traps for Class V-VIII vehicles at an annual production of 570,000. These total costs are shown in Table VI-11 and have been inflated to 1980 dollars. The total tooling cost for a trap is $8 million including the cost of capital (14 percent).

The tooling costs for the remaining trap-oxidizer system components are shown in Table VI-12. It was assumed as before that tooling costs vary with production volume but not part size. Once again, Lindgren's projections were revised to account for EPA's production volume. For the stainless steel exhaust pipe and for the muffler, EPA's production volume is 400,000 and is based on 3/4 of the heavy-duty diesel fleet having a single exhaust system, and 1/4 having a dual exhaust system. The remaining components have one unit per vehicle with a resulting production volume of 300,000. As discussed in Appendix II, the components other than the trap and control units would vary with each engine design. In Appendix II it was assumed that ten basic engine designs would cover the great majority of heavy-duty diesel production, with Classes IIB-IV allotted two designs, Classes V and VI allotted two designs, Class VII allotted three designs, and Class VIII allotted three designs. It was further assumed that an equal number of

Table VI-11

Estimated Tooling Costs of Parts to Heavy-Duty Diesel Trap-Oxidizer 1/

Part	Lindgren's Economic Volume	Lindgren's Tooling Costs (1977 dollars)	EPA's Economic Volume	EPA's Tooling Cost (1980 dollars) 2/
Converter Assembly	2,000,000	4,636,000	600,000	3,676,000
Shell	2,000,000	636,000	600,000	504,000
Ring	4,000,000	222,000	600,000	123,000
Inlet Cone	2,000,000	222,000	600,000	176,000
Outlet Cones	2,000,000	222,000	600,000	176,000
Inlet Pipe	2,000,000	222,000	600,000	176,000
Flanges	4,000,000	131,000	600,000	73,000
Mesh	2,000,000	222,000	600,000	176,000
Hardware	10,000,000	106,000	600,000	36,000
Substrate	2,000,000	900,000	600,000	714,000
Vehicle Assembly	300,000	516,000	600,000	1,073,000
Body Modification	300,000	51,600	600,000	107,000
Total				7,010,000
Total with Cost of Capital				8,000,000

1/ From Lindgren's analysis of a 1.0-liter (63 cu. in.) monolithic oxidation catalyst (p. 115), without the washcoat and noble metals.

2/ This is the sum of capital costs determined for Class IIB-IV traps at an annual production of 30,000 and for Class V-VIII traps at an annual production of 570,000.

Table VI-12

Estimated Tooling Costs of Trap-Oxidizer System Components for Heavy-Duty Diesel Vehicles

Part	Lindgren's Economic Volume	Lindgren's Tooling Costs 1/ (1977 dollars)	EPA's Production Volume	EPA's Tooling Cost (1980 dollars) 2/
Trap	2,000,000	8,086,000 (p. 115)	600,000	8,000,000
Port Liners	400,000	1,076,000 (p. 193)	300,000 3/	2,400,000
Stainless Steel Exhaust Pipe	1,000,000	733,000 (p. 262, 271)	400,000 3/	1,600,000
Insulated Exhaust Manifold	1,000,000	516,000 (p. 178)	300,000 3/	2,030,000
Electronic Control Unit (50% of Total NOx and Part.)	2,000,000	865,000 (p. 299)	300,000	460,000
Sensors 4/			300,000	114,000
Throttle Body Actuator 4/			300,000	200,000

1/ Pages in Lindgren from which these values are taken are shown in parenthesis.
2/ This column is based on a 30 percent cost reduction for halving of production, an 8 percent inflation rate, and includes the cost of capital (14 percent).
3/ Production volume for these units occur for two engine designs of Class IIB-IV vehicles, two engine designs of Class V and VI vehicles, three engine designs of Class VII vehicles, and three engine designs of Class VIII vehicles. The annual production volume for components of engines with the same design is about 15,000 for Class IIB-IV vehicles, 35,000 for Class V and VI vehicles, 13,000 for Class VII vehicles, and 55,000 for Class VII vehicles, except for stainless steel exhaust pipes, where the production volume is 4/3 the amount in each group. The total tooling costs is the sum of tooling costs determined for each engine design group.
4/ No estimates made by Lindgren. These values assume ratio of tooling costs to RPE is same as ratio of tooling costs to RPE for the ECU.

engines would be produced according to each engine design in a vehicle group. The annual production for each vehicle group is approximately 30,000 for Class IIB-IV vehicles, 70,000 for Class V and VI vehicles, 40,000 for Class VII vehicles, and 160,000 for Class VIII vehicles, and the annual production of each engine with the same basic design would then be about 15,000 for Class IIB-IV vehicles, 35,000 for Class V and VI vehicles, 13,000 for Class VII vehicles, and about 55,000 for Class VIII vehicles. For stainless steel exhaust pipes, the production volume for each engine design group would be about four-thirds times the engine production with the same basic engine design due to the presence of dual exhausts on one-third of the engines. For the remaining trap-oxidizer system components other than the trap and control units the production volume for each engine design group is equal to the engine production. The tooling costs must be determined separately at the production volume for each of these ten basic engine design groups. The total cost for a trap-oxidizer component is the sum of the tooling costs determined for each design group. These total costs are shown in Table VI-12 including a cost of capital of 14 percent.

Lindgren did not estimate capital costs for the sensors or the throttle-body actuator. It was assumed that the ratio of tooling costs to retail price equivalents (RPE) for these items was proportional to that for electronic control units (ECU). Both costs are known for the ECU; the tooling cost is $406,000 and the RPE from Table A-II-4 is $37. (Both of these costs reflect the allocation of half the ECU cost to particulate control and half to NOx control.) Based on the ECU ratio of $406,000/$37, the tooling costs for sensors and throttle body actuator, with RPE's of $9 and $16, respectively, would then be about $100,000 and $175,000, respectively. With a cost of capital of 14 percent, these costs increase to $114,000 and $200,000, respectively.

The tooling costs for the complete trap-oxidizer system can be determined by adding the components for Systems III and IV of Table A-II-5, as these are the two systems used in calculating the range of the system RPE in Section A of this chapter. The total tooling cost for the industry is $10.4 to $14.8 million. To reflect the uncertainty contained in these projections, an added range of plus and minus 20 percent will be included, resulting in an overall projection of $9-18 million.

Next, the R & D expenses will be estimated for the trap-oxidizer system. Two components are expected to require R&D, the trap and the ECU. Looking first at the trap itself, it is expected that most of the research and development already taking place for light-duty diesel traps due to the 1985 light-duty diesel particulate standard will apply directly to heavy-duty diesel traps so that the entire process will not need to be repeated. However, a trap-oxidizer manufacturer will still recover this R&D expense from both light-duty and heavy-duty diesel sales. It is not possible to directly determine the cost of R&D needed to develop trap-oxidizers. The best estimate comes from past experience with similar developmental efforts. The most similar development would appear to be that of the catalyst, again. Lindgren estimated that the cost of R&D for the monolithic catalyst was $25 million (1977 dollars, or $31.5 million (inflated to 1980 dollars). This will be assumed to be the total R&D expense for both light-duty and heavy-duty diesel traps. The percentage of R&D expense allocated to heavy-duty diesel traps can be determined by looking at the projected sales data for both light-duty diesel and heavy-duty diesel vehicles. Betweeen 1986 and 1990, about 2-3 million light-duty diesel vehicles with traps will be sold annually,3/ and as previously determined, about 600,000 heavy-duty diesel traps will be sold annually. This means that 15-25 percent of all traps sold between 1986 and 1990 will be heavy-duty diesel traps. Thus, the portion due to heavy-duty diesel traps would be 15 to 25 percent of $31.5 million, or about $5 to 8 million (1980 dollars).

The R&D costs associated with the ECU are the last to be determined. Lindgren estimated that the development of ECU's for three-way catalysts would cost $6 million (1977 dollars), or $7.6 million (inflated to 1980 dollars). Most of this knowledge should be directly attributable to ECU's use to control trap oxidation. Thus, the total R&D effort associated with ECU's for trap-oxidizers should be much less, roughly, between 25 and 50 percent of $7.6 million, or $1.9-3.8 million. Allocating half of this to NOx control would leave $1-2 million due to particulate control. As there will be only one ECU per heavy-duty diesel, unlike the nearly two traps per vehicle, the heavy-duty fraction of overall production will be less than 15-25 percent and close to 10-15 percent. Thus, the R&D costs associated with ECU's for heavy-duty ECU's is $100,000-300,000 (1980 dollars). Total R&D expenses associated with the trap-oxidizer come to about $5 to $8 million. When a 14 percent cost of capital is added, the total R&D expenditure becomes $6-8 million.

The total tooling and R&D cost associated with trap-oxidizers is about $15 to 26 million and would be borne by the entire industry of heavy-duty diesel manufacturers should they decide to manufacture their own trap-oxidizer systems. However, as explained in Section A and Appendix II, it appears that it would be more economical for outside suppliers (about three) to manufacture trap-oxidizers. Therefore, heavy-duty diesel manufacturers should not have to raise all of this capital, but most of it will be raised by suppliers whose market will be greatly improved by the use of trap-oxidizers and who should be in good financial shape because of it.

The only capital expenditures remaining to be calculated are those associated with engine modification. In setting the particulate standard at 0.25 g/BHP-hr (0.093 g/MJ), the baseline was taken from the average of each major manufacturer's best engine (see Chapter IV for details). Implicit in this decision is the expectation that manufacturers can make basic improvements on their "worst" engines based on the existing designs of their "best" engines. These improvements should not increase the cost of these "worst" engines in the long run, since the "best" engines do not currently cost more because of better particulate emission characteristics. However, these "worst" engines will need redesigning to some extent and that will require capital investment in the areas of 1) design and engineering and 2) retooling for production. These capital investments will need to be recovered and this could raise the cost of these engines somewhat for a few years.

Determining the capital costs involved in such redesign is a difficult task for a number of reasons. One, the modifications necessary will vary from engine to engine and cause the resulting costs to vary similarly. Two, and this may be the dominant reason, in any engine improvement program undertaken by a manufacturer, improvements are made in more than just the area of particulate emissions. Once a decision is made to redesign an engine, or some part of it, full advantage is taken and many changes are incorporated affecting performance, fuel economy, and other regulated pollutants. Not only can some of these other improvements piggyback a decision to improve the particulate emission characteristics of an engine, but design changes to improve particulate emissions can also fit into an existing redesign problem that was initiated for other reasons.

This situation is particularly likely today as there are a number of factors causing manufacturers to look at basic engine design. One factor is the stringent 75 percent reduction NOx standard due in 1986. As the level of this standard is clearly outlined in the Clean Air Act (Section 202(a)(3)(A)(ii)), manufacturers have been working toward achieving it for some time and much of this effort centers around basic combustion chamber and injection design. Another factor is the drive for improved fuel economy in these days of ever-increasing fuel costs. Some of this effort centers around the combustion system, but some of it also involves more external devices such as turbocharging, improved aftercooling, etc., which can also have beneficial results in the emissions area. Last, the need for improved fuel economy is also extending the application of diesel engines to a wider range of trucks, particularly into the lighter classes of heavy-duty vehicles. This is resulting in the development of totally new diesel engines for these vehicles and the improvement of existing engines for wider application.

A good example of this situation would be work currently underway by Caterpillar on their 3406 engine. In a meeting with EPA, Caterpillar described some of the engine modifications they were considering to reduce NOx emissions.8/ These modifications included high-pressure injection, a separate-circuit after-cooler and piston redesign as well as many others. While these modifications resulted in a 20 percent decrease in NOx emissions, fuel consumption decreased 1-2 percent and particulate emissions decreased 50 percent (as indicated by continuous smoke measurements). These modifications will be introduced between 1983 and 1985.

As listed in Table IV-2 in Chapter IV, the particulate emissions from this engine are already quite low, 0.37 g/BHP-hr (0.138 g/MJ), the fact that particulate emissions could be reduced further via a NOx reduction program is significant. Albeit, the reduction was measured via continuous smoke measurement, as Caterpillar was not yet able to measure particulate directly. However, given the facts that 1) the smoke measurements were coupled with exhaust flow rate and integrated over the test, 2) the estimated particulate emission of the unmodified engine correlated well with transient mass measurements taken at Southwest Research Institute and 3) only one engine is involved, it would seem reasonable to extend the decrease in smoke to decrease in particulate mass, although the degree of reduction may differ somewhat. Thus, here is a case where particulate reductions resulted from basic engine modifications which were not intended for particulate control. In cases like this, of course, the cost of the particulate reduction is negligible, as the costs of the modifications will be allocated elsewhere.

There are other examples of this happening that are known to EPA. EPA has tested two redesigned versions of the Cummins NTC-350 engine, one California version and one 49-state version, with neither redesign being performed for particulate control. Rather, improved performance and fuel economy appear to be the main purposes behind the redesign, with the California version also being designed for low NOx emissions. In both cases, while both NOx emissions and fuel consumption decreased, so did particulate emissions over EPA's transient cycle.

While these are two positive examples of particulate reductions accompanying general engine improvements, this is unlikely to always be the case. For some engines, design work will need to be initiated primarily to reduce particulate. Other improvements may be able to accompany these changes and minimize the costs of change-over, but the primary reason for the changes will be particulate emissions. At the present time it is not possible to determine exactly how many engines will fall into this category. However, as outlined in the description of heavy-duty diesel engine manufacturers (Chapter III, Section C1), most manufactures rely on only a small number of basic engine designs for the great majority of their sales. Given that a number of these basic designs already have met the 0.41 g/BHP-hr (0.156 g/MJ) mark and many will meet this through design changes occurring before 1986 for other reasons, a reasonable estimate would be that 2-8 basic engine designs may need work specifically for particulate control.

The cost of each of these programs is equally difficult to estimate. But again, a reasonable guess would be $2 million per engine design, including research, development and retooling. This would put the total cost to the industry at $4-16 million. As it is not possible to determine which engines will require this work, it is also not possible to allocate this cost among the various manufacturers. Over the entire industry, however, this cost would amount to $2-10 per engine produced over five years (1986-1990).

The total capital expenditures due to this heavy-duty diesel particulate regulation is the sum of test equipment, certification, tooling, R&D, and engine redesign costs. This amounts to about $21-44 million. However, it is emphasized again that outside suppliers are expected to make trap-oxidizer systems and would be confronted with the tooling costs and R&D expenses totaling about $15-26 million. Heavy-duty diesel manufacturers will need to raise capital for test equipment and certification and engine redesign, which amounts to $6-18 million. Thus, less than half of the total capital expenditures involved with a diesel particulate regulation would be borne by the heavy-duty diesel manufacturers. This is a small amount when compared to the capital expenditures for diesel engines due to the 1984 heavy-duty gaseous emissions regulation, and the manufacturers should be able to raise the money involved.

b. Sales of Heavy-Duty Vehicles

The second area of impact of these regulations on manufacturers occurs in the area of increased vehicle prices due to emission control hardware. Cash flow problems should not be significant since the money invested in emission control devices (e.g. trap-oxidizers) is recovered soon after from the sale of controlled vehicles. The sticker price increase due to these devices, though, could potentially affect sales. Between 1986 and 1990, projected price increases are expected to average between $527-$642 per vehicle. This represents about 0.5-3 percent of initial vehicle prices based on a heavy-duty diesel cost of $16,000-140,000 in 1980 (see the following section, "Impact on Users of Heavy-Duty Diesels.") The credit for maintenance cost brings the net cost to consumer down to $349-472. This real price increase could affect sales in two ways. Purchasers of diesel-powered vehicles might switch to gasoline-powered vehicles. Or some purchasers may decide to wait an additional year before buying a new diesel.

It should be realized that the price of a gasoline-powered vehicle will also increase by 1986 due in part to the new gaseous emission standards being implemented in 1984 and the reduced NOx standard in 1986. Using the same cost methodology as that used for trap-oxidizers, a catalytic converter system and other costs of compliance for the 1984 standards are expected to raise the total cost of gasoline-fueled vehicles by about $394 in 1979 dollars,1/ or $444 in 1980 dollars. Operating costs of $259 (1979 dollars)1/ or $280 (1980 dollars) for switching to unleaded gasoline and maintenance savings of $176 (1979 dollars)1/ or $190 (1980 dollars) for elimination of spark plug and exhaust system replacements brings the total net cost to $534. (Lifetime fuel savings for heavy-duty gasoline vehicles were estimated to be $788 (1979 dollars)1/ or $851 (1980 dollars) with respect to heavy-duty gasoline vehicles with 1979-level emission controls. However, no fuel savings were projected with respect to uncontrolled engines. Thus, no such savings should be incorporated in this analysis).

The cost per vehicle for a diesel to meet the 1984 gaseous emission standards should be about $195 in 1979 dollars,1/ or $211 in 1980 dollars. It would appear, then, that the 1984 standards would give diesels a $323 advantage over gasoline engines. This is slightly misleading, however, because the sources of these costs are quite different. Over 62 percent of the diesel cost is the result of amortized (5-year) one-time capital investments in test equipment and research and development.1/ Only 7 percent of the gasoline engine cost is of this type. Thus, after five years of these price increases, the diesel costs will decrease to $80 per engine, while the costs for gasoline engines will only decrease to $497 per engine. Here the difference is $417 per engine. As it is unlikely that the manufacturers will actually spread their fixed costs evenly over just these five years, the actual difference between diesel and gasoline engine costs will likely be between $323 and $417 per engine and last longer than five years. However, as can be seen, this difference negates most of the diesel engine price increase expected from this particulate regulation.

In 1986, it is likely that a three-way catalyst will be used on heavy-duty gasoline vehicles to meet the reduced NOx standard. A three-way catalyst system includes the three-way catalyst, a feed-back carburetor, an electronic control unit system, and an oxygen sensor. The oxidation catalyst and the air pump already on the vehicle would be replaced. The net increase from 1984 to 1986 is expected to be roughly $100-$200. Thus, the combined effect of all emission regulations will impact diesel and gasoline engines roughly equally. Any absolute decrease in diesel sales should be no greater than any decrease in sales of gasoline-powered vehicles and this particulate standard should be no less acceptable than the Congressionally-mandated gaseous emission standards from this standpoint.

With respect to the entire economy, this regulation should have no adverse effect. If sales of heavy-duty diesels should decrease somewhat due to the increase in vehicle prices resulting from this regulation, the increase in jobs and sales from the production of trap-oxidizers will more than make up for any losses in the heavy-duty industry itself. Indeed, given the projected growth rates for sales of heavy-duty diesels, any reduction in sales due to this regulation would only reduce growth and should not result in a real decrease in sales. Thus, this regulation should not have any adverse local effects on employment.

EPA does not expect diesel heavy-duty vehicle sales or the heavy-duty industry in general to suffer in the long run because of a shift in the mode of freight transportation used. As will be shown in the next section, the impact of this regulation on the cost of owning and operating a heavy-duty diesel is very small (less than one-half a percent). Such a small increase should have little or no effect on the demand for heavy-duty diesels.

Thus, these regulations should not adversely affect the heavy-duty diesel industry, either through unreasonable capital requirements or reductions in sales.

2. Impact on Users of Heavy-Duty Diesels

Users of heavy-duty diesels will be affected through higher initial vehicle costs averaging $527-$650 for 1986 and on. The average retail price of a new heavy-duty diesel truck in 1979 was estimated to be between $15,000 and $50,000,1/ ($16,000 and $54,000 in 1980 dollars). In addition, as described in the next section, new diesel-powered buses cost approximately $140,000. This means that the average vehicle sticker price will increase 0.5-3 percent in 1986 and beyond. However, accompanying this sticker price increase will be a reduction in maintenance costs of $178 per vehicle (discounted to year of vehicle purchase). This savings would reduce the overall impact of this regulation to $349-$472 per vehicle.

