SUMMARY AND ANALYSIS OF COMMENTS TO THE NPRM:

"1983 AND LATER MODEL YEAR HEAVY-DUTY ENGINES

PROPOSED GASEOUS EMISSION REGULATIONS"

December, 1979

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I. Introduction

The Environmental Protection Agency (EPA) published a Notice of Proposed Rulemaking (NPRM) on Tuesday, February 13, 1979, proposing new heavy-duty engine (HDE) emissions regulations for 1983 and later model years. The proposed rule prescribed more stringent hydrocarbon and carbon monoxide emission standards, and established an assembly-line testing program and nonconformance penalty system for 1983 and later model year heavy-duty (HD) gasoline-fueled and diesel engines as mandated by the Clean Air Act Amendments of 1977. Substantial changes were also proposed to the emission test procedures, the definition of useful life, and the procedures used to verify the durability of emission control systems over their useful life.

This document presents a summary and analysis of the comments received in response to the NPRM. The comments have been grouped into two parts. Part I addresses the major issues which, for the most part, are the proposed changes to the HDE regulations that were listed in the Preamble to the NPRM. The analysis of these major issues leads directly to final recommendations on the proposed changes. Part II supplements the discussion of the major issues by supplying the technical details. These details do little to offset EPA's final recommendation on the respective major issue.

II. LIST OF COMMENTERS

1.	Professor Philip S. Myers	
2.	American Trucking Association, Inc.	ATA
3.	IVECO Trucks of North America	IVECO
4.	Motor Equipment Manufacturers Association	MEMA
5.	Caterpillar Tractor Company	CAT
6.	Chrysler Corporation	Chrysler
7.	Council on Wage and Price Stability	COWPS
8.	Cummins Engine Company, Inc.	Cummins
9.	Engine Manufacturers Association	EMA
10.	Ford Motor Company	Ford
11.	General Motors Corporation	GM
12.	International Harvester Corporation	IHC
13.	Perkins Engines	
14.	Mack Trucks, Inc.	Mack
15.	Mercedes-Benz of North America, Inc.	M-B
16.	Motor Vehicle Manufacturers Association	MVMA
17.	Spector Freight Systems, Inc.	
18.	Garrison Motor Freight	
19.	Environmental Action of Michigan, Inc.	
20.	United States Department of Commerce	DOC
21.	United States Department of Interior	DOI
22.	Detroit Diesel Allison	DDA
23.	Connecticut Construction Industries Association	
24.	University of Waterloo	

PART I

Analysis of Major Issues

A. Issue - Test Procedure

1. Summary of the Issue

EPA has proposed that the steady-state test procedures presently used for the certification testing of heavy-duty engines be abandoned. In their place, the use of a transient test has been proposed. This transient procedure was developed by statistical analysis of on-road operational data collected in the New York and Los Angeles urban areas. The transient test covers the full range of engine operation; the steady-state tests are limited to specific speeds and loads.

2. Summary of the Comments

Heavy-duty engine manufacturers were unanimous in their criticism of the transient test, and in their desire to retain the steady-state procedures.

a. Justification

First of all, they claimed that no substantive justification for its promulgation has been advanced by EPA. EPA purportedly has not proven that concrete air quality improvements will result from implementation of the new test procedure. Furthermore, EPA purportedly has not presented "hard" technical data supporting its contention that the current test procedures inadequately predict future on-road emissions. It was claimed that this lack of "hard" technical data constitutes regulatory action on the basis of conjecture. Furthermore, the commenters maintained that this approach does not satisfy the judicially-determined requirements (International Harvester vs. Ruckelshaus) that the Agency "bear a burden of adducing a reasoned presentation supporting the reliability of its methodology." The Agency has been expressly accused of being "arbitrary and capricious" in its methodology and its reasoning.

In the case of diesel engines, it was claimed that EPA's justification for the transient test is especially weak, based primarily upon regulations and standards which have yet to be proposed (future particulate and NOx standards). A diesel engine does not possess transient enrichment devices (chokes, accelerator pumps), has HC and CO emission levels conceded by EPA* to be "quite close to the 90 percent reduction level," and at that level, manufacturers claimed that emissions are adequately predicted by the current steady-state procedure. The industry argued that future and unknown requirements for NOx and particulate control are unsubstantiated justification for a transient test, and represent an abridgement of the industry's rights to comment on regulatory methodology.

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* In NPRM Draft Regulatory Analysis, pp. 132-133.

For both gasoline and diesel engines, manufacturers commented that EPA's arguments attempting to prove the inadequacy of the current test procedure (the lack of transient operating modes, limited number of engine speeds, absence of cold start operation, improper and unrepresentative weighting factors, and lack of correlation with on-road data) constitute insufficient justification for a transient test. It was claimed that EPA has presented no evidence that a transient test will alleviate these shortcoming nor that these shortcomings need be alleviated to obtain on road emission reductions. It was argued that modifications to the current test procedure could adequately correct these problems at a much lower cost. In fact, data does exist (California in-use vehicle surveillance study) that purportedly shows 9-mode testing does correlate with a proven transient cycle (LA-4).

The manufacturers' claimed that the change in test procedure unreasonably hinders the industry for no substantiated benefit. It was argued that the substantial data base and technological experience acquired through steady-state testing will be rendered useless; the lack of identifiable operational modes in the transient test will make the design of new emission control technology difficult. The cost of the procedural change purportedly outweighs its proven benefits.

It was unanimously suggested that the Agency implement standards for 1983 based upon the steady-state procedures.

b. Representativeness

The specific transient test cycles proposed by EPA also came under considerable attack. The industry almost unanimously claimed that the proposed cycles are unrepresentative of actual truck operation, having been generated from a questionable data base using a questionable methodology. Specific problems with the Cape-21 data and the proposed cycle which were cited by the manufacturers include:

i) The use of transient manifold vacuum and rack positions to approximate transient engine torques and horsepower was technically incorrect and resulted in erroneous and physically unrealistic acceleration rates.

ii) The cold/hot weightings in the proposed cycles are different from those indicated in the Cape-21 study.

iii) The overspeed in the cycles is highly unrepresentative and indicative of the questionability of the data.

iv) The Monte Carlo technique, used as it was without time sequencing of more than one second, resulted in erratic cycles with unrepresentative speed/load patterns.

v) A large percentage of the Cape-21 data is "spurious," due to vehicle vibration exciting the optical encoder used to measure vehicle speed, and to electrical noise present in the rack position indicators. The transient cycles were developed from this highly-spurious data base, and thus are inherently unrealistic.

vi) All engines in the data base were naturally-aspirated; since future engines will be almost exclusively turbocharged, the data base is highly unrepresentative of the future fleet.

vii) The proposed cycles have average idle and cruise time different from the data base.

viii) The actual trucks in the data base were unrepresentative of current and future truck populations both in number and GVW, and in some cases were in questionable mechanical condition.

ix) The distribution of cycle acceleration rates are different from those in the individual truck data.

x) Engine inertia was ignored in developing acceleration rates for the proposed cycle, resulting in an overstatement of the power an engine is capable of delivering.

xi) Only two cities were used in the data base, and only urban driving was represented.

xii) Horsepower models for Cape-21 data analysis were developed from extremely limited data bases.

xiii) Motoring torques were not measured during the Cape-21 study; those present in the test cycle are the result of guesswork and inherently unrealistic.

xiv) Evidence was presented at the Public Hearings that no engine could follow the cycles without help of a motoring dynamometer. It was claimed no vehicle could follow it at all.

Aside from Cape-21, Chrysler Corporation maintained that loadings on the transient tests were unrepresentative of those found on smaller GVW trucks - a majority of Chrysler's production. Chrysler suggested EPA recognize the noncommercial usage (e.g., motor homes) of some of the heavy-duty engines they manufacture, and recommended the use of a chassis procedure using an appropriate road load. In short, shouldn't there be separate certification requirements for non-commercial HDV's?

The comment was also received that the operation of engines in speed control mode on EPA's and SwRI's transient dynamometers was unrepresentative of actual on-road operation and would result in artificial emissions. Torque control is a more logical and technically-correct strategy. EPA's transient data base is exclusively speed control-generated and thus claimed to be highly unrepresentative.

c. Validation

Another major concern of the industry pertained to the lack of knowledge about the correlation of emissions measured on the transient test with those in the real world. The assertion was made that EPA has failed to show that the proposed procedure correlates with real world emissions any better than the current procedures. Furthermore, should better correlation be established, it was argued that it must be of a sufficiently superior degree to justify the capital expenditures necessary to adopt the transient test. It was claimed that the only method which can establish this correlation is an actual on-road testing program. Most commentors supported the validation approach outlined by Professor Philip Meyers at the May Public Hearings.

EPA used an on-road program (San Antonio Road Route) to conclude that the current test procedures are unrepresentative. The industry claims it is only logical that the same procedure be applied to conclusively demonstrate the validity of the new procedure. Yet it was claimed that EPA has not even demonstrated emission correlation between laboratories testing on the new procedure, let alone correlation with the real world. Furthermore. in light of the purportedly questionable methodology used in developing the cycle, and in light of the legal decision in Paccar, Inc. vs. National Highway Traffic Safety Administration (i.e., that administrative agencies are obliged to test whether their standards and procedures perform in the manner to which they are designed) EPA is obligated to validate the proposed procedure on the road prior to its implementation.

d. Evaluation of Alternatives

The manufacturers also claimed that the Agency failed to adequately explore alternatives to the complex and expensive proposed procedure. Industry claimed that errors in the Cape-21 methodology are serious enough to warrant review of the data and to regenerate alternate test cycles. The main thrust of their arguments, however, claimed that EPA violated its expressly stated intention and its legal responsibility under the CAA to consider alternatives; EPA's sole rationale for this approach was a lack of time. It was advanced that nowhere in the regulatory support documents is there evidence that EPA considered simpler, more cost-effective procedures.

A case in point of EPA's rejection of alternatives involved a simpler transient procedure submitted to the Agency by MVMA on February 13, 1978. It is claimed that this proposal was rejected without adequate consideration of its merit (i.e., based upon EPA's limited resources available to evaluate the proposal).

e. Inability to Comment

A legal issue raised in the comments involved the industry's claim that they have been deprived of the due process of law. The majority of the industry does not have experience with transient engine testing, nor do they have the facilities needed to acquire this experience. The few manufacturers who are running transient cycles have only been operational for a short time. This scarcity of data and experience with the proposed procedure has purportedly curtailed the industry's ability to knowledgeably comment on the proposed procedure and its feasibility. It was claimed that this has effectively resulted in a deprivation of due process and the industry's right to comment under the law.

f. Technical Adequacy

Further comments pertained to the questionable ability of the proposed procedure to accurately and repeatably measure emissions. The opinion was expressed that there may be significant emission variability problems. To operate on different equipment at the full range of the permitted validation specifications may result in excessive variability and serious correlation problems between laboratories.

g. Alternative Cycles (Caterpillar Cycle)

Caterpillar suggested that slight modifications to the proposed cycle would allow diesel manufacturers to retain their eddy current dynamometers for transient testing, thus saving time and money. A specific cycle capable of being run on an eddy current dynamometer was proposed.

h. Technical Details

Several manufacturers questioned the need for a CVS system, citing both technical problems with bagged NOx measurements and the existence of cheaper and more readily available alternatives.

Diesel manufacturers claimed that no need existed for a 12-hour cold soak for diesel engines; in fact, cold start diesel emissions were characterized as equivalent to those measured on a hot start. A cold start requirement for diesels was described as overly burdensome and technically unjustified. Gasoline manufacturers also cited the fact that a 12-hour soak requirement unnecessarily tied up dynamometers and recommended consideration of a forced cool-down. Should the cold cycle be reweighted to a smaller degree, as also advanced by the industry, a cold start would be even less technically justified.

The remaining comments on the test procedures were highly technical and detailed in nature. Resolution of these issues is expected to have a minimal effect on the outcome of the test procedure issue as a whole. These comments will be addressed in Part II of the Summary and Analysis of Comments.

3. Analysis of the Comments

a. Justification

The argument of "arbitrary and capricious" is easily refuted. The explicit goal of the Agency from the early 1970's onward has been to develop a representative certification test procedure for heavy-duty engines. A consistent and deliberate progression towards a transient procedure ensued, based upon the Agency's early judgment that a transient test was inherently more representative of in-use operation. The allegation that EPA's methodology and technical judgment were "arbitrary and capricious" is rhetorical and not based on fact. A brief synopsis of the history of the proposed test procedure will serve to illustrate that the development process was technically sound, consistent through time, and based upon a reasonably perceived need. The final justification for a change in test procedures relies upon proof of the current procedure's inadequacy, quantification of the incremental air quality benefits, and an evaluation of the overall cost effectiveness of the proposed procedural change.

The Agency's dedication to development of a transient procedure is well documented in Agency records. The exact methodology used in deriving the transient test was identified as early as 1972:

"Most of the activity on this project will be directed toward the long range development of the realistic test procedure. This effort will involve several elements, the most important ones being 1) the acquisition of truck-operating data in New York and Los Angeles through the APRAC-CRC CAPE-21 project, 2) the use of a computer program to process the road data and generate representative engine duty cycles, 3) the development of a technique for determining mass emissions of HC, CO, (and) NOx.... emissions from gasoline and diesel engines, the refinement of a suitable test procedure and 4) the preparation of regulations."* Table A-1 highlights the events and decisions which followed.

It is significant to note that the fundamental methodology cited above was not arrived at by EPA alone. This approach was arrived at through cooperative interaction between EPA and the regulated industry in the form of a jointly-funded on-road data

* Summary of ECTD program plans for FY 1973, Project II.2., "HDV Revised Exhaust HC, CO, NOx, and Smoke."

acquisition program. The New York phase of the Cape-21 project was managed by committee with representatives from both industry and EPA. (EPA withdrew from the committee following the New York study due to concerns about conflict of interest implications of jointly-funding programs with a regulated industry (see Exhibit A-1) The Agency carried out the Los Angeles half of the study on its own, but using identical methods and instrumentation as in the cooperatively conceived New York study. (Further discussion of the industry's awareness and involvement in this test procedure development process appears later.)

The Agency's early decision to push for a transient certification procedure was initially brought on by observations of light-duty emission control. The manufacturer's ability to selectively optimize emission control systems to pass simplistic test procedures (in this case, the 1968 California 7-mode) was recognized early on; this resulted in the eventual selection of the transient LA-4 driving cycle for light-duty certification. Furthermore, the "Ethyl Study"** comparison of steady-state and on-road tests vs. transient cycles concluded that transient tests are inherently superior predictors of actual in-use emissions.

Whereas the duty cycles for light-duty passenger vehicles were relatively easy to model, the tremendous variety and interchangeability of heavy-duty engines, driveline, and vehicle applications presented a serious logistical problem in deriving a driving cycle representative of an "average" truck. The next three years were spent in the accumulation of a vast data base from which urban truck usage patterns could be modeled. This was followed by two years of data editing and the generation of driving cycles. At the same time, various EPA contracts (summarized in Table A-2), studied the relationships of various transient, modal, and on-road tests.

The data collected in these contracted studies led EPA to the following conclusions:

i) At intermediate levels of emission control, emissions reductions measured on steady-state procedures were somewhat related to on-road reductions, and formed the basis for interim emission standards.

ii) No combination of steady-state modes or modal weighting factors could consistently predict transient emission reductions, i.e., transient tests were inherently superior. (See Exhibits A-2 and and A-3.) Furthermore, based upon this and light-duty experience, at higher levels of emission control current test procedures failed to correlate with the on-road data.

** Study 2, Table A-2.

Based upon conclusion i), and recognizing the fact that a transient procedure was far from finalization, interim emission standards based upon the steady-state tests were promulgated in 1977. Note, however, the following excerpt from the Environmental Impact Statement accompanying these interim regulations (August 4, 1977):

"...[C]urrent test procedures are inadequate predictors of on the road CO and NOx emissions* (i.e., a given reduction in emissions measured...results in a much smaller reduction...on-the-road ... Development of a new heavy-duty engine test procedure is currently under way...In the interim, modifications to the current test procedure...will improve...[their]...accuracy...and result [in] greater reduction in on-the-road emissions than is now being obtained."

The transient test procedure development continued with the selection of candidate cycles, upgrading dynamometer control systems, and actual baseline testing.

This transient baseline work established the practical feasibility of the proposed transient procedure, during which time the test procedure was refined, and allowed in-laboratory comparisons between transient and modal procedures.

This in-house testing provides the "hard data" demonstrating the inadequacy of the 9-mode gasoline procedure for prediction of in-use emission reductions at the future levels of control. Table A-3 summarizes the current technology and prototype engine testing to date. The current technology summary indicates that even at today's level of control, the 9-mode underestimates emissions measured over a transient test. (For HC, this underestimation is on the order of a factor of 6, for CO a factor of 3.5.)

An examination of applied catalyst technology (that level of technology universally conceded by manufacturers in their comments and testimony to be necessary to comply with the proposed standards on either test procedure - see Summary and Analysis: Standards, Standards Feasibility) reveals even larger discrepancies. Note that the GM 400 and the Ford 351 were originally certified in light-duty vehicles and consequently the 9-mode results exceed the proposed standards. The addition of an air pump to the 400, while reducing the 9-mode emissions to virtually insignificant levels, reduced the transient emissions to a much lesser extent. In fact, transient CO emissions were virtually uncontrolled. This, plus the

* Following the accumulation of actual transient test data in 1978, it was determined that all gaseous emissions are inadequately predicted by steady-state tests. See data presented below in this analysis.

data from the remaining retrofit heavy-duty engines, prove that certification of gasoline engines on a steady-state procedure would result in serious underestimation of on-road emissions. Engines equipped with catalysts sized merely to pass the 9-mode test would emit CO at virtually uncontrolled levels under transient and high power operation on the road.

This in-house data supports EPA's early judgments based on light-duty experience, supports the results of the on-road studies outlined in Table A-2, and graphically contradicts the manufacturer's claim that a 9-mode can be representative at future levels of emission control.

The only study referenced by the manufacturers proving 9-mode correlation with a transient test was "Surveillance Testing of Medium-Duty Gasoline-Powered Vehicles" (California Air Resources Board Report No. VE-78-021, April 1978). This study showed equivalent percentage reductions, reflecting the increasing stringency of standards through the years of various model year vehicles, measured both on a chassis 9-mode and the transient LA-4 light-duty test. However, no trucks with a GVW greater than 8,500 lbs. were tested and in the words of the report, "...these vehicles are primarily vans and pickup trucks which are functionally light-duty vehicles..." The fact that the 9-mode predicts percentage reductions for light-duty vehicles operated on a light-duty procedure does little to assure the same degree of effectiveness on heavy-duty vehicles and gives further evidence of the 9-mode's inadequacy for heavy-duty. Light-duty tests results are not indicative of heavy-duty working emissions. The light-duty LA-4 test procedure was derived from on-road vehicle speed traces and represents an "average" trip for an urban passenger car. For a given trip a passenger car engine "transports" less than 6,000 lbs.; a heavy-duty engine "transports" vehicles and cargoes totaling into the tens of thousands of pounds. Furthermore, for a given vehicle acceleration, a heavy-duty engine undergoes many more transients due to the higher number of gear ratios. For a cruise at a given speed, heavy-duty engines work substantially harder to overcome higher windage and rolling resistance. In short, the operational characteristics of heavy-duty engines are so different from light-duty engines (a point brought out in all of the commenters' submissions which pointed out the severity of the heavy-duty working environment), that separate test procedures for heavy and light-duty were developed in the past. The emissions generated over the procedures are not comparable, regardless of the level of technology. The fact that the test procedures were not comparable, and the fact that the 9-mode seriously understates transient emissions was conlusively demonstrated at the EPA laboratory when a General Motors light-duty van with a 1979 prototype, catalyst-equipped 400-CID engine was first tested on the light-duty LA-4 and Highway Fuel Economy chassis cycles. The engine was then removed, set-up on the engine dynamometer and run through a transient test. The results are presented below:

	Proposed Transient Cycle (g/lb fuel)	9-Mode FTP (g/lb)	LA-4 (g/lb)	HWFE (g/lb)
HC	3.53	1.77	1.51	0.420
CO	210.50	100.20	31.70	32.48
NOx	3.71	5.66	3.05	3.40

The transient light-duty cycle is not comparable to heavy-duty cycles, nor are the measured emissions.

The proposed transient procedure contains several modes of operation not present in the steady-state tests;* these were cited in the Draft Regulatory Analysis as rationale for a transient procedure on the logical presumption that the more accurately a test procedure reflects operation in the real world, the more accurately emissions measured on that test procedure will reflect real world emissions. If the proposed cycles do indeed contain all significant modes of heavy-duty engine operation in their proper sequence and proportion, then it is only logical to assume that emissions generated over the cycle are also representative. Furthermore, given the choice of two test procedures, each yielding different results, is it not logical to presume that the emission results generated through the more representative test would more accurately model the real world, especially when actual on-road and laboratory data substantiate the inaccuracy of the less-representative test? It is concluded that not only is the 9-mode unrepresentative, but its use would result in gross and unacceptable errors in the prediction of on-road emissions, especially when incorporated with catalyst technology. A 90 percent reduction in on-road emissions utilizing the 9-mode test procedure is impossible to guarantee.