Users of heavy-duty diesels will have to recover their increased investment by increasing the handling costs of freight. Operating costs for intercity trucks in 1975 were about $1.70 per mile,8/ or about $2.50 per mile in 1980 dollars. The average operating revenue in 1975 was about $1.80 per mile,8/ or about $2.65 in 1980 dollars. The average life-time of a heavy-duty diesel is about 9 years with a lifetime mileage of 475,000 miles.9/ The total freight revenue per truck would then be $825,000, discounted back to the year of purchase, according to the distribution of mileage throughout its life. The maximum impact of this regulation on a Class VIII vehicle should be no more than $472 (the upper limit of the previously determined range). Thus, this regulation should only increase operating costs by 0.06 percent. This should have little effect on the trucking industry.

The smaller, Class IIB-VII diesels should have a smaller lifetime mileage due to different usage characteristics. As described in Chapter IV, these vehicles are expected to be used much like their gasoline-fueled counterparts, which have a lifetime mileage of 114,000 miles.9/ The freight costs (on a per mile basis) on these trucks were not readily available, but they should be higher than that for the intercity diesels due to shorter trips and more loading and unloading. The lower lifetime mileage would tend to decrease lifetime operating expenses by about a factor of four, but a high expense per mile could remove half or all of this difference. At most, the impact of this regulation on the operating costs of these smaller diesels would be four times that determined for the larger diesels. This would be an increase of 0.24 percent, which is still quite small. Or the impact could be as low as that for the large diesels, 0.06 percent, if the operating costs per mile for the smaller diesels were four times that for the larger diesels. In either case, the impact of this regulation on the use of these vehicles to haul freight should be hardly measurable and prove to be no problem. Thus, this regulation should not have an adverse impact on the users of heavy-duty diesels.

3. Impact on Urban Areas and Specific Communities

The purpose of this section is to identify the socioeconomic impact of this heavy-duty diesel particulate regulation on urban areas and specific communities. The analysis has been broken down into three parts which will evaluate the impacts of this regulation on personal income, employment, and fiscal condition of urban areas and specially-affected communities, respectively. As will be seen, no adverse urban or community impacts are expected from this regulation.

a. Personal Income

One important aspect of this regulation is its effect on the use of personal income in urban areas in general and in specific localities. In other words, would this regulation cause urban dwellers to pay for a disproportionate share of the costs of control or to shift a significant portion of their income to pay for heavy-duty diesel particulate control?

Concerning the direct costs of this regulation, its effect on low income groups and on urban dwellers in general should be negligible since these individuals are not involved to any significant degree in the purchasing of heavy-duty diesels for personal or business use. Businesses located in urban areas will have to pay more for their diesel-powered trucks, but they will pay no more than those located outside urban areas. The absolute effect of the price increase for urban businesses is addressed for cities purchasing diesel-powered buses in the section below entitled "Fiscal Condition." As will be seen there, the effect of this regulation on the purchase price of heavy-duty diesels is very small. It is also true that most of the trucks purchased for urban use are powered by gasoline and not diesel engines, though any future shift is expected to be toward diesels.

The users of heavy-duty diesels will have to recover their increased investment by increasing the handling costs of freight. The magnitude of this one-time increase has been estimated to be less than 0.06-0.3 percent (Section D.2. of this chapter). This should have little effect on the trucking industry, urban or rural. Consumers in all localities and of all income levels will have to pay for this increased operating cost, since it will probably be applied to the costs of most food and consumer items. However, since transportation represents only a fraction of the total cost of consumer goods, the rise in prices should be even less than 0.06-0.3 percent, which itself is negligible. Thus, the burden on low income level groups should be negligible and will be no different from the burden imposed on higher income groups.

It should be mentioned at this time that the primary benefit of this regulation, that of improved air quality, will occur primarily in urban areas. As outlined in Chapter V, the largest concentration of heavy-duty diesels and their emissions occurs in urban areas. Similarly, the greatest air quality improvements will occur in urban areas. However, as was seen above and will be seen below, the bulk of the cost of control will be spread fairly evenly between urban and non-urban areas. Thus, this regulation actually tends to favor urban areas by providing benefits primarily to urban areas, where they are legitimately needed the most, and spreading the cost rather evenly across the whole nation. This is somewhat unavoidable since nearly all heavy-duty diesels enter urban areas for a fraction of their travel and controls cannot be placed on them only when they are in urban areas.

b. Employment

The production of heavy-duty diesel engines in the U.S. is spread across a number of states and no one locality has more than one manufacturer. Of the five major manufacturers, two are located in Indiana (Columbus and Fort Wayne), one in Michigan, one in Pennsylvania and one in Illinois. The heavy-duty vehicle industry is even less concentrated. Given this, any effect of this regulation on employment would not be concentrated in a single city or even in a single state, but be spread over a number of states. However, each manufacturer tends to be located in or near a single mid-size city. Any decrease in employment for a given manufacturer would then affect a single area and the workers affected would be primarily urban dwellers, though a fraction of those affected would certainly have commuted into the city from rural areas.

As was outlined earlier (Section D.1.b. of this chapter), however, the negative effect of this regulation on sales should be negligible. However, there is a general trend toward the increased use of diesel engines in heavy-duty vehicles (see Chapter III, section C) and heavy-duty diesel sales should actually increase 20 percent between 1980 and 1990. Thus, total employment in the heavy-duty diesel industry should increase substantially. In addition, new jobs will be created to research, develop and produce emission control equipment for these vehicles. Overall, then, this regulation should not have any adverse impact on employment in any specific localities or in urban areas in general.

c. Fiscal Condition

The identification of specific cities or the types of cities that are likely to incur an economic burden due to the costs associated with the heavy-duty diesel particulate regulation is an important part of this urban analysis. The two primary factors affecting the fiscal viability of cities have already been discussed: employment and income, both personal and business. As was seen, neither factor will be adversely affected by this regulation. However, there is one possible way that this regulation could affect cities which deserves further attention. The increase in the first cost of heavy-duty diesel engines could affect the larger cities that support a large mass transit system primarily consisting of buses.

Cities that need to purchase new buses with heavy-duty diesel engines in 1986 and later years to upgrade their fleets will initially have to pay higher initial costs due to this regulation. It is estimated that the average first price increase for heavy-duty vehicles will be $521-$632 due to this regulation (see section B). However, these modifications will also reduce maintenance costs by $178 over the life of the vehicle (discounted to year of purchase). As this regulation is not expected to affect fuel economy, the cost of owning and operating a heavy-duty diesel should increase $349-$472 per vehicle beginning in 1986.

The biggest effect on the cities will be the purchase price increase of roughly $520-630 per bus. However, this increase only represents a 0.4 to 0.5 percent increase in the purchase price of a intracity transit bus, which at the present time is approximately $140,000 per vehicle.10/ This small increase due to this regulation will not offset the fact that buses are the best option for intracity transport and should also not prevent any city from buying buses that needs them. Likewise, the effect of this regulation on intracity bus ridership, due to fare increases, should be negligible.

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3/ "Regulatory Analysis - Light-Duty Diesel Particulate Regulation," MSAPC, OANR, EPA, January 29, 1980.

4/ "Summary and Analysis of Comments to the NPRM: 1983 and Later Model Year Heavy-Duty Engines, Proposed Gaseous Emission Regulations," EPA, December 1979.

5/ "Gaseous Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines," EPA, 45FR4136, January 21, 1980.

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8/ Passavant, Glenn W. "Average Lifetime Periods for Light-Duty Trucks and Heavy-Duty Vehicles," EPA, November 1979, SDSB-79-24.

9/ "Alternative Fuels and Intercity Trucking," Ryder Program in Transportation and Escher Technology Associates for U.S. Department of Energy, June 1978, HCP/M3294-01, pp. 71-72.

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Chapter VII

COST EFFECTIVENESS

Intuitively, cost effectiveness is a measure of the economic efficiency of an action towards achieving a goal. Historically, however, the cost effectiveness of emission control regulations has been expressed in such terms as "dollars per ton of pollutant controlled." This expression is a measure of the cost of the regulation, not necessarily its efficiency. The presence of this conflict makes it awkward to speak in relative terms about cost effectiveness since a low cost-effectiveness value implies a highly effective regulation. To escape this conflict and still follow the precedent of placing cost in the numerator, the measure of cost effectiveness will be referred to as the cost-effectiveness ratio, or C/E ratio.

Furthermore, air pollution control regulations have multiple and frequently differing goals and, therefore, do not easily lend themselves to direct comparison of C/E measures. In the past, the principal application of comparing C/E measures has been the evaluation of alternative control strategies applicable to the same source, in the same time frame, and with the same objective. This markedly simplifies the analysis and, as will be seen below, avoids many problems. Nevertheless, a rough measure of one aspect of the relative merit of the proposed heavy-duty diesel standard can be achieved by comparing the C/E measures of alternative diesel standards with other strategies designed to control particulate emissions. One area where EPA has adopted regulations to limit particulate emissions is the New Source Performance Standards (NSPS) for Stationary Sources called for by Section 111 of the Clean Air Act. While the statutory purposes and tests in Section 111 are different from those applicable to this diesel particulate standard, a rough comparison has been made which indicates that this decision is not inconsistent with other decisions the Agency has made to control particulate emissions.

In this chapter, the C/E measures for the level of diesel particulate control will be calculated and compared to those from other control strategies. As will be seen, it is not possible to take into account all of the environmental factors such as meteorological conditions, location, population exposures, etc., due to a lack of data. However, as many of the factors for which data are available will be incorporated.

A. 1985 Heavy-Duty Diesel Particulate Standard

The calculation of the C/E ratio for heavy-duty diesel particulate control is quite simple. Most of the necessary input data have already been determined in past chapters. The uncontrolled emission level is 2.0 g/mi (1.24 g/km). Under the 0.25 g/Bhp-hr (0.093 g/MJ) standard the in-use emission level should be about

0.67 g/mi (0.42 g/km). If these levels are assumed to occur over the entire life of the vehicle, the improvement due to regulation is 1.33 g/mi (0.82 g/km).

The average life of a heavy-duty diesel in the 1986-1995 time-frame now has to be determined. EPA has examined past data in this area and found the average lifetime of heavy-duty vehicles to be 114,000 miles/8 years (gasoline engine) and 475,000 miles/9 years (diesel engines).1/ While the differences between the durability of the two types of engines may cause a part of the difference in lifetime mileage, most of the difference is due to the different usage characteristics of the vehicles equipped with each type of engine. Line-haul inter-city trucks have been equipped with diesel engines, while short-haul trucks have been equipped with gasoline engines.

However, as outlined in Chapter III, diesels are expected to start capturing the shorter-haul market. It is doubtful that the lifetime mileage of these vehicles would change with a switch to diesels, as the basic function of the vehicle wouldn't change. Thus, as diesels begin to capture the market from gasoline engines, their lifetime mileages should decrease, moving toward the lifetime mileage for vehicles with gasoline engines. For simplicity, it will be assumed that all Class VI and lighter heavy-duty vehicles have an average lifetime mileage of 114,000 miles (183,000 kilometers) and that all Class VII and heavier vehicles have an average lifetime mileage of 475,000 miles (764,000 kilometers). From the data in Table III-9, the fraction of total diesel sales which are Class VI or lighter can be determined. In 1986, the fraction is 0.33 and in 1995 it is 0.51. An average would then be 0.42. If the above mentioned lifetime mileages are combined using this average split, the average lifetime of heavy-duty diesels between 1985 and 1995 becomes 323,000 miles (520,000 kilometers). Coupling this lifetime mileage with the 1.33 g/mi (0.82 g/km) emission reduction yields a lifetime particulate reduction of 0.430 metric tons.

The cost of control has been calculated in Chapter VI to be $349-472 per vehicle. Thus, the C/E ratio is $349-472 divided by 0.430 metric tons, or $800-1100 per metric ton of particulate control. This is the C/E ratio for emission reductions arising from both improved engine design and the use of trap-oxidizers. It is possible to separate out the cost effectiveness of the use of trap-oxidizers alone. This latter figure could be termed the incremental cost effectiveness, while the figure already determined would be the overall cost effectiveness.

The calculation of the incremental cost effectiveness primarily requires the calculation of the emission reduction and cost of trap-oxidizers alone. As determined above, emissions of a trap-oxidizer-equipped vehicle are 0.67 g/mi (0.42 g/km). Given that the trap is 60 percent efficient, the emissions from the vehicle without the trap would be 1.67 g/mi (1.05 g/km). The emission reduction due to trap-oxidizer use is 1.0 g/mi (0.62 g/km), or 0.322 metric tons over the vehicle's life. The cost of trap-oxidizers can be taken from Table VI-8 and is $343-454 per vehicle (includes maintenance costs and credits). The C/E ratio is then $1,070-1,410 per metric ton. This incremental cost effectiveness will be used for comparison purposes in the next section.

B. Comparison of Strategies

The purpose of this section is to determine the C/E ratios of other particulate control strategies and demonstrates that the C/E ratio of the heavy-duty diesel regulations is not inconsistent with those of past strategies. All of the C/E ratios examined should be incremental in nature. This is necessary because the comparison must be made between the cost of the last level of control and cannot be influenced by the costs at less stringent control levels.

The incremental C/E ratios for several stationary sources are shown in Table VII-1. Except for the industrial boiler category, all of the C/E measures shown represent the costs and emission reductions of a Federal New Source Performance Standard over the less stringent alternative rejected by the Agency in selecting the level of the standard. The C/E ratio for the industrial boiler category represents the costs and effectiveness of two alternative control devices which are available.

The incremental cost effectiveness for the control of particulate emissions from light-duty diesels is also shown in Table VII-1. The control increment examined was the 1985 standard of 0.2 g/mi (0.12 g/km) for light-duty vehicles (0.26 g/mi (0.16 g/km) for light-duty trucks) over the 1982 standard of 0.6 g/mi (0.37 g/km) for both vehicle classes.8/

As mentioned earlier, the most direct and easiest use of a cost-effectiveness measure is to compare various levels of control of a single source. In this case, most of the factors pertinent to the environmental impact, such as source location, dispersion characteristics, and pollutant characteristics, are the same for all the levels considered and the 'dollar per ton' measure is a good relative measure of the cost effectiveness of the various strategies. Given enough knowledge and data, there is no reason that this same kind of analysis cannot be used to compare various strategies for controlling different sources. The problem is, of course, that the necessary data is usually very difficult to obtain and not available. The comparisons being made in this section are not true comparisons of the cost effectiveness of any of the strategies being examined. The necessary data is simply not available. However, comparisons such as these are being made elsewhere and will be made in the future. The goal here will be to make the comparisons, while at the same time stating clearly the limitations involved, insuring that any use of the results of this section is accompanied by full knowledge of their meaning.

Table VII-1

Incremental Cost Per Ton of Particulate Removed for Selected New Stationary Sources (1980 Dollars)

Source	Cost-$/Metric Ton for Particulate Collected in Incremental Range	Reference
Medium Sized Industrial Boilers1/	$1000	2
Electric Utility Coal-Fired Steam Generator2/	$900-$1000	3
Kraft Recovery Furnace3/	$1400-$1900	4
Kraft Smelt Tank4/	$160-$220	4
Rotary Lime Kiln5/	$1200-$1300	5,6
Electric Arc Furnaces - Steel6/	$700	7

1/ Baghouse (0.03 lb/10^6BTU) versus cyclone (0.3 lb/10^6BTU).
2/ High efficiency ESP (0.03 lb/10^6BTU) versus lower efficiency ESP (0.1 lb/10^6 BTU).
3/ High efficiency ESP (99.5 percent) versus lower efficiency ESP (99.0 percent).
4/ Venturi scrubber versus Demister (80 percent efficiency).
5/ High efficiency ESP (0.3 lb/ton limestone) versus lower efficiency ESP (0.6 lb/ton limestone) for 500 TPD plant; baghouse (0.3 lb/ton) versus lower efficiency ESP for 125 TPD plant.
6/ Direct evacuation with 90 percent efficient canopy hood versus direct evacuation with open roof.

The strategies being examined here all address particulate emissions on a nationwide scale. Both diesel regulations will apply to every new diesel sold in the U.S., regardless of where the vehicle is bought or used. Likewise, the New Source Performance Standards (NSPS) for stationary sources also apply to all new significantly modified plants of a certain type nationwide.

While both the mobile source and stationary source strategies being examined control particulate emissions into the atmosphere, there are differences in their primary purposes. An examination of Title II of the Clean Air Act, particularly Section 202, shows that the primary purpose of mobile source regulations is to protect the public health and welfare. The primary purpose of the NSPS's, on the other hand, is to reduce inequities in interstate competition for economic growth, while minimizing emissions through the nationwide use of the best available control technology. A nationwide NSPS prevents those states and localities without severe air pollution problems from having an unreasonable advantage in drawing new plants from areas where strict controls are required.

While the primary purpose of the two types of strategies differ, the levels of control they represent do have a common purpose, that of protecting the public health and welfare. The NSPS's exist because some states and localities require at least this level of control to protect the public health and welfare in their areas. There are factors that affect the relative stringency of the two types of standards. For example, economics may be a more critical parameter for NSPS's than mobile source standards and the requirements for the demonstration of technology are stricter for NSPS's than mobile source standards. In a rough sense, however, both represent control levels implemented to protect the public health and welfare.

To take one rough step toward making the measure of cost effectiveness more relevant to health and welfare impacts, the basis of the previously cited 'dollar per ton' figures shall be modified to reflect the cost of controlling inhalable and fine particulate. In Chapter V, it was shown that it is these particulates that have the greatest potential for adverse health impact. Thus, it is appropriate to emphasize the control of these particles. Also, it is these smaller particles (inhalable particles have diameters of less than 15 micrometers and fine particles have diameters of less than 2.5 micrometers) which have the greatest effect on visibility, which is likely one of the largest welfare effects of diesel particulate emissions.

Particle size data currently available for these sources are limited and the figures presented below should only be considered to be rough approximations. The size of diesel particulate has already been discussed in Chapter V. All of the uncontrolled diesel particulate is inhalable (diameter less than 15 micrometers) and between 94 and 100 percent fine (less than 2.5 micrometers). The trap-oxidizer, however, may be more efficient in trapping large particles than small ones. To be conservative, it will be assumed that all coarse particles (diameter greater than 2.5 micrometers) are captured and burned and that only that amount of fine particles necessary to meet the 1986 standard are also captured and burned. Given this assumption and a 60 percent efficient trap-oxidizer, the result is that 100% (by weight) of the additional particulate controlled by the 1986 standard is inhalable and 91-100% is fine.

Power plants (large steam generators) tend to emit larger particles than diesel engines. EPA has measured the particle size distribution of electrostatic precipitator (ESP) effluent at both the previous emission standard of 0.1 pounds per million BTU (43 nanograms per joule) and the revised standard of 0.03 pounds per million BTU (13 nanograms per joule). Of the additional particulate collected at the revised standard, 90-100 percent (by weight) is inhalable and 20-40 percent is fine.9/

Medium-sized boilers are commonly spreader stoker-type boilers which emit coarser particles than pulverized coal-fired boilers. As an approximation, it is estimated that 70 percent of the particulate collected in the incremental range between a cyclone and baghouse is inhalable and 25 percent is fine. For electric arc furnaces, the particulate removed by a baghouse installed with a canopy hood is about 90 percent inhalable and 60 percent fine.7/ For a kraft recovery furnace the incremental particulate collected by an ESP in the range from 99.5 to 99.0 percent is about 100 percent inhalable and 70 percent fine. The differential quantity of entrainment collected by a venturi scrubber in comparison with a demister on a kraft mill smelt tank is about 85 percent inhalable and 55 percent fine. High efficiency collection versus medium efficiency collection of particulate from a rotary lime kiln captures particulate that is about 80 percent inhalable and 50 percent fine.

Using these approximations, the C/E ratios for these six sources can now be placed on an inhalable and a fine particulate basis. The results are shown in Table VII-2. As can be seen, the cost effectiveness of the heavy-duty diesel standard is not inconsistent with those of past Agency actions or with a possible future Agency action (medium-size industrial boilers).

It is important to emphasize a point made earlier, i.e., that in some respects the mobile stationary source strategies for particulate control have certain differences in their primary purposes. Therefore, selection of a measure of effectiveness for comparison purposes has inherent limitations. In spite of these, however, a comparison may still be useful to the degree that it focuses on one of their common purposes, protection of public health and welfare.