The only remaining alternative would be to restructure the 9-mode test. Necessary modifications would entail the inclusion of 100 percent power modes to include WOT and power valve operation which would more accurately simulate the power levels present in the LA-freeway, and more accurately subject the catalyst to power levels present in the real world and ensure its proper sizing. Furthermore, as illustrated by actual test results presented in Figure 1, cold start HC and CO emissions will have significant effects on measured emission levels. Note that hot start hydrocarbons for this engine lie well below the proposed standard, yet properly weighted cold start emissions result in a composite test result exceeding the standard. With the catalyst properly sized to handle the CO emissions, the same effect occurs (see Figure A-2). Therefore, any restructured steady-state test would also require

* Transient operation, a full range of engine speeds and loads, cold start operation, representative weightings of test modes.

cold modes to adequately simulate the real world. However, no steady-state gasoline procedure has ever demonstrated an ability to correlate with on-road and transient procedures at lower levels of control on anything but an engine specific basis (see Report 7, Table A-2). The presence of transient enrichment devices, the operation of which are completely ignored in any steady-state procedure, operate a large percentage of the time in the real world.*

Figure A-2 presents the test results of a catalyst-equipped engine which meets the proposed standards.** Note that CO levels on the highly transient, yet low horsepower New York non-freeway segments, are significant. (Mass CO emissions were 34.5 grams for high-powered Bag 7(LA Freeway), 12.0 grams for highly-transient Bag 8, New York Non-Freeway)). Therefore, not only are high power modes necessary to model the real world, but transient modes are also significant in their effects on measured emissions at catalyst levels of technology. Finally, the industry has demonstrated an ability to optimize emission control performance on any given test procedure. Caterpillar stated this fact rather bluntly in their written comments:

> "This circumvention may be unintentional, but manufacturers have no choice but to design engines to meet whatever test is prescribed. For this reason the cycle must be as representative as possible of real world operation." (Emphasis ours).

Furthermore, many comments were received claiming that the proposed cycle defies modal analysis and would be very difficult to design to. ECTD interprets this to mean that it is easier to design around a test procedure than it is to design a clean engine.

Based upon this ability, the historical inability of any steady-state procedure to consistently correlate with any transient operation, and a rational engineering judgment firmly supported by the available data that the inherent transient carburetion characteristics of gasoline engines have a significant effect on emissions, the ECTD technical staff concludes that no steady-state procedure will be better than the proposed transient test for gasoline engines.

The case for the transient diesel test rests on the cost-effectiveness of additional HC control, to some extent on consideration of future regulations, and on proof of the inadequacy of the 13-mode for prediction of HC emissions at the 1.3 g/BHP-hr level.

Test results for diesel engines tested at Southwest Research

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* Cape-21 data indicated that 53.4 percent of all gasoline truck operation was transient in nature: 26.2 percent accelerations and 27.2 decelerations.

** 1979 GM 292 I-6 retrofit with a single Englehardt catalyst.

Institute are summarized in Table A-4. On the average, 13-mode HC understates the transient HC by a factor of 2.5. CO levels are low enough to conclude that a change in test procedure is not justified for CO control.

To assess the benefits of the proposed test procedure change for diesels, this analysis makes use of 1979 diesel certification data, industry testimony at the July 16-17, 1979 Public Hearings, and engineering judgments and assumptions explained below.

To predict the incremental HC reductions over the average diesel engine's useful life due to a change in test procedure, the following information must be known, or predicted to a reasonable degree of accuracy:

i) Current (1979) HC emission levels for all diesel engines, as measured on the 13-mode test (these are available from certification records).

ii) Projected 1979 sales for all HD diesel engines (confidential certification records).

iii) All available transient HC data for 1979 diesel engines.

iv) An average BSFC for diesel engines (for our purposes, we shall assume 0.430 lb/BHP-hr).*

v) Average on-road diesel fleet fuel economy (for our purposes, we assume 5.6 mpg).**

To achieve a 1.3 g/BHP-hr transient standard, assuming a 10 percent AQL, Chapter 7 of the Regulatory Analysis determined that a production target of .89 g/BHP-hr will be necessary. This target level represents the low mileage production emission mean levels necessary to assure with 90 percent confidence that 90 percent of all engines selected for a Selective Enforcement Audit (based upon a sample size of three engines) will meet the 1.3 g/BHP-hr HC standards.

Table A-5 summarizes transient vs. 13-mode HC emissions on engines tested at SwRI and Cummins.

Caterpillar has quantified the transient/13-mode ratio, based upon SwRI and their own limited data, at 2.65. Furthermore, Caterpillar also notes that this ratio increases as transient HC decreases (i.e., at lower levels, the 13-mode increasingly under-

* Based upon SwRI transient data (13-mode data is comparable).

** 1978 sales-weighted fleet average (see "Cost Effectiveness," Chapter 7 of Regulatory Analysis).

states transient HC). On this basis, if engines with transient HC less than 0.8 (as presented in Table A-5) are excluded, the revised transient/13-mode ratio becomes 2.40. Within the range of emissions which will most likely have to be reduced for compliance with the 1.3 g/BHP-hr transient standard, this appears to be a reasonable estimate.

The final consideration is the emission reductions which would have occurred if the 13-mode were retained and the standards derived from the gasoline steady state test.. A 90 percent reduction from sales-weighted 9-mode data acquired in the 1969 baseline program indicates a HC standard of 1.0 g/BHP-hr. For an accurate assessment of reduction due solely to implementation of the transient procedure, any reduction needed to bring 13-mode HC below 1.0 g/BHP-hr could not be counted. Assuming a slightly smaller production distribution as compared to that for the transient standard, the manufacturers' likely target goal would be approximately 0.7 g/BHP-hr.* Table A-6 contains the tabulated summary of this analysis.

Total sales-weighted grams HC/BHP-hr per truck is 0.318. Based upon a density of 7.1 lb/gallon for diesel fuel, an average diesel fleet fuel economy of 5.6 mpg, an average useful life of 496,000 miles, and an average BSFC of .430 lb/BHP-hr, then the sales-weighted average lifetime reduction attributable only to a change in test procedure equals .316 g/BHP-hr/.430 lb/BHP-hr x 7.1 lb/gallon x 1/5.6 mpg x 475,000 miles x 1/454 g/lb x 1/2000 lb/ton = .49 tons.

Based upon our analysis of the expected benefits versus the cost of compliance for HC using a transient test, the cost effectiveness of this strategy for diesel engines attributable solely to the change in test procedure is $77/ton, assuming a 10 percent AQL.**

Other considerations cited in the Draft Regulatory Analysis for the implementation of a transient procedure for diesel engine certification still apply. Due to the anticipated difficulty in attaining forthcoming NOx and particulate standards, a transient test will be even more important in assuring compliance with these regulations. The legitimacy of EPA's "future regulations" argument was severely questioned. There is merit in the manufacturers' arguments that unproposed regulations cannot justify present proposals; justification must rely on the technical merit and cost effectiveness of the proposed procedure. However, it would be technically nearsighted for the Agency to ignore the potentially significant impact of future proposals either mandated

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* This assumes that the standard deviation of production emission means is proportional to the level of the emission standard, as testified by various manufacturers.

** See Economic Impact Analysis.

by Congress (75 percent NOx reduction in 1985) or currently under preparation by the Agency (particulates). It is not responsible for EPA to leave in place a procedure we know full well to be inadequate now, and which is expected to be even worse in the future. Furthermore, diesel engines are increasingly being equipped with turbochargers; it is well known that turbocharger performance is influenced by transient engine operation. Increased dieselization of the future fleet due to fuel economy pressures is also cause for ECTD's concern, especially in the market segment consisting of smaller, higher-speed diesels. Caterpillar testified in their supplementary written statement to the July 16, 1979 Public Hearings that smaller, higher-speed diesels tend to produce higher levels of HC. In relation to their 3208, Dina family 3 engine, Caterpillar stated:

> "...This engine has a greater surface-to-volume ratio in the combustion chamber because of a smaller displacement and stroke-to-bore ratio. Finally, and most importantly, this engine operates at higher speeds than other engines in our product line. The fact that smaller high speed diesel engines produce higher HC emissions was also voiced by Cummins Engine Company in their testimony at the July public hearing. Such engines are generally used to replace gasoline engines (which operate at high speeds) to achieve significantly improved fuel consumption. Small high speed diesel truck engines represent a significant fraction of all diesel truck engines manufactured in this country."

Not mentioned was the fact that economic pressures demanding higher fuel economy will increase the market share of smaller diesels, effectively increasing their impact on overall air quality problems.

In summary, continued use of the 13-mode for certification to the proposed standards would result in an understatement of the hydrocarbons generated during transient operation in an urban environment; this is the basis for EPA's claim that use of a transient procedure would result in greater confidence of a true 90 percent reduction. The fact that additional HC control will actually occur was vividly illustrated by the testimony and comments of several manufacturers; it was claimed that several of each manufacturer's engine family's would not meet the proposed transient HC standard (i.e., additional emission control is required). Finally, it has been demonstrated above that the additional emission control attributable only to the change in test procedure will be cost effective.

The question now arises: can an equivalent degree of emission control be predicted by a more stringent standard based upon the 13-mode procedure? Data from SwRI and Cummins is presented in Figure A-3. Correlation between transient and 13-mode BSHC emissions is weak. In their testimony in the July 16-17 Public Hearings on the proposed standards, Cummins made the statement that they have been unable to derive a correlation between the two test procedures. The predictive value of the 13-mode test procedure disappears at emission levels at and below the proposed standard, and consequently is not a viable test procedural alternative. The only remaining alternative is a new steady-state procedure. The only data available to the Agency at this time (Report 7, Table A-2) (Exhibit A-3) suggest that this is not acceptable, especially in light of the increasing stringency of other standards.

To summarize the Agency's analysis of comments pertaining to justification of the transient test, on the basis of engineering judgment, on-road studies, and laboratory testing, it is believed that current steady-state test procedures are overly simplistic and inadequate predictors of actual in-use emissions. It has been demonstrated that concrete air quality benefits will result from implementation of a transient test, and that the change in test procedure is cost effective and economically justifiable.

b. Representativeness of the Proposed Test Cycles

Inherent in the justification for any test procedure is the requirement that the procedure be representative of real world usage. EPA's derivation of the transient procedure from the Cape-21 data base was harshly criticized as producing an unrepresentative result.

The manufacturers claim that the engine torque estimation techniques (i.e., using manifold vacuum, rail pressure, and rack position) were invalid during transient operation, over 53 percent of the Cape-21 data base.

First of all, it must be noted that at the time of the Cape-21 study, the use of manifold vacuum, rail pressure, and rack position were generally accepted methods of engine load estimation within the heavy-duty industry. Secondly, this very approach was recommended by the CRC-EPA Joint Committee, primarily in light of the fact that no practical alternative existed.

The major fault of these estimation techniques is the inherent time delay between a change in the measured parameter and a change in engine output load, the extent of that delay depending on the rapidity of the change. For example, the use of manifold vacuum for gasoline engines anticipates by some fraction of a second the output shaft torque; opening of the throttle plate immediately changes the vacuum level in the carburetor throat, yet an increment of time is necessary for that change in pressure to manifest itself in increased fuel flow, travel of the new charge through the intake manifold into the cyclinder, compression of the charge, and smooth power transmission during the combustion expansion cycle. To measure instantaneous engine flywheel torque, the accuracy of the measurement within time depends upon the proximity of the measured parameter to the output shaft.

The ideal situation is the actual measurement of shaft torque by use of a shaft torquemeter. This approach was rejected for Cape-21 as being impractical and cost prohibitive. For a truly representative sample to be obtained in Cape-21, observation of actual in-use commercial trucks was a necessity. In order for EPA to acquire, instrument, and deinstrument these trucks, they had to be taken out of service; one of the conditions of the usage agreements with the vehicle's owners was the fact that the vehicles' time out-of-service be limited to overnight. Installation of driveshaft torque meters, entailing custom driveshaft modifications for each individual truck, would have been time-consuming and expensive, and thereby would have limited those trucks available for EPA study. Furthermore, as outlined in Report 6, Table A-7, p. 30, commercially available torquemeters had a tendency to oscillate under transient conditions on the road, resulting in technical problems as well.

The most technically correct compromise involves measurement of a load factor parameter as close as possible to the output shaft. No measurable parameters were closer in time to the output shaft than manifold vacuum for gasoline engines, and rail pressure and rack position for diesels. (It could be argued that direct measurement of instantaneous fuel flow rate would have resulted in a slightly smaller time delay for diesels. ECTD does not view this as a significantly better alternative, however, due to the absence of accurate fuel flow instrumentation which could be readily installed on a vehicle. In fact, the parameters measured are themselves excellent indicators of instantaneous fuel flow.) For gasoline and naturally-aspirated diesel engines in on-road vehicles, the time delay associated with these measured load factor parameters is on the order of less than one second. ECTD does not consider these small time lags (and resulting reference torque overestimations (see below)) as large enough to invalidate the data base, and ECTD considers the load factors measured as reasonable estimates of shaft torque.*

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* Cape-21 pressure transducers were installed on gasoline engines at the EPA Motor Vehicle Laboratory, and a continuous record of manifold vacuum vs. shaft feedback torque was taken. In the case of a radical step change of engine speed and load, shaft torque lagged manifold vacuum by as much as two seconds; however, a step change on a dynamometer is considerably more drastic service than that seen on the road. During running of the highly-transient New York Non-Freeway cycle, indicative of transient, in-vehicle operation, at no time did feedback shaft torque lag manifold vacuum by more than <u>three tenths of a second</u>.

In the case of turbocharged engines, however, longer time delays are present due to the added inertia of the turbocharger itself. This had been observed at SwRI by the apparent "sluggishness" of turbocharged diesels over the transient cycle, and by the lower totals of integrated brake horsepower-hour achievable over the cycle while remaining within the valid regression limits. It will be useful at this point to detail what was actually measured in Cape-21, and its resultant impact on the proposed cycle.

Consider an instrumented Cape-21 turbocharged diesel truck cruising with constant engine parameters. The driver opens the rack to affect a vehicle acceleration. The instrumentation records the open rack as an increase in shaft torque although the increase in actual shaft torque is delayed. Yet an actual vehicle acceleration, as recorded by a change in vehicle speed, must wait until that actual shaft torque is available. For any given acceleration, opening of the rack preceded shaft torque and vehicle acceleration by a constant time increment. This effectively anticipated shaft torque has been carried over into the transient diesel cycle. Note the percent torque commanded at 25, 26, 214, 215, 321, 322, 377, 558, 927, 928, 1,116, and 1,117 seconds of the proposed diesel cycle. In these cases, acceleration from idle is preceded by a full one to two seconds of open rack--precisely what would happen in real life, until the engine/vehicle accelerates. The cycle performance criteria, however, do not penalize an engine for this real lag. That the reference cycle itself overestimates the torque achievable is indicated by the high integrated brake-horsepower-hour levels. Yet, what actually occurs during an emission test over the proposed cycle, as has been observed at SwRI, is that the engine undershoots the integrated brake-horsepower-hour target by as much as 15 percent (the validation limit) per the performance capability of the engine, while the torque regression line statistics approach the upper limit of validation (reflecting nonpenalization of the engine for "sluggishness" and the accumulation of high torque points at relatively high power non-turbocharger or power lag affected points). The net affect is a "validation window" within which the engine performance is permitted to fall. It is ECTD's technical opinion that although the proposed reference cycle may overestimate transient torque available--especially for turbocharged diesels--the actual cycle the test engine will follow in response to this command cycle is indicative of what was observed on the road in Cape-21, and is not unrepresentative due solely to turbocharger or nonturbocharger lag. (The relative amount of turbochargers present in the Cape-21 data base is evaluated later in this analysis.)

It was claimed that the cycle hot/cold weighting factors were unrepresentative of the data base. This claim is made based upon Report 11, Table A-7, which when subjected to Ford Motor Company's and MVMA's analyses, yielded significantly lower cold start weightings. It is our judgment that Ford's analysis misinterpreted the data. Were the report to be read more carefully, it would be ascertainable that the 1.6 percent of gasoline operation quoted by Ford and MVMA represented that portion of operation which was "truly cold." Based upon the warm-up characteristics of the Cape-21 trucks, there was 100 percent certainty that engine temperature had not stabilized (i.e., 1.6 represents a lower bound of cold operation for gasoline trucks); 3.0 percent was the lower bound for diesels. Also in the report and overlooked by Ford and MVMA was an upper bound above which there was 100 percent certainty that the engine temperature had stabilized, and as such represented the upper limit of percent cold operation. (The upper bounds were 7.4 percent for gasoline and 11.1 percent for diesels.) The report's objective was to quantify these ranges, knowing that the average percent of cold operation lay somewhere between. This study served to verify the accuracy of the weighting factors which were derived in another report (Report 13, Table A-7), and also served to characterize the fact that operational differences between cold and hot trucks were negligible. The applicable Cape-21 data from that report is summarized below:

	Median Trips Per Day			Median Trip Length (Mins.)		
	LA	NY	Sample Size Weighted Avg.	LA	NY	Sample Size Weighted Avg.
Diesel Trucks	5.93	2.92	4.43	27	26	26
Gasoline Trucks	7.83	10.38	9.06	12	8	10

Assuming a nominal engine warm-up time of 5 minutes, as did Ford in their analysis, the average percent cold operation derived from the above data is:

- Gasoline: 100% x 5 min. x 1/(9.06 x 10) = 5.5%.
- Diesel: 100% x 5 min. x 1/(4.43 x 26) = 4.3%.

The proposed test procedure, assuming again a 5-minute warm-up time, yields:

- Gasoline: 100% x 1/7 (5 min. x 60 sec/min)/ 1167 = 3.7%
- Diesel: 100% x 1/7 (5 min. x 60 sec/min)/ 1199 = 3.6%

In point of fact, EPA's cold weighting for the transient test procedure is very close to that observed in the Cape-21 data, and contrary to the comments received, slightly understates the cold emissions.

Manufacturers claimed that the proposed cycles contained unrepresentative overspeed. However, the overspeed in the cycles is indicative of the overspeed actually observed on the roads of Los Angeles and New York. The EPA technical report on cycle selection (Report 12, Table A-7) explained the meticulous screening process for candidate cycles which was performed to ensure that their speed and power distributions accurately resembled the data base. Figures A-4 to A-15 are reproduced from this report and show the actual distribution of speeds and powers for both the derived cycles and the Cape-21 data base input. (A candidate cycle, the New York Freeway, did exhibit excessive amounts of overspeed; this was eventually traced to an erroneously recorded rated speed for the engine in NY Truck 9.* The cycle was discarded.) ECTD finds no basis for the claim of existence of unrepresentative speeds in the proposed cycles.

The industry harshly criticized the cycle generation technique, whereby pattern sequencing of greater than one second was ignored (i.e., use of the one-second Monte Carlo technique).

It is acknowledged that the Monte Carlo cycle generation technique did not result in the characteristic rpm/load traces normally seen during vehicle accelerations as the driver upshifts through the several gears. The proposed engine cycles were developed in the following way: Each % rpm/% power pair observed during the Cape-21 study was assigned a "transition probability" for every % rpm/% power pair in the data base (i.e., the change from Engine Condition A to Engine Condition B was assigned a definite probability of occurrence). These probabilities reflected the frequency of occurrence observed in the Cape-21 data base. The cycle generation technique produced a continual progression of engine transitions which accurately represent the actual transitions and their frequency of occurrence observed in the 88 trucks in New York and Los Angeles. Additional statistical tests were performed on the numerous cycles generated to determine which cycles were "closest" to the data base in terms of several other parameters. (See Report 12, Table A-7 for a more detailed discussion of the final selection procedure). The cycles eventually selected are statistically equivalent in composition to the data base, and every pertinent engine state and engine state transition observed in Cape-21 is accurately represented. On the overall question of use of the Monte Carlo technique for cycle generation, Malcolm Smith in his June 7, 1979 submission to J. Hafele of Caterpillar declared "...unrealistic rpm excursions have a very small frequency of occurrence and hence have a very low probability of being selected during the cycle development process."

The claim was made that a large percentage of the recorded

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* 6.9 percent of the New York non-freeway cycle data base stems from New York Truck 09. Assuming a 20 percent error in rated speed carried through 6.9 percent of the cycle results in less than 1.4 percent error throughout the entire cycle.

Cape-21 data was "spurious," arising from electrical and vibrational "noise" and not actual truck operation. In particular, Professor Meyers questioned the accuracy of the vehicle speed and rack position indicators, and argued that "spikes" observable on rpm versus vehicle speed plots were indicative of erroneous instrumentation. EPA was also criticized for purported failure to calibrate the instrumentation after each truck day.

First of all, the instrumentation and methodology developed for the Los Angeles Cape-21 was identical to that used in New York, and developed by the industry and EPA. Secondly, in EPA's two year's experience with the instrumentation, the only occasion that highly erratic, "spurious" engine/vehicle parameters were recorded was the occasion outlined in the appropriate report (Report 9, Table A-7, p. 40) (i.e., the vehicle speed encoder at zero speed). Professor Meyers testified that he believed that this encoder gave off erratic signals at all speeds. This was not the case. The report clearly states the problem and its resolution:

"The optical encoder, however, because of vibration when the vehicle was idling, sometimes recorded speeds as high as 15 mph when the vehicle speed was zero. That is, a vehicle might stop where the target was partly in view of the encoder window. As a result of vehicle vibration, the target would oscillate into and out of the window, generating an input signal to Channel 5. The tach generator was, therefore, put back in the system and its output fed to Channel 10. Thus, when the vehicle was moving, Channel 5 gave an accurate measure of vehicle speed. When the vehicle was stopped, the tach generator gave a reliable zero-speed signal in Channel 10. Therefore, whenever Channel 10 showed zero speed, Channel 5 was zeroed."

This "fix" was also accomplished in the LA study (Report 1, Table A-7, p. 21). There is no basis for the assertion that the chopped wheel, which was coupled directly to the speedometer drive, gave erratic signals when rotating (i.e., the vibration produced speed voltages only at zero speed). Finally, Report 8, Table A-7 summarizes Olson Laboratories' report to the MVMA concerning EPA's Cape-21 data collection techniques. Conclusion 7, p. 1-3 states "...The vehicle speed measured with the EPA instrumentation correlated well with the speeds measured with a 5th wheel..."

On the overall question of sensor integrity, adequate precautions were taken to ensure accurate recordings of vehicle parameters. Refer to Report 6, Table A-7, pp. 103-104, in which the four separate instrumentation validation procedures were described. These procedures included visual checkout of transducer output every half hour during truck operation, and three distinct checks for unusual signal variation during and after the raw data tape transcription process. Anything out of order was immediately corrected or thrown out after-the-fact. In the New York study, instrumentation was calibrated both before and at the end of each truck day (Report 6, Table A-7, pp. 34-38) and also prior to installation in a new truck (Report 6, Table A-7, p. 39). Calibration at the end of each truck day was not performed in LA due to time constraints (the vehicles had to be returned to their owners immediately after testing); however, transducer calibrations were monitored from truck-to-truck. No truck-to-truck changes were observed, leading ECTD to believe that no significant calibration discrepancies occurred during a single day.

Finally, both Professor Meyers and Caterpillar attempted to quantify the "spurious" content of the Cape-21 data. They assumed that all out-of-range points were "spurious," and that these out-of-range points deviated by a constant percentage from the true signal. Extrapolating this constant percentage throughout the entire data base, an estimate of total spurious points was made.

A review of the data collection and editing processes is necessary to adequately respond to the above analysis. Prior to on-road data gathering, each truck was instrumented and run on a chassis dynamometer. On the dynamometer, the engine was "mapped," (i.e., at 250 rpm increments across the entire range of engine speeds). Fifteen levels of engine torque were measured at each speed. The result was the matrix graphed in Figure A-16 (referred to in Cape-21 as an EVSL matrix). As explained in Report 9, Table A-7, p. 49, 100 percent load for any truck was approximated as a linear function of speed. Measured on-road load factors were thus "normalized" during the editing process, i.e., expressed as percentages of this approximated 100 percent load. (The same was also done for the zero-load function.) This linear interpolation of maximum load was not without error. In actuality, a maximum load function is curved; this linear interpolation therefore approximates the maximum torque available at all speeds. It is not surprising that actually measured on-road load factors sometimes exceeded this 100 percent approximation (see Figure A-16).

Table A-8 presents the actual edited output for a particular truck. This is the output analyzed by Professor Meyers in estimating the "spurious" content of the signal. A step-by-step review of the editing record is warranted:

i) RPM above MAXIMUM: This represents the number of points exceeding 150 percent rated speed. (150 percent was an arbitrarily chosen cut-off point. As explained above, it is believed that overspeed in the data is indicative of overspeed actually occuring on the road). 150 percent was intended as a gross check on the data; note that no points were deleted.

ii) RPM between 0 and 300: 300 rpm was arbitrarily chosen as the minimum speed at which continuous engine operation was reasonable. This by no means biased the cycle since actual time at a given speed determined the probability of the speed ending up in the cycle. Furthermore, speeds measured below 300 rpm (7 points for this summary) are reasonable; engine starts and stops were included in the data base and it's only logical to presume that some engine speeds were measured during starting and stopping.

iii) RPM below 0: This would be a fair indication of "spurious" data. Note that there are none.

iv) Load factor above 100 percent plus 13mV: To allow for small transducer calibration variations, transducer feedback of 13 millivolts in excess of 100 percent were allowed to be retained in the data base. For this edit summary, 71 points were measured in excess of this upper limit. As outlined above, ECTD believes that these out-of-range points were actually achieved on the road and were only considered excessive due to the conservatism of the linearly interpolated EVSL model. Another possibility for on-road out-of-range maximum loads was inherent in the chassis dynamometer; any tire slip at maximum power would result in less torque being measured at the engine for that speed. The chassis dynamometer therefore may have slightly underestimated maximum available torque. These underestimations are not serious, however, as evidenced by the small number of on-road points actually measured in excess of the model (.4%).

v) Load factor between 100 percent and 100 percent plus 13 mV: See D.

vi) Load factor between 0% load and 0% load minus 13 mV: Similar to the maximum load method, 13 millivolts were also allowed for transducer variation below the minimum load factor line.

vii) Load factor below 0% minus 13 mV: Both F and G reveal the number of on-road torque parameters (i.e., manifold vacuums, rack displacements, etc.) measured to produce less than zero power. Should random spurious signals exist as claimed, it is only logical to presume they would be evident here also. Note that none exist.

vii) Speed above 70 MPH: It was arbitrarily decided that truck operation over 70 mph would not be used for cycle development purposes. Any points measured in excess of 70 mph were discarded.

ix) Speed negative while moving: This would also be a good measure of random "spurious" signal noise, yet only one point was measured. It is reasonable to assume that for at least one second during the entire day, the truck actually rolled backwards (e.g., while engaging the clutch from stop on an uphill grade).

x) Delta speed exceeding AMAX: EPA developed a theoretical maximum acceleration model for use as a check on the on-road speed data. It was highly conservative, assuming low vehicle mass and maximum engine torque, and was meant to eliminate obviously impossible accelerations in the development of chassis dynamometer cycles. (Decelerations were not characterized, nor worried about, in the data base simply because decelerations are not solely attributable to engine motoring, but primarily to braking.) Only 0.6% of all accelerations were thrown out as unrealistic. (This assumes 36 discarded points, 19,680 total records, and 30.2% of the driving time - the LA gasoline truck average - spent in accelerations.)

xi) Speeds to be zeroed: As discussed above, this is simply the number of speed points registered as positive due to vibrational excitation of a stopped optical encoder, and registered as zero by the tach generator; this occurred only when the vehicle was at rest.

The remainder of the edit output in Table A-8 relates which points were interpolated or eliminated. (The interpolation and elimination process is described in Report 9, Table A-7, p. 41.)

As explained above, Professor Meyers and Caterpillar assumed out-of-range points were generated by random signal noise. In point of fact, this "noise" was never observed during sensor calibration on the chassis dynamometer when significant vehicle vibration was present; all sensors when observed at steady-state engine conditions yielded steady and repeatable results. (Electrical ignition noise was an initial problem, however, on gasoline trucks. This noise was eliminated by the use of capacitors and spark suppressors in the ignition system, and the use of a separate power supply for the data logger and support instrumentation.) In summary, no random "spurious" signal noise was observed during calibration, and as presented above, out-of-range data was in all likelihood physically real and represented the slight inaccuracy of the load factor models. ECTD has confidence in the accuracy of the recorded data and rejects any claim of significant spurious content. <u>Engine operational parameters used for cycle development were those actually measured on the road</u>.

The comment was made that future diesel engines will be exclusively turbocharged, and that the proposed cycles were developed from a non-turbocharged data base. In point of fact, some turbocharged engines were included in the data base, yet it must be conceded that the percentage of turbocharged engines in the Cape-21 study (21 percent) was significantly less than that anticipated in the future. EPA is faced with the practical problem of studying a constantly changing fleet; given a finite time interval required to analyze data and produce cycles, the present and future fleet will always be different from that which was studied. ECTD believes that the test cycles are representative of the data base studied. ECTD has no data, however, which shows that turbocharged truck's usage patterns are different enough from non-turbocharged vehicles to warrant abandonment of this transient test. However, future modification of the test cycles to incorporate the performance characteristics of new technologies is by no means precluded by retention of the proposal at this time.

It has also been claimed that discrepancies exist between operational mode distributions in Cape-21 and the distribution in the proposed diesel cycles. Table A-9 details the time distribution of the four major modes.

These comments arose due to erroneously compiled data published in the Draft Regulatory Analysis. Table VI-C, p. 122 of the DRA simply presented the arithmetic mean of the tabulated modal data from Cape-21, without regard for freeway/non-freeway weighting factors. Reports 12 and 13, Table A-7, present an in-depth discussion of the cycle selection and weighting procedures; however, data from these reports are presented in Table A-10, and summarized in Table A-9. The Cape-21 weighting factors were derived from the amount of time individual trucks spent in freeway/non-freeway operation; the actual cycle weighting factors were derived from the length (in time) of each segment relative to the total cycle length. Upon examination of Tables A-9 and A-10, it should be obvious that the only gross discrepancies between modal percentages arise from the steady-state procedures. The proposed cycle adequately represents the operational mode distribution observed in the Cape-21 data. (The largest deviation between Cape-21 and the proposed cycles lies in the 5.1 percent difference in idle percentages on the diesel cycle. This corresponds to .051 x 1,199 = 61 seconds of additional idle. For the dirtiest (by a factor of two) diesel engines tested to date at SwRI, a 1978 Caterpillar 3208 with an idle HC emission rate of 38 grams/hour, the total effect of the additional 60 seconds of idle is insignificant--approximately .027 grams/BHP-hr*-less than the tests' round-off error.

It was claimed that engine power was overstated due to lack of consideration of engine inertia in computing acceleration rates. In point of fact, engine inertia was ignored in the study and resulting cycle development. Engine crankcase torque is composed of four components:

i) Torque necessary to accelerate inertial masses (including vehicle, wheels, and drivetrain, but not the engine**);

ii) Torque due to gravitational effects on vehicle mass while on gradients;

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* 38 grams/hr x 60 seconds x 1/3600 hours/second = .63 additional grams. .63/23.3 BHP-hr (transient integrated BHP-hr for a 1978 Cat. 3208) = .027 g/BHP-hr difference.

** Torque arising due to engine inertia can only be observed at the driveshaft when the engine is being driven, not when the engine is driving.

iii) Torque necessary to overcome driveline and tire-to-road friction, and

iv) Torque necessary to overcome aerodynamic friction.

Measurement of the engine load parameter at the engine resulted in measurement of the sum of these four components; the magnitude of any individual component was irrelevant. Acceleration rates for the cycle were determined by the transition probability matrix from the accumulated Cape-21 data (i.e., the probability of a given change in engine speed is directly dependent upon the observed frequency of occurrence of that change in speed in the Cape-21 data base).

Engine inertia and available power pertain more directly to operation of a given engine over the proposed cycle itself. Comments were made that engines would be unable to follow the speed cycle without the help of a motoring dynamometer; engine inertia was too high and available horsepower too low.

Engine driveability over the transient cycle is engine-specific. Based upon observations and cycle performance summaries of engines run on the transient cycle at EPA's laboratory, most engines are capable of generating sufficient torque during speed accelerations to produce residual positive torque at the drive-shaft. Some engines, however, when subjected to a step change in throttle position (i.e., a step acceleration command, tend to stumble, develop insufficient torque, and are motored up to speed by the dynamometer. This occurs on a minority of engines and at worst 10-15 places during a test. Assuming 3 seconds per stumble, this corresponds to less than 2 percent of the test. The remaining 98 percent of the time the engine drives properly and representatively. Not only is this true for carbureted gasoline engines, but also for the most sluggish turbocharged diesels observed at SwRI.

The prime cause of this performance lag phenomenon is most likely the inherent driveability characteristics of individual engines. It must be reiterated that it is an average cycle. The transition probability matrix used in cycle development determined a probable transition from one speed/torque pair to another, based upon frequencies of occurrence of such transitions in the data base. The data base was varied (i.e., different engines were used in different vehicles in different applications). This is further complicated by the effects of vehicle speed and gear ratios, up and downhill operation, and by the presence of many different engines in many different vehicles. The speed/load transitions in the test cycles accurately represent the frequency of those transitions' occurrence in the Cape-21 study. It is quite probable, however, that transitions arising from an engine in a lightly-loaded truck in low gear in the Cape-21 fleet are present in the cycles, and quite frankly overstate the performance capability of another engine on a test stand trying to follow the accelerations and demanded torques under its own power. This has been complicated by the use of throttle parameters as engine power approximations during the Cape-21 study. As discussed earlier, however, the inherent time lag between throttle movement and a torque increase is represented in the cycle itself (as evidenced by engine speed accelerations lagging torque accelerations by one to two seconds), and is not so drastic as to prohibit the majority of engines from following the cycle under their own power. The few which can't are motored for 2 to 3 seconds several times during the test. For a test whose most significant emission contributions come from the high-power, low-transient LA-freeway, these few points (at worst less than 2 percent of the cycle) are insignificant contributors to the final emission test results. It is emphasized, however, that the test procedure validation criteria do not penalize an engine for inability to develop full torque during steep accelerations.

Caterpillar testified that certain portions of the proposed cycle violated laws of mechanics, in particular where 100 percent power occurred simultaneously with an engine acceleration, the point being made that no power remains to cause an acceleration. This is indicative of confusion in the industry between road load horsepower and engine horsepower. Operation at 100 percent road load horsepower would indeed curtail desired accelerations; EPA's proposed cycle, however, is designed around engine horsepower. Consider a vehicle traveling at an intermediate speed at an intermediate level of power. Calling for wide-open throttle at this point results in 100 percent engine power, a portion of which continues to nullify road load resistance and the remaining portion represents the inertial power leading to vehicle acceleration. As clarified above, the proposed cycle makes no distinction between the four components of engine torque. Assuming 100 percent engine power operation, an increase in the inertial power component (i.e., an acceleration) results simply from a decrease in one or more of the remaining road load components (e.g., coming over the crest of a hill).

In summary, ECTD recognizes the fact that some engines may have a more difficult time developing torque during certain accelerations; this is inherent in the technical compromise resulting from development of an average cycle. As mentioned in the earlier discussion on cycle development history, this average cycle performed on an engine dynamometer is the only practical certification method available. Those speed/load transitions asked for in the cycle are representative of those seen in real life. ECTD has modified the test validation criteria to forestall penalizing any engine incapable of following these few accelerations. Most importantly and contrary to comments received, at no times are physical laws of mechanics violated nor does the dynamometer drive the engine through accelerations, except for the few cases outlined above.

Certain comments were directed at EPA's selection of only two cities for the road study, and the use of only urban driving. It can only be reiterated that time and resource constraints limit the scope of any research project, be it marketing research, election voter polls, or on-road truck studies. It should be noted that the industry-staffed Coordinating Research Council, in conjunction with EPA, selected New York and Los Angeles as two cities representing both the worst air pollution problems and the two most diverse in terms of traffic flow and usage patterns. (Refer to Report 7, Table A-7, for further discussion). Furthermore, mobile source pollution is an urban problem and requires urban characterization. The choice of equal weightings of New York and Los Angeles data was a judgement made in the absence of any data or rationale to the contrary.

Furthermore, the truck samples observed by EPA in New York and Los Angeles were claimed to be unrepresentative of the urban and national truck populations with respect to vehicle GVW. ECTD argues that this claim is inaccurate. Tables A-11 and A-12 depict Cape-21 vs. U.S. yearly production GVW distributions for both all trucks and diesel trucks only. Agreement between the sample and the population percentages is good. Furthermore, Reports 2, 3, 6, and 7 (Table A-7) document the truck population research and the resulting sampling plans derived for Cape-21 for both New York and Los Angeles. The truck sampling plans incorporated all relevant truck characteristics as defined by the population studies (e.g., two axle, three axle, tractor-trailer; Reports 2 and 3, Table A-7), and the actual sample followed the sampling plans with little deviation (Reports 6 and 7, Table A-7).

Several commenters criticized EPA for failure to include trucks of GVW less than 10,000 pounds, claiming they represent a majority of truck population. In point of fact, most trucks under 10,000 lbs. GVW are classified as light-duty, and it was not EPA's intention to generate driving cycles for light-duty vehicles. The truck percentages of heavy-duty vehicles between 8,500-10,000 lbs. GVW are presented in Table A-11. The physical difference between trucks rated at 8,500-10,000 lbs. and those rated 10,000-14,000 lbs. GVW are small; in many cases they are identical vehicles. At the time of the Cape-21 study, this weight class of trucks represented a small percentage of the total. (One reason why the percentage of HDV's less than 10,000 lbs. GVW has increased in recent years is that many light-duty trucks were rerated into the heavy-duty class to escape the light-duty certification test procedure.) Several vehicles rated exactly at 10,000 lbs. GVW were included in the Cape-21 study; these were included in the 10,000-14,000 lbs. class.

In summary, EPA went to great lengths to assure that the sample observed in the Cape-21 study was as representative as possible of the overall truck population. Furthermore, to assure that the survey would be even more representative, actual in-use commercial vehicles driven by their owners in normal day-to-day operation were used. ECTD is confident that the trucks sampled in Cape-21 were highly representative of the real world.

One manufacturer ventured to comment that the distribution of cycle acceleration rates in the proposed cycle was different from those observed in individual truck data. These claims were made on the basis of one truck's plotted operational data; it is no surprise that any given truck's operational data could apppear different from an average cycle derived from the data contributed by a total of 88 trucks. It has already been shown that the overall percentages of operational mode distributions for Cape-21 and the proposed cycle agree closely, and that the cycle's second-by-second transitions accurately reflect the frequency of such transitions' occurrence in the data base.

The horsepower models used by EPA in translating Cape-21 data to power levels used in the proposed cycles came under attack. The main criticism claimed inaccuracy of the models and too small a data base from which the models were derived. In Report 8,* Table A-7, Olson Laboratories reported to the MVMA that:

i) "The EPA finding for Cummins diesels that percent power is a function only of percent fuel pressure, and is independent of engine rpm, was validated by the engine-dynamometer data for the two sample engines." (p. 1-2)

ii) "The EPA finding that percent power for gasoline engines is equal to percent load factor (manifold vacuum), computed at each engine rpm, was essentially validated by the engine dynamometer data for the two sample engines." (p. 1-3)

The only discrepancy with the Cape-21 models discovered by Olson in their analysis was the percent rack travel procedure used for Detroit Diesel engines. Based upon dynamometer data for two DDA engines, Olson concluded that the EPA model--derived from a single DDA engine--understated percent power to a significant degree. The error was on the order of 10 percent at 80 percent power, and increased as the actual level of power decreased.

ECTD's original assumption in development of these models was that a single model could be used for all engines utilizing the same load factor parameter (i.e., rail pressure, manifold vacuum, and rack position). This assumption was validated in the cases of rail pressure (Cummins) and manifold vacuum (gasoline engines). However, the engine-to-engine differences in rack position (DDA) engines appears significant enough to cast doubt upon the universal validity of any single model. At the time, however, ECTD's model

* This study was initiated and funded by the MVMA.

was based upon the best data available. (In fact, the data used by ECTD was collected and supplied by DDA.) Due to engine-to-engine differences, there is no assurance that the engines tested by Olson for MVMA are any more representative than the engines tested by DDA, yet due to this variability, ECTD recognizes that some error in the horsepower model may exist. It is, however, a predictable error, occurring only at lower horsepowers where emissions are impacted least and does not diminish the overall validity of the test procedure. The error is further minimized by 50 percent of the data base consisting of the accurately modeled Cummins engines. On the whole, horsepower models used in converting Cape-21 data to power levels for cycle development were accurate and relatable to all engines; where inaccuracy occurred, its impact was minimized by the factors listed above.

Finally, since the absolute level of motoring torque was never measured in the Cape-21 study, its inclusion in the data base was described as "guesswork." While motoring torque was never measured, we are confident when it occurred. (Each truck was instrumented to indicate throttle position.) The test procedure will be proposed such that any cycle point described as motoring actually means closed throttle or any negative torque command necessary to achieve closed throttle.*

To summarize ECTD's analysis of comments pertaining to representativeness of the proposed test cycles, it is acknowledged that certain compromises were made, and indeed had to be made, in the data collection and cycle generation processes if any practical on-road study of truck usage patterns and cycle development programs were to be accomplished in a reasonable time at reasonable cost. Many of these early compromises in data collection (e.g., manifold vacuum and rack position as approximations for flywheel torque) were made by the industry-staffed Coordinating Research Council; for the industry to demand that EPA do the impossible or the impractical while they themselves claim "unreasonable burdens" or "impossibility" is self-contradictory. Consider a statement made by MVMA in its February 13, 1978 letter to J. DeKany (EPA-former ECTD Division Director):

> "...Considering the diversity of design and use of heavy-duty gasoline powered vehicles, it is probable that no "representative" driving cycle exists. Heavy-duty vehicles include ambulances, school buses, pickup trucks, cement mixers, delivery vans and tractor/trailer hauling rigs. Each of these classes of vehicles have drivetrains and usage patterns peculiar to their design function..."

* See Summary and Analysis of Comments - M. Numerical Standards/Standards Derivation. An exception to this closed throttle mode is the use of -10 percent torque command during motoring modes for gasoline engine tests.

"...No single cycle can accurately characterize the emissions of these...types of vehicle usage."

MVMA went on to propose an alternate procedure, substantiated by no on road data whatsoever, which it claimed:

"...Would encompass all emission related transient conditions of engine operation...and be representative of real world heavy-duty engine operation."