Up to this point, however, we have only incorporated one factor which may improve the comparability of the cost-effectiveness measures for different source strategies. There are many

Table VII-2

Incremental Cost-Effectiveness Ratios of Particulate Control Strategies Using Three Measures of Effectiveness (1980 Dollars per Metric Ton)

Controlled Source	Total Particulate Basis	Inhalable Particulate Basis	Fine Particulate Basis
Heavy-Duty Diesel 1986 Standard	1070-1410	1070-1410	1070-1550
Light-Duty Diesel - 1985 Standard	2600-3270	2600-3270	2600-3600
Utility Steam Generators*	900-1000	900-1100	2900-3300
Medium-Size Industrial Boilers	1000	1400	4200
Electric Arc Furnaces			
Steel	700	800	1100
Lime Kilns	1200-1300	1500-1600	2400-2500
Kraft Pump Mills			
Recovery Furnaces	1400-1900	1400-1900	2100-2600
Smelt Tank	160-220	200-260	300-400

* Assumes that an average of 30 percent of controlled particulate matter is fine. If the full range of the fine fraction is used (20-40 percent), then the cost-effectiveness is $2,200-4,900 per metric ton.

other factors which would need to be accounted for before a truly valid comparison could be made, such as emission dispersion characteristics, source location, chemical composition (and resulting health effects) of the particulate, etc. As these factors cannot be incorporated at this time due to lack of data, even the comparison performed in Table VII-2 must be taken cautiously. The incorporation of the factors mentioned above could change the results drastically.

To indicate this possibility, one rough calculation will be made comparing the air quality impact of a given rate of emissions for both types of diesels and power plants. Only rough large-scale impacts will be considered, so this will not be an exhaustive comparison by any measure. However, it will serve to highlight the possible effects that these missing factors may have on any comparison of the cost effectiveness of different strategies.

As a rough approximation of the relationship of ambient impact to emission rate, the ratio of the maximum ground level concentration to the annual emission rate will be used. The maximum ground level concentration was chosen as an indicator of air quality impact because: 1) it was available for both sources, and 2) particulate levels near this maximum should occur over large areas for both sources. From 2), no localized concentrations of diesel particulate will be used in this analysis, only regional concentrations, nor will unusually high impacts from power plants due to unique topography or poor design be used. The annual emission rate was chosen as the indicator of emission levels because it is a good indicator of long-term emission impact.

EPA has already analyzed the air quality impact of power plants and it will only be summarized here.3/ Three sizes of steam generators were examined along with stack heights typical for those plants. The dispersion of emissions were then modeled to determine the maximum downwind concentration at ground level. The results are shown in Table VII-3. As can be seen, the ratio of the maximum ground level concentration to the annual emission rate is larger for the smaller plants. This is primarily due to shorter stacks.

The same calculation for both heavy- and light-duty diesels is slightly more complicated in that there are many individual diesels in close proximity to each other at various concentrations. No one source can be modeled and at the same time, no one source has a very large impact on air quality. With diesels, then, a geographical area must be examined rather than a single vehicle.

A metropolitan area would be appropriate since it represents a large area (on the order of that affected by a large power plant, though possibly smaller) and it contains areas of high concentrations (downtown) and low concentrations (rural areas). Kansas City will be chosen for this task even though it appears to have a smaller diesel impact relative to other cities its size. The

Table VII-3

Air Quality Impact of Three Steam Generators at Ground Level 3/*

	Plant Size (Megawatts)		
	25	300	1000
Annual Emission Rate (metric tons per year)	99.3	1192	3974
Typical Stack Height (meters)	75	175	275
Maximum Ground Level Concentration (micrograms per cubic meter):			
Annual Mean	0.1	0.1	<0.1
24-Hour Maximum	1.3	1.3	1.3
Ratio of Maximum Ground Level Concentration to Annual Emission Rate (micrograms per cubic meter/metric tons per year)			
Annual	.0010	0.00008	<0.000025
24-Hour Maximum	.0131	0.0011	0.00033

* Numbers bracketed (_/) indicate references at the end of this chapter.

necessary data is available for Kansas City, and the metropolitan area does contain both urban and rural areas.

The Kansas City area examined here will be that examined by PEDCo.10/ It comprises 660 square kilometers. Total vehicle travel in this area in 1974 was 2.85 x 10^9 miles per year. The impact from light-duty diesels will be examined first, using Chapter V of the Regulatory Analysis for light-duty diesel particulate regulations.10/ Using a 1% per year growth rate, total vehicle travel in 1990 will be 3.34 x 10^9 miles per year. If the low estimate of diesel-dieselization is examined here, 9.57% of total vehicle travel will be by light-duty diesel in 1990. At a particulate emission rate of 1.0 g/mi (0.6 g/km), light-duty diesels would emit 321 metric tons per year. Using this scenario, the ambient concentration at a typical TSP monitor would be 1.5 micrograms per cubic meter (Table V-7).10/ The ratio of ambient concentration to the annual emission rate would be 0.0047 microgram per cubic meter (per) metric ton per year. The maximum 24-hour impact for light-duty diesels is about 3.16 times the annual geometric mean (see Chapter V).10/ Thus, the ratio of the 24-hour ambient concentration to annual emission rate would be 0.015 microgram per cubic meter (per) metric ton per year. These results are summarized in Table VII-4.

The impact of heavy-duty diesels will now be considered using the results contained in Chapter V of this document. If the low estimate of dieselization is again assumed, 4.2 percent of total vehicle travel will be by heavy-duty diesel in 1995. Total travel in the area in 1995 would be 3.51 x 10^9 miles. At an emission rate of 2.0 g/mi (1.24 g/km), heavy-duty diesels would emit 295 metric tons per year. Using this scenario, the ambient concentration at a typical TSP monitor would be 1.4 micrograms per cubic meter. The ratio of ambient concentration to the annual emission rate would be 0.0047 microgram per cubic meter (per) metric ton per year. These figures are shown in Table VII-4. They are the same ratios as calculated above for light-duty diesels and for good reason. Particulate matter is emitted from either type of diesel from the same general locations (i.e., roadways) and any difference in overall vehicle concentration or vehicle emission rate affects both total emissions and ambient concentration proportionately. Thus, the ratio of these two parameters remains constant.

A comparison of the values in Table VII-4 with those in Table VII-3 shows that the ambient concentrations per unit emission rate of diesels is 4.7 and 188 times that for small and large steam generators on an annual basis, respectively. On a 24-hour basis, the ambient concentration per unit emission rate for diesels is actually 1.1 and 45 times larger than that for small and large power plants, respectively.

As mentioned earlier, the above ratios are only an extremely rough estimate of the relative air quality impacts of diesels and power plants. Many simplifications were necessary to be

Table VII-4

Air Quality Impact of Light-Duty and
Heavy-Duty Diesels in the Kansas City Metropolitan Area

	Light-Duty (1990)	Heavy-Duty (1995)
Total vehicle miles traveled in area per year	3.34×10^9	3.5×10^9
Fraction of travel by light-duty diesel (low estimate of dieselization)	0.0957	0.042
Emission factor (g/mi)	1.0	2.0
Annual emissions (metric tons per year)	321	295
Maximum regional air quality impact (micrograms per cubic meter)	1.5	1.4
Maximum 24-hour average per year (micrograms per cubic meter)	4.74	4.42
Ratio of maximum ground level concentration to annual emission rate (micrograms per cubic meter (per) metric tons per year):		
Annual	0.0047	0.0047
24-Hour	0.015	0.015

able to make this comparison at all. However, the results do indicate the size of the factors which may occur if an extensive analysis were performed and how the results of Table VII-2 might change if other factors were incorporated.

If the decision is made to restrict the comparison to only the two diesel standards, there is one last step which can be taken to improve the cost-effectiveness methodology and that involves taking into account the population exposed. The similarity between light- and heavy-duty diesels reduces the need for accurate population exposure data and allows more general source characteristics to be sufficient. Indeed, there is little more population exposure data for diesel emissions available than are available for other sources. In a relative sense, however, the two diesel sources can be compared.

Due to the lack of available exposure data, a very simple source characteristic will be used to estimate population exposure. This characteristic will be the fraction of total source emissions which are urban. In other words, the cost effectiveness will now be determined on an urban basis. This is justified by the fact that 85% of the nation's population that lives in areas exceeding the primary NAAQS for TSP are metropolitan (Figure V-8). The practical effect on the calculation of the C/E ratios is that the costs will be divided by the fraction of the emissions which are urban. This recognizes that an emission standard requires all vehicles to reduce emissions irrespective of where they are used, but it is those in operation in urban areas which affect the most people. From Table V-4 about 56 percent of light-duty diesel emissions are urban and about 36.4 percent of heavy-duty diesel emissions are urban. Thus, the C/E ratios of Table VII-2 need to be divided by these fractions.

These final C/E ratios are shown in Table VII-5. As would be expected, the difference between the C/E ratios of the two sources has diminished. Control of light-duty diesels is now only about 50-60 percent more costly than heavy-duty diesel control, due to the greater urban impact of light-duty diesels.

In conclusion, the heavy-duty diesel particulate standard appears to be no less cost effective than other cost-effective measures adopted in the past by EPA, using the cost-effectiveness methodology developed in this chapter. Even after the incorporation of urban/rural differences, the control of heavy-duty diesels is still more cost effective than the control of light-duty diesels.

Table VII-5

C/E Ratios for Heavy- and Light-Duty Diesel Particulate Control Only Considering Urban Effectiveness (Total Dollars per Metric Ton of Particulate Controlled In Urban Areas)

	Inhalable Basis	Fine Basis
Heavy-Duty Diesel 1986 Standard	2900-3800	2900-4200
Light-Duty Diesel 1985 Standard	4600-5800	4600-6400

References

1/ Passavant, Glenn W., "Average Lifetime Periods for Light-Duty Trucks and Heavy-Duty Vehicles," Technical Report, SDSB, EPA, November 1979, SDSB #79-24.

2/ "Particulate Emission Control Costs for Intermediate-Sized Boilers," Industrial Cleaning Institute for EPA, February 1977.

3/ "Electric Utility Steam Generating Units - Background Information for Proposed Particulate Matter Emission Standards," OAQPS, EPA, July 1978, EPA 450/2-78-006a.

4/ "Standards Support and Environmental Impact Statement, Volume 1: Proposed Standards of Performance for Kraft Pulp Mills," OAQPS OAWM, EPA, September 1976.

5/ "Standards Support and Environmental Impact Statement, Volume 1: Proposed Standards of Performance for Lime Manufacturing Plants," OAQPS, OAWM, EPA, April 1977, EPA 450/2-77-007a.

6/ Compilation of Air Pollutant Emission Factors, AP-42, Supplement No. 7, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1977.

7/ "Background Information for Standards of Performance: Electric Arc Furnaces in the Steel Industry Volume 1: Proposed Standards," OAQPS, OAWM, EPA, October 1974, EPA-450/2-74-017a.

8/ "Regulatory Analysis, Light-Duty Diesel Particulate Regulations," MSAPC, OANR, EPA.

9/ Personal communication with Jim Abbot, Industrial Emissions Research Laboratory Studies, ORD, EPA, January 10, 1980, unpublished emission control test results.

10/ "Air Quality Assessment of Particulate Emissions from Diesel-Powered Vehicles," PEDCo Environmental for EPA, March 1978, EPA-450/3-78-038.

CHAPTER VIII

ALTERNATIVE ACTIONS

These particulate regulations for heavy-duty diesels were required by Congress in the 1977 Amendments to the Clean Air Act. Nonetheless, possible control of other sources of particulate emissions were examined to ensure that these regulations were consistent with EPA's program to improve the nation's air quality. Also, Congress left it to EPA to determine the actual level of the emission standard, so many alternatives were available in this area. In the following pages these alternative actions will be presented and discussed. In the first two sections, those actions which would preclude control of heavy-duty diesels will be presented. These would include 1) further control of stationary sources, and 2) the control of mobile sources other than heavy-duty diesels. Strategies for controlling fugitive dust or reentrained dust have been discussed previously and will not be repeated here.1/ Finally, in the third section specific alternative emission standards to the 0.25 g/BHP-hr (0.093 g/MJ) standard for 1986 will be presented and discussed.

The use of an averaging approach upon which to base the actual particulate standard was not considered for this rulemaking. This decision is based primarily on the findings of the Regulatory Analysis for Light-Duty Diesel Particulate Regulations. A more thorough investigation of averaging approaches is being performed as part of the heavy-duty NOx standard revision for 1986.

A. Control of Stationary Sources

The majority of major urban areas have severe particulate non-attainment problems. The need for reductions in particulate emissions from some sources is clear. However, these areas have also demonstrated that attainment is not feasible even after adoption of all reasonable stationary source controls. While new source performance standards can definitely help to mitigate increased emissions and ambient impacts due to industrial growth, they cannot be expected to reduce TSP concentrations in urban areas from current levels (see Chapter V, 1/2/). Thus, it is concluded that further control of stationary sources is not a viable alternative to these heavy-duty diesel regulations.

B. Control of Other Mobile Sources

In addition to considering further control of stationary sources of particulate emissions as an alternative to controlling heavy-duty diesels, the control of other mobile sources was also considered. These alternative mobile sources include gasoline-powered light- and heavy-duty vehicles, diesel-powered light-duty vehicles, locomotives and aircraft.

Light-duty vehicles and light-duty trucks powered by the gasoline engine and using lead fuel were once a very significant source of particulate emissions. In 1974, it is estimated that exhaust emissions from these vehicles totalled 250,000 metric tons of particulate, with 107,000 metric tons classfiable as suspended particulate.3/ The great majority of this particulate matter consisted of particles related to the lead and lead scavengers used in the fuel. Since 1975 though, the majority of new vehicles have required the use of unleaded fuel in order to prevent premature catalyst degradation. With unleaded fuel and catalysts, these vehicles produce less than 3% of the particulate emissions of a diesel-powered vehicle. By 1981, when more stringent gaseous emission standards for light-duty vehicles will have come into effect, it is expected that almost all manufacturers will require the use of unleaded fuel in their vehicles. Thus, by 1986, when these heavy-duty diesel particulate regulations come into effect, new gasoline-powered light-duty vehicles and trucks will be producing very low levels of particulate emissions. Thus, control of these vehicles does not present an alternative to controlling light-duty diesel particulate emissions.

Light-duty diesels, even more than their heavy-duty counterparts, were expected to be a significant source of particulate emissions by 1990. However, EPA has already implemented stringent particulate standards for these vehicles and further control is not feasible at this time.3/ Thus, further control of particulate emissions from light-duty diesels is not a viable alternative to these heavy-duty diesel regulations. At the same time, control of light-duty diesel emissions does not reduce the need for regulating heavy-duty diesels. The rationale for the level of the light-duty standards was based only on the projected impact of light-duty emissions. The light-duty standards were not set at a level to alleviate the total diesel contribution to ambient TSP levels. Reductions will be required from heavy-duty diesels and were assumed in the process of determining the light-duty standards. Also, reductions from heavy-duty diesels are necessary from an air quality standpoint if the contribution of diesel particulate to ambient TSP levels is to be reduced as far as technology and economics permit. Thus, controlling particulate emissions from light-duty diesels is not an alternative to these heavy-duty regulations, but is a necessary complement to the overall mobile source scheme for reducing particulate emissions.

The contribution of heavy-duty vehicles powered by gasoline engines to total particulate emissions was also examined. In 1974, heavy-duty vehicles (gasoline) emitted about 30,000 metric tons of particulate (see Chapter V). Because today's heavy-duty trucks (gasoline) are still being built for operation on leaded fuel, this figure would still be a rough estimate of emissions in 1978. While the particulate emission level of heavy-duty vehicles (gasoline) does not compare with the particulate emission level of light- and heavy-duty diesels, it is still significant. By 1984, however, it is expected that most heavy-duty vehicles (gasoline) will be equipped with catalysts due to new emission standards which will come into effect that year. This will require unleaded fuel, and the particulate emissions from these vehicles will decrease drastically, as in the light-duty case. Thus, it appears that particulate emissions will be low from the new vehicles of this class by 1984, and no further control will be required.

Locomotives are another source of particulate emissions in the U.S. In 1975, locomotives emitted nearly 45,000 metric tons of particulate.4/ While this is not insignificant, a complete removal of all locomotive particulate emissions would only be a fraction of the necessary reductions of emissions from heavy-duty diesels. Also, reductions in locomotive emissions will not decrease the effect of automotive diesels near the roadway, where the largest impacts will occur. Thus, while locomotive particulate emissions may merit control at some time in the future, such control is not a feasible alternative to the proposed heavy-duty diesel regulations, either in magnitude or locality of emissions.

Finally, the control of particulate emissions from aircraft was examined as a possible alternative to the proposed regulations. In 1975, civil and commercial aircraft emitted 18,000 metric tons of particulate.4/ This emission level is even less than that from locomotives and amounts to only 7-8 percent of the projected heavy-duty diesel emissions in 1995. Thus, control of aircraft particulate emissions is not a viable alternative to the proposed standards for heavy-duty diesels.

C. Alternative Individual Vehicle Standards

Now that it has been shown that a particulate standard for heavy-duty diesels is necessary (i.e., no other alternatives are preferable), the timing and stringency of the standard is all that remains to be discussed. In the case of heavy-duty diesel particulate regulations the question of timing can be expanded. This expansion involves whether there should be a single final standard or an interim standard and then a final standard, to be implemented at a time when technology will have developed to a point where significant reductions can occur beyond those available at the earlier date. This option of a one or two step standard will be examined first.

While there are many internal factors which could affect the number of steps and timing of the standard, there is one external factor which deserves mentioning first. That external factor is the stringent NOx standard to be proposed for 1986. With the negative interaction which can occur between particulate and NOx control, the presence of this stringent NOx standard could cause an increase in particulate emissions if a particulate standard were not in effect. With a particulate standard in place by 1986, the NOx controls used will be those having less of a deleterious effect on particulate emissions. Thus, it would be advantageous to have some particulate standard in place by 1986 to prevent an increase in particulate emissions which might otherwise occur.

The other factors affecting the timing of the standard are internal to this rulemaking. The primary factor is the availability of control technology. The two general categories of control techniques available are trap-oxidizers and engine modifications. The availability of trap-oxidizers for heavy-duty diesel use should be able to follow that for light-duty diesels by one year, or 1986. Most of the past and current trap work has been performed on light-duty diesels and not on heavy-duty diesels. However, the results of these efforts should be directly applicable to the use of trap-oxidizers on heavy-duty diesels. Some additional effort will be required to optimize regeneration on heavy-duty diesels (due to longer idle periods) and to ensure that they can withstand the additional vibrations and the frequent high-load operation characteristic of heavy-duty diesels. The leadtime remaining after promulgation of the heavy-duty diesel particulate standard should be sufficient for optimizing these systems for heavy-duty use.

The leadtime necessary for manufacturers to improve the engine-out particulate emissions of their engines to 0.41 g/BHP-hr (0.153 g/MJ) is more difficult to determine and will vary from manufacturer to manufacturer. The technology already exists, as evidenced by the emission results of existing engines shown in Table IV-2. The necessary leadtime will consist primarily of the time needed to incorporate the available technology into the engines with relatively high levels of particulate emissions. As evidenced in Chapter IV, many engines are currently being redesigned for various reasons and many of the necessary modifications for particulate control could already be in process. For the other engines, the specific changes needed for particulate control may not be in process, but they could easily fit into the existing redesign program for that engine and be completed by 1986. For still others, and this is expected to be a small number, the magnitude of internal design changes and the lack of proper timing with existing redesign programs could put the implementation of these changes out past 1986. In these cases, the manufacturers could always continue production via non-conformance penalties, which in the first few years after 1986 should not seriously hamper sales. However, there are other alternatives. If the manufacturer (for the short-term) can improve production variability, decrease his deterioration factor, build more prototypes, or use a more efficient trap, he could meet the standard even though his engine-out emissions were well above 0.41 g/BHP-hr (0.153 g/MJ). Thus, it would appear that for the majority of engines, the availability of trap-oxidizers will be the limiting factor rather than the leadtime connected with engine modifications. This implies that the standard, or the final standard of a two-step standard, could be implemented in 1986.