Recognizing the difficulty of establishing true "representativeness," and constrained by the requirements of a workable certification program, ECTD has been convinced from the beginning that use of a single certification test cycle required development from an actual on-road data base to assure the maximum representativeness possible. ECTD is confident that in any subsequent review, be it technical or legal, it can be proven that the judgments and decisions made were sound, were based upon practicalities and the resulting data represents the most comprehensive and the highest quality data available. Although a virtually infinite number of transient cycles are possible, ECTD believes that those chosen adequately represent the data base.

In most other cases, manufacturers' criticism of the data collection and cycle development processes arose from a lack of information, or misinterpretation of data or the processes themselves.

It is ECTD's judgment that the proposed transient cycles were the best attainable within the resources of the Agency. The Cape-21 survey was the largest and most ambitious road survey of heavy-duty truck usage patterns in history. The resulting cycles were not perfect and as such are subject to change; however, they adequately represent usage of the average truck, and will predict in-use emissions significantly better than any of the available alternatives.

Aside from the cycles themselves, ECTD's method of dynamometer control was also attacked as unrepresentative (i.e., use of speed control versus the use of torque control). This will be elaborated on in greater detail later (see "Caterpillar cycle"); suffice it to say here that ECTD does not consider this dynamometer control strategy a threat to representativeness, but rather a more expensive option for the diesel industry.

Chrysler Corporation's comments pertaining to the chassis testing of non-commercial, low-GVW HDV's have merit. The Agency, however, is not in a position to adopt Chrysler's proposed resolution of this matter. Following the decision to pursue engine dynamometer testing (see "Evaluation of Alternatives," later in this analysis), ECTD diverted resources towards development of an engine procedure. No emission work has been performed to characterize chassis vs. engine dynamometer cycle emission differences. Furthermore, all transient data to date was derived from engine testing. Two alternatives exist, however. See §86.083-27(b)(1) of the Proposed Rules in which any manufacturer who feels the proposed procedure is unsatisfactory for a given engine may prescribe a new test procedure by written application to, and subject to approval by, the Administrator. Furthermore, current regulations allow optional certification on the light-duty chassis procedure for all trucks rated at 10,000 lb. GVW or less. This test is equivalently stringent, yet consists of the lighter duty cycle for which Chrysler has argued.

c. Validation

Manufacturers raised the issue of on-road validation of the transient cycles. It was argued that EPA could not conscionably promulgate a transient test without this on-road study.

No on-road or chassis dynamometer study of emissions from late model trucks has been performed, nor is one forthcoming to address this issue.

The manufacturers have argued that the transient cycle must be conclusively proven on-road. This is an acceptance criteria never required for promulgation of the 9- or 13-mode. Furthermore, the manufacturers recommended retention of the steady-state tests, one of which (9-mode) has been proven to be grossly unrepresentative of future levels of control both in-lab and on-road (Tables A-2 and A-3), and the other (13-mode) deemed to be highly questionable at less stringent emissions levels now, and expected to be even worse in the future.

To argue for retention of unrepresentative, invalidated test procedures on the premise of a need for on-road validation is logically contradictory. It is the ECTD technical staff's judgment that on-road validation is really a question of representativeness and based on the following premise: the closer to real life operation an engine is operated in the laboratory, the closer the emissions measured in the laboratory will be to those actually found on the road. Heavy-duty truck operation, and therefore heavy-duty emissions, are application-specific. The objective of CAPE-21 was to arrive at an "average" duty cycle for an "average" urban truck. Any given application wouldn't necessarily correlate with emissions measured on the average cycle. To choose an on-road application identical in duty cycle to the test procedure itself would prove nothing. A road validation of the average cycle would require a CAPE-21-sized study, but of a significantly higher complexity due to the need to measure emissions both on controlled and precontrolled vehicles. Such an endeavor would delay promulgation of a transient procedure for years, while retaining steady-state procedures which ineffectively measure transient emissions, which can easily be designed around, which guarantee no real world emission reductions, and which are grossly inadequate for assuring attainment of the mandated 90 percent reductions.

Furthermore, EPA has always recognized that on-road validation of any single test cycle would be virtually impossible. For this reason, the Agency took great pains to assure that the cycles developed were based upon extensive on-road data and utilized meticulous cycle generation processes to assure that emissions generated over these cycles would be representative of in-use vehicles.

In summary, while no actual on-road testing of the proposed cycles has been performed, to do so would require a massive effort of several years duration. To delay promulgation of a transient procedure would assure non-attainment of the legislated 90 percent reductions in the time desired. Moreover, the technical staff believes the proposed cycles are sufficiently representative for the reasons discussed above to guarantee that emission reductions measured on the proposed procedure would be repeatable in real life.

d. Inability to Comment

Another major issue raised by the commenters was the fact that industry lacked transient testing experience and facilities; this effectively hampered their ability to comment on the proposed rules.

Inherent in this argument is the claim that the industry was surprised and unable to respond adequately. Such is not the case; the development of the transient test procedure has been well publicized to the industry for the last seven years. From the initial cooperation on CAPE-21 to the publication of the February 13, 1979 NPRM, the communicative interaction between industry and EPA has been open, comprehensive, and deliberate:

i) Over 6 years prior to the February 13, 1979 NPRM, EPA and the industry-staffed Coordinating Research Council (CRC) managed a jointly-funded on-road truck usage study for the specific purpose of deriving representative test procedures.

ii) Over 4 years before the NPRM, the then Deputy Assistant Administrator, Eric Stork, chaired a meeting between the EPA staff and the Engine Manufacturer's Association (EMA) in Ann Arbor, Michigan on November 20, 1974. Exerpts from the meeting's record include the following statements by EPA:

- "Advanced test procedures including representative urban engine cycles are under development and expected to be proposed..."

- "Gasoline and diesel engines are being treated separately in cycle development, however, both will be evaluated against common standards..."
- "Transient duty cycles are likely to result but EPA is open to a modified steady-state test if transient operation of diesel engines is not a significant influence on emissions."
- "Equipment associated with transient duty cycles will likely be DC-motor generator dynamometers with multi-channel tape control. Possibly, an eddy current absorber with AC motor, also tape controlled would suffice."

iii) Over 28 months before the NPRM, a detailed briefing of the industry covering all aspects of CAPE-21 and the test procedure development programs was given by EPA staff members in Ann Arbor, Michigan on September 30, 1976. In attendance were representatives of the entire heavy-duty industry.

iv) Twenty-three months before the NPRM, at the March 17, 1977 EMA meeting in Ann Arbor, Michigan, EMA was briefed on the status of the cycle development. EPA requested that EMA member companies evaluate the transient control capabilities of dynamometers at their own facilities. (This was eventually followed-up by limited transient testing at Cummins Engine Company during the summer of 1977.)

v) Twenty-one months before the NPRM, RFP No. CI 77-0147 was released in May 1977, to solicit bids for a baseline testing contract. The RFP's detailed Scope of Work outlined the procedural details and the equipment needed to perform transient testing of heavy-duty gasoline and diesel engines. At least one company, General Motors, obtained a copy. The actual Scope of Work of the eventual contract was sent to EMA in the September 7, 1978 letter of R. Nash (EPA) to D. Carey (EMA).

vi) Twenty months before the NPRM, a June 21, 1977 letter from the Deputy Assistant Administrator Eric Stork, to Thomas Young of EMA declared, "The benefits of a transient procedure are sufficiently attractive to commit us to the development and study of transient cycles through a baseline emission program....[T]he intent of this plan is to develop a transient procedure so that it may be used in future regulations."

vii) Over 15 months before the NPRM, EPA requested production statistics and sales data for 1969 MY gasoline engines from the Motor Vehicle Manufacturers' Association (MVMA) in an October 20, 1977 meeting. EPA's explicitly declared intention was to use the data in the design of a transient baseline testing program from which emission standards would be derived.

viii) Over 11 months before the NPRM, EPA began transient baseline testing of 1969 and current technology gasoline engines in March of 1978. Not only were manufacturers contacted for assistance in providing engines and repairing malfunctioning parts, but several manufacturers sent representatives to the MVEL to observe the actual transient testing and testing facilities.

ix) Six months prior to the NPRM, the Draft Recommended Practice for the proposed transient test procedure was published in August 1978. The Foreword of the Recommended Practice stated,

> "These procedures are expected to form the basis for new test procedures that will be implemented concurrently with the new, more stringent emission levels for 1983 model year HD vehicles....A Notice of Proposed Rulemaking (NPRM) incorporating the new standards and transient test procedure will be forthcoming."

The procedure published in this draft document was practically identical to that published in the NPRM. No comments from the industry pertaining to the Recommended Practice were received.

In summary, the industry has no right to claim that it was not informed of test procedural developments, nor that it has not had the ability to comment, criticize and provide inputs to the procedure development process. EPA has freely shared all transient emission data acquired by the Agency, and its contractor. Any inability of the industry to comment based upon the inadequacy of their own facilities is largely self-imposed. As shown above, in March of 1977 EPA requested EMA to evaluate transient dynamometer capabilities, followed-up by limited transient testing at Cummins. Since that time, the majority of the industry* has done little to acquire transient capability.

Secondly, the lack of transient testing ability was not necessarily a deprivation of due process.

The gasoline engine industry received the detailed information and data acquired during all transient testing at EPA's laboratory. Furthermore, the process of standards derivation was throughly documentd and distributed to the industry before the Public Hearings and well before the close of the comment period. (See Report 14, Table A-2.) Enclosed in this report were detailed information

* It is interesting to note that of all the companies affected by this package, Cummins was the first to acquire transient testing capabilities, and has been the most progressive company in terms of emission control. This is reflected in the fact that 93 percent of Cummins 1979 unit engine sales already comply with the proposed 10 percent AQL production targets necessary for compliance with a 1.3 g/BHP-hr HC standard, as compared to a 36 percent industry average.

on the transient test procedure and associated equipment, and a summary of EPA's accumulated experience with the procedure. In terms of feasibility analysis, (the area in which an inability to conduct transient testing would be most restrictive), the gasoline engine industry has unanimously realized for some time that catalyst technology will be required. The cycle information included in the NPRM (which gives the specific power levels required by the transient procedure), the availability of transient light-duty catalyst data, and the dissemination of transient catalyst data resulting from testing at the EPA laboratory all allowed the industry to make a well reasoned extrapolation of what their product lines require to achieve compliance. In fact, the major criticism embodied in the feasibility comments and the major feasibility problem is not test procedure related, but the issue of in-use durability of heavy-duty catalysts. In short, the gasoline industry did have a basis for comment on the proposed rules, and these comments have been addressed.

The diesel industry was also given the results of EPA's transient data, which was acquired at SwRI. Furthermore, both Cummins and Caterpillar were able to submit data during the comment period which was acquired through actual transient testing at their own facilities. As with the gasoline industry, the major area in which an inability to test would restrict the ability to comment would be feasibility analyses. Data acquired at SwRI allowed a reasonable comparison of transient results relative to the industry's steady state data base, and as stated above, two diesel manufacturers were conducting transient tests on their product lines. For those manufacturers who were not running transient tests, data was made available to provide a basis for comment.

In short, the development of the transient test for heavy-duty engines is a logical extension of the earlier rationale for requiring a transient test for light-duty vehicles. The Agency has freely communicated this intention since 1972. The Agency has shared all available data, and openly broadcasted its intentions and solicited comments through the years. In all fairness to the diesel manufacturers, however, it has been EPA's position throughout the cycle development process that should a steady-state procedure yield comparable results with the transient, the simpler procedure would be used. Transient diesel data has only recently become available, resulting in a relatively late decision to retain the transient test. However, diesel manufacturers were alerted in the NPRM and we can only reiterate our position of having openly disseminated all data upon its availability, and having openly announced our desire through the years to implement a transient procedure if one were warranted.

e. Evaluation of Alternatives

Most commenters criticized EPA for purportedly ignoring

Executive Order 12044 by failing to consider simpler and less-expensive alternatives to the complex transient procedure. ECTD disputes this contention; Figure A-17 and the discussion below outline ECTD's thought processes while evaluating test procedural alternatives.

Use of a given test procedure entails an inherent compromise between practicality and representativeness. For heavy-duty engine emission testing, the ultimate procedural simplification is the use of a steady-state test. Based upon several studies, in-house and contractual testing, and reasonable technical judgments based upon the preceding data and light-duty experience, EPA reached the conclusion that the current steady-state procedures at present and especially future levels of control are unjustifiably simplistic. (See arguments for justification, earlier in this analysis.) In short, the present tests are unacceptable alternatives.

Questions then arise as to the viability of modifying the steady-state procedures (i.e., adding and/or reweighting steady-state modes to produce a more representative test. A 23-mode test procedure was performed in 1972 on 8 gasoline and one diesel engines (Table A-2, Report 3, Part III); it was concluded that the additional modes did little to improve the test. Furthermore, the results of the "Sensitivity Study," (Table 2, Report A-7) indicated that reweighting of any steady-state test could not achieve consistently correlatable results with emissions generated over a variety of transient tests (i.e., the probability of a reweighted 9- or 13-mode proving viable was minimal (see Exhibits A-2 and A-3).)

Based upon this and upon experience with the industry, EPA concludes that no steady-state test can remain valid as technology progresses. Technology is developed based upon the test procedure, and an overly simplistic test becomes less realistic as more technology is applied to certify on it. (A case in point is the 9-mode itself: Compare 9-mode vs. transient emissions for pre-controlled engines and then current technology engines. The discrepancies between the two procedures increased dramatically with increasing control technology. Furthermore, both Cummins and Caterpillar in the Public Hearings expressed no basic disagreement with the concept of a transient test. In the evaluation of test procedural alternatives, the Agency chose to use most of its resources in that area where the highest probability of success existed (i.e., a transient procedure based upon real world operational characteristics of trucks). To further pursue the steady-state alternatives when those alternatives seemed inadequate and represented approaches which were not likely to succeed, would in all likelihood have delayed development of the representative test procedure.

Having judged that a transient test is preferable, remaining alternatives to be considered are modification of the proposed cycles, or the substitution of alternate cycles.

It is sufficient to state here that modifications to the proposed cycle and procedure based upon comments received are being responsibly considered in this Summary and Analysis, and if feasible and meritorious, will be adopted. EPA is therefore addressing its legal responsibility under Executive Order 12044 to evaluate simpler and more cost-effective alternatives. (Specific modification and procedural details are addressed later in this analysis.) The question of alternate and presumably simpler transient cycles (including chassis cycles) now arises.

Considerable internal debate within ECTD occurred over the viability of a transient chassis procedure.* Performance of an actual emissions test on a chassis dynamometer would be simple (much like a light-duty LA-4), but the actual certification program would by necessity be extremely complex and much more costly due to the large number of engine/vehicle configurations and the need for very large chassis dynamometers. A manufacturer would be required to certify an engine for several different applications and vehicle configurations. The MVMA realized this fact early, and in a January 16, 1974 Discussion Paper presented to EPA on April 11, 1974, strongly advocated an engine dynamometer test.

Furthermore, EPA also considered the alternative of certification based upon numerous cycles, to be selected based upon a vehicle's application. This, however, would have entailed a much more burdensome certification program, and to minimize burdens on the industry, EPA consolidated the cycles as much as was justifiable.

Finally, in a February 13, 1978 letter to John DeKany of EPA, MVMA proposed a simpler transient procedure. This letter represented the only in-depth transient procedure alternative submitted to EPA during the entire cycle development process. It came at a time when EPA was already running 1969 baseline tests (i.e., after EPA had already devoted considerable money, time, and manpower to development of the Cape-21 generated cycles, and to the Congressionally-mandated uncontrolled baseline test program). ECTD's formal response (letter of May 17, 1978, C. Gray (EPA) to H. Weaver, MVMA) to this proposal follows:

> "...(ECTD)... staff has reviewed MVMA's proposed alternate test cycle. It is their opinion that, even with appropriate restructuring, it would not be representative of actual truck operation. EPA recently ran a test program where transient chassis cycles were "linearized." That is, steady state

* Issue papers from both the Heavy-Duty Group and the Certification Division were written, and are on file.

accelerations, cruises, and decelerations were used to duplicate, to the extent possible, the full transient cycles. Results were disappointing, with the linearized cycles giving significantly less HC and CO. One must remember that, even though the cycles were linearized, the engine was run through several gear shifts with resulting rapid changes in speed and torque. The MVMA cycle would be much milder, with smoothly changing torque and speed. Based on our experiment, it is not logical to assume that MVMA's cycle would yield results equivalent to the fully transient cycle while maintaining the long mode times MVMA desires. The MVMA cycle appears to be an improvement over the 9 mode, but we are concerned that a cycle with longer modal times might be easier to "design around" than a fully transient cycle. Finally, EPA does not have either the resources or the time (due to Clean Air Act requirements) to investigate the alternate MVMA cycle."

Acceptance of MVMA's offer of alternate cycle development would have effectively delayed promulgation of any transient test without any assurance that the alternative cycle would yield representive results.

In summary, EPA had neither the time nor resources to investigate every possible test procedure alternative. Regardless of this fact, the ECTD staff believes that only a transient procedure is technically correct, and that an engine dynamometer test is the most practical. As to the specific transient cycle, there are an infinite variety of possible transient tests, and it is categorically impossible to evaluate all possibilities. EPA never pursued the option of deriving a simplified transient procedure based upon the Cape-21 data base; it was believed that any simplification significant enough to result in substantial cost savings would also be substantial enough to seriously compromise test representativeness.* ECTD is, however, fulfilling its legal obligation by evaluating and addressing all comments received pertaining to the NPRM, and where possible, simplifications will be made to the procedure.

f. Technical Validity

Many comments were also addressed to the technical validity of the test procedure itself. The concern was raised that when the full range of dynamometer calibrations, validation statistics, throttle actuator performance, and transient control strategies are utilized, correlation between laboratories will be very hard to achieve. The resulting certification program will be confused and technically impossible to work with.

In general, the transient procedure as run in the past by EPA

* Exception: see "Caterpillar cycle," later in this analysis.

and SwRI was cumbersome at times and slow to produce results, due primarily to inexperience, equipment debugging and refinement, and general efforts at test procedure development. On the other hand, test results have been repeatable and not indicative of gross emission variability within the range of validation statistics. Furthermore, correlation on transient gasoline testing between EPA and SwRI has been reasonably established (see Table A-13), although some variability remains. General Motors has recently begun tentative transient testing on a 1979 Chevrolet 350-CID V-8 originally tested at EPA. Using a completely different emission sampling system (fuel based mass measurement integration versus EPA's CVS dilute sampling), GM achieved comparable results:

	BSHC	BSCO
EPA*	3.14 ± .70	118.1 ± 6
GM*	3.05 ± .13	107.5 ± 2.4

* Average of three tests.

Furthermore, Cummins has achieved comparable emission results with SwRI on an NTC-350:

	BSHC	BSCO
SwRI	0.74	4.51
Cummins	0.82	5.27

(Note: Cummins uses an integrated sampling technique for CO, HC, and NOx. Dilute bag sampling of NOx appears to be technically deficient insofar as unexplained losses of measurable NOx occur; the values presented above for NOx are bag values.)

In short, every lab for which transient emission data is available achieved some degree of correlation. Manufacturer's fears of gross correlation difficulties appear unfounded.

At any rate, we recognize that the test procedure itself requires fine tuning and streamlining. These problems, however, are not inherent in a transient test, and will be addressed in this document for inclusion in Final Rule. Actual certification tests are four years away; as industry experience is gained with the procedure, there should be no problem in modifying procedures, changing validation and dynamometer specifications, and making any changes deemed sound if actual testing experience suggests that additional changes to the test procedure are warranted. As was shown in the 1969 Baseline Technical Report, repeatability with the transient test was equivalent to the steady-state; ECTD finds no reasonable grounds for concluding that the test procedure is technically unsound.

g. Alternative Cycles - "The Caterpillar Cycle"

Diesel manufacturers suggested that the proposed diesel cycle be modified so that eddy current absorption dynamometers could be retained, resulting in substantial cost and time savings. Both EPA's and SwRI's transient diesel controllers use direct current motoring dynamometers, as do Cummins' and Caterpillar's prototype facilities. All transient diesel data to date have been obtained on motoring systems; we are forced to consider this suggestion in the absence of eddy current data.

Each dynamometer system would control the engine in different ways. Motoring dynamometers to date have operated in "speed control" modes (i.e., the dynamometer follows the speed cycle independent of engine performance, while the engine is "driven" over the torque cycle by automatic manipulation of the throttle or rack position). On the other hand, eddy current dynamometers operate in "torque control" modes (i.e., the dynamometer is simply a source of electric friction which loads down the engine over the torque cycle while the engine is driven through the speed cycle by operation of the rack.* These two control strategies could effectively result in different second-by-second speed/torque pairs at highly-transient portions of the cycle, possibly resulting in differences in the measured emissions. These emission differences, if any, are uncharacterized at this time.

Modifications to the proposed cycle would be aimed at eliminating highly transient and motoring portions where the two dynamometer systems would operate differently. Caterpillar has proposed exactly such a cycle in which 18 percent of the speed/torque pairs have been slightly modified, based upon the inertia/power characteristics of a single engine (see Figure A-18), i.e., the Caterpillar cycle is engine-specific.

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* Motoring dynamometers are capable of operating either in torque or speed control. EPA's original rationale for testing in speed control was an expedient, based upon the judgment that transient control of an engine dynamometer in speed control would be simpler and more guaranteed of success than the available options. Furthermore, there is a compelling safety reason for speed control: the engine is always restrained by the dynamometer and engine "runaways" are avoided.

Each change to the cycle in Figure A-18 is labeled to give the purpose of the change. The key to the change symbols is as follows:

A - speed cycle changed to allow coastdown during motoring.

B - torque cycle changed to eliminate motoring during a constant speed condition.

C - speed cycle changed to make acceleration compatible with a turbocharged engine and the prescribed inertia.

D - torque cycle changed to increase the torque to achieve the corresponding acceleration in the speed cycle.

The change to the torque cycle labeled E in Figure A-18 is only apparent in the unnormalized cycle. This change occurs in the cycle between 216 and 219 seconds.

ECTD's analysis of the Caterpillar proposal has taken two forms; a statistical analysis identical to the test validation regression analysis to determine how different from the proposed cycle the Caterpillar cycle actually is, and actual comparative emission tests on SwRI's motoring dynamometer.

The statistical analysis is presented in Table A-14. (For purposes of this analysis, the following engine parameters were assumed: idle speed = 700 rpm, rated speed = 2200 rpm, and maximum torque at all speeds = 100 ft-lbs.) All of the statistical parameters met the cycle validation criteria.* Based upon this analysis, the Caterpillar cycle is similar enough to the proposed cycle to qualify as a statistically equivalent cycle. The comparative emission tests run at SwRI produced somewhat similar results, which are shown in Table A-15. Of the two engines tested, one produced identical emissions, while the other produced 14 percent less HC and 8 percent less CO on the Caterpillar cycle. Cycle performance statistics for each test were comparable, as were total integrated BHP-hr's.

From this limited data, the ECTD technical staff reached the following conclusions:

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* This analysis regressed Caterpillar's command cycle against EPA's command cycle. The analysis assumed all "motoring points" represented closed throttle, and as such were thrown out of the regression calculation. Inclusion of a -25 percent motoring command unrepresentatively biased the regression, particularly where Caterpillar eliminated motoring points. Even so, a regression including motoring commands of -25 percent produced only one out-of-bounds statistic, the torque y-intercept (+26.0 ft. lbs.).

i) If in fact the Caterpillar cycle can be accurately run on an eddy current dynamometer (as Caterpillar has claimed to have done manually, and if in fact the modified cycle eliminated portions of the proposed cycle which were unachievable on the eddy current machine, then operation of the modified cycle on SwRI's motoring dynamometer should not be significantly different from the operation achievable on eddy current systems). Emissions measured on either system should be comparable, but not necessarily identical.

ii) Statistically, the cycles are similar enough to be deemed equivalent, at least insofar as emissions are concerned. Furthermore, the cycles are close enough that emissions generated over the proposed cycle can be estimated by operation of the proposed cycle, or even a slightly modified cycle, on eddy current equipment.

Based upon the above data, correlation between both dynamometer systems should be feasible. The implications this holds for certification is contingent on other factors, however. First of all, EPA and SwRI use motoring dynamometers. To date, manufacturers have consistently copied EPA's equipment for certification testing (e.g., Clayton dynamometers),* with an extra expense providing insurance or interlaboratory correlation. Every diesel manufacturer has already placed orders for at least one motoring dynamometer and CVS system, so there is no indication of a change in trend.

Secondly, although the limited data available indicates that correlation between motoring and eddy current systems is probable, this correlation is by no means guaranteed. Different control systems with different response characteristics will be used, and the degree of emission sensitivity to these differences is a legitimate technical question. Furthermore, the differences between diesel torque control and speed control have never been established. (SwRI is unable to run in torque mode; EPA's facility is still being debugged.) Correlation between eddy current and motoring dynamometers will not be established before Final Rulemaking. (No eddy current transient emission testing facility exists, nor can one be built up in less than six months.) Finally, EPA's proposed test regression tolerances, by demanding excellent speed statistics, essentially require a speed control test.

This lack of data will contribute to the manufacturers' avoiding the exclusive development of eddy current dynamometers if both the cycle and EPA's own certification facility remain the same. It appears that the proposed cycle is sufficiently similar to the modified cycle that it can be run on eddy current equipment closely enough to achieve comparable emissions relative to a motoring facility. In essence, there is no need to change the

* In the light-duty vehicle testing area.

proposed cycle if both motoring and eddy current dynamometers are anticipated. It is unreasonable to expect, however, that manufacturers will accept this and rush headlong into the development of exclusively eddy current facilities. Were ECTD to agree to either develop an eddy current facility, run the motoring facility in torque control mode (possibly voiding all SwRI data to date and in the near future), or establish definitive correlation between eddy current torque control and EPA/SwRI speed control, then exclusive development of eddy current dynamometers would be likely, resulting in the anticipated cost and leadtime savings. Torque control (or use of eddy current dynamometers) for certification would also require revision of the cycle validation statistics, most likely tightening the torque specifications and loosening the speed; in the absence of eddy current/torque control experience, such a revision would be no better than an educated guess. Due to the potential "runaway" engines, always a possibility when running under automatic control, torque control is riskier from a safety aspect. Finally, although instinctively one would expect no major difficulties running in torque control, it has actually never been done and at best remains unproven.

In summary, there is a lack of eddy current data. A decision to modify the cycle and pursue eddy current/torque control facilities could void all existing data, and a test procedure and control system known to produce repeatable and reasonable results; changes to the procedure at this time would be based upon conjecture and absolutely no data or experience. It is probable that the proposed cycle can be run on eddy current dynamometers with sufficient emission accuracy to allow characterization and development work, although manufacturer's certification facilities would almost certainly model EPA's and consist of motoring dynamometers. There is sufficient economic incentive for manufacturers to explore the validity of the eddy current option for development while developing motoring certification facilities, although their behavior in this respect is by no means certain. The viability of the eddy current development option is not guaranteed; it is our judgment that correlation between the two dynamometer systems on the proposed cycle is probable. Based upon this judgment, no modification to the proposed diesel cycle would be warranted.

One alternative would be to delay promulgation of the diesel transient test until definitive eddy current data is available. The timely acquisition of eddy current data would depend on substantial contributions by the industry, and the heavy-duty industry has never been in a hurry to regulate itself. EPA would be accepting certain delays when a viable, although certainly more expensive, transient procedure already exists.

Another alternative would be directed simply to allow additional time for investigation of the eddy current option. Optional use of either the transient or the 13-mode test would be allowed for one model year, the first model year for which the proposed regulations take effect. This effectively allows one additional year for the industry to aggressively investigate the viability of the eddy current option. This option should not be construed as an admission that EPA considers the 13-mode to be technically comparable with the transient test. EPA would be willing, however, to accept this compromise of technical validity for the sole and explicitly stated purpose of possibly reducing the financial burdens placed upon the diesel industry. The optional 13-mode standard would be derived to reflect the approximate stringency of the transient 1.3 g/BHP-hr standard (i.e., there is no relaxation in relative standard stringency, merely a test procedure option).

A final alternative can be considered. Should EPA modify the cycle to allow the use of eddy current dynamometers and run its own certification facility in torque control, then diesel manufacturers would not be compelled to invest in motoring facilties, resulting in a substantial cost savings without substantially impacting the air quality improvements attributable to a transient procedure (as evidenced by the agreement between the two cycles at SwRI). This has certain negative ramifications, however:

i) The data base at SwRI could be adversely impacted and possibly voided. This is tempered by the fact that only a few 1979 diesels have been tested to date and the loss of data would not be sizeable. More importantly, however, SwRI's equipment is not readily convertible to torque control. The particulate and NOx baseline work would be delayed by as much as two months.

ii) Eddy current dynamometers have never been characterized or proven for transient control. (Caterpillar has claimed otherwise.) It could be reasonably presumed that eddy current dynamometers are fully capable, if modified, for accurate and responsive transient control, but this is by no means a certainty.

iii) EPA is faced with the decision of how to modify the cycle. It has been shown above that the proposed cycle and Caterpillar's modified cycle are relatively similar. The proposed cycle could be maintained, or Caterpillar's engine-specific cycle accepted at face value with the explanation that the arbitrary cycle modification is justified on cost considerations above. ECTD could also invest engineering time (with or without the cooperation of the industry) in effecting its own modification to the proposed cycle. This would be time consuming if actual testing were required (due to lack of facilities); if a theoretical analysis were deemed sufficient or expedient the task could be accomplished in a matter of weeks.

iv) Cycle validation statistics for eddy current or torque control machinery would necessarily be a best guess. Due to the considerable test procedural refinements anticipated as necessary prior to real certification testing, this is not a problem.

The most salient point of this discussion is the fact that no emission data or performance capabilities of eddy current machines have ever been characterized. To promulgate Final Rules based upon uncertainty is not sound regulatory practice. ECTD is investigating the eddy current system as best it can prior to Final Rulemaking (e.g., running gasoline engines in torque control, running small diesels in torque control on the gasoline dynamometer, and attempting torque control vs. speed control comparisons on the diesel dynamometer); all efforts will be made to resolve this question, yet a definite resolution of the question of eddy current viability in time for Final Rules must remain in doubt.

h. Test Procedural Details

Several commenters argued that use of a CVS for emission sampling during the transient test was unnecessary, and in one case, technically incorrect. Both Caterpillar and Cummins argued that use of their home-built sampling systems be permitted.

Cummins presented data which indicated that bag sampling of diesel exhaust results in NOx measurement errors. In a bag, there appears to be a 15-20 percent loss in measurable NOx. (The same type of problem lead to the continuous sampling of HC.) Resolution of this discrepancy is anticipated to be continuous heated sampling of NOx by integration. There is a possibility, however, that EPA will be criticized for establishing an interim NOx standard based upon a test procedure which understates NOx, while proposing a procedure which does not for Final Rules. The interim NOx standard, however, is already so lax that no difficulty in its attainment using either sampling system is anticipated.*

Since the precise measurement of NOx is not a critical question in view of the lax NOx standard, the ECTD Technical Staff believes that use of either bag or continuous dilute sampling systems should be permitted for 1984. It is understood that technical problems exist in bagged NOx measurements with diesels, yet its use in 1984 should be permitted in 1984 due to its minimal impact (i.e., lax standard), and to preclude criticism that adoption of the dilute continuous measurement technique represents increased standard stringency. It should be understood, however, that dilute continuous NOx measurement will be adopted as part of the forthcoming 1985 NOx NPRM, and bag sampling of NOx will be abandoned.

The issue of alternate sampling systems is presently addressed in the proposed regulations. Any sampling system adequately

* See Summary and Analysis of Comments "Feasibility of Compliance" Chapter.

demonstrated to yield equivalent results is permissible. (See §86.1309-83(a)(1) of 44 FR, Part 86, February 13, 1979 NPRM.)

The final major test procedural issue pertains to the need for a 12-hour cold soak. This requirement ties up dynamometers and drastically reduces test rates. It is judged that due to the inherent cold start emission characteristics of gasoline engines and catalysts, a cold start for gasoline engines is technically justified. For diesels, however, the manufacturers are correct in pointing out that a cold start requirement is less necessary. Diesel emissions observed at SwRI are considerably more stable and less sensitive to engine temperature (see Table A-16). ECTD is concerned, however, that when the Congressionally-mandated NOx reduction and the forthcoming particulate standards take effect in conjunction with the proposed HC reduction, cold start emissions may reach significant levels. It is not desirable to promulgate a test procedure which may be adversely affected by these definite future standards. The major criticism of the cold start involved the 12-hour soak, and it is here that changes are warranted.

Recent data acquired by EPA in-house and from Cummins indicate that the 12-hour soak requirement can be abandoned in favor of a forced cool-down technique. The forced cool-down technique is currently being refined, by no major difficulties are expected. It is anticipated that a single engine temperature parameter (e.g., oil temperature) will replace the 12-hour soak requirement, and define the point at which a cold start may begin. (Gasoline engines will also have a catalyst temperature parameter.) There will be general restrictions on the cool-down procedure (e.g., coolant type, coolant temperature, etc.), however, the EPA laboratory has achieved cold-start soak times of less than two hours. This approach should eliminate all of the adverse effects of a 12-hour soak, and allow transient testing to be accomplished within the time currently needed for the steady-state tests while retaining the cold start cycle.

4. Recommendation

a. Retain the transient test for both diesels and gasoline engines.

b. Retain the proposed cycle for diesel engines. Allow optional certification on the 13-mode for the first applicable model year (1984) at an approximately stringent standard. Test cycle modifications may be made in the future, pending industry investigation of eddy current dynamometer capabilities.

c. Substitute a forced cool-down procedure in place of the 12-hour cold soak for both gasoline and diesels.

d. Allow both continuous dilute and bagged NOx measurement systems for diesel engines in 1984.

e. Modify the proposed procedure in the case of many technical details (discussed in Part II of Test Procedure, Summary and Analysis of Comments) to effectively streamline the procedure, clarify intentions, and eliminate unnecessary requirements.

Table A-1

Heavy-Duty Test Procedure Development

Year	Decisions	Events
pre-1973	1. Methodology for transient procedure development established and begun. 2. 9-mode procedure to be retained for future interim standards.	1. Ethyl study (1967). 2. 9-mode proposed as certification test for 1970 MY. 3. 23-mode test evaluated. 4. EPA/CRC joint contract awarded to William Smith & Associates (4/72).
1973		5. Negotiations completed with Olson Laboratories for computer development of test cycle (1/22/73). 6. Final report: 25 controlled gasoline trucks run on San Antonio road route (2/73). 7. NYC Cape-21 data collection begun (11/73).
1974	3. Engine dynamometer procedure selected as top priority over a chassis procedure. 4. Conflict of interest considerations lead EPA to plan and implement Los Angeles CAPE-21 survey on its own (see Exhibit 1).	8. Diesel engine certification on 13-mode test begun (1974 MY). 9. Contract awarded to Olson Laboratories for heavy-duty cycle development. 10. Final report: 10 diesel engines--SARR vs. 13-mode chassis tests (8/74). 11. NYC CAPE-21 data collection completed (10/74).
1975		12. LA CAPE-21 data collection begins (1/75).

Table A-1 (cont'd)

Heavy-Duty Test Procedure Development

Year	Decisions	Events
		13. Final report: 10 pre-controlled gasoline trucks on SARR vs. chassis 9-mode (3/75). 14. LA CAPE-21 data collection completed (5/75).
1976		15. Interim heavy-duty regulation NPRM (5/24/76). 16. Final report: comparative data on various transient and modal chassis dynamometer tests (5/76). 17. Formal industry briefing on CAPE-21 and transient procedure status (9/76).
1977	5. Based upon Events #1, 6, 10, 13, and 18, the 9-mode test was rejected as a future test procedure alternative; the 13-mode was deemed questionable. 6. Based on CAAA, uncontrolled baseline programs were initiated.	18. Final report: "Sensitivity Study" (1/77) (arising from data published 5/76). 19. EPA requests GM and Cummins to attempt transient dynamometer operation at their own facilities (2,3/77). 20. RFP to SwRI for transient baseline testing (5/77). 21. Cummins attempts transient dynamometer control through EMA's Transient Dynamometer Evaluation Committee (7/77). 22. Clean Air Act Amendments of 1977 (8/77). 23. Final Rulemaking, 1979 MY Interim Standards (9/13/77).

Table A-1 (cont'd)

Heavy-Duty Test Procedure Development

Year	Decisions	Events
		24. Candidate heavy-duty driving cycles selected (11/77).
1978	7. MVMA's alternate approach to transient cycle development rejected by the Agency (see text). 8. In-house prototype gasoline engine tests reveal significant discrepancies between 9-mode and transient procedures; the 9-mode is further discredited.	25. EPA's transient gasoline dynamometer operational; 1969 baseline study begins (2/78). 26. MVMA submits alternate cycle development plan (2/13/78) 27. MVMA's alternate approach rejected (5/17/78). 28. SwRI's transient gasoline dynamometer operational (6/78). 29. Recommended Practice for the transient procedure published (8/78). 30. SwRI's transient diesel cell operational (10/78).
1979	9. Level of diesel emission reductions achieved relative to 13-mode plus lack of correlation makes transient procedure for diesels attractive, especially in light of future NOx and particulate standards.	31. SwRI begins transient diesel baseline (2/79). 32. NPRM for transient procedure and 90 percent reductions published (2/13/79). 33. 1969 baseline program completed (5/79). 34. Final standards proposed (6/79). 35. Anticipated Final Rulemaking (12/79).

Table A-2

Comparative Studies

Study Title/Date	Study Summary/Conclusions
1. "Survey of Truck and Bus Operating Modes in Several Cities," June 1963.	Over the road data collection (RPM and manifold vacuum).
2. "Exhaust Emission Analysis and Mode Cycle Development for Gasoline Powered Trucks," September, 1967. (The "Ethyl Study").	Development of transient chassis dynamometer cycles from Study 1. Emissions measured on transient chassis cycles, road routes having same average speeds and same operational mode distribution, and the then in-use California steady-state test (equivalent to the manifold vacuum 9-mode). Correlation between transient and matched road emissions were excellent. None of the transient cycles compared well with the California 9-mode.
3. "Exhaust Emissions from Gasoline Powered Vehicles Above 6,000 Lb. Gross Vehicle Weight," by SwRI under EPA Contract, April 1972.	
Part I	Four heavy-duty, 1969 MY gasoline engines run on chassis and engine dynamometers under steady-state and transient conditions. For these uncontrolled vehicles, "steady state conditions, including motoring at closed throttle, can adequately represent the emissions."
Part II	Over-the-road emission data collected over stop-and-go operation, and various cruising speeds, for four heavy-duty 1969 MY trucks (gasoline). Over-the-road HC was directly proportional to the amount of transient operation, NOx inversely, and CO relatively stable.
Part III	Nine 1970 and later MY trucks run on experimental 23-mode test (engine and chassis dynamometers).

Table A-2 (Cont'd)

Comparative Studies

Study Title/Date	Study Summary/Conclusions
4. "Mass Emissions from Trucks Operated Over a Road Course, Part I," by SwRI under EPA Contract, February 1973.	Twenty-five gasoline trucks (1970-73 MY) tested over chassis 9-mode and San Antonio road route (SARR). Regression analysis of chassis results (Y) vs SARR (X): | | R^2 | SE | Slope | Y-Intercept | HC .660 2.14 .499 -3.96 CO .813 44.3 1.176 -70.96 NOx .837 2.67 1.411 -1.57 Regression analysis indicates that as emissions decrease, the agreement between test methods disappears, nor is correlation at these levels acceptable.
5. "Mass Emissions from Diesel Trucks Operated Over a Road Course," by SwRI under EPA Contract, August 1974.	Ten diesel trucks (1970-73 MY) tested over chassis 13-mode and SARR): Regression analysis of chassis results (Y) vs SARR (X): HC .778 1.26 1.012 -.254 CO .644 4.57 .305 6.604 NOx .786 5.04 2.90 -17.09 Concluded two test methods agreed somewhat at these levels of emissions; agreement was questionable as emissions decreased.
6. "Mass Emissions from Ten Precontrolled Gasoline Trucks, and Comparisons Between Different Trucks on a Road Course," by SwRI under EPA Contract, April 1975.	Ten gasoline trucks (1965-69 MY) tested for emissions over chassis 9-mode and SARR:

Table A-2 (Cont'd)

Comparative Studies

Study Title/Date	Study Summary/Conclusions
	Regression analysis at EPA:

	R^2	SE	Slope	Y-Intercept
HC	.795	3.25	.794	6.43
CO	.461	33.69	.441	134.33
NOx	-.124	1.99	.399	2.67

Study Title/Date	Study Summary/Conclusions
	Concludes that poor correlation exists between the two test procedures at this level of emissions; no correlation exists at lower levels.
7. "Heavy-Duty Fuel Economy Program - Phase I, Specific Analysis of Certain Existing Data," by EPA, January 1977, ("Sensitivity Study).	Eighteen gasoline and twelve diesel truck analyzed for emissions over: - Eight different steady-state tests, - Three sinusoidal cycles, and - Four average speed transient cycles. Conclusion: no reweighting of any steady state modes achieved consistent correlati with any of the transient tests.

Table A-3

9-Mode Versus Transient Emissions

Current Technology Engines

Engine	BSHC		BSCO	
	9-Mode	Transient	9-Mode	Transient
1979 GM 292	0.42	2.12	26.86	54.98
1979 GM 454	0.39	2.30	17.33	51.55
1978 IHC 404	0.63	3.98	18.07	54.56
1979 GM 350	0.79	3.14	14.62	118.07
1979 IHC 446	0.42	3.27	24.28	90.40
1979 GM 366	0.50	2.16	17.40	43.43
1979 IHC 345	2.73	2.44	17.68	34.44
1979 GM 350	0.59	2.48	20.40	64.76
1979 Ford 400	2.15	4.89	53.16	112.43
1979 Ford 370	1.20	3.51	37.12	47.75
1979 Chrysler 360	1.18	2.67	21.38	98.14
1979 Chrylser 440	0.83	3.83	10.47	112.38
1979 GM 454	0.47	1.31	20.11	78.49

Catalyst-Equipped (Prototype) Engines

Engine	BSHC		BSCO	
	9-Mode	Transient	9-Mode	Transient
1979 GM 400 1/	0.81	2.21	45.91	131.80
1979 GM 400 2/	0.06	1.00	2.46	99.24
1979 Ford 351 1/	0.97	1.24	70.86	99.86
1980 Chrysler 360 3/	0.11	1.16	0.31	96.58
1979 GM 350 4/	0.21	2.29	0.18	89.54

1/ Certified in light-duty vehicle; equipped with catalyst.
2/ Same as 1/, but retrofit with air pump.
3/ California package with production catalyst.
4/ Heavy-duty engine retrofit with catalyst.