However, 1986 is also the year that the more stringent NOx standard is to be implemented. Since the transient test procedure will not be available until 1985, an interim standard prior to this date would be based on the less representative 13-mode steady-state test and serve only to prevent increases in particulate emission levels at a time when none are expected. The one external event that could cause an increase in particulate emissions will not occur until 1986 (the application of more NOx control). Given these two facts, it does not appear reasonable to promulgate a standard before 1986. With the first year of implementation being 1986 and the final level of control being achievable in 1986, the two-step standard approach appears unnecessary. It would only be useful if an interim particulate standard was needed in 1986 to prevent unnecessary increases in particulate emissions due to NOx control until a final standard could be implemented based on trap-oxidizers, or if such an approach could provide a significant economic benefit for the manufacturers and the public without adversely affecting air quality to an unacceptable degree.

One such alternative, which will be examined here, would be to implement a 2-step standard where the first, interim, stage would take effect in 1986 and be based on the particulate levels achievable from today's best engines. The final level could follow some time later, e.g., one or two years, and be based on further reductions through the application of trap-oxidizers. A 2-year delay in the final standard will be used specifically, instead of a 1-year delay primarily due to the cost of completely recertifying the heavy-duty diesel fleet after only one year. To recertify the entire fleet would cost about $7.1 million (1980 dollars, inflated from $6.58 million (1979 dollars)).5/ The entire cost (or at least 90 percent of it) would be due to the second particulate standard since no other emission standard will be changing in 1987 or 1988. Normally, only about 10 percent of the engines go through full certification testing each year and the rest obtain carryover from previous years' testing. Thus, any delay in the final standard will cost $7.1 million in certification costs, but a 2-year delay would allow that much more time for trap-oxidizer development and separate this work from the engine modification work also underway in a way that a one-year delay would not.

The prime beneficiary of a 2-year delay in the final standard would be the heavy-duty diesel manufacturers. They would have an additional two years to perfect trap-oxidizer designs. This would also delay most of the investments needed to develop and produce trap-oxidizers for two years. The public might also benefit economically if this delay would reduce the cost of compliance.

The cost of the delay would be borne primarily by the public in terms of poorer air quality and its accompanying health effects. Congress has already made the decision that mobile source particulate emissions should be controlled as much as technology allows, with due consideration being given to leadtime, cost, noise, safety and energy. A 2-year delay primarily affects the factors of leadtime and cost. A more detailed analysis of the effect of delay on each of these factors is needed before the delay can be accepted or rejected.

First, with respect to leadtime, a 2-year delay would allow heavy-duty diesel manufacturers to delay introduction of trap-oxidizers until light-duty diesel manufacturers have utilized these devices for three years. Thus, heavy-duty diesel manufacturers would be able to draw on three years of in-use experience (on light-duty diesels) before having to use the devices. This would tend to follow the history of the oxidation and three-way catalyst, where their use on heavy-duty vehicles followed their use on light-duty vehicles by a number of years. However, the situation differs here in a number of ways. One, Congress mandated the delays for catalyst use on heavy-duty vehicles, but in Section 202(a)(3)(A)(iii) of the Clean Air Act, Congress gave the same mandate for particulate control to both light- and heavy-duty vehicles and made no provision for a special delay to any class. Two, the manufacturers of gasoline-fueled light-duty vehicles are for the most part the same as those who produce heavy-duty gasoline engines. Thus, they bore the cost of developing catalysts for both classes. With respect to diesels, only General Motors produces large amounts of vehicles/engines in both classes, while the other four major heavy-duty diesel manufacturers produce few, if any, light-duty diesels. Thus, for the most part, the heavy-duty diesel manufacturers are not bearing any costs associated with the light-duty particulate standard and a delay based on past precedence alone does not appear to be merited.

The degree of benefit of an additional 2 years of leadtime depends primarily on the degree of difficulty of developing trap-oxidizers for heavy-duty use for 1986. If the task is a reasonable one for 1986, the benefit of waiting two years is not great. If completion of the task is very questionable for 1986, then there is a greater benefit from delay. In Chapter IV, the technological argument for applying trap-oxidizers to heavy-duty diesels is based, in great part, on their use on light-duty diesels. To determine the difficulty of development for heavy-duty application, the development for light-duty application must be examined and any pertinent differences between the two applications considered.

In EPA's analysis of light-duty diesel trap-oxidizer availability, strong evidence was found to support the availability of trap-oxidizers in 1984.3/6/ However, to minimize the economic risk of the 0.2 gram per mile standard, the standard was delayed a year. For our purposes here, then, it is reasonable to say that the leadtime available prior to 1984 was likely sufficient to develop a light-duty trap-oxidizer and that 1985 represents a certain margin of safety. One reason for this safety margin is the nonavailability of nonconformance penalties for most light-duty diesels. If an engine family or two could not meet the 0.2 g/mi standard in 1984, then there would have been no recourse for EPA but to prohibit their sale and the economic impact could have been quite large, depending on the projected sales of that family. The economic risk is not nearly as great for heavy-duty diesels due to the potential availability of nonconformance penalties. Thus, the leadtime criteria is somewhat less crucial for heavy-duty diesels than it was for light-duty diesels, due simply to the differences in the economic risks involved.

With respect to the heavy-duty diesel situation, then, there was enough leadtime available (as of March, 1980) to develop and produce trap-oxidizers for light-duty applications in time for the 1984 model year, and certainly well before the beginning of the 1985 model year. Given that the heavy-duty diesel model year begins four months later than the light-duty model year, it would appear that there is about one full year of leadtime available to the heavy-duty diesel manufacturers after the date at which light-duty diesel manufacturers were expected to have a trap-oxidizer available to them. However, it is possible that the heavy-duty diesel particulate standard will not be promulgated until late 1981 and this will be a full year and a half after the light-duty regulation was promulgated. This delay would more than erase the extra year of leadtime between 1984 and 1985, unless the work performed on light-duty trap-oxidizers prior to mid-1981 was also applicable to heavy-duty applications.

Trap-oxidizer research has been underway for well over two years and has centered primarily on light-duty applications.3/ However, the earliest trap work on diesels occured on heavy-duty diesels,7/ as prior to 1977 there were very few light-duty diesels sold in the U.S. The difficulties associated with trap-oxidizer development center in three general areas. First and primary is the trapping efficiency, as this sets the upper limit on the effectiveness of the trap over its life. Second is the ability to oxidize the trapped particulate, as this allows the trap to be regenerated and useable for more than a few hundred miles. Third is the durability of the trap material, both with respect to structural durability and to a continued efficiency in trapping.

The first area, that of trapping efficiency, is a similar problem for both light- and heavy-duty diesels. As described in Chapter IV of this document and the light-duty regulatory analysis,3/ the character of the particulate from both light- and heavy-duty diesels is similar, if not indistinguishable, given the degree of variation within a single vehicle's particulates and that between vehicles in each class. Thus, the ability to trap particulate from the exhaust of vehicles in either class should be the same and traps developed for one class should have the same trapping efficiency on a vehicle of the other class if sized properly. Much of the work already performed on trap-ozidizers has centered on trapping efficiency and a number of materials have been found with an efficiency of at least 60 percent.* These materials (and thus, the work performed in this area to date) should have equal applicability to heavy-duty applications.

* See Chapter IV for technical details here and in the rest of the discussion of this alternative.

The second area of development, that of particulate oxidation, is one where some differences between light- and heavy-duty applications could exist. The primary difficulty in this area is to keep or cause the exhaust temperature to be sufficiently high to start the oxidation of the particulate. Also, the oxidation must occur with enough frequency to keep the maximum temperature of the oxidation process low enough to protect the trap materials. If too much particulate is trapped prior to oxidation, the ability of the exhaust and outside air to cool the trap can be overridden and the temperature of the trap can exceed its design limit. The most important criterion involved in designing such an oxidation system is the exhaust temperature, which is determined primarily by engine design and the operating conditions imposed on it. The biggest problem is keeping the exhaust temperature high enough to begin oxidation. Also, the closer the oxidation can be made to be continuous (i.e., consistently high temperatures), the less overheating is a problem. The trap and the exhaust system can easily handle the exhaust temperatures, even at their maximum. It is the temperatures of the combusting particulate in the trap itself that can cause structural design limits to be exceeded. The temperatures normally occuring in light-duty applications appear to be too low to assure oxidation at regular intervals under all feasible operating conditions. Thus, a number of techniques have been devised to raise the temperature of the exhaust. Insulating the exhaust system between the exhaust ports and the trap is a passive system which raises the exhaust temperature at all times. Others, such as intake air throttling or electrical heating at the trap, operate periodically to begin oxidation at regular intervals.

The available evidence indicates that the exhaust temperatures of heavy-duty diesels are higher than those of light-duty diesels. One reason is that the horsepower-to-weight ratios of heavy-duty diesels are much lower than occur with light-duty diesels. Because of this, the former operate at higher relative loads than the latter where the fuel/air ratios are higher, which causes exhaust temperatures to be higher. Turbocharging, which is more common on heavy-duty diesels than light-duty diesels can tend to counteract this, but further evidence indicates that the effect of the fuel/air ratio is the overriding factor. Analysis of the heavy-duty particulate test procedure has indicated that higher dilution ratios are necessary to lower the exhaust temperature of heavy-duty diesels to less than 125°F (51.7°C) than is necessary for light-duty diesels.8/ This indicates that the heavy-duty exhaust temperatures are higher, even with turbocharging. Coupled with the fact that all of the temperature-raising techniques currently being examined are equally applicable to heavy-duty use as to light-duty use, the problem of ensuring periodic oxidation of particulate could actually be easier for heavy-duty diesels than light-duty diesels if it were not for the sometimes long (several hours) periods of time that heavy-duty diesels are left to idle. This could present regeneration problems because exhaust from idling engines is cooler than that from engines under normal operating conditions. If, for example, a heavy-duty trap-oxidizer is very near the point where it needs to be regenerated when the operator leaves the vehicle in the idling mode for several hours, particulate could build up to the point where the trap would clog. This problem, though not insurmountable is a unique aspect of heavy-duty trap-oxidizer applications which must be addressed before they are applied to these vehicles. Also, the high-load operation that should make it easier to initiate regeneration may also make it easier for the trap to overheat. Thus, some additional effort will be required to fully develop a trap for heavy-duty application even after a light-duty trap is available.

The third technological area, that of trap durability, is also an important one to examine for differences in light- and heavy-duty application. For one, the mileage life of a heavy-duty diesel is much longer than that of a light-duty diesel (475,000 vs. 100,000 miles). However, in terms of time, the lives of the two types of vehicles are about the same (9-10 years). The fact that the mileages are very different while lifetimes are the same indicates one of the differences in the usage patterns of the two types of vehicles. Heavy-duty diesel driving is more concentrated and continual (higher mileage per day). Heavy-duty use also tends to occur under more warmed-up conditions. This is evidenced by the vast differences in the cold start-hot start weighting of the two test procedures (43/57 for light-duty and 14/86 for heavy-duty). While higher mileages do increase durability problems, frequent cold-hot operation should be a more important factor. Given that the lifetimes are the same and that heavy-duty operation tends to be more warmed-up, it would appear that trap durability problems for heavy-duty diesels should be no greater than those for light-duty diesels. An additional factor would also be the higher exhaust temperatures of heavy-duty diesels mentioned in the preceding discussion. These should allow for more continual oxidation which should definitely help to retain trap efficiency and structural stability.

In all, the problems of developing a trap-oxidizer for heavy-duty application appear to be only slightly more difficult than the task facing light-duty manufacturers; not sufficient to justify a three year delay between their respective applications. Also, the work performed to date appears equally applicable to either class of vehicle. Certainly, light-duty diesel manufacturers might have more direct experience with trap-oxidizer operation than do heavy-duty diesel manufacturers at the present time. However, this expertise has been shared with the independent trap suppliers and can be easily transferred to heavy-duty diesel manufacturers. Thus, the tasks of developing a heavy-duty trap oxidizer for 1986 appears at least as accomplishable as the task facing light-duty diesel manufacturers for 1985.

Besides leadtime, the other prime consideration is one of cost. Already mentioned was the $7.1 million cost of recertification which would occur whenever an emission standard is substantially revised. The 1986 standard avoids this by occuring at the same time as the forthcoming revision of the NOx standard. A later standard, however, will bear the entire cost of recertification.

On the positive side, however, is the belief that three additional years would allow some improvements in design that will reduce the cost of production. These savings could occur in two ways. One, light-duty production experience could lead to more economical heavy-duty trap production techniques. Two, light-duty design experience could lead to more economical heavy-duty trap designs. The one year delay should provide for some benefits here.

The first effect, while aiding the production of heavy-duty traps, does so at some expense to light-duty trap production. In other words, light-duty trap production will be deprived of its benefit from heavy-duty experience. There should still be a positive effect of delay, as it is nearly always more economical to start on one project and use that experience toward the next, compared to starting both at once. Also, heavy-duty production itself (in 1988) is derived from three years' experience. While heavy-duty traps in 1988 (under a 1988 trap-oxidizer based standard) might be expected to be cheaper than 1986 traps, the former will be more costly than a 1988 trap under a 1986 trap-oxidizer based standard. Thus, some savings has been obtained by the three year delay relative to the first year of trap introduction under an earlier standard. However, this savings is obtained by 1) delaying the benefits of emission controls two years and 2) causing the eventual use of trap-oxidizers to be more expensive than would have occurred in that year if the standard was implemented earlier. The same arguments hold for the effects of design improvements. Unfortunately, the available data do not allow the quantification of the net savings. However, an estimate can be made. In Chapter VI, Table VI-1, it can be seen that assuming a 12 percent learning curve, trap-oxidizer costs decrease 20 percent between 1986 and 1988. The effect of a 2-year delay should be less than this since direct heavy-duty experience is not available. Thus, it would appear reasonable to project that delaying two years would reduce the first year of trap-oxidizer costs by something less than 20 percent.

There could also be a positive effect of delay on captial costs. One, the additional light-duty experience could solve some of the heavy-duty problems and reduce the total heavy-duty research effort. Two, the delay might provide flexibility as to the source of the necessary capital and reduce the cost of the capital.

First, it will be helpful to examine the actual capital expenditures which this regulation could impose on the heavy-duty diesel industry. As discussed in Chapter VI, there are three sources of capital costs which are related to this regulation. First, there is the cost of test equipment, which is $2 million. It will be borne directly by the heavy-duty diesel industry and will occur prior to 1986 regardless of whether or not a two-year delay is granted. Second, there are the costs of trap-oxidizer development and tooling for production, which have been estimated to be $6-8 million and $9-18 million, respectively. The former cost, as a capital cost, will likely be split between the heavy-duty diesel industry and the trap suppliers and would at least partially be delayed if a two-year delay in the final particulate standard were granted. The latter will almost entirely be borne by independent suppliers and would almost entirely be delayed by a two-year delay. Third, there is the cost of engine redesign and tooling and this could range between $4 and $16 million. This cost will be borne entirely by the heavy-duty diesel manufacturers and would not be affected by a delay in the trap-oxidizer based standard. In all, the heavy-duty diesel manufacturers and suppliers will be required to raise about $21-44 million because of this regulation and between $15-26 million would be deferred if the final standard were delayed two years.

As can be seen from the size of these capital costs, the total requirements are not very large for five major engine manufacturers and their suppliers, and the capital costs which would be deferred by the two-year delay are also not significant. A two-year delay will defer capital expenditures of between $15-26 million for the manufacturers and suppliers and would impose a recertification cost of about $7 million on the manufacturers. These numbers show that the cost savings from a two-year delay may not outweigh the capital expenditures necessary to meet a model year 1986 standard. Given that trap-oxidizers can be available in 1986 and that the benefits of a two-year delay do not appear to substantially outweigh the costs of a model year 1986 standard, EPA is not proposing a two-step approach at this time. However, EPA will reconsider this approach if additional data warrants such action.

The alternatives remaining are 1) the implementation date of the one-step standard and 2) the level of this standard. In analyzing the question of a one- or two-step standard above, however, the implementation date of the one-step standard has been all but determined. From the above analysis the choice must be 1986. That is the year the trap-oxidizer should be available and the year of the revised NOx standard. Thus, the only real choice remaining is that of the level of the standard.

The methodology used to set the level of the proposed standard has been outlined in detail in Chapter IV. In essence, the level is based on 1) an engine-out particulate level of 0.41 g/BHP-hr (0.153 g/MJ), 2) the use of a trap-oxidizer, and 3) the reservation of certain engine-related control techniques (e.g., high-pressure injection) for the mitigation of particulate increases due to NOx control in 1986. The alternatives to setting the technologically-achievable level of engine-out particulate emissions at 0.41 g/BHP-hr (0.153 g/MJ) were considered in Chapter IV and the logic for choosing this level can be found there in detail also. It will not be repeated here, except that the prime consideration was the Clean Air Act mandate to achieve the greatest emission reduction possible, while taking into account leadtime, energy, cost, and safety.

The second factor is the use of a trap-oxidizer as a viable control technique. Given that the device should be available for use on heavy-duty diesels in 1986 and that the analysis in Chapter VII shows it to be a cost-effective control technique, it would appear to violate the congressional mandate not to base the standard on its use. Thus, the alternative of rejecting its use was rejected.

Finally, the factor of the 1986 NOx standard requiring a 75 percent reduction from baseline levels must be considered. The methodology leading to the proposed level of particulate control reserves the use of some particulate control techniques for their possible use in reducing the negative effects of NOx control. In complying with the mandate of the Clean Air Act with respect to particulate control, one could also have conceivably taken the opposite stand, and set the particulate standard based on every available control technique and left no cushion for increases due to NOx control. Which is the proper choice in this case?

It is known that certain NOx control techniques can cause increased particulate emissions, namely exhaust gas recirculation and retarded timing. At the same time, other techniques do not have this trade-off. This is evidenced by the fact that many of the lowest particulate emitters also have low NOx emissions (Figure IV-1) and the Cummins and Caterpillar experiences where redesigns of certain engines have reduced both particulate and NOx emissions (Chapter IV). There is also the specific congressional mandate calling for a 75 percent reduction in heavy-duty NOx emissions from uncontrolled baseline levels. As this NOx mandate is more specific than the particulate mandate, it would seem proper that the particulate standard impact the achievability of the 75 percent NOx standard as little as possible. The use of trap-oxidizers complies with this approach as trap-oxidizers do not have an adverse effect on NOx emissions. Also, the engines used to determine the 0.41 g/BHP-hr engine-out particulate level had relatively low NOx emissions as well as the lowest particulate emissions. However, this still has the effect of setting a limit on future particulate increases since these low NOx levels are still far from the level expected to be required in 1986. To rule out any increases in particulate emissions entirely would appear to overly restrict the ability of heavy-duty diesel manufacturers to meet the 1986 standard as well as restrict the Agency from attaining those required reductions. Thus, some allowance appears reasonable. However, the Agency has not yet determined what NOx level is achievable by heavy-duty diesel and what would be the effect of various levels of particulate control. This information will be gathered as the Agency proposes and promulgates the NOx standard.

At this time then, it is not possible to quantify the particulate allowance required. Yet some allowance is appropriate to balance the two congressional mandates. The present allowance would appear reasonable in this vein; that of the exclusion of some control techniques from consideration in setting a technologically-achievable particulate standard. Without being able to quantify the effect of NOx control at this time, one could of course argue for a larger allowance to be safe, or for a smaller allowance to propose the most stringent particulate standard conceivable. Without data, it is difficult to definitively argue against either view. However, the presence of arguments on either side calling for changes in the standard in opposite directions is in itself some evidence of reasonableness. Thus, on that basis, the decision was made to give the above mentioned allowance.

It now appears that the 0.25 g/BHP-hr (0.093 g/MJ) particulate standard is the best alternative available. It is based on trap-oxidizer technology, which does not affect NOx control and on some of the best existing engines with both low particulate and low NOx emissions. The standard also allows for some increase in engine-out particulate levels due to further NOx control and reserves particulate reductions available from other control technologies for negating these increases. It appears to be cost-effective (Chapter VII), to be a necessary standard for the protection of both the public health and welfare (Chapter V) and to comply fully with all congressional mandates (Section 202(a)(3)(A)(ii) and (iii)). Thus, it should be proposed.