Table A-4

13-Mode Versus Transient Emissions

SwRI

Engine	BSHC 13-Mode	BSHC Transient	BSCO 13-Mode	BSCO Transient
1978 Caterpillar 3208	1.71	3.37	3.34	3.79
1976 Cummins NTC-350	0.24	0.68	2.20	4.99
1978 DDA 6V-92T	0.56	0.78	2.54	3.15
1979 Cummins NTCC-350	0.32	0.86	3.30	2.62
1978 DDA 8V-71N (#1 Fuel)	0.84	1.49	6.43	3.75
1978 DDA 8V-71N (#2 Fuel)	0.69	1.30	8.00	4.35

Table A-5

Transient Versus 13-Mode HC Emissions

Engine	Transient	13-Mode	Lab	Ratio, Transient/ 13-Mode
1978 Caterpillar 3208	3.37	1.71	SwRI	1.97
1976 Cummins NTC-350	0.68	0.24	SwRI	2.83
1978 DDA 6V92T	0.78	0.56	SwRI	1.39
1979 Cummins NTCC-350	0.86	0.32	SwRI	2.69
1978 DDA 8V-71N (#1 Fuel)	1.30	0.69	SwRI	1.88
1978 DDA 8V-71N (#2 Fuel)	1.49	0.84	SwRI	1.77
A *	0.99	0.36	Cummins	2.75
B	0.76	0.38	Cummins	2.00
C	0.72	0.27	Cummins	2.67
D	0.86	0.43	Cummins	2.00
E	1.83	0.68	Cummins	2.69
F	2.22	1.14	Cummins	1.95
G	1.25	0.27	Cummins	4.63
H	0.55	0.14	Cummins	3.93
1979 Caterpillar 3208	1.96	1.20	Caterpillar	1.63
			Average:	2.40

* Cummins' and Caterpillar data extracted from comments submitted.

Table A-6

All Values in Grams/BHP-hr

Manufacturer	Engine Family	(a) Certification 13-Mode	(b) Transient	(c) Transient Target	(d) Reduction Due to Transient	(e) Less 13-Mode Reduction	Total Sales Percent	(f) Transient Reduction	(g) Sales-Weighted Grams/BHP-hr Reduction
GM	4L-53T	0.83	1.99	0.89	1.10	0.31	1.54	0.79	.012
GM	6L-71N	0.84	2.02	0.89	1.13	0.34	3.52	0.79	.028
GM	8V-71N	0.82	1.97	0.89	1.08	0.29	1.32	0.79	.010
GM	6V-71NC	1.27	3.05	0.89	2.16	1.37	0.91	0.79	.007
GM	8V-71NC	0.80	1.49*	0.89	0.60	0.19	2.37	0.36	.009
GM	6V-92TA	0.58	1.17*	0.89	0.28	0	8.37	0.28	.023
GM	8V-71TA	0.51	1.22	0.89	0.88	0	1.98	0.33	.007
GM	8V-92TA	0.50	1.20	0.89	0.33	0	5.06	0.31	.016
GM	6L-71T	0.55	1.32	0.89	0.31	0	1.23	0.43	.005
CEC	091	0.38	0.91	0.89	0.43	0	0.15	0.02	.000
CEC	092A	0.32	0.77	0.89	0	0	11.36	0	0
CEC	092C	0.26	0.62	0.89	0	0	5.06	0	0
CEC	092E	0.26	0.86*	0.89	0	0	13.55	0	0
CEC	172A	1.20	2.88	0.89	1.99	1.20	0.35	0.79	.003
CEC	172C	0.53	1.27	0.89	0.38	0	0.28	0.38	.001
CEC	192B	0.30	0.72	0.89	0	0	0.04	0	0
CEC	193	0.38	0.91	0.89	0.02	0	0.06	0.02	.000
CEC	221	0.79	1.90	0.89	1.01	0.22	0.04	0.79	.000
CEC	222	0.69	1.66	0.89	0.77	0	0.75	0.77	.006
IHC	DT-466B	0.64	1.54	0.89	0.65	0	6.61	0.65	.043
IHC	9.0-Liter	1.38	3.31	0.89	1.42	1.63	0.66	0.79	.005
IHC	DTI 466B	0.56	0.81*	0.89	0	0	0.44	0	.0
Mack	8	0.31	0.74	0.89	0	0	0.40	0	0
Mack	9	0.76	1.82	0.89	0.93	0.14	7.92	0.79	.063
Mack	10	0.12	0.29	0.89	0	0	0.04	0	0
Mack	11	0.58	1.39	0.89	0.50	0	6.11	0.50	.031
Mack	SIB	0.87	2.09	0.89	1.20	0.41	0.22	0.79	.002
Cat	3	1.20	1.97*	0.89	1.08	0.82	11.02	0.26	.029

Table A-6 (Cont'd)

All Values in Grams/BHP-hr

Manufacturer	Engine Family	(a) Certification 13-Mode	(b) Transient	(c) Transient Target	(d) Reduction Due to Transient	(e) Less 13-Mode Reduction	Total Sales Percent	(f) Transient Reduction	(g) Sales-Weighted Grams/BHP-hr Reduction
Cat	4	0.21	0.50	0.89	0	0	0.20	0	0
Cat	9	0.23	0.55	0.89	0	0	0.02	0	0
Cat	10	0.34	0.82	0.89	0	0	2.25	0	0
Cat	11	0.53	1.27	0.89	0.38	0	1.00	0.38	.004
Cat	12	0.15	0.36	0.89	0	0	0.31	0	0
Cat	13	0.68	1.63	0.89	0.74	0	1.54	0.74	.011
Cat	14	0.22	0.53	0.89	0	0	0.30	0	0
Cat	15	0.63	1.51	0.89	0.62	0	0.21	0.62	.001
Cat	16	0.30	0.72	0.89	0	0	1.98	0	0
Cat	17	0.37	0.89	0.89	0	0	0.36	0	0

Total Sales-Weighted Grams/BHP-hr per Truck = 0.316

* Based upon actual transient emission data.
(a) 1979 certification records.
(b) 2.40 x a.
(c) Target g/BHP-hr
(d) b-c.
(e) (a - [13-mode target g/BHP-hr]) x (either 2.40 or actual transient/13-mode ratio)
(f) d-e.
(g) (sales/total sales) x F.

Table A-7

Cycle Development and CAPE-21 Studies and Technical Reports

Report Number	Report/Summary
1	"Truck Driving Pattern and Use Survey, Phase II, Implementation Plan," by William Smith and Associates, May 7, 1973. This report outlines a sampling and instrumentation plan by which on-road heavy-duty engine operational parameters can be recorded.
2	"Heavy-Duty Vehicle Driving Pattern and Use Survey, Final Report, Part I, New York City," Report No. APT.D-1523, by William Smith and Associates, May, 1973. This report characterizes usage patterns and population data for heavy-duty trucks in New York City.
3	"Heavy-Duty Driving Pattern and Use Survey: Part II - Los Angeles Basin Final Report," Report No. EPA-460/ 3-75-005, by William Smith and Associates, February, 1974. This report characterizes usage patterns and population data for heavy-duty trucks in Los Angeles.
4	"Engine Horsepower Modeling for Diesel Engines," EPA Technical Report No. HDV 76-03, by C. France, October, 1976. This report summarizes the methodology used in deriving horsepower models for diesel engines used in the CAPE-21 study.
5	"Engine Horsepower Modeling for Gasoline Engines," EPA Technical Report No. HDV 76-04, by L. Higdon, December, 1976. This report summarizes the methodology used in deriving horsepower models for gasoline engines used in the CAPE-21 study.
6	"Truck Driving Pattern and Use Survey, Phase II, Final Report, Part I," Report No. EPA-460/3-77-009, by William Smith and Associates, June, 1977.

Table A-7 (Cont'd)

Cycle Development and CAPE-21 Studies and Technical Reports

Report Number	Report/Summary
	This report summarizes the sampling plan, instrumentation, and data collected in the New York phase of CAPE-21.
7	"Truck Driving Pattern and Use Survey, Phase II, Final Report Part II, Los Angeles," EPA Technical Report No. HDV 78-03, by L. Higdon, May, 1978.
	This report summarizes the sample plan, instrumentation, and the data collected in the Los Angeles phase of CAPE-21.
8	"Analysis of CAPE-21 Horsepower Models," by Systems Control, Inc., July, 1978.
	In this report to the MVMA, the horsepower models used in CAPE-21 were investigated and checked for their validity.
9	"Heavy-Duty Vehicle Cycle Development," Technical Report No. EPA 460/3-78-008, by Malcolm Smith, July, 1978.
	This report summarizes the data editing, data manipulation, engine parameter models used, and the overall statistical methodology used in generating heavy-duty engine and chassis dynamometer test cycles.
10	"Category Selection for Transient Heavy-Duty Chassis and Engine Cycles," EPA Technical Report No. HDV-78-01, by C. France, May, 1978.
	This report summarizes the methodology and statistical comparative procedures used to meaningfully combine truck categories to simplify the CAPE-21 data base.
11	"Analysis of Hot/Cold Cycle Requirements for Heavy-Duty Vehicles," EPA Technical Report No. HDV-78-05, by C. France, July, 1978.
	This report analyzes the need for separate cold cycles for heavy-duty emission testing; it extrapolates the amount of cold operation present in the CAPE-21 data base.

Table A-7 (Cont'd)

Cycle Development and CAPE-21 Studies and Technical Reports

Report Number	Report/Summary
12	"Selection of Transient Cycles for Heavy-Duty Engines," EPA Technical Report No. HDV 77-01, by T. Wysor and C. France, November, 1977. This report summarizes the statistical methodology used in selecting the final test cycles from the several cycles generated in Report No. 9.
13	"Transient Cycle Arrangement for Heavy-Duty Engine and Chassis Emission Testing," EPA Technical Report No. HDV-78-04, by C. France, August, 1978. This report summarizes the final analysis used in arranging the cycles selected in Report No. 12 for the transient certification test cycles, and also selects the final cold/hot weighting factors.
14	"1969 Heavy-Duty Engine Baseline Program and 1983 Emission Standards Development," EPA Techinical Report, by T. Cox, G. Passavant, and L. Ragsdale, May 1979. This report summarizes the baseline test program from which the transient standards were derived, and summarizes experience and technical disoveries gained in an actual transient test program.

A-
Table 8
EDIT OUTPUT FOR LA - TRUCK 17, DAY 1

------EDITING SUMMARY------

TOTAL NUMBER OF RECORDS REQUIRING EDITING	=	1324
NUMBER OF ZEROED RECORDS ON INPUT TAPE	=	243
NUMBER OF ENGINE-OFF RECORDS	=	881
NUMBER OF RECORDS WITH OUT-OF-RANGE VALUES	=	200

NUMBER OF RECORDS WITH:

RPM ABOVE RPM MAXIMUM(3950.)	=	0
RPM BETWEEN 0 AND 300	=	7
RPM BELOW 0	=	0
LF ABOVE L100+13	=	71
LF BETWEEN L100 AND L100+13	=	85
LF BETWEEN LF C/O AND LF C/O-13	=	0
LF BELOW LF C/O-13	=	0
SPEED ABOVE 70	=	0
SPEED NEGATIVE WHILE MOVING	=	1
DELTA-SPEED EXCEEDING AMAX	=	36
SPEED TO BE ZEROED (NOT AN OUT-OF-RANGE VALUE)	=	316

TOTAL NUMBER OF INTERPOLATED RECORDS	=	166
RPM ABOVE RPM MAXIMUM INTERPOLATIONS	=	0
RPM BETWEEN 0 AND 300 INTERPOLATIONS	=	1
RPM BELOW 0 INTERPOLATIONS	=	0
LF ABOVE L100+13 INTERPOLATIONS	=	0
LF BELOW C/O-13 INTERPOLATIONS	=	0
SPEED ABOVE 70 INTERPOLATIONS	=	0
NEGATIVE SPEED INTERPOLATIONS	=	1
SPEED INTERPOLATIONS DUE TO AMAX CRITERION	=	27
ZEROED RECORD INTERPOLATIONS	=	137

TOTAL NUMBER OF RECORDS ELIMINATED DURING EDIT	=	1072
RPM ABOVE RPM MAXIMUM	=	0
RPM BETWEEN 0 AND 300	=	6
RPM BELOW 0	=	0
LF ABOVE L100+13	=	70
LF BELOW C/O-13	=	0
SPEED ABOVE 70	=	0
NEGATIVE SPEED	=	0
AMAX CRITERION	=	9
CONSECUTIVE ZEROED RECORDS	=	106
CONSECUTIVE ENGINE-OFF RECORDS	=	881

TOTAL NUMBER OF NON-ZEROED, ENGINE-ON RECORDS ELIMINATED	=	85
TOTAL NUMBER OF ZEROED RECORDS ON OUTPUT TAPE	=	69
THOSE DUE TO TIME DISCREPANCIES	=	1
TOTAL NUMBER OF RECORDS NOT REQUIRING EDITING	=	18356
TOTAL NUMBER OF GOOD RECORDS ELIMINATED	=	5
TOTAL NUMBER OF RECORDS ON INPUT TAPE	=	19680
TOTAL NUMBER OF RECORDS ON OUTPUT TAPE	=	18672

-----END OF CONVERT AND EDIT FOR LA TRUCK 17, DAY 1

Table A-9

Summary Percentages*

GASOLINE

	Acceleration	Deceleration	Cruise	Idle
Cape 21	27.2	26.2	20.6	26.1
Proposed Cycle	26.5	25.4	20.3	26.6
9-mode	0	0	76.8	23.2

DIESEL

	Acceleration	Deceleration	Cruise	Idle
Cape 21	28.1	26.8	13.8	31.5
Proposed Cycle	25.8	26.8	11.5	36.6
13-mode	0	0	80.0	20.0

* From Table 10.

Table A-10

Modal Percentages: CAPE-21 vs. Proposed Cycles

	Cape-21 Modal Percentage A	D	C	I	Freeway/Non-Freeway Cycle Weighting Factors	Desired Weighted Modal Percentage A	D	C	I	Modal Percentage Generated Cycles A	D	C	I	Actual Time-Weighting Factor	Actual Time-Weighted Modal Percentages A	D	C	I
Gasoline:																		
NYNF	23	23	14	40	0.44	10.1	10.1	6.2	17.6	23	22	12	41	0.47	10.8	10.3	5.6	19.3
NYF	33	31	26	10	0.06	2.0	1.9	1.6	.6	33	31	24	12	0	0	0	0	0
LANF	31	28	16	25	0.30	9.3	8.4	4.8	7.5	31	29	14	26	0.26	8.1	7.5	3.6	6.8
LAF	29	29	40	2	0.20	5.8	5.8	8.0	.4	28	28	41	2	0.27	7.6	7.6	11.1	.5
					Total CAPE-21 Composite:	27.2	26.2	20.6	26.1					Proposed Cycle:	26.5	25.4	20.3	26.6
Diesel:																		
NYNF	21	21	7	51	0.41	8.6	8.6	2.9	20.9	19	21	6	55	0.50	9.5	10.5	3	27.5
NYF	32	32	17	19	0.09	2.9	2.9	1.5	1.7	32	31	12	25	0	0	0	0	0
LANF	30	26	10	35	0.24	7.2	6.2	2.4	8.4	28	29	10	34	0.25	7	7.3	2.5	8.5
LAF	36	35	27	2	0.26	9.4	9.1	7.0	0.5	37	36	24	2.3	0.25	9.3	9	6	0.6
					Total CAPE-21 Composite:	28.1	26.8	13.8	31.5					Proposed Cycle:	25.8	26.8	11.5	36.6

Table A-11

CAPE-21 Study vs. U.S. Trucks and Buses Subject to HD Regulations
(U.S. Production) - (Exports) + (Imports from Canada)

Year	6,000-10,000	10,000-14,000	14,000-16,000	16,000-19,500	19,500-26,000	26,000-33,000	33,000 and over	Yearly Totals
1977	18.8%	6.4%	.7%	1.1%	34.3%	6.9%	31.8%	100%
1976	17.6%	10.9%	-	2.2%	37.5%	5.8%	25.9%	100%
1975	13.8%	5.8%	1.9%	4.1%	45.0%	7.3%	22.1%	100%
1974	7.4%	1.8%	1.7%	5.0%	44.3%	6.7%	33.1%	100%
1973	7.2%	9.9%	1.6%	6.9%	37.4%	7.6%	29.2%	100%
1972	6.3%	11.9%	2.1%	7.7%	36.7%	8.3%	26.9%	100%
CAPE-21	0%	13.5%	2.1%	14.6%	22.9%	11.5%	35.4%	100%

Source: MVMA data from Draft Regulatory Analysis, CAPE-21 Records.

Table A-12

Diesel Usage in Heavy-Duty Vehicles
vs CAPE-21 Study

Year	0-6,000	6,000-10,000	10,000-14,000	14,000-16,000	16,000-19,500	19,500-26,000	26,000-33,000	33,000 and over	Totals
1977	-	.5%	-	-	-	7.0%	11.0%	81.4%	100%
1976	-	1.3%	-	-	-	5.3%	8.7%	84.8%	100%
1975	-	-	-	-	.2%	6.2%	13.4%	80.2%	100%
1974	-	-	-	-	-	2.2%	7.6%	90.1%	100%
1973	-	-	-	.2%	-	2.4%	10.2%	87.2%	100%
1972	-	-	-	.2%	-	2.8%	9.4%	87.7%	100%
CAPE 21*	-	-	5.9%	2.9%	5.9%	5.9%	14.7%	64.7%	100%

Source: MVMA data, CAPE-21 records.

* based upon number of trucks, not truck days.

Table A-13

EPA/SwRI Transient Emission Correlation

Engine	Test Data (SwRI)	Test Data (EPA)	Comments	SwRI HC	EPA HC	SwRI CO	EPA CO	SwRI NOx	EPA NOX
1969 IHC 304	--	6/78	--		11.64		127.4	--	6.07
1969 IHC 304	10/78	1/79	*SwRI-No Stats	8.75	10.49	121.86	126.4	6.24	7.65
1978 IHC 404	11/78	11/78	*SwRI-No Stats	3.01	3.86	72.91	54.1	5.50	5.01
1978 IHC 404	1/79	--	*SwRI-No Stats	4.40	--	76.5	--	6.3	--
1978 IHC 404	2/79	5/79	Stats	3.85	3.72	57.5	73.3	5.0	4.42
1979 GM 454	--	10/78	--	--	2.26	--	48.7	--	6.92
1979 GM 454	2/79	--	--	2.50	--	51.0	--	6.5	--
1979 GM 454	--	6/79	--	--	2.36	--	55.4	--	6.55
1969 Ford 360	--	3/79	--	--	5.92	--	75.32	--	6.88
1969 Ford 360	6/79	--	--	6.14	--	97.3	--	5.26	--

* At this time SwRI was incapable of data acquisition necessary to perform cycle performance regression analyses. The test data is therefore qualified.

Table A-14

Regression Analysis: Caterpillar Cycle (Y) Versus Proposed Cycle (X)

Speed

Cycle Segment	Standard Error	Slope	R^2	Y-intercept
1	44.3 (rpm)	0.979	0.991	9.08 (rpm)
2	99.4	0.957	0.972	37.0
3	17.7	1.00	0.997	-3.4
4	44.4	0.979	0.991	9.04
Total	60.9 (rpm)	0.987	0.990	5.85 (rpm)

Torque

Cycle Segment	Standard Error	Slope	R^2	Y-intercept
1	1.3 (%)	1.00	0.998	-0.40 (ft-lbs)
2	9.4	0.955	0.909	28.0
3	5.3	0.971	0.976	23.9
4	1.3	1.00	0.998	-0.41
Total	5.6 (%)	0.986	0.971	11.2 (ft-lbs)

Horsepower

Cycle Segment	Standard Error	Slope	R^2	Y-intercept
1	1.6 (%)	0.983	0.991	0.09 (Bhp)
2	6.6	0.960	0.939	8.30
3	2.9	0.981	0.991	5.70
4	1.6	0.983	0.991	0.09
Total	3.8 (%)	0.984	0.981	2.98 (Bhp)

Table A-15

Emission Data: Caterpillar Cycle
Versus Proposed Cycle

Cummins NTCC 350 (1979 MY)

	Proposed Cycle							Caterpillar Cycle						
	D4-10			D4-11				D4-13			D4-14			
	CS	HS	T	CS	HS	T	Mean	CS	HS	T	CS	HS	T	Mean
BSHC	0.72	0.73	0.73	0.88	0.83	0.84	0.79	0.86	0.69	0.71	X	0.70	X	0.7[illegible]
BSCO	2.32	2.19	2.21	2.37	2.22	2.24	2.22	2.24	2.19	2.20	2.23	2.18	2.19	2.2[illegible]
BSNOx	5.06	4.92	4.94	5.12	4.95	4.97	4.96	4.87	5.11	5.08	4.98	4.78	4.81	4.9[illegible]
BSpart	X	0.42	X	0.44	0.41	0.41	0.41	0.42	0.41	0.41	0.43	X	X	0.4[illegible]

DAA 8V-71N (1978 MY)

	Proposed Cycle					Caterpillar Cycle				
	HS1	HS2	HS3	HS4	Mean	HS1	HS2	HS3	HS4	Mean
BSHC	1.39	1.54	1.39	1.42	1.44	1.29	1.20	1.17	1.32	1.25
BSCO	4.20	4.11	4.38	4.25	4.24	3.77	3.73	4.12	3.98	3.90
BSNOx	4.96	5.38	5.29	5.21	5.21	5.06	5.55	5.24	5.30	5.29
BSpart	1.05	1.09	0.78	0.85	0.94	0.78	0.72	1.00	0.77	0.82

X: voided results

Table A-16

Cold/Hot Diesel HC Emissions
(g/Bhp-hr)

Caterpillar 3208

Test	D1-5	D1-6	D1-7	D1-8	D1-11	D1-13	D1-14
Cold	3.95	3.80	3.66	3.43	4.07	3.98	3.89
Hot	3.18	3.26	3.23	2.96	3.53	3.53	3.35

Cummins NTC-350

Test	D2-7	D2-9	D2-10	D2-12	D2-13	D2-15	D2-16
Cold	1.12	1.14	1.11	1.02	1.00	1.01	1.10
Hot	0.64	0.70	0.69	0.67	0.61	0.60	0.60

DDA-6V92T

Test	D3-4	D3-5	D3-7 (w/ #2 fuel)
Cold	0.76	0.81	0.77
Hot	0.79	0.75	0.70

Cummins NTCC-350

Test	D4-4	D4-7	D4-13 (Caterpillar Cycle)
Cold	0.74	0.93	0.86
Hot	0.79	0.94	0.69

DDA-8V71N

Test	D5-1*	D5-2*
Cold	1.01	1.26
Hot	1.26	1.31

* Tentative.