References

1/ "Summary and Analysis of Comments to Proposed Particulate Regulations for Light-Duty Diesels," MSAPC, EPA, October, 1979.

2/ "Impact of New Source Performance Standards on 1985 National Emissions from Stationary Sources," EPA-450/3-76-017, April 1977.

3/ "Regulatory Analysis, Light-Duty Diesel Particulate Regulations," MSAPC, OANR, EPA, January 29, 1980.

4/ "1975 National Emissions Report," OAQPS, EPA, May 1978, EPA 450/2-78-020.

5/ "Regulatory Analysis and Environmental Impact of Final Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines," OMSAPC, EPA, December 1979.

6/ 45 FR 14496, March 5, 1980.

7/ Shahed, Syed M., Personal Communications with Richard A. Rykowski, EPA, at the Symposium on Diesel Particulate Emission Measurement and Characterization, May 17-19, 1978, Ann Arbor, Michigan.

8/ Heiser, Daniel P., "Summary and Analysis of Comments to the Draft Recommended Practice for Measurement of Gaseous and Particulate Emissions from Heavy-Duty Diesel Engines Under Transient Conditions," Technical Report, SDSB, EPA, August 1980.

Appendix I

An estimate of the nationwide fraction, F_n, of heavy-duty vehicle-miles traveled (VMT) attributable to diesels in 1995 can be obtained from the following equation:

$$F_n = \frac{g \sum_{i=1}^{20} (ab)_i + h \sum_{i=1}^{20} (cde)_i}{g \sum_{i=1}^{20} (ab)_i + h \sum_{i=1}^{20} (cde)_i + h \sum_{i=1}^{20} (cdf)_i}$$

Where:

ai = fraction of total registration of Class VII and VIII heavy-duty diesels (HDD's) i years old;

bi = annual mileage accumulation rate of Class VII and VIII HDD's;

ci = fraction of total registration rate of Class II through VI heavy-duty vehicles i years old;

di = annual mileage accumulation rate of Class II through VI heavy-duty vehicles i years old;

ei = diesel sales fraction of Classes II through VI for ith model year (i = 1 being 1995, i = 2 being 1994, etc.);

fi = gasoline sales fraction of Classes II through VI for ith model year;

g = 0.31, the fraction of total heavy-duty sales from Classes VII and VIII (see Table III-7);

h = 0.69, the fraction of total heavy-duty sales from Classes II through VI (see Table III-7);

The two items in the numerator represent diesel VMT in Classes VII and VIII and diesel VMT in Classes II through VI, respectively. The third term in the denominator represents the gasoline VMT in Classes II through VI. Based on discussion in Chapter III, it is assumed that gasoline-powered vehicles constitute a negligible fraction of Class VII and VIII heavy-duty vehicles.

Values for the above variables are given in Table A-1. The fraction of total registration and annual mileage accumulation rate of Class VII and VIII heavy-duty diesels are taken from EPA's Mobile Source Emission Factors document.1/ Although they were intended to apply to all classes of heavy-duty diesels, the record of past heavy-duty diesel sales (see Table III-2) indicates that

Table A-1

Model Year	Heavy-Duty Diesels Classes 7 and 8 1/ (a) Fraction Total Registration	(b) Annual Mileage Accumulation Rate	Heavy-Duty Vehicles Classes 2 thru 6 (c) 2/ Fraction Total Registration	(d) 2/ Annual Mileage Accumulation Rate	(e) 3/ Diesel Sales Fraction	(f) 3/ Gasoline Sales Fraction
1995	0.077	73600	0.037	19000	0.46	0.54
1994	0.135	73600	0.070	19000	0.43	0.57
1993	0.134	69900	0.078	17900	0.41	0.59
1992	0.131	63300	0.086	16500	0.38	0.62
1991	0.099	56600	0.075	15000	0.36	0.64
1990	0.090	50000	0.075	13500	0.33	0.67
1989	0.082	45600	0.075	12000	0.30	0.70
1988	0.062	41200	0.068	10600	0.28	0.72
1987	0.045	38200	0.059	9500	0.25	0.75
1986	0.033	36000	0.053	8600	0.22	0.78
1985	0.025	34600	0.044	7800	0.19	0.81
1984	0.015	33800	0.032	7000	0.17	0.83
1983	0.013	33100	0.038	6300	0.07	0.93
1982	0.011	32400	0.036	5900	0.07	0.93
1981	0.010	30900	0.034	5300	0.07	0.93
1980	0.008	28700	0.032	4900	0.07	0.93
1979	0.007	25700	0.030	4700	0.07	0.93
1978	0.006	21300	0.028	4600	0.07	0.93
1977	0.005	18400	0.026	4400	0.07	0.93
1976	0.004	15400	0.024	4200	0.07	0.93

1/ From Table IV-5 of Mobile Source Emission Factors EPA-400/9-78-006.
2/ From Table III-5 of Mobile Source Emission Factors EPA-400/9-78-006.
3/ Columns (e) and (f) are used to estimate the capture by diesels in classes 2 thru 6; based on Chapter 2 sales estimates.

Classes VII and VIII constituted the great majority of diesels on the road at the time of the document's publication-1978. For this reason, the values given in Mobile Source Emission Factors for the fraction of total diesel registration by vehicle age and annual mileage accumulation rates were in this study used for Class VII and VIII diesels only.

Values of these parameters as they apply to heavy-duty gasoline engines are also taken from Mobile Source Emission Factors. Since sales estimates outlined in Chapter 3 project the capture by diesels of portions of the existing heavy-duty gasoline market, the assumption has been made that the mileage accumulation and yearly registration fraction characteristics of the heavy-duty gasoline vehicles (predominantly Classes II through VI) also apply to diesel vehicles in those classes. That is, diesels in Classes II through VI will have useage characteristics similar to their gasoline counterparts rather than the heavier Class VII and VIII diesels. This is apparent since, for example, a Class III delivery truck will make the same number of deliveries per day whether it is gasoline or diesel powered.

In order to add the diesel VMT fraction from Classes VII and VIII to the diesel VMT fraction from Classes II through VI, the 2 categories must be normalized for sales (the 0.31 and 0.69 factors). After incorporating this normalization and the values in Table A-1 into the aforementioned equation, the nationwide fraction, F_n, of heavy-duty VMT in 1995 due to diesels is determined to be 78.6 percent. Because sales projections as well as any assumptions are subject to error, this study projects that a range of 71.5 to 86.5 percent of nationwide heavy-duty VMT in 1995 will be attributed to diesels; reflecting a 10 percent margin of error.

The same methodology was followed to determine the urban fraction, F_u of heavy-duty VMT in 1995 due to diesels. This value is given by:

$$F_u = \frac{jg \sum_{i=1}^{20} (ab)_i + kh \sum_{i=1}^{20} (cde)_i}{jg \sum_{i=1}^{20} (ab)_i + kh \sum_{i=1}^{20} (cde)_i + kh \sum_{i=1}^{20} (cdf)_i}$$

where all parameters except the urban fraction of heavy-duty diesel VMT (Classes VII and VIII), j (equal to 0.33), and the urban fraction of heavy-duty gasoline VMT (plus Class II-VI diesels), k (equal to 0.43), are the same as those used to determine F_n. The urban-rural breakdown was obtained from a PEDCo report based on DOT data.2/

The urban fraction, F_u, of heavy-duty VMT by diesels was thus determined to be 74.6 percent; 67.1-82.1 percent, allowing for a 10 percent margin of error.

References

1/ "Mobile Source Emission Factors," EPA March 1978, EPA-400/9-78-005.

2/ Air Quality Assessment of Particulate Emissions from Diesel-Powered Vehicles, PEDCo Environmental for EPA, March 1978, EPA-450/3-78-038.

APPENDIX II

Appendix II contains a detailed cost analysis for trap-oxidizer system components and for potential savings due to elimination of muffler and exhaust system maintenance.

A. Emission Control System Costs

The technology necessary to meet the 1986 particulate emission standard was discussed in Chapter IV. Heavy-duty engines are expected to be able to meet the 1986 standard with trap-oxidizers along with incorporating the design features of those current engines with low particulate emissions. The trap-oxidizer represents additional equipment and will increase the cost of the engine (and vehicle). The design modifications, however, should not raise production costs, except through the amortization of new tooling and engineering costs. These design features of the lower particulate emitting diesels are present on these engines at no apparent price differential and should be similarly available to others. It is possible that some of these heavy-duty vehicles will be able to use other techniques to meet the standard; however, to be conservative, this economic analysis will assume that all vehicles will require trap-oxidizers.

In summary, EPA estimates the average cost of a trap-oxidizer system for heavy-duty vehicles to be \$521-\$632 (1980 dollars). The cost of the trap itself represents about 80 percent of this total. Necessary modifications to the engine and exhaust system represent 10 percent of the total cost. The remaining costs are associated with the control system used to initiate oxidation of the trapped particulate. The use of the trap-oxidizer system as described in this section should also reduce maintenance costs by \$197 (1980 dollars, discounted back to year of vehicle purchase) due to reduced exhaust system maintenance. A detailed analysis of the cost estimates for trap-oxidizer components follows.

Because the costs of trap-oxidizers will likely depend on the production volume, the first step in this analysis will be to estimate heavy-duty diesel production volumes between 1986 and 1990. This five-year period was chosen because it will correspond with the period used to calculate the aggregate cost of the 1986 standard, which will be performed in Section C of Chapter VI, Economic Impact.

Projections of overall heavy-duty diesel production and the breakdown by vehicle class from 1986 to 1990 are needed in this analysis. These projections can be found in Section III, Description of Industry, in the discussion of future heavy-duty diesel sales. Table A-II-1 shows the breakdown of heavy-duty sales by vehicle class projected for 1986 to 1990. As will be discussed later in this section, nearly all the costs of components of the trap-oxidizer system will be dependent on engine size, which will be assumed to be related to vehicle class. For the purposes of this analysis, it will be assumed that the same basic trap-oxidizer system can be used within each of four vehicle groups. The groups

Table A-II-1

Projected Heavy-Duty Diesel Sales By Class

	IIB	III	IV	V	VI	VII	VIII	TOTAL
1986	22,316	4,179	710	1,735	72,490	35,824	165,600	302,854
1987	26,511	4,965	843	2,061	80,984	37,979	168,623	321,966
1988	30,841	5,776	981	2,398	89,755	40,187	171,645	341,583
1989	35,308	6,612	1,123	2,745	98,804	40,895	174,668	360,155
1990	39,910	7,474	1,269	3,102	108,132	41,602	177,691	379,181

are gross vehicle weight dependent and each group consists of one or more of the traditional heavy-duty vehicle classes.

Group	Gross Vehicle Weight (Pounds)	Classes
1	8,500-16,000	IIB,III, IV
2	16,001-26,000	V, VI
3	26,001-33,000	VII
4	33,001 and over	VIII

Classes III and IV were grouped with Class IIB due to the small relative sales of Classes III and IV. The same reasoning applies for grouping Class V with Class VI. Vehicle Class IIB in this section will always refer to vehicles in the traditional Class II category with a weight above 8,500 pounds (i.e., those Class II vehicles which fall into EPA's heavy-duty vehicle category).

In manufacturing, it is a common occurrence that the cost of production decreases with experience. This experience is usually measured in terms of accumulated production. The relationship between cost and accumulated production is called a learning curve and is usually described by the logarithmic function:

$$\frac{C_2}{C_1} = \left(\frac{P_2}{P_1}\right)^{-\left(\frac{\ln(1.0+z)}{\ln 2}\right)} \qquad (1)$$

Where:

P_1 and P_2 = two different levels of accumulated production.
z = the fraction or percentage that costs are increased each time the accumulated production is halved.
C_1 and C_2 = costs of the item with total accumulated production of P_1 and P_2.

For the purposes of this analysis, z will be assumed to be 0.12, or that the cost of a trap-oxidizer system will increase 12 percent each time the accumulated production is halved.* Given the cost at a specified accumulated production, a new cost at a different production can then be found using equation (1). The effect of this assumption will be examined in Section C of this appendix, "Sensitivity Analyses," where costs will be calculated assuming that a learning curve does not apply.

It is highly unlikely that each manufacturer will produce his own trap-oxidizer for three reasons. One, the area involves sophisticated technology that each manufacturer cannot really afford to develop independently. Two, a number of firms have already developed an expertise in the area in response to light-duty diesel particulate standards and have a head-start on the

* This 12 percent factor is the same as that used on page 107 of the Regulatory Analysis for the Light-Duty Diesel Particulate Regulations, which in turn came from a contractors meeting with LeRoy Lindgren of Rath and Strong on August 18, 1979.

heavy-duty diesel manufacturers. Three, the production volumes of many heavy-duty diesel manufacturers are too small to justify in-house development and production given that the expertise and production capability will likely exist outside. Thus, for costing purposes, it will be assumed that there will be only three suppliers of trap-oxdizers, each having a third of the market shown in Table A-II-1. However, the effect of this assumption will be examined in Section C of this appendix, where costs will be determined assuming that each manufacturer produces his own control systems.

The cost of each component to a trap-oxidizer supplier will depend upon his total production, and the number of different components needed. For items such as traps, throttle assemblies, exhaust pipes, etc., a different component will be assumed to be needed for each vehicle group. To facilitate the costing of these components, each vehicle group will be assigned an average engine displacement. These engine displacements are 5.7 liters (350 CID) (Classes IIB, III, and IV), 8.2 liters (500 CID) (Classes V and VI), 10.5 liters (640 CID) (Classes VII), and 13.9 liters (850 CID) (Class VIII). Once again assuming that each trap-oxidizer supplier shares a third of the production as shown in Table A-II-1, using equation (1) the average cost to each trap-oxidizer supplier per vehicle group is as follows:

$$Cij = Cref \times \left(\frac{\sum_{K=1}^{j} Pik}{3 \times Pref}\right)^{-\frac{\ln(1.0 + z)}{\ln 2}} \qquad (1A)$$

Where:

Cij = Cost of item in vehicle group i, year j.
Cref = Cost of component at a production volume of Pref.
Pij = Production of vehicle group i, year j.
Pref = Reference production volume.

For other items such as thermocouples and electronic control units, one type can be used on all heavy-duty diesel engine models. In this case, the trap-oxidizer suppliers will produce these components at one-third the total annual engine fleetwide production. The average cost per vehicle group will then be:

$$Cij = Cref \times \left(\frac{\sum_{K=1}^{j} AP_k}{3 \times Pref}\right)^{-\left(\frac{\ln(1.0 + z)}{\ln 2}\right)} \qquad (1B)$$

Where:

APj = Total production in year j = $\sum_{i=1}^{M} Pij$

M = Number of vehicle groups.

The fleetwide average cost is simply a sales-weighted average of the costs to each trap-oxidizer supplier and is described by the equation:

$$Cave,j = \frac{\sum_{i=1}^{M} Cij \times Pij}{APj} \qquad (2)$$

Where:

Cave,j = Sales-weighted average cost in year j.

Equations 1A and 1B can be substituted into equation 2. For traps and other components that differ among vehicle groups, equation (2) becomes:

$$Cave,j = \frac{Cref}{APj} \times \sum_{i=1}^{M}\left(Pi,j \times \sum_{k=1}^{j}\left(\frac{Pik}{3 \times Pref}\right)^{-\left(\frac{\ln(1.0+z)}{\ln 2}\right)}\right) \qquad (2A)$$

Similarly, for electronic control units, equation (2) becomes:

$$Cave,j = \frac{Cref}{APj} \times \sum_{i=1}^{M}\left(Pi,j \times \sum_{k=1}^{j}\left(\frac{APk}{3 \times Pref}\right)^{-\left(\frac{\ln(1.0+z)}{\ln 2}\right)}\right) \qquad (2B)$$

If 0.12 is substituted for z, then equation (1A) and (1B) become, respectively:

$$Cij = Cref \times \sum_{k=1}^{j}\left(\frac{Pik}{3 \times Pref}\right)^{-0.164} \qquad (3A)$$

$$Cij = Cref \times \sum_{k=1}^{j}\left(\frac{APk}{3 \times Pref}\right)^{-0.164} \qquad (3B)$$

Also, equations (2A) and (2B) become:

$$Cave,j = \frac{Cref}{APj} \times \sum_{i=1}^{M}\left(Pi,j \times \sum_{k=1}^{j}\left(\frac{Pik}{3 \times Pref}\right)^{-0.164}\right) \qquad (4A)$$

$$Cave,j = \frac{Cref}{APj} \times \sum_{i=1}^{M}(Pi,j \times \sum_{k=1}^{j}(\frac{APk}{3 \times Pref})^{-0.164}) \quad (4B)$$

Once the reference production (Pref) is chosen and the reference cost determined, equations 3A, 3B, 4A, and 4B will allow the costs for each vehicle group and the average cost over the entire fleet to be determined in any given year.

Two final adjustments must be made here to determine the actual cost to reference cost ratio for each item. First, it will be assumed that two traps will be required for each Class V-VIII vehicle. The (Ci,j/Cref) and (Cave, j/Cref) ratios for each of these traps can be calculated by multiplying the results of equations 2A, 3A, and 4A by 2 to the -0.164 power, or 0.89. Second, it is expected that items other than electronic control units and traps will be manufactured according to each basic engine design. For purposes of this analysis it is assumed that the heavy-duty diesel industry consists of about ten basic engine designs. These can be broken down into two designs for Class IIB-IV vehicles, two designs for Class V and VI vehicles, three designs for Class VII vehicles, and three designs for Class VIII vehicles. Assuming an equal number of engines per engine design within each vehicle group, the actual cost to reference cost ratio for these components can be calculated by dividing the results of equations 2A, 3A, and 4A by 2 to the -0.164 power, or 0.89, for Class IIB-VI vehicles, and by 3 to the -0.164 power, or 0.84, for Class VII and VIII vehicles.

The production data shown in Table A-II-1 can now be used directly to calculate (Cave,j/Cref) for the years 1986-1990 (j = 1-5). Pref will be set at 300,000 units. The results are shown in Table A-II-2. As can be seen, the cost of components such as traps starts out 83 percent greater for Classes IIB, III, and IV than the cost at an accumulated production of 300,000 units (1986) and 4 years later is only 32 percent greater than the cost at 300,000 units. A similar result occurs for the Class V-VIII traps. In 1986, the cost is 37 percent greater than the cost at the reference production and by 1990 the cost is 1 percent greater than Cref for Class V and VI traps. For electronic control units, the cost in 1986 is 21 percent greater than the cost at the reference production and by 1985 the cost is 9 percent less than Cref. Similar results occur for components that vary with engine design.

EPA's original cost estimates of the individual components of a trap-oxidizer system were taken from a study of the costs of emission control systems.1/ The formula used to determine the retail price equivalent of each item is shown below.

$$\text{Retail Price Equivalent} = [[(\text{Direct Material}) + (\text{Direct Labor}) + (\text{Fixed (Variable) Overhead})]$$

Table A-II-2

Values for the Ratio of the Actual Cost of a Component to Its Cost at an Accumulated Production of 300,000 Units 1/

	1986	1987	1988	1989	1990
Electronic Control Units	1.21	1.07	1.00	0.95	0.91
Cost Ratios if Component Production Equals Vehicle Group Production					
Class IIB, III, IV	1.83	1.61	1.48	1.39	1.32
Class V, VI	1.53	1.36	1.26	1.19	1.13
Class VII	1.71	1.52	1.42	1.34	1.29
Class VIII	1.32	1.18	1.10	1.05	1.01
Traps2/					
Class IIB, III, IV	1.83	1.61	1.48	1.39	1.32
Class V, VI	1.36	1.21	1.12	1.06	1.01
Class VII	1.52	1.35	1.26	1.19	1.15
Class VIII	1.17	1.05	0.98	0.93	0.90
Components that Vary with Engine Design3/					
Class IIB, III, IV	2.06	1.81	1.66	1.56	1.48
Class V, VI	1.72	1.53	1.42	1.34	1.27
Class VII	2.04	1.81	1.69	1.60	1.54
Class VIII	1.57	1.40	1.31	1.25	1.20

1/ Assumes each supplier shares one-third of the market at production shown in Table A-II-1.

2/ Assumes 1 trap for each Class IIB-IV vehicle, and two traps for each Class V-VIII vehicle.

3/ Assumes 2 basic engine designs for Class IIB-IV vehicles, 2 basic engine designs for Class V and VI vehicles, 3 basic engine designs for Class VII vehicles, and 3 basic engine designs for Class VIII vehicles. These components include port liners, stainless steel exhaust pipes, insulated exhaust pipe, insulated exhaust manifold and throttle-body actuators.

$$\times \left[1 + \left(0.2 \begin{matrix}\text{Corporate}\\\text{Allocation}\end{matrix}\right) + \left(0.2 \begin{matrix}\text{Supplier}\\\text{Profit}\end{matrix}\right)\right] + \left(\begin{matrix}\text{Tooling}\\\text{Expense}\end{matrix}\right)$$

$$+ \left(\begin{matrix}\text{Land \&}\\\text{Building}\\\text{Expense}\end{matrix}\right)\Bigg] \times \left[1 + \left(0.2 \begin{matrix}\text{Corporate}\\\text{Allocation}\end{matrix}\right) + \left(0.2 \begin{matrix}\text{Corporate}\\\text{Profit}\end{matrix}\right) + \left(0.4 \begin{matrix}\text{Dealer}\\\text{Overhead}\\\text{\& Profit}\end{matrix}\right)\right]$$

$$+ \left(\begin{matrix}\text{Research \&}\\\text{Development}\end{matrix}\right) + \left(\begin{matrix}\text{Tooling}\\\text{Expense}\end{matrix}\right) \qquad (5)$$

$$RPE = [(DM + DL + OH)(1.4) + TE + LBE](1.8) + RD + TE \qquad (6)$$

Direct materials entail those materials of which a given component is comprised. Direct labor includes the cost of laborers directly involved in the fabrication of a given component. Overhead includes both the fixed and variable components of overhead. The fixed portion includes supervisory salaries, building maintenance, heat, power, lighting, and other costs which are substantially unaffected by production volume while the variable portion includes small expendable tools, devices, and materials used in production, repairs and maintenance made to machines directly involved, and other overhead costs which tend to vary with production volume. A straight 40 percent of the direct labor amount was used to determine all overhead costs.

A figure of 20 percent applied to the sum of material, labor, and overhead costs was used to determine corporate allocation. In other words, this is the amount needed to cover the supplier's support from its front office. Also, to the sum of material, labor, and overhead costs, a figure of 20 percent was applied to determine the supplier's profit. Approximately half of this 20 percent is used to pay corporate taxes with the remaining portion being divided between dividend disbursements to stockholders and retained earnings, which are used to finance working capital requirements (increases in current assets and/or decreases in current liabilities) and/or new capital expenditures (long-term assets).

Tooling expense consists of four components: one year recurring tooling expenses (tool bits, disposable jigs and fixtures, etc.); three year non-recurring tooling expenses (dies, etc.); twelve year machinery and equipment expenses; and twelve year launching costs (machinery foundations and other incidental set-up costs) which was assumed to be 10 percent of the cost of machinery and equipment.

The sum of the above costs, material, labor, plant overhead, tooling expense, corporate allocation, and profit, makes up the price (or, in the case to a division, transfer price) which the supplier charges the vehicle manufacturer for a given component. At the vehicle assembly level, 20 percent of this price is charged or allocated for the vehicle manufacturer's corporate level support and 20 percent for corporate profit. Also, a figure of 40 percent is applied to the supplier price to account for the dealer's margin which includes sales commissions, overhead, and profit.

There is a need, in many instances, to make modifications to the engine or body to incorporate a component and to assemble it into a vehicle. These costs have also been accounted for at the division level and transferred to the corporate level at vehicle assembly.

Lindgren's study primarily focused on determining the manufacturing costs of emission control equipment. Much effort was expended to accurately determine the cost of materials, labor, tooling, etc. EPA has available a number of confidential cost estimates from emission-control equipment suppliers and these costs confirm Lindgren's estimates at the vendor level.

Less resources were available to Lindgren to determine overhead costs and profit margins and, in general, rules of thumb were used in equation (6). These estimates of overhead costs and profit margins at the corporate and dealer levels would profit from a more detailed analysis. Overhead and profit at the vendor level will not be reexamined because the independent vendor estimates mentioned above confirmed Lindgren's estimates up to that level.

The first two factors to be examined are those indicating the corporate overhead and corporate profit. Typical levels of overhead and profit can be obtained from Moody's Industrial Manual.2/ For diesel engines, EPA examined the 1976, 1977, and 1978 financial data for five manufacturers: General Motors, Cummins, Caterpillar, Mack, and International Harvester. The corporate overhead and profit (in terms of the fraction of the cost sales) for each of these manufacturers in 1976, 1977, and 1978 are shown in Table A-II-3. The before-tax corporate profit (as a percentage of cost of sales) ranged from 5.5 percent to 17.2 percent with an average of about 11.9 percent. The corporate overhead of the five manufacturers (as a percentage of cost of sales) over the 3 year period ranged from 8.5 percent to 33.6 percent with an average of 16.7 percent.

If Cummins' corporate overhead is excluded from the latter range, the range of corporate overheads is narrowed to 8.5 percent to 19.3 percent. With the exclusion of the Cummins overhead figure, the two ranges (profit and overhead) are actually quite small, considering the variety of firms involved and the number of years being examined. The Cummins overhead figure requires some examination. Cummins does have the most limited product line in that they manufacture only diesel engines. All of the other manufacturers also produce vehicles of some sort in addition to engines. This difference could be the cause of an increased level of overhead. However, it would seem more likely that the difference would be associated with the method of accounting rather than an actual difference in the level of overhead. Cummins, being solely a producer of engines, may not have the complex corporate structure of a General Motors (GM) or International Harvester

Table A-II-3

Corporate Overhead and Profit as a Fraction of Cost of Sales for Five Manufacturers 2/

	1976		1977		1978	
	Overhead	Profit	Overhead	Profit	Overhead	Profit
GM	0.117	0.145	0.109	0.141	0.117	0.129
IHC	0.172	0.075	0.169	0.074	0.193	0.056
Caterpillar	0.121	0.165	0.113	0.172	0.109	0.172
Cummins	0.308	0.169	0.335	0.150	0.336	0.115
Mack	0.123	0.055	0.096	0.067	0.085	0.099

(IHC). Much of the division level overhead, which is assigned to the cost of sales by GM or IHC, may be assigned to Cummins' corporate level. Equation (5) recognizes that there will be overhead costs (and profits) at lower than corporate levels and increased costs by 40 percent at that level to account for these costs. Thus, it would seem likely that some of these overhead costs, which are included here at the vendor or divisional level, are included in Cummins' corporate overhead figures. If this were the case, then it would be appropriate to exclude the Cummins overhead figures from the analysis. However, to be conservative, the Cummins figures will be included and weighed equally with the others.

Given the moderate size of the range of overhead and profit figures for these five manufacturers (with the exception of the Cummins overhead figure), the mean of the corporate overhead and profit figures of all five manufacturers should adequately represent them all. Thus, 16.7 percent and 11.9 percent, or a sum of 29 percent, will be used in equation (5) as appropriate allocations of corporate overhead and profit, respectively.

Turning finally to dealer overhead and profit, EPA sees no incremental increase in dealer or franchise overhead as a result of these regulations. No additional personnel or engine servicing will be necessary. Most heavy-duty diesel engines sold in the United States are not sold through conventional dealers as are automobiles and light-duty trucks; instead, they are sold through either dealer franchises which specialize in trucks or through manufacturers' representatives. The individual retail price of a diesel truck or bus may exceed $50,000 and multiple unit sales to city transit systems, inter-city bus companies, or large trucking companies are quite common. Admittedly, dealers might try to get a small profit on their increased investment in the engine. However, this profit should be very small given the very short period of investment (a few days) and fall within other possible errors in estimating manufacturing costs or corporate overhead and profit.

Now that revised estimates of corporate and dealer overhead and profit have been developed, these revised estimates can be substituted into equation (5) to form a new costing equation. The new factor for corporate overhead and corporate profit is 0.29. Also, since research and development costs and tooling expense were included in the cost of sales upon which these factors were based, the two costs (RD and TE) should also be increased by the overhead and profit factors in the costing equation. The resulting equation is shown below:

$$RPE = [(DM + DL + OH)(1.4) + TE + LBE + RD + TE](1.29) \qquad (7)$$

Now that the revised retail cost methodology is available, the next step will be to calculate the cost of the various components which together form a trap-oxidizer system. A standard production volume of 300,000 units will be used for the time being. After the cost of all the components has been determined, the ratios shown in

Table A-II-2 will be used to calculate the fleetwide average costs.

The major portion of the cost of a trap-oxidizer is the trap itself. The most promising trap designs fall close to that of a monolithic catalyst. In some cases, actual monolithic substrates are being used with and without washcoat and noble metals for prototype trap testing.3/ In other cases, the trapping material is alumina-coated steel wool or saffil fiber.4/ In either case, the manufacturing of a trap out of these materials should follow closely to that of a monolithic catalyst. Since no cost data are available for the other trap designs, the cost of a similarly-sized monlithic catalyst will be used to approximate the cost of the trap.

The costs for four trap volumes will be calculated, accounting for the different sizes which will be required by different engine sizes. The basis for the sizes is the successful testing of a 5.3-liter trap fitted to an Opel 2100D, which has a fuel economy of 31.5 miles per gallon.5/ Extrapolations of trap size were made to larger and smaller engines using the ratios of the fuel consumptions of the various engines (vehicles). Fuel consumption is a good, available indicator of volumetric flow through the trap, which should be one of the main considerations in sizing the trap. The average fuel economies of Class V and VI, Class VII, and Class VIII for the late 1980's and early 1990's will be taken as 8.3, 7.2, and 6.7 miles per gallon, respectively.6/ A fuel economy of 13.0 miles per gallon will be used for Classes IIB, III, and IV. This last fuel economy was determined by interpolating the above fuel economies with their respective gross vehicle weights along with the fuel economy and GVW of a standard light-duty diesel truck (20 miles per gallon, 7,500 pounds).7/ The trap volume for a Class IIB, III, and IV vehicle is then calculated to be 12.8 liters (785 cubic inches)(5.3 liter x 31.5 mpg/13.0 mpg). For the other vehicle classes, it is assumed that two traps will be required for each vehicle.* The trap volumes for a single trap for Class V and VI, Class VII, and Class VIII are 10.0 (612), 11.6 (710), and 12.4 (762) liters (cubic inches), respectively.

Lindgren (p. 145) has determined the cost of a monolithic catalyst as a function of volume and noble metal content and put it in a formula equivalent to equation (6):

$$\text{RPE (Trap)} = (\text{NM} + \$2.52 + 0.101 \times V) \times 2.52 + \$6.00 \qquad (8)$$

Where:

RPE (Trap) = Retail price equivalent of a trap (monolithic catalyst).

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* Trap-oxidizers will be assumed to be in series unless a dual exhaust system is used.

NM = Cost of noble metals at manufacturing level.

V = Volume of trap in cubic inches.

The multiplicative factor of 2.52 in equation (8) is the product of the factors for vendor overhead and profit (1.4) and corporate and dealer overhead and profit (1.8). In the revised methodology of equation (7), the first factor remains the same, but the second factor becomes 1.29. Also, the factor of 1.29 is applied to the $6.00 cost of research and development and tooling. Thus, in terms of the revised methodology of equation (7), equation (8) becomes:

$$RPE(Trap) = ((NM + \$2.52 + 0.1013 \times V) \times 1.4 + \$6.00) \times 1.29 \qquad (9)$$

The trap volumes needed for equation (9) are already available, but the noble metal loadings are not. At this point in time, it is not known whether or not diesel particulate traps will require noble metals. The purpose of the noble metals, if present, would be to lower the temperature necessary to ignite the trapped particulate and possibly to aid the oxidation process to reach carbon dioxide and water. To cover the range of possibilities, two loadings will be assumed, one with no noble metals and one with oxidation-promoting metals (Pt and Pd) at a level found in current oxidation catalysts for gasoline engines, which is around 0.012 gram per cubic inch with a 2:1 ratio of Pt to Pd. Noble metal costs are currently around $10.40 per gram for Pt and $3.71 per gram for Pd.8/* However, since the Lindgren costs represent 1977 prices and a general inflation rate of 8 percent per year will be used to adjust these Lindgren costs, these current 1980 noble metal costs will be divided by 1.26 so that when they are adjusted for inflation later, they will represent current prices. Using Lindgren's formula for the cost of the noble metals (p. 134):

$$NM = \$8.26 \times 0.008\ V + \$2.94 \times 0.004\ V + \$0.14 \times 0.0012\ V$$

or

$$NM = \$0.0780\ V \qquad (10)$$

The last term (0.0012V) accounts for manufacturing costs.

Equation (9) includes the cost of a washcoat. However, if no noble metals are to be present, the washcoat should not be necessary and its cost should be deleted. From a breakdown of catalyst costs at various volumes (Lindgren p. 360), it is found that the cost of the washcoat is proportional to the volume of the catalyst and represents 10.3 percent of the 0.101 term in equation (9), or

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* Prices stated here are 77 percent of the market prices quoted in the reference and represent prices available to larger volume buyers.

0.010 V. Subtracting this and the noble metal cost from equation (9) yields the cost for a trap without washcoat or noble metals:

RPE (Trap) = (($2.52 + 0.091V) x 1.4 + 6.00) x 1.29 (9A)

Two final adjustments are needed before calculating the costs of the traps. One, inflation needs to be considered. The costs that Lindgren quotes are from 1977. An 8 percent per annum inflation rate will be used to convert costs to 1980 costs. While this inflation rate is below the Consumer Price Index (CPI) inflation rate for 1978 and 1979, it is actually above the New Car Price Index (NCPI) for these two years.9/ The NCPI should be a better indicator of the inflation rate to be used here even though the NCPI may reflect some lowering of profits to sell cars in the last few years. However, an eight percent inflation rate is still greater than the NCPI for 1978 and 1979 and thus should take care of any change in pricing structure. For traps, Lindgren quotes costs for 1977, and these costs must be multiplied by a factor of 1.26. Two, production volume needs to be taken into account. Lindgren assumed a production volume of 2,000,000 catalysts (p. 115). The production volume of interest here is 300,000 units. Using equation (1) with z = 0.12, it is found that the cost should be a factor of 1.36 higher at the lower production volume. Combining the inflation and production factors, the costs determined by equations (9) and (9A), should be increased by a factor of 1.72.

The necessary equations ((9), (9A), and (10)) are now available with which the cost of the trap can be determined. Substituting equation (10) into equation (9) and multiplying equations (9) and (9A) by 1.72:

Trap cost - No noble metals

RPE (Trap) = (($2.52 + 0.0909 V) x 1.4 + 6.00) x 1.29 x 1.72

or

RPE (Trap) = $21.10 + 0.282 V (11)

Trap cost - With noble metals

RPE (Trap) = (($2.59 + 0.101 + 0.0780 x 1.4 + 6.00) x 1.29 x 1.72

or

RPE (Trap) = $21.10 + 0.556 V (11A)

Using equations (11) and (11A) the costs of the traps at various volumes can now be calculated. These are shown in Table A-II-4.

Port liners, insulated exhaust manifolds and an insulated

Table A-II-4

Estimated Cost of a Trap-Oxidizer System (1980 Dollars)
(Production Volume = 300,000) 1/

Item	Class IIB, III, IV	Class V, VI 2/	Class VII 2/	Class VIII 2/
Trap 3/				
Without Catalyst	243	388	443	472
With Catalyst	458	723	832	890
Port Liners	20	25	29	36
Stainless Steel Exhaust Pipe 4/	30	39	50	66
Insulated Exhaust Pipe 5/	69	99	125	172
Insulated Exhuast Manifold	25	36	46	58
Electronic Control Unit (50% of Total NOx and Part.)	37	37	37	37
Sensors	9	9	9	9
Throttle Body Actuator	16	16	16	16
Electro-Mechanical Control	6	6	6	6
Muffler (Credit)6/	(44)	(52)	(53)	(58)

1/ "Cost Estimation for Emission Control Related Components/ Systems and Cost Methodology Description," Rath and Strong for EPA, March 1978, EPA-460/3-78-002.
2/ Cost is for total of two traps.
3/ Costs are shown for an oxidation catalyst, 12.8 liters for a Class IIB, III, and IV vehicle, 10.0 liters for each of the two traps for a Class V and VI vehicle, 11.6 liters for each of the two traps for a Class VII vehicle, and 12.4 liters for each of the two traps for a Class VIII vehicle.
4/ Includes credit for steel exhaust pipe which it replaces; $14 for a Class IIB, III, and IV vehicle, $22 for a Class V and VI vehicle, $27 for a Class VII, and $35 for a Class VIII vehicle.
5/ Includes only cost for insulating an exhaust pipe, cost of exhaust pipe itself is not included.
6/ Production volume equal to in-use production and not at 300,000.

exhaust pipe may also be necessary to ensure that the exhaust gas temperature remains high enough to permit oxidation in the trap. From Lindgren (p. 195), the manufacturer's cost (vendor cost plus research and development and tooling) of port liners for a 8-cylinder light-duty engine is $11.30. Taking inflation (26 percent) and corporate and dealer overhead (29 percent) into account would increase this to $18.30. The production volume assumed was 400,000 engines. Using equation (1), with z = 0.12, to convert to 300,000 units results in a cost increase of 4.8 percent to $19.20, or $19. It will be assumed that material costs for port liners are proportional to engine size. The engine size for a 8-cylinder vehicle used in Lindgren's calculations was 5.20 liters (318 CID). The final calculated costs for port liners for the four engine sizes, 5.7, 8.2, 10.7, and 13.9 liters, are shown in Table A-II-4.

The cost of an insulated exhaust manifold has also been indirectly determined by Lindgren (pp. 171-90). From Lindgren's treatment of a thermal reactor, the cost of simply insulating the manifold can be determined. For a 8-cylinder light-duty engine, the manufacturer's cost of ceramic liners and insulation is $13.10 (p. 179). Research and development cost of $1.00 per manifold (p. 180) will be assumed to be entirely due to the thermal reactor function and will be assumed to be zero for simply insulating a manifold. Vehicle assembly and engine modifications amount to $0.69 for the entire thermal reactor (p. 180). Subtracting from this the cost of assembling a standard manifold ($0.56 for a 6-cylinder engine, p. 188) results in a negligible net cost and will not be considered. It will be assumed that the cost of the manifold itself will not change. The cost of insulating should be multiplied by 1.29 (see equation (7) to obtain the retail price equivalent, which is $16.90. The production volume assumed was the same as in the case of port liners above, or 400,000 units. Thus, the conversion factor for inflation and production volume is the same as above, 1.32 (1.26 x 1.05). Taking this factor into account, the cost of insulating an 8-cylinder manifold in a light-duty vehicle (engine size = 5.2 liter) in 1979 is then $22.30 or $22. As with the port liners, the costs of insulated exhaust manifolds for the larger heavy-duty engines have been calculated by taking the ratio of material costs to engine size. These costs are shown in Table A-II-4.

Looking next at the exhaust pipe, there are two levels at which it can be improved. One, the standard steel material must be converted to stainless steel if the system will be expected to last the entire life of a heavy-duty diesel vehicle. There is no guarantee that people would replace a rusted-out exhaust pipe before it developed holes, which would allow exhaust to bypass the trap and also cool the exhaust, possibly to the point of preventing any oxidation from ocurring. Two, the exhaust pipe may have to be insulated to keep the exhaust temperature high enough for oxidation to occur.