Figure A-1

HEAVY DUTY GASOLINE BAG ENGINE TEST   DATE: 02-17-79 TIME: 00:29:36   HD-796435

TRANSIENT TEST RESULTS / IDLE TEST REPORT

	HC				CO				NOX				F.E.			
	GMS/ BHPHR	GMS/ KW-HR	GMS	GMS/MI	GMS/ BHPHR	GMS/ KW-HR	GMS	GMS/MI	GMS/ BHPHR	GMS/ KW-HR	GMS	GMS/MI	GAL.	LBS.	LBS/ BHPHR	GMS KW-HR
BAG 1 NYNF CS	32.94	24.56	21.24	39.06	239.56	178.64	154.52	284.13	4.34	3.23	2.80	5.14	0.14	0.84	1.300	439.7
BAG 2 LANF	2.47	1.84	4.97	3.16	38.58	28.77	63.51	49.32	6.88	5.13	11.33	8.80	0.21	1.27	0.772	261.1
BAG 3 LAF	1.20	0.89	7.06	1.77	118.55	88.40	700.76	175.30	5.45	4.06	32.20	8.06	0.63	3.87	0.655	221.5
BAG 4 NYNF	1.00	0.75	0.70	1.19	49.17	36.67	34.37	58.32	6.15	4.58	4.30	7.29	0.11	0.69	0.984	332.8
BAG 5 NYNF HS	2.40	1.79	1.80	3.31	44.13	32.90	33.02	60.95	4.51	3.36	3.37	6.23	0.12	0.76	1.020	345.0
BAG 6 LANF	1.22	0.91	2.08	1.61	26.98	20.12	45.92	35.66	7.62	5.68	12.97	10.07	0.21	1.32	0.773	261.5
BAG 7 LAF	1.09	0.82	6.43	1.61	116.44	86.98	686.45	171.72	5.42	4.04	31.91	7.98	0.62	3.83	0.651	220.2
BAG 8 NYNF	0.64	0.48	0.54	0.91	40.26	30.02	33.58	56.98	5.39	4.02	4.50	7.63	0.12	0.72	0.859	290.6
	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
COMPOSITE CS	3.72	2.77		5.15	107.08	79.85		148.51	5.69	4.24		7.89	1.08	6.67	0.749	253.3
COMPOSITE HS	1.18	0.88		1.69	87.14	64.99		124.52	5.75	4.29		8.22	1.07	6.63	0.723	244.6
	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
TOTAL TEST	1.53	1.14		2.18	89.91	67.05		127.95	5.74	4.28		8.17	2.15	13.30	0.727	245.9

Transient Gasoline Engine (w/Catalyst) Test Results

Figure A-2

HD-800165 40 GM292 L25 PCTES 0 DATE: 03-15-79 TIME: 14:45:00 HD-800165

HD-800165
40 GM292 L25 PCTES 0

HEAVY DUTY GASOLINE BAG ENGINE TEST DATE: 03-15-79 TIME: 14:45:10 HD-800165

TRANSIENT TEST RESULTS REPORT T

	HC				CO				NOX				F.E.			
	GMS/ BHPHR	GMS/ KW-HR	GMS	GMS/MI	GMS/ BHPHR	GMS/ KW-HR	GMS	GMS/MI	GMS/ BHPHR	GMS/ KW-HR	GMS	GMS/MI	GAL.	LBS.	LBS/ BHPHR	GMS KW-HR
BAG 1 NYNF CS	36.76	27.41	24.16	42.25	285.30	212.75	187.55	327.89	2.18	1.63	1.44	2.51	0.13	0.82	1.252	423.5
BAG 2 LANF	0.35	0.26	0.58	0.45	4.55	3.39	7.46	5.80	7.06	5.71	12.56	9.76	0.19	1.17	0.712	240.8
BAG 3 LAF	0.02	0.02	0.12	[illegible]	6.27	4.67	32.51	8.13	7.06	5.71	39.72	9.94	0.48	2.97	0.573	193.8
BAG 4 NYNF	0.03	0.03	0.03	0.04	15.57	11.61	12.04	20.43	5.46	4.07	4.22	7.17	0.10	0.60	0.772	261.1
BAG 5 NYNF HS	1.33	1.00	0.88	1.54	37.98	28.32	25.00	43.71	3.72	2.78	[illegible]	4.28	0.09	0.57	0.869	293.9
BAG 6 LANF	0.21	0.16	0.35	0.27	4.79	3.57	8.01	6.22	7.65	5.71	12.79	9.93	0.19	1.15	0.688	232.7
BAG 7 LAF	0.03	0.02	0.17	[illegible]	6.57	4.90	34.54	8.64	8.01	5.98	42.11	10.53	0.48	2.96	0.564	190.8
BAG 8 NYNF	0.08	0.06	0.06	0.11	15.13	11.28	12.00	20.36	5.39	4.02	4.27	7.25	0.10	0.60	0.762	257.7
	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
COMPOSITE CS	3.01	2.25		3.96	29.01	21.63		37.16	7.02	5.23		8.99	0.90	5.56	0.673	227.6
COMPOSITE HS	0.18	0.13		0. 3	9.50	7.08		12.34	7.36	5.49		9.56	0.86	5.29	0.632	213.8
	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
TOTAL TEST	0.58	0.43		0.75	12.25	9.14		15.89	7.31	5.45		9.48	1.76	10.85	0.638	215.8

Transient Gasoline Engine Test (w/Catalyst, Meeting Standards)

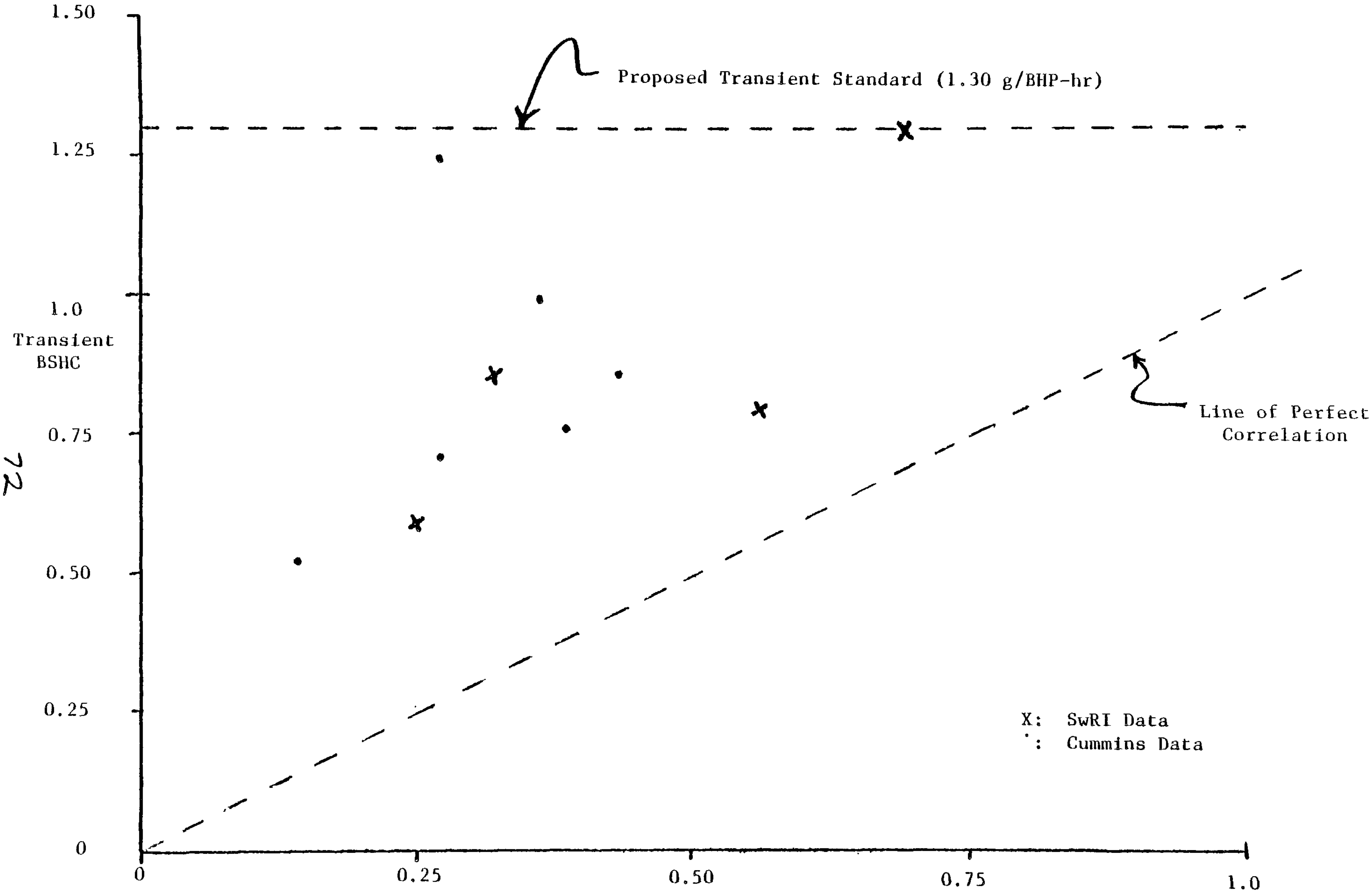


Figure A-3. Transient Versus 13-Mode BSHC Emissions

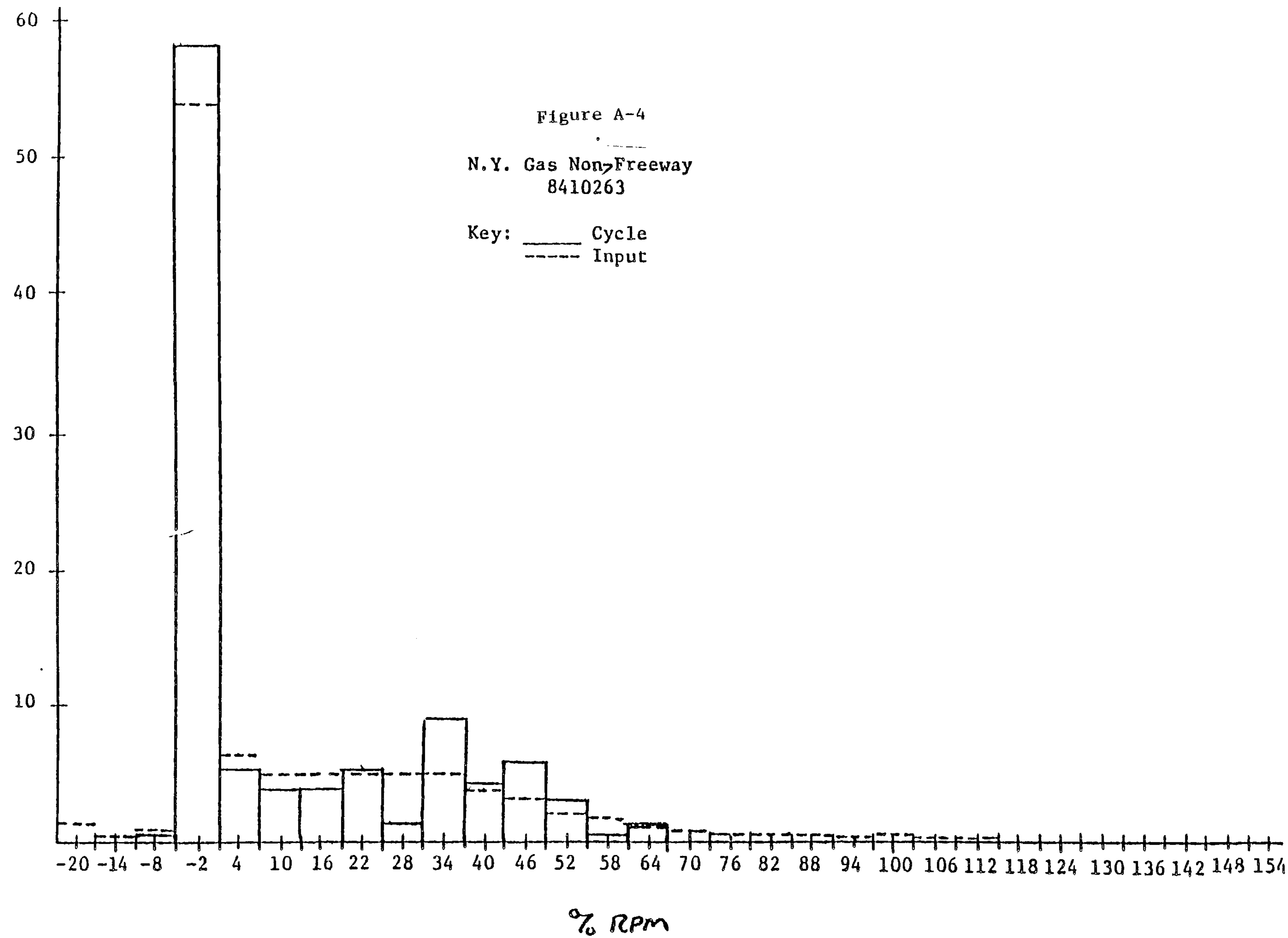


Figure A-4
N.Y. Gas Non-Freeway
8410263
Key: ______ Cycle
------ Input
60
50
40
30
20
10
%
-20 -14 -8 -2 4 10 16 22 28 34 40 46 52 58 64 70 76 82 88 94 100 106 112 118 124 130 136 142 148 154
% RPM

73

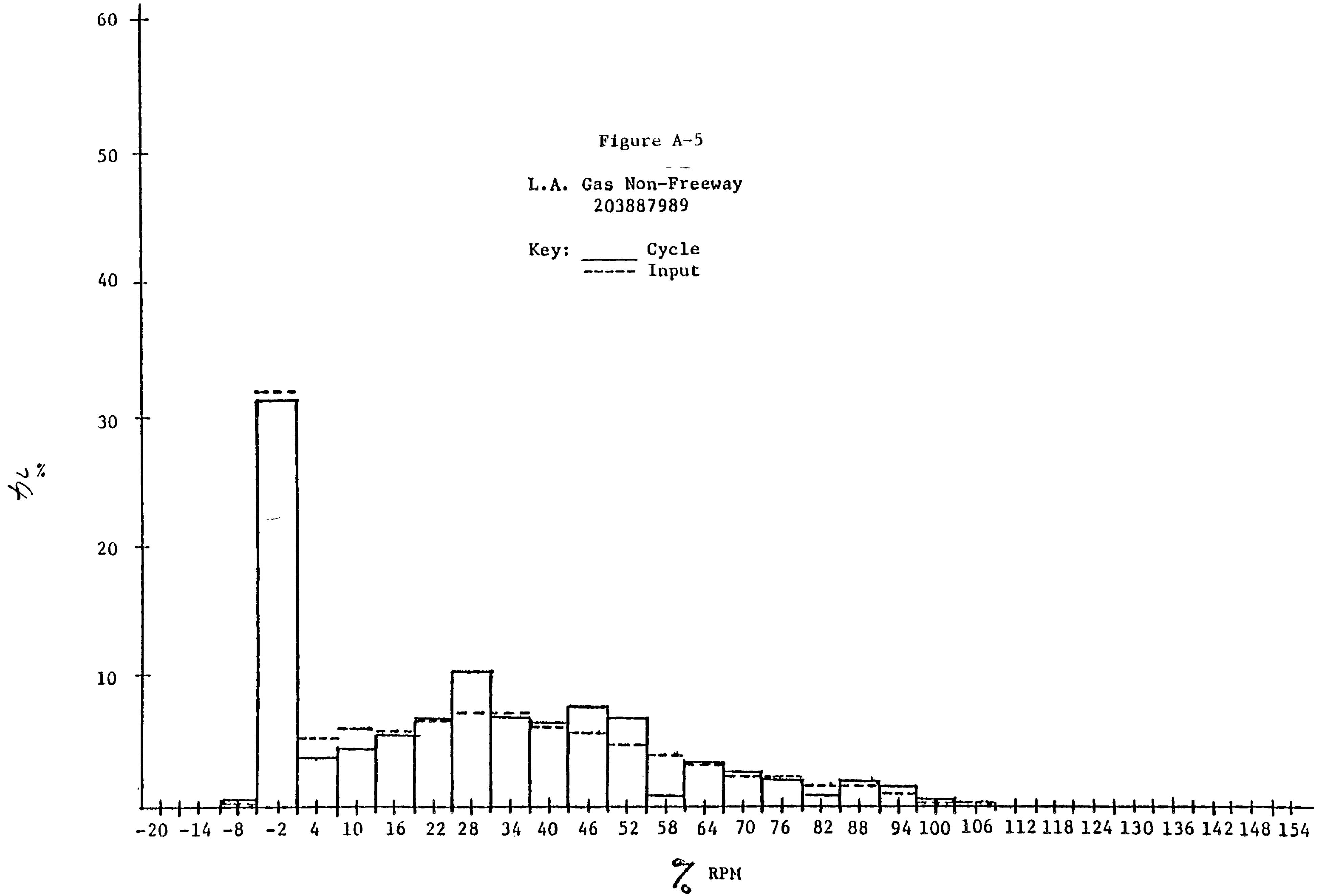


Figure A-5
L.A. Gas Non-Freeway
203887989
Key: Cycle
Input
60
50
40
30
20
10
%
-20 -14 -8 -2 4 10 16 22 28 34 40 46 52 58 64 70 76 82 88 94 100 106 112 118 124 130 136 142 148 154
% RPM