The cost of changing the exhaust pipe to stainless steel can be taken from Lindgren. Lindgren performed a cost analysis for two types of exhaust systems, the first system attaching to the single exhaust manifold of a 6-cylinder (3.7 liter) light-duty engine (p. 255), and the second system for a V-8 (5.2 liter) light-duty engine (p. 256). In the case of heavy-duty diesel engines, about three-fourths of the systems are of the single, non-branching variety and one-fourth are dual exhaust systems, where two entirely separate exhaust systems are used. (The source and details of this is contained in Section B.) This breakdown is assumed to apply to each vehicle class as well as the entire fleet. From this, it would appear that Lindgren's cost analysis for the 6-cylinder engine would be most analagous to that of heavy-duty diesels. For those heavy-duty diesels, the cost of a single exhaust pipe will be calculated. For those heavy-duty diesels with dual-exhaust systems, the cost will be doubled (i.e., two exhaust pipes assumed).

The manufacturing cost (DM + DL + OH in equation (6)) of a standard steel exhaust pipe is $3.27 (6-cylinder light-duty engine, 3.7 liter) (p. 254). Tooling costs are only $0.10 per pipe. Using equation (7), the retail price equivalent of this pipe is $5.94. The retail price equivalent of a stainless steel exhaust pipe is $15.91 (p. 247 and equation (7)). The cost of converting to stainless steel is then $9.07 for a 5.2 liter engine. The assumed production in both cases was 1,000,000. Using equation (1), these costs need to be increased by 21.8 percent to convert to a production of 300,000 units. They also need to be increased by 26 percent because of inflation. In total, then, the cost of converting the exhaust pipe to stainless steel is $14 for an 6-cylinder light-duty engine. Again, the costs for heavy-duty engines will be calculated by prorating material costs to engine displacement with 75 percent of the heavy-duty diesel engines requiring one exhaust pipe and 25 percent of heavy-duty diesel engines requiring two exhaust pipes. These costs are shown in Table A-II-4.

The cost of adding a double wall to the exhaust pipe with insulation in between is next to be determined. Again from Lindgren (p. 272 and equation (7)), the retail price equivalent of a double-walled, stainless steel, insulated pipe is $38.40 for a 6-cylinder engine. Subtracting the costs of the stainless steel pipe calculated above leaves $23.30. Using the same adjustments for production volume and inflation, and the same assumptions concerning engine size and single exhaust-dual exhaust breakdown, the cost of converting a stainless steel exhaust pipe to a double-walled, insulated, stainless steel pipe is shown in Table A-II-4.

The cost of the oxidation control unit will include costs for sensors, thermocouples, and a throttle for raising the temperature of the exhaust. The estimates shown in Table A-II-4 are based on the following. In his study, Lindgren solicited estimates of the cost of an electronic control unit (ECU) which monitored and controlled a large number of sensors and controllers (p. 320). This type of ECU should be of the same capacity as that needed to control the oxidation process of a trap-oxidizer system. The industry estimate was $45. Taking this to be a vendor level cost, the retail price equivalent would be $57. Inflating this to 1980 prices, the cost increases to $73. However, half of this cost will be alotted to particulate control and half to NOx control. The presence of the electronic control unit will allow the use of programmed NOx control systems (e.g., timing, exhaust gas recirculation) which should provide reductions in NOx emissions from heavy-duty diesels. Thus, the cost of the unit due to diesel particulate regulations is $37, which is shown in Table A-II-4.

The costs of the sensors, throttle body and actuator can also be taken from the same Lindgren table (p. 320). Allowing for two thermocouples near the trap, an engine speed sensor, and a rack position sensor, the vendor cost at a production volume of 300,000 is approximately $5. With three year's inflation, this cost would increase to around $6. If equation (7) is used to calculate the retail price equivalent, the cost becomes $9. The throttle switch and body should cost about $10 at the vendor level (p. 320) at a production volume of 300,000 units. With inflation and conversion to retail price equivalents, the cost should be $16. Both costs are shown in Table A-II-4.

It may also be possible that a much simpler control device would suffice in the situation. If all that was needed was a periodic boost in exhaust temperature during some general engine condition, then a controller on the order of an automatic choke or an odometer-controlled maintenance light (e.g., EGR light) should be satisfactory. For example, if the throttle actuator was keyed to the odometer and rack position, it could operate periodically, for a set period of time at a certain rack position. This type of control system would only require two or three sensors and mechanical or electrical connections to the throttle actuator. From sensor costs shown by Lindgren (p. 320) and equation (7), this system should only cost about $16. This option has been included among the components shown in Table A-II-4.

It is also very likely that the addition of a trap to the exhaust system would allow the muffler to be deleted.10/,11/ This would result in a savings to the consumer, not only initially, but every time the standard steel exhaust system would need replacement. The reduction in initial vehicle sticker price will be examined here, while the reduction in vehicle operating costs will be examined later in Section B of Chapter VI, "Costs to the Users of Heavy-Duty Diesels."

Lindgren only estimated the cost of mufflers for passenger cars. Due to this and the fact that aftermarket muffler costs are available for heavy-duty diesels, it would appear to be more accurate to convert these heavy-duty aftermarket costs to retail price equivalents than to extrapolate the light-duty costs to heavy-duty. A survey of heavy-duty diesel dealerships has shown that the cost of a typical replacement muffler is about $136 (Class IIB-IV vehicle), $161 (Class V and VI), $164 (Class VII), and $181

(Class VIII). These aftermarket costs were taken from an analysis of the replacement costs of mufflers on heavy-duty diesels, the details of which can be found in Section VI-B. Lindgren estimated that the aftermarket cost is about four times the vendor cost1/ and this has been confirmed for light-duty exhaust systems.12/ Thus, the vendor cost for a muffler for a Class IIB-IV vehicle would be about $34, for a Class V and VI vehicle about $40, for a Class VII vehicle about $41, and for a Class VIII vehicle about $45. Using equation (7), the retail price equivalent would be $44, $52, $53, and $58 for a Class IIB-IV, Class V and VI, Class VII, and Class VII vehicle, respectively. This would be the savings resulting from eliminating the need for a muffler on these vehicles. These savings are shown in Table A-II-4 and should be deducted from the cost of trap-oxidizer systems calculated below. These muffler savings are based on existing in-use production volumes and should not be multiplied by the cost ratios in Table A-II-2.

Now that the cost of all the components has been determined, the decision needs to be made concerning which of these components will be needed on any given vehicle. As this is inherently a projection, there will be a number of component combinations which may be able to reduce particulate emissions to required levels, but it is also possible that they may not. There will also be variations between models and manufacturers, as is usually the case with a system as complex as a trap-oxidizer.

Four basic combinations appear to have varying degrees of probability in being able to trap and oxidize diesel particulate safely and efficiently. These are shown in Table A-II-5. At this time, it does not appear likely that a simple trap will be able to perform adequately by itself. Some additional features will be necessary to ensure that the particulate will be oxidized effectively and safely. Systems I, II, and III all include one or two such features. System I includes a trap plus exhaust insulating features to help retain exhaust temperature and promote oxidation. It also includes a throttle to raise exhaust temperature controlled by an electro-mechanical system. This control system would be envisioned to be much simpler than that for a three-way catalyst or electronic fuel injection. The control system would be more on the order of an automatic choke or an odometer-controlled maintenance light (e.g., EGR). The insulation of the exhaust pipe has been omitted primarily because of its cost, which is $69-172. Road tests on a light-duty vehicle (Mercedes-Benz 300D) have shown that the temperature drop between the exhaust manifold and the trap inlet is only 15-20°C with an uninsulated exhaust pipe.13/ It would seem that this small decrease in temperature can be made up elsewhere more economically; using, for example, a throttle. Actually, the omission of an insulated exhaust pipe was one of the prime reasons for including a throttle in this system.

System II consists of a trap, a throttle and simple control system, but instead of insulating features it will use a coating of noble metals to promote oxidation. System III consists of a trap,

Table A-II-5

Components Included in
Potential Trap-Oxidizer Systems

System I	System II	System III	System IV
Trap (no noble metals)	Trap (w/noble metals)	Trap (no noble metals)	Trap (no noble metals)
Stainless Steel Exhaust Pipe	Stainless Steel Exhaust Pipe	Stainless Steel Exhaust Pipe	Stainless Steel Exhaust Pipe
Port Liners	Throttle Body and Switch	Electronic Control Unit	Port Liners
Insulated Exhaust Manifold	Mechanical Control	Sensors	Insulated Manifold Exhaust
Throttle Body and Switch		Throttle Body and Switch	Sensors
Mechanical Control			Electronic Control Unit
			Throttle Body and Switch

a throttle and a sophisticated control system, but uses no insulating techniques or catalytic materials.

Any one or all three of these systems may be able to trap and oxidize diesel particulate successfully. However, there is some chance that a more advanced system will be needed, which leads to System IV. System IV combines the oxidation-promoting features of Systems I and III, consisting of a trap, throttle, port liners, insulated exhaust manifold and sophisticated control. This system should be sufficient in any case, and represents an upper bound of necessary technology.

The costs of the four systems are shown in Table A-II-6. System I and III are the least expensive, which is to be expected. However, System II, which could be considered less likely to be viable than System IV, is more expensive than System IV. This is primarily due to three assumptions used to estimate the amount of catalytic material on the trap. One, it was assumed that Pt and Pd would be the catalysts used. Two, it was assumed that the catalyst loading would be that found on current oxidation catalysts, around 0.012 gram per cubic inch. Three, it was assumed that this loading would be needed throughout the whole trap. It is possible that expensive catalysts such as Pt and Pd may be avoided and more inexpensive catalysts, such as silver nitrate, may prove sufficient. It is also possible that the loading could be decreased or that the catalyst would only be needed near the inlet to begin the oxidation process, which would proceed thermally thereafter. Any of these changes would lower the costs of System II and could make it competitive with Systems I and III.

It is not possible to place any probability on the possibility of any of these systems being used. It is quite possible that System I will be used on some models, particularly those which may be relatively close to the 1986 standard without a trap-oxidizer. It is also possible that some models will need System IV. Rather than give the systems a probability weighting which would have little basis, the entire range of costs between Systems III and IV will be used hereafter, as it does indicate the range of costs which could occur. The cost of System IV will be taken to be the maximum cost. It will be assumed that System II will be used only if the catalytic material or its loading can be changed to make it economically competitive with Systems I and III.

The range of system costs (III-IV) of Table A-II-6 can now be combined with the actual cost to reference cost ratios of Table A-II-2 to yield the actual cost of trap-oxidizer systems at the production volumes expected. The costs for the traps should be multiplied by the ratios corresponding to each vehicle group shown for traps in Table A-II-2. The costs for the port liners, stainless steel exhaust pipe, insulated exhaust pipe, insulated exhaust manifold, and the throttle body and actuator should be multiplied by the ratios corresponding to components that vary with engine designs. The costs for the control units and sensors should be

Table A-II-6

Cost of Four Potential Trap-Oxidizer Systems (1980 dollars) 1/

System	Vehicle Class IIB, III & IV	V, VI	VII	VIII
I	296	458	541	596
II	466	732	851	920
III	292	437	502	542
IV	336	501	580	636

1/ Production Volume = 300,000.

multiplied by the ratios shown in Table A-II-2 for the electronic control units. The results are shown in Table A-II-7.

A closer look at Table A-II-7 shows that a Class VII trap-oxidizer system costs more than a Class VIII trap-oxidizer system, despite the fact that a Class VII trap-oxidizer is smaller and requires less material to manufacture. The costs of Class VII trap-oxidizer Systems III and IV (as shown in Table A-II-6) are $43-59 less than the Class VIII systems, at a constant production volume of 300,000 for each group of vehicle classes. However, the lower sales of Class VII vehicles result in a higher overall cost of manufacturing Class VII trap-oxidizer systems. With the exhaust flow of a Class VII vehicle being less than that of a Class VIII vehicle there is no reason that a Class VIII trap cannot be placed on a Class VII vehicle. This would reduce the cost of the Class VII trap to that of the Class VIII trap and also reduce the cost of the Class VIII trap by increasing the production volumes. For example, in 1986 the cost ratio for both classes combined would be 1.15 for the traps (over a production of 300,000) and the new cost would be $543. This is less than the $673 and $552 costs of traps for Class VII and Class VIII vehicles, respectively. This would also lower the trap-oxidizer system cost to $652-805 for Class VII vehicles and $642-789 for Class VIII vehicles.

Further analysis shows that the same holds true for the Class V-VI systems. Overall it is less expensive to fit Class V and VI vehicles with Class VIII traps than to manufacture traps specifically sized for the Class V and VI vehicles. For example, a Class V and VI system in 1986 costs $528, using the cost ratio for traps in Table A-II-2 and the cost of traps in Table A-II-4. Using the 1986 cost estimate of $543 calculated above for Class VII and VIII traps, a sales weighted average (again, based on Table A-II-1) of Class V-VIII traps is $539. If Class V and VI vehicles are fitted with Class VIII traps, the cost ratio in 1986 for traps would be 1.09 (as shown in Table A-II-8), and the cost would be $514. This is less than the sales-weighted average of $539 calculated above. This also has the effect of lowering trap-oxidizer system costs to $611-688 for Class V and VI vehicles, $652-805 for Class VII vehicles, and $642-789 for Class VIII vehicles. This reduction in cost holds true for every year. New cost ratios for traps (compared to an accumulated production of 300,000 units) grouping Classes V-VIII traps together are shown in Table VI-8. The revised cost estimates of trap-oxidizer systems are shown in Table A-II-9. The fleet-average cost for each year is again a sales-weighted average (based on the sales scenerio in Table A-II-1) of costs for the four basic vehicle groups. The fleetwide average cost in 1986 would then be $629-$756 and should decrease to $458-$559 in 1989.

B. Savings Due to Maintenance Reductions

The addition of a trap-oxidizer system is also expected to reduce maintenance in two ways. One, the system will include a

Table A-II-7

Estimated Costs of Trap-Oxidizer Systems
At Predicted Production Volumes (1980 dollars)

	Vehicle Class	Vehicle Class Average
1986	IIB, III, IV	551-644
	V, VI	626-730
	VII	811-964
	VIII	679-826
Sales Weighted:		672-806
1987	IIB, III, IV	480-562
	V, VI	551-645
	VII	714-850
	VIII	601-733
Sales Weighted:		592-711
1988	IIB, III, IV	438-513
	V, VI	507-593
	VII	658-785
	VIII	558-681
Sales Weighted:		547-657
1989	IIB, III, IV	410-480
	V, VI	477-559
	VII	624-744
	VIII	528-645
Sales Weighted:		515-619
1990	IIB, III, IV	384-451
	V, VI	449-531
	VII	598-714
	VIII	505-618
Sales Weighted:		489-590

Table A-II-8

Revised Values for the Ratio of the Actual Cost of a Component to Its Cost at an Accumulated Production Of 300,000 Units 1/

	1986	1987	1988	1989	1990
Electronic Control Units	1.21	1.07	1.00	0.95	0.91
Cost Ratios if Component Production Equals Vehicle Group Production					
Class IIB, III, IV	1.83	1.61	1.48	1.39	1.32
Class V, VI	1.53	1.36	1.26	1.19	1.13
Class VII	1.71	1.52	1.42	1.34	1.29
Class VIII	1.32	1.18	1.10	1.05	1.01
Traps 2/					
Class IIB, III, IV	1.83	1.61	1.48	1.39	1.32
Class V-VIII	1.09	0.97	0.90	0.86	0.83
Components that Vary with Engine Design					
Class IIB, III, IV	2.06	1.81	1.66	1.56	1.48
Class V, VI	1.72	1.53	1.42	1.34	1.27
Class VII	2.04	1.81	1.69	1.60	1.54
Class VIII	1.57	1.40	1.31	1.25	1.20

1/ Assumes each supplier shares one-third of the market at production shown in Table A-II-1.

2/ Class V-VIII production combined.

Table A-II-9

Revised Estimated Costs of Trap-Oxidizer Systems
At Predicted Production Volumes (1980 dollars) 1/

	Vehicle Class	Vehicle Class Average
1986	IIB, III, IV	551-644
	V, VI	611-688
	VII	652-805
	VIII	642-789
Sales Weighted:		629-762
1987	IIB, III, IV	480-562
	V, VI	540-632
	VII	574-709
	VIII	564-695
Sales Weighted:		552-670
1988	IIB, III, IV	438-513
	V, VI	497-584
	VII	530-649
	VIII	520-643
Sales Weighted:		508-618
1989	IIB, III, IV	410-480
	V, VI	472-553
	VII	502-622
	VIII	495-612
Sales Weighted:		482-586
1990	IIB, III, IV	384-451
	V, VI	449-527
	VII	480-596
	VIII	472-588
Sales Weighted:		458-559

1/ Assumes Class VIII traps are fitted to Class V-VIII vehicles.

stainless steel exhaust pipe which will eliminate the normal need to replace it. Two, the presence of the trap itself should eliminate the need for the muffler,10/11/12/ which in turn eliminates the need to replace the muffler.

In order to calculate the savings resulting from the elimination of these two maintenance items, two pieces of data are needed for both muffler and exhaust pipe replacements; timing and costs. These two items will be examined below.

EPA has performed a statistical analysis to determine the number and timing of muffler replacements that normally occur during the lifetime of a heavy-duty vehicle. Muffler failure probability as a function of service time was obtained from an SAE report,14/ and this is shown in Table A-II-10. It is likely that this study only included light-duty vehicles. However, it was the only study available examining the lifetime of exhaust systems. The heavy-duty vehicle scrappage rate as a function of service time was obtained from an EPA study.15/ This relationship is shown in Table A-II-11.

A Monte Carlo technique was used to couple muffler life with vehicle life. In this analysis a muffler life and a heavy-duty vehicle life were randomly chosen according to their probability of occurance.16/ It was assumed that muffler replacement was uneconomical one-half year before the truck life ended. If the muffler life was equal to or greater than the truck life minus one-half year, then the truck was assumed to use only one muffler. If the muffler life was less than the truck life minus one-half year then another muffler life was randomly chosen until the sum of the muffler lives for that truck was equal to or greater than the truck life minus one-half year. The number of mufflers required by 90 random vehicles was determined. It was found that an average of 1.27 muffler replacements were necessary for each heavy-duty vehicle. More specifically, 66 percent of the heavy-duty vehicles required at least one muffler replacement which occurred on the average after 5 years, 38 percent required at least two mufflers, the second replacement occurring after 10 years, 19 percent require at least three mufflers, the third replacement occurring after 15 years, 4 percent required at least four replacements, the fourth occurring after 17 years, and 1 percent required five mufflers, the fifth replacement occurring after 20 years. These figures were used to determine the discounted cost of the muffler savings in the year the vehicle was purchased. Using a 10 percent discount rate, these replacement rates are equivalent to 0.61 replacement at the time of vehicle purchase, or to 0.98 replacements when the vehicle is five years old. As no similar data could be found which related specifically to exhaust pipe replacements, these findings will also be used for exhaust pipes as well as mufflers.

A survey of diesel equipment suppliers has shown that the average cost of a replacement muffler is $136 for a Class IIB-IV

Table A-II-10

Variation of Aluminized Steel
Muffler Failure Probability With Service-Time 13/

Years	Percent Failure Per Year	Cumulative Percent Failure
1.5	2	2
2.5	8	10
3.5	17	27
4.5	18	45
5.5	17	62
6.5	11	73
7.5	9	82
8.5	10	92
9.5	8	100

Table A-II-11

Truck Life Scrappage Rates
As a Function of Service Time 14/

Years	Percent Scrapped Per Year	Cumulative Percent Failure
1.5	9	9
2.5	7	16
3.5	7	23
4.5	6	29
5.5	7	36
6.5	6	42
7.5	5	47
8.5	5	52
9.5	5	57
10.5	4	61
11.5	4	65
12.5	4	69
13.5	3	72
14.5	4	76
15.5	3	79
16.5	2	81
17.5	3	84
18.5	2	86
19.5	3	89
20.5	2	91
21.5	2	93
22.5	2	95
23.5	2	97
24.5	1	98
25.5	1	99
26.5	1	100

vehicle, $161 for a Class V and VI vehicle, $164 for a Class VII vehicle, and $181 for a Class VIII vehicle.17/ These costs have already been used in Section A of Chapter VI to estimate the retail price equivalents of mufflers for each of the four basic vehicle groups. From this survey it was found that muffler costs are affected by two major factors. First, the costs depended on the physical muffler requirements of each engine. Second, the costs were related to services rendered by the dealer selling the muffler. A dealer providing services such as installation would have a higher material cost for these engine parts (including mufflers) than would a dealer who only sells the parts. From the range of costs discovered by the survey, a single average cost has been estimated which should be a representative aftermarket muffler cost for each group of vehicle classes.

For example, the cheapest muffler found for a Class IIB-IV heavy-duty diesel engine with a single exhaust system costs $47 17/ from a dealer who did not perform any services. This same muffler costs $70 if sold from a dealer that did have services available. Assuming that the average of these costs would best represent the actual prices paid in-use, the typical cost would then be $58, which will be used as the minimum cost. The maximum muffler cost for a Class IIB-IV heavy-duty diesel engine with a single exhaust system was $146 from a dealer with no services, or $219 from a dealer providing services. The average of these two costs, $182, will again be used as the typical cost. In the absence of a breakdown of sales by vehicle type (which is very difficult to obtain) the average of the least expensive and most expensive muffler, in this case $120, will be assumed to be the average muffler cost for a Class IIB-IV vehicle with a single exhaust system. Similarly, the minimum least expensive muffler for a Class IIB-IV engine with dual exhaust costs $108-$164, (average of $136), while the most expensive muffler costs $188-$282, (average of $235). The average of these costs is $185. As mentioned earlier, 3/4 of heavy-duty diesel engines are expected to require a single exhaust system and 1/4 of all heavy-duty diesel engines are expected to require a dual exhaust system. With this in mind, the aftermarket cost of a Class IIB-IV muffler would then be $136 ((3/4 x 120) + (1/4 x 185)). Applying the same method as above, aftermarket muffler costs of $161, $164, and $181 were estimated for Classes V and VI, Class VII, and Class VIII engines, respectively. These costs will be assumed to occur at in-use production volumes.

For the light-duty market, the cost of labor and incidental parts amount to 25 percent of the cost of the muffler.12/ This also holds for the heavy-duty situation, and these muffler costs need to be increased by 25 percent to represent the total cost of a muffler replacement. These total costs are $170, $201, $205, and $226, respectively. Using the sales figures of Table VI-1, the sales-weighted average of these costs is $211 per muffler replacement. Undiscounted, 1.27 muffler replacements would amount to $268 per vehicle. Using the actual schedule of replacements described above and a 10 percent discount rate, the savings from eliminating muffler replacements would be $129 per vehicle, discounted back to the year of vehicle purchase.

The cost of steel exhaust pipes has already been examined in Appendix II-A. In that section, it was assumed that 3/4 of heavy-duty diesel engines required one non-branching exhaust pipe. This fraction corresponds to the fraction of turbocharged diesel engines sold by the five largest manufacturers, as discussed in Chapter 3, the Description of the Industry. The remaining 1/4 of the engines (those being naturally-aspirated) are assumed to have dual exhaust systems. While a cross-over pipe could be used instead of a dual exhaust system, this is highly unlikely for heavy-duty diesel engines due to their large engine size. Thus, these naturally-aspirated engines are assumed to require two exhaust pipes. This breakdown of single and dual exhausts is assumed to apply to each vehicle class. Using the data presented in Appendix II-A, the retail price equivalents for the four vehicle groups are $14 (IIB, III, IV), $22 (V, VI), $27 (VII), and $35 (VIII). From equation (7) of Section VI-A, the vendor level costs can be found by dividing these costs by 1.29. From Lindgren1/ aftermarket costs are four times vendor level costs and this relationship has been confirmed for light-duty exhaust system components.12/ Adding 25 percent for labor and incidental parts, the total cost of exhaust pipe replacements becomes $54, $85, $105, and $136, respectively. Again using the sales figures of Table A-II-1, a sales-weighted average cost is $111 per replacement.

Using 1.27 replacements per vehicle, the undiscounted savings become $141 per vehicle. Using the actual replacement schedule determined for mufflers above and a 10 percent discount rate, the savings resulting from eliminating exhaust pipe replacements is $68 per vehicle (discounted to year of vehicle purchase). Adding to this the savings determined for mufflers above, the total maintenance savings is $197 per vehicle (discounted to year of vehicle purchase).

C. Sensitivity Analyses

Two assumptions were made in Section A to aid in determining the control system costs associated with particulate control. One, it was assumed that a 12 percent learning curve applied. Two, it was assumed that the trap-oxidizer systems would be supplied by three outside suppliers. The effect of these assumptions on the final costs will be examined here by recalculating the costs based on two new sets of assumptions. One, rather than using a 12 percent learning curve, it will be assumed that a learning curve does not apply and that the costs are the same at all production volumes. The number of outside suppliers and/or manufacturers providing their own systems has no effect in this case. Two, rather than assuming that three outside suppliers will produce all of the control systems, the assumption will be made that each manufacturer will produce his own control systems. Here the 12 percent learning curve will be used again to convert the changes in production to changes in costs.

1. Learning Curve

To remove the effect of the learning curve is actually a fairly simple process. All that needs to be done is to return to Section A and retrieve the costs determined by Lindgren,1/ adjusted for component size and inflation. These costs will be the same as those shown in Table A-II-4, except that they will be divided by the learning curve factor which was used to adjust the costs to 300,000 units in the first place. These component costs, assuming no learning curve, are shown in Table A-II-12, with the production volumes originally used by Lindgren.

As production does not affect costs in this case, the costs of the various components of Systems III and IV (See Section A) can simply be added up and will apply to the five years of production, 1986-1990. These system costs for each of the four vehicle groups are shown in Table A-II-13, along with the costs determined in Section A, which used a learning curve. As can be seen, the costs are markedly less without a learning curve; 37-62 percent in 1986 and 15-40 percent in 1990, depending on the vehicle class. Sales-weighting all classes, the costs determined without a learning curve are 41 percent less in 1986 and 20 percent less in 1990, or roughly 30 percent less over the five years, 1986-1990.

This difference is quite significant and occurs primarily because the original production volumes used by Lindren were quite large compared to the production volumes projected for heavy-duty trap-oxidizer system components. Due to these large differences in production volume, one would expect some difference in costs to occur. Thus, at least some of the cost differential is certain to occur. However, it is possible that the learning curve may not be as steep as 12 percent and that the costs determined in Section A are overestimated by something less than 30 percent. Due to the lack of more detailed information on the actual learning curves for these types of components, the more conservative costs of Section A will be used with the knowledge that the costs could decrease significantly as additional information becomes available after proposal.

2. Number of Suppliers

The evaluation of the effect of the number of suppliers on cost will require returning to Section A of this chapter and slightly modifying the equations used to modify costs per production changes. As described in Section A, Equations (3A) and (3B) give the ratio of the actual cost to the cost at some reference production for components which differ between vehicle group and those which don't, respectively. In these two equations, a factor of three is used in the denominator to split the total production equally among three suppliers. This factor will require modification to reflect the assumption that each manufacturer will be producing his own trap-oxidizers. The actual adjustment will be to remove the factor of three from the denominator (representing

Table A-II-12

Emission Control System
Component Costs Assuming No Learning Curve

Item	Lindgren's Production	Class IIB-IV	Class V,VI	Class VII	Class VIII
Trap*	2,000,000	179	285	326	347
Port Liners	400,000	19	24	28	34
SS Exhaust Pipe	1,000,000	25	32	41	54
Insulated Exhaust Pipe	1,000,000	57	81	103	141
Insulated Exhaust Manifold	400,000	24	34	44	55
Electronic Control Unit	200,000-500,000	37	37	37	37
Sensors	200,000-500,000	9	9	9	9
Throttle Body Actuator	200,000-500,000	16	16	16	16
Electro-Mechanical Control	200,000 500,000-	6	6	6	6
Mufflers	-	(44)	(52)	(53)	(58)

* Without noble metals.

Table A-II-13

Trap-Oxidizer System Costs Both
With and Without Use of a Learning Curve

Vehicle Classes	With 12 Percent Learning Curve 1986	1990	Without Learning Curve
IIB-IV	551-644	384-451	222-265
V-VI	611-688	449-527	327-385
VII	652-805	480-596	376-448
VIII	642-789	472-588	405-494
All	629-562	458-559	369-445

one third of the production) and to insert into the numerator the fraction of total sales belonging to that particular manufacturer.

The actual fractions of sales to be used will be taken from Table III-4, representing the distribution of 1979 sales, and are shown below:

Cummins	38.0%
Detroit Diesel	24.6%
Caterpillar	15.7%
Mack	14.1%
IHC	7.6%

It has been assumed that the 1979 market share will hold constant throughout 1990. Also, the foreign manufacturers have been assumed to buy their traps from the other manufacturers since their combined sales were less than three percent of total sales in 1979. Their sales have been distributed among the domestic manufacturers in proportion to the latter's sales.

When the above fractions are used in Equations (3A) and (3B) and the calculations of Section A are repeated, actual cost-to-reference cost ratios for each manufacturer are generated. These are shown in the upper two sections of Tables A-II-14 through A-II-18. The uppermost section includes the factors generated from Equation (3A) which apply to electronic control units and sensors. The second section (Equation (3B)) applies to exhaust system components.

To determine these ratios as they apply to traps, the same modifications must be made as was done in Section A. That is, the production of Classes V-VIII must be considered together and multiplied by two to represent the use of one size trap on all those vehicles and the use of two traps per vehicle. The ratios for Classes II-B-IV remain the same as those in the second section of the tables. These trap ratios are shown in the third section of Tables A-II-14 through A-II-18.

Lastly, the ratios for those components that vary with engine design must be determined. In Section A, it was assumed that there were ten basic engine designs throughout the industry. Here, for convenience, a very conservative assumption will be made that each manufacturer produces five basic engine designs, one in each of the three lightest groups of vehicle classes and two in Class VIII. This would total 25 engines across the industry and will help to make this a worst-case analysis. Since the first three vehicle groups have exactly one engine per group, the engine production is the same as the vehicle group production and the actual-to-reference cost ratios are the same as in the second section of the five tables. In Class VIII, however, engine production is only half the vehicle group production, so the ratios there are 12 percent higher than those in the second section (by definition of the 12 percent learning curve). These engine-dependent ratios are shown in the bottom-most section of Tables A-II-14 through A-II-18.

Table A-II-14

Cummins

Revised Values for the Ratio of the Actual Cost of a Component to Its Cost at an Accumulated Production Of 300,000 Units 1/

	1986	1987	1988	1989	1990
Electronic Control Units	1.18	1.05	0.98	0.93	0.89
Cost Ratios if Component Production Equals Vehicle Group Production					
Class IIB, III, IV	1.79	1.58	1.45	1.36	1.30
Class V, VI	1.50	1.33	1.23	1.16	1.11
Class VII	1.68	1.49	1.39	1.32	1.26
Class VIII	1.30	1.15	1.08	1.03	0.96
Traps2/					
Class IIB, III, IV	1.79	1.58	1.45	1.36	1.30
Class V-VIII3/	1.07	0.95	0.88	0.84	0.81
Components that Vary with Engine Design					
Class IIB, III, IV	1.79	1.58	1.45	1.36	1.30
Class V, VI	1.50	1.33	1.23	1.16	1.11
Class VII	1.68	1.49	1.39	1.32	1.26
Class VIII	1.46	1.29	1.21	1.16	1.08

1/ Assumes Cummins captures 38.0% of the production shown in Table A-II-1.

2/ Class V-VIII production combined.

3/ Assume two traps per vehicle.

Table A-II-15

Detroit Diesel

Revised Values for the Ratio of the Actual Cost of a Component to Its Cost at an Accumulated Production Of 300,000 Units 1/

	1986	1987	1988	1989	1990
Electronic Control Units	1.27	1.12	1.05	0.99	0.95
Cost Ratios if Component Production Equals Vehicle Group Production					
Class IIB, III, IV	1.92	1.69	1.55	1.46	1.39
Class V, VI	1.61	1.42	1.32	1.24	1.19
Class VII	1.80	1.60	1.49	1.41	1.35
Class VIII	1.39	1.24	1.11	1.03	1.00
Traps2/					
Class IIB, III, IV	1.92	1.69	1.55	1.46	1.39
Class V-VIII3/	1.15	1.02	0.95	0.90	0.87
Components that Vary with Engine Design					
Class IIB, III, IV	1.92	1.69	1.55	1.46	1.39
Class V, VI	1.61	1.42	1.32	1.24	1.19
Class VII	1.80	1.60	1.49	1.41	1.35
Class VIII	1.56	1.39	1.25	1.16	1.12

1/ Assumes Detroit Diesel captures 24.6% of the production shown in Table A-II-1.

2/ Class V-VIII production combined.

3/ Assume two traps per vehicle.

Table A-II-16

Caterpillar

Revised Values for the Ratio of the Actual Cost of a Component to Its Cost at an Accumulated Production Of 300,000 Units 1/

	1986	1987	1988	1989	1990
Electronic Control Units	1.36	1.21	1.13	1.07	1.03
Cost Ratios if Component Production Equals Vehicle Group Production					
Class IIB, III, IV	2.07	1.82	1.67	1.57	1.49
Class V, VI	1.73	1.53	1.42	1.34	1.30
Class VII	1.93	1.72	1.60	1.52	1.46
Class VIII	1.49	1.33	1.25	1.19	1.14
Traps2/					
Class IIB, III, IV	2.07	1.82	1.67	1.57	1.49
Class V-VIII3/	1.23	1.10	1.02	0.97	0.93
Components that Vary with Engine Design					
Class IIB, III, IV	2.07	1.82	1.67	1.57	1.49
Class V, VI	1.73	1.53	1.42	1.34	1.30
Class VII	1.93	1.72	1.60	1.52	1.46
Class VIII	1.67	1.49	1.40	1.34	1.28

1/ Assumes Caterpillar captures 15.7% of the production shown in Table A-II-1.

2/ Class V-VIII production combined.

3/ Assume two traps per vehicle.

Table A-II-17

Mack

Revised Values for the Ratio of the Actual Cost of a Component to Its Cost at an Accumulated Production Of 300,000 Units 1/

	1986	1987	1988	1989	1990
Electronic Control Units	1.39	1.24	1.15	1.09	1.05
Cost Ratios if Component Production Equals Vehicle Group Production					
Class IIB, III, IV	2.11	1.86	1.71	1.61	1.53
Class V, VI	1.77	1.56	1.45	1.37	1.31
Class VII	1.98	1.75	1.55	1.49	1.44
Class VIII	1.53	1.36	1.27	1.21	1.17
Traps2/					
Class IIB, III, IV	2.11	1.86	1.71	1.61	1.53
Class V-VIII3/	1.26	1.12	1.04	0.99	0.95
Components that Vary with Engine Design					
Class IIB, III, IV	2.11	1.86	1.71	1.61	1.53
Class V, VI	1.77	1.56	1.45	1.37	1.31
Class VII	1.98	1.75	1.55	1.49	1.44
Class VIII	1.72	1.53	1.43	1.36	1.31

1/ Assumes Mack captures 14.1% of the production shown in Table A-II-1.

2/ Class V-VIII production combined.

3/ Assume two traps per vehicle.

Table A-II-18

International Harvester

Revised Values for the Ratio of the Actual Cost of a Component to Its Cost at an Accumulated Production Of 300,000 Units 1/

	1986	1987	1988	1989	1990
Electronic Control Units	1.56	1.39	1.29	1.22	1.17
Cost Ratios if Component Production Equals Vehicle Group Production					
Class IIB, III, IV	2.37	2.08	1.91	1.80	1.71
Class V, VI	1.98	1.75	1.62	1.53	1.47
Class VII	2.21	1.97	1.83	1.74	1.67
Class VIII	1.71	1.52	1.42	1.36	1.31
Traps2/					
Class IIB, III, IV	2.37	2.08	1.91	1.80	1.71
Class V-VIII3/	1.41	1.25	1.17	1.11	1.07
Components that Vary with Engine Design					
Class IIB, III, IV	2.37	2.08	1.91	1.80	1.71
Class V, VI	1.98	1.75	1.62	1.53	1.47
Class VII	2.21	1.97	1.83	1.74	1.67
Class VIII	1.92	1.71	1.60	1.53	1.47

1/ Assumes IHC captures 7.6% of the production shown in Table A-II-1.

2/ Class V-VIII production combined.

3/ Assume two traps per vehicle.

To determine the ratios for the entire industry, the ratios of the five tables must be sales-weighted using the sales breakdown shown above. This has been done and the results are shown in Table A-II-19.

All that remains to be done to determine whole trap-oxidizer system costs is to apply the ratios of Tables A-II-13 through A-II-18 to the component costs of Table A-II-4. This will be done for Cummins (largest manufacturer, least cost), IHC (smallest manufacturer, greatest cost), and the industry average. A sales-weighted average across vehicle groups for each year is also shown using Equation (2) of Section A.

The results are shown in Table A-II-20. As can been seen, the results are quite close together. Cummins' costs would be about 9 percent below the industry average and IHC's cost would be about 23 percent higher than the industry average. Also, the industry averages calculated here are only 4-5 percent higher than those calculated in Section A (Table A-II-9). Thus, the sensitivity analysis has shown that industry average costs are not sensitive to the assumption that three outside suppliers will provide all of the trap-oxidizers for the industry. Two, it has shown that some spread could occur between manufacturers (maximum of 35 percent), but given that this is a worst case spread, it is actually quite reasonable. Thus, given the small likelihood of this situation occurring, the costs calculated in Section A should be indicative of the actual costs seen in the field even if the actual number of suppliers differed from three.

Table A-II-19

Industry-Wide Average

Revised Values for the Ratio of the Actual Cost of a Component to Its Cost at an Accumulated Production Of 300,000 Units 1/

	1986	1987	1988	1989	1990
Electronic Control Units	1.29	1.18	1.07	1.01	0.97
Cost Ratios if Component Production Equals Vehicle Group Production					
Class IIB, III, IV	1.95	1.72	1.58	1.48	1.41
Class V, VI	1.64	1.45	1.34	1.26	1.21
Class VII	1.83	1.62	1.50	1.43	1.37
Class VIII	1.41	1.26	1.17	1.11	1.06
Traps2/					
Class IIB, III, IV	1.95	1.72	1.58	1.48	1.41
Class V-VIII3/	1.17	1.04	0.96	0.92	0.88
Components that Vary with Engine Design					
Class IIB, III, IV	1.95	1.72	1.58	1.48	1.41
Class V, VI	1.64	1.45	1.34	1.26	1.21
Class VII	1.83	1.62	1.50	1.43	1.37
Class VIII	1.58	1.42	1.31	1.25	1.19

1/ Assumes each manufacturer supplies his own trap-oxidizer.

2/ Class V-VIII production combined.

3/ Assume two traps per vehicle.

Table A-II-20

Revised Estimated Costs of Trap-Oxidizer Systems
At Predicted Production Volumes (1980 dollars)

Vehicle Class	Industry-Wide Average	Cummins	IHC
1986:			
IIB, III, IV	579-667	500-580	713-819
V, VI	650-750	589-681	794-915
VII	680-817	617-743	830-996
VIII	683-832	621-758	837-1017
Sales Weighted:	664-795	604-724	817-975
1987:			
IIB, III, IV	507-585	461-524	621-715
V, VI	573-661	518-599	698-805
VII	599-721	542-654	731-879
VIII	604-737	544-666	736-897
Sales Weighted:	586-702	531-637	717-858
1988:			
IIB, III, IV	462-533	420-485	567-653
V, VI	524-606	488-563	648-747
VII	548-661	499-603	679-817
VIII	552-675	502-615	685-835
Sales Weighted:	537-644	491-589	665-795
1989:			
IIB, III, IV	430-497	377-438	532-613
V, VI	498-575	451-522	612-706
VII	522-629	526-572	642-772
VIII	525-643	476-585	647-791
Sales Weighted:	508-610	465-553	625-749
1990:			
IIB, III, IV	408-472	373-431	504-581
V, VI	475-548	432-500	588-677
VII	497-600	453-548	616-694
VIII	500-611	454-555	621-760
Sales Weighted:	483-578	438-525	598-710
Sales Weighted, 1986-1990	550-660	501-600	679-810

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