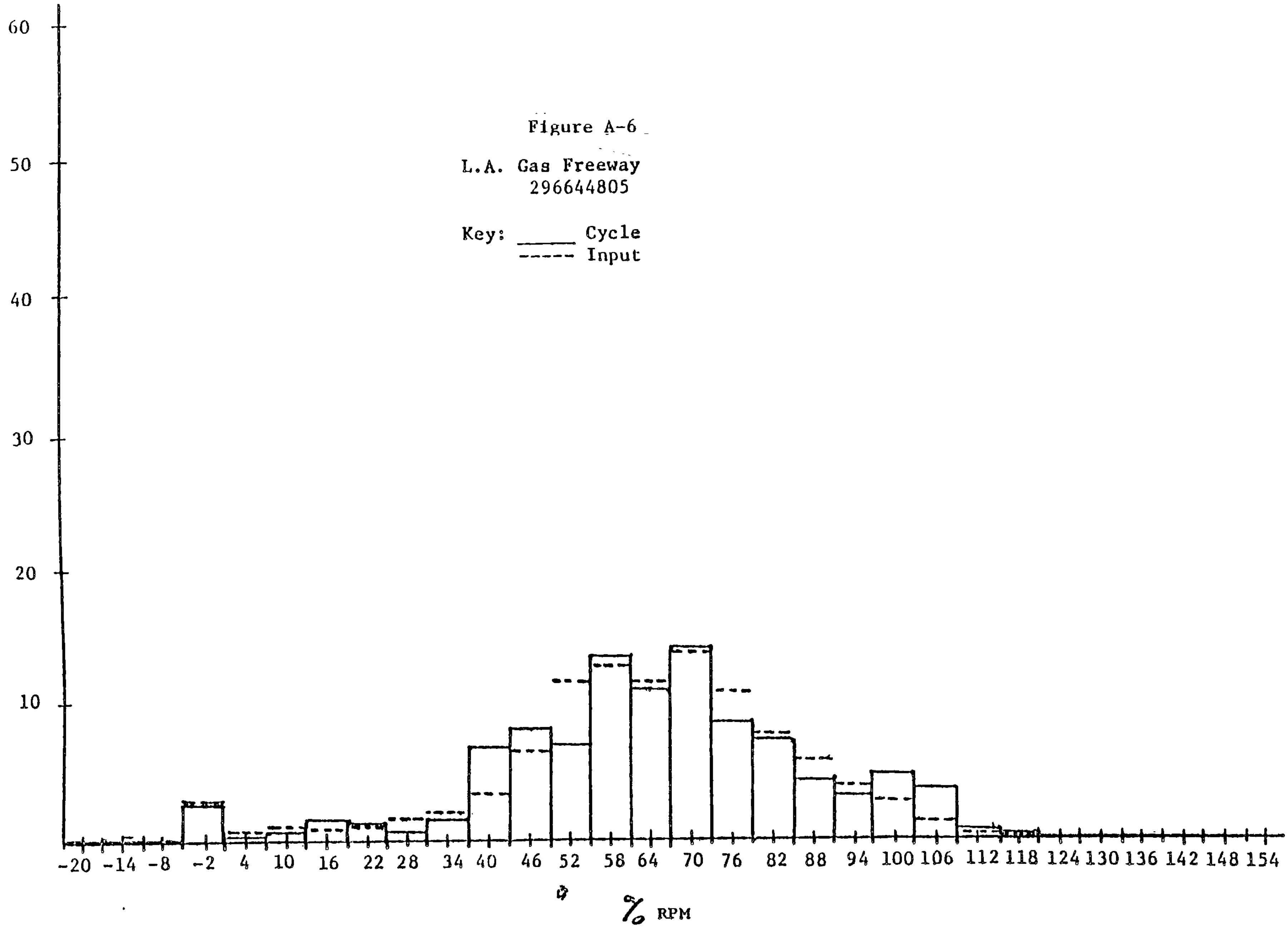
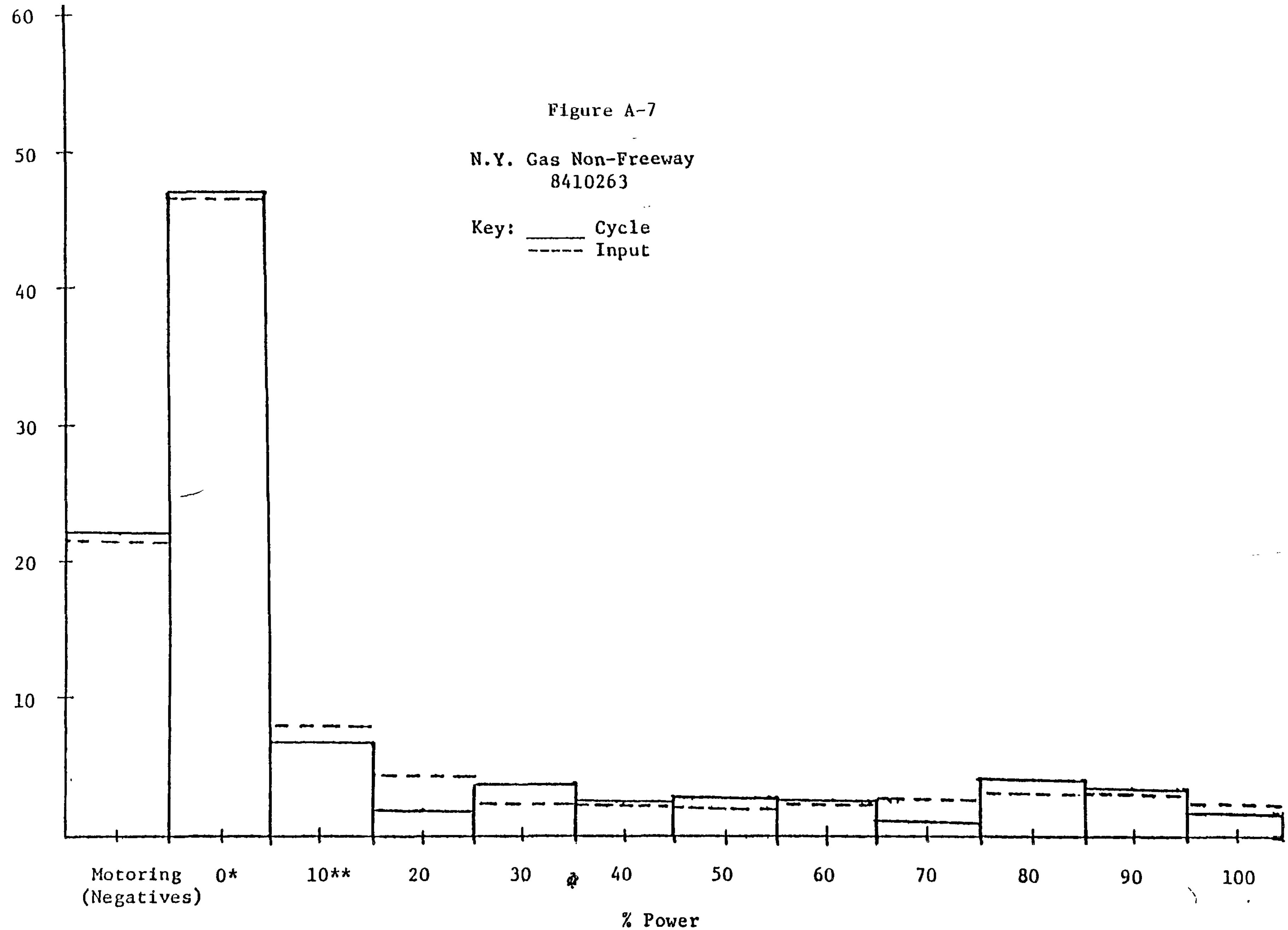


Figure A-6
L.A. Gas Freeway
296644805
Key: _____ Cycle
----- Input
60
50
40
30
20
10
%
-20 -14 -8 -2 4 10 16 22 28 34 40 46 52 58 64 70 76 82 88 94 100 106 112 118 124 130 136 142 148 154
% RPM

Figure A-7

N.Y. Gas Non-Freeway
8410263



* 0 < % < 5

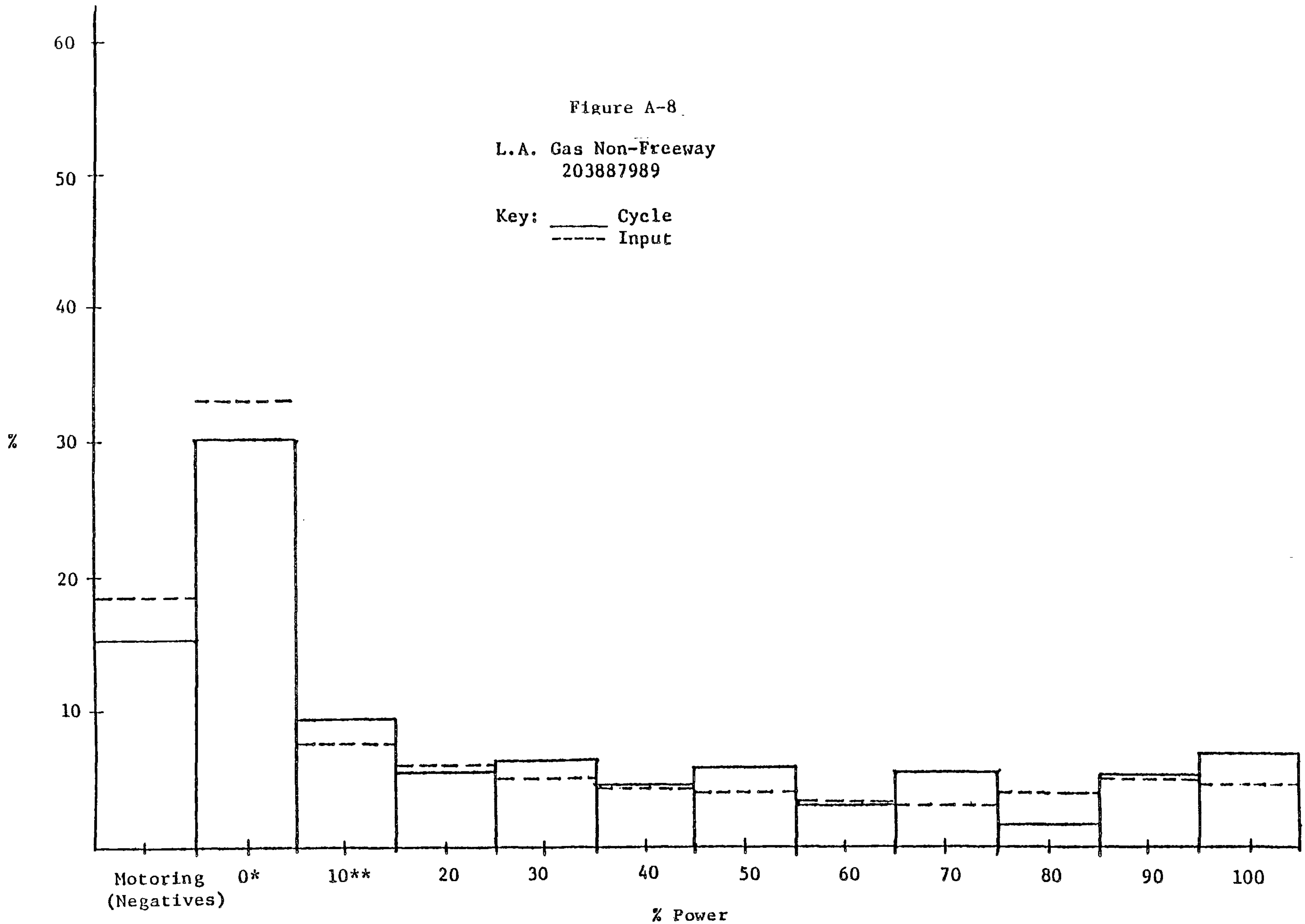


Figure A-8

L.A. Gas Non-Freeway
203887989

* $0 \leq \% < 5$

** $5 \leq \% < 15$

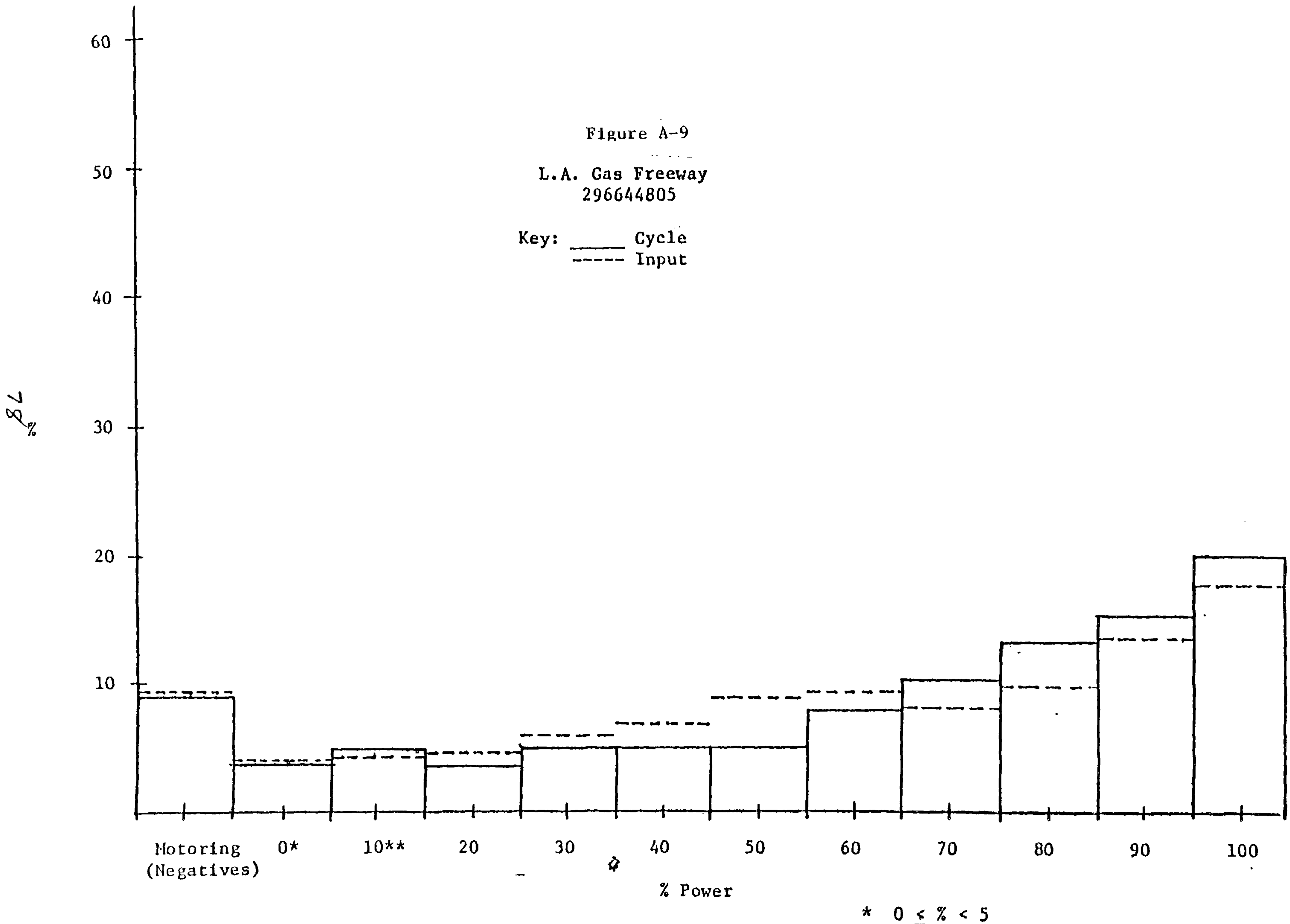


Figure A-9
L.A. Gas Freeway
296644805
Key: Cycle
Input
60
50
40
30
20
10
%
Motoring
(Negatives)
0*
10**
20
30
40
50
60
70
80
90
100
% Power
* 0 ≤ % < 5

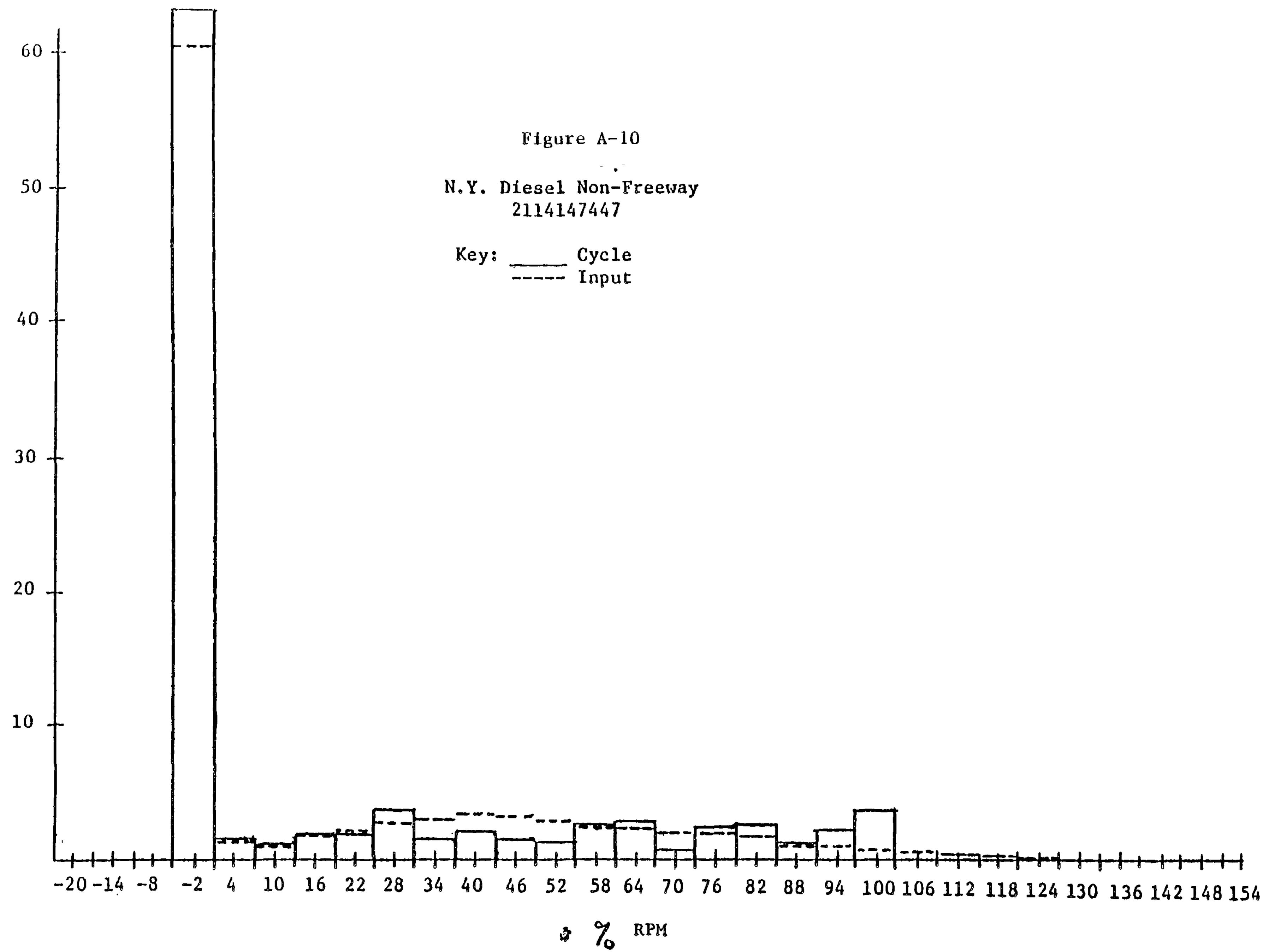


Figure A-10

N.Y. Diesel Non-Freeway
2114147447

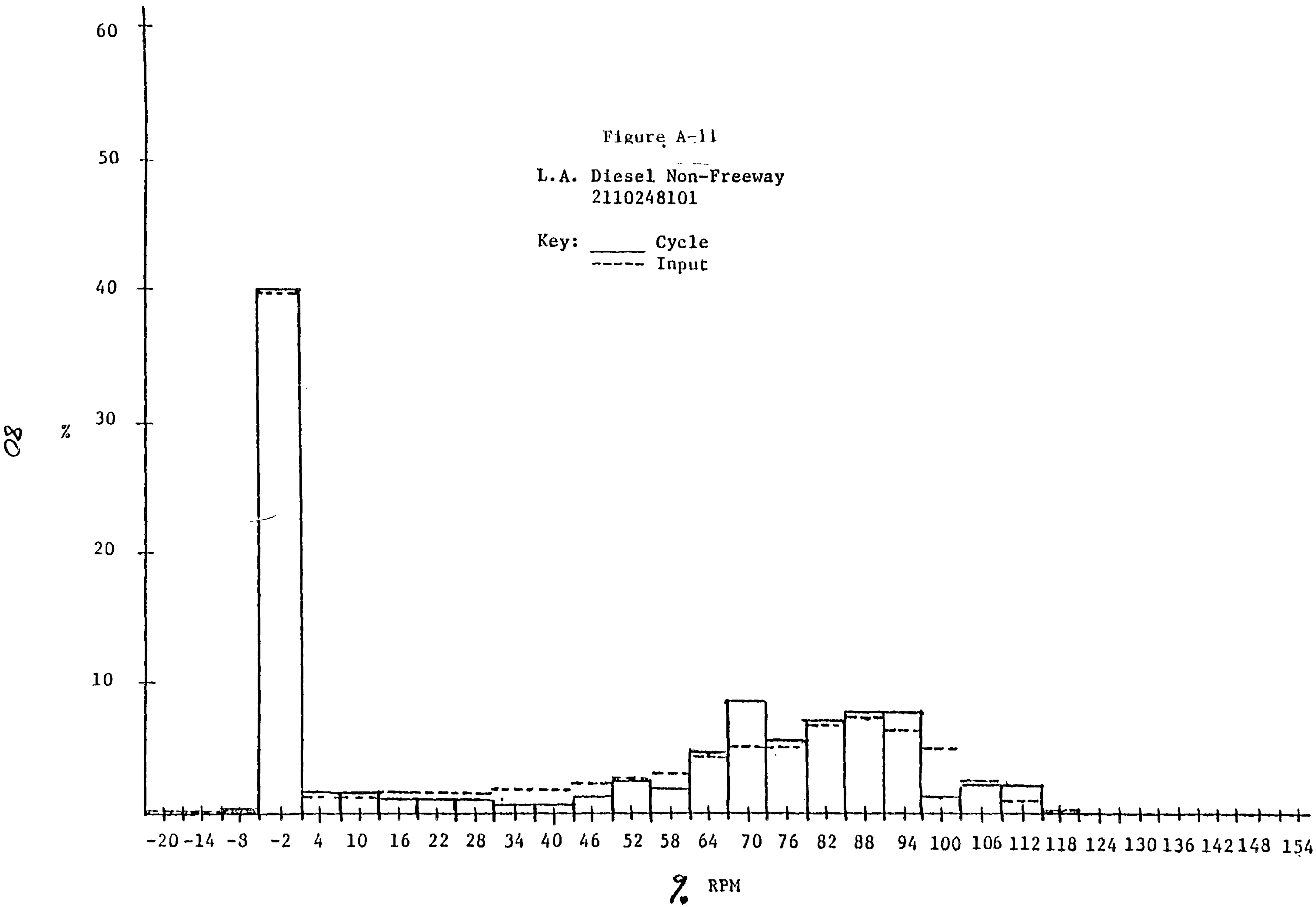


Figure A-11
L.A. Diesel Non-Freeway
2110248101
Key: _____ Cycle
----- Input
60
50
40
30
20
10
%
-20 -14 -8 -2 4 10 16 22 28 34 40 46 52 58 64 70 76 82 88 94 100 106 112 118 124 130 136 142 148 154
RPM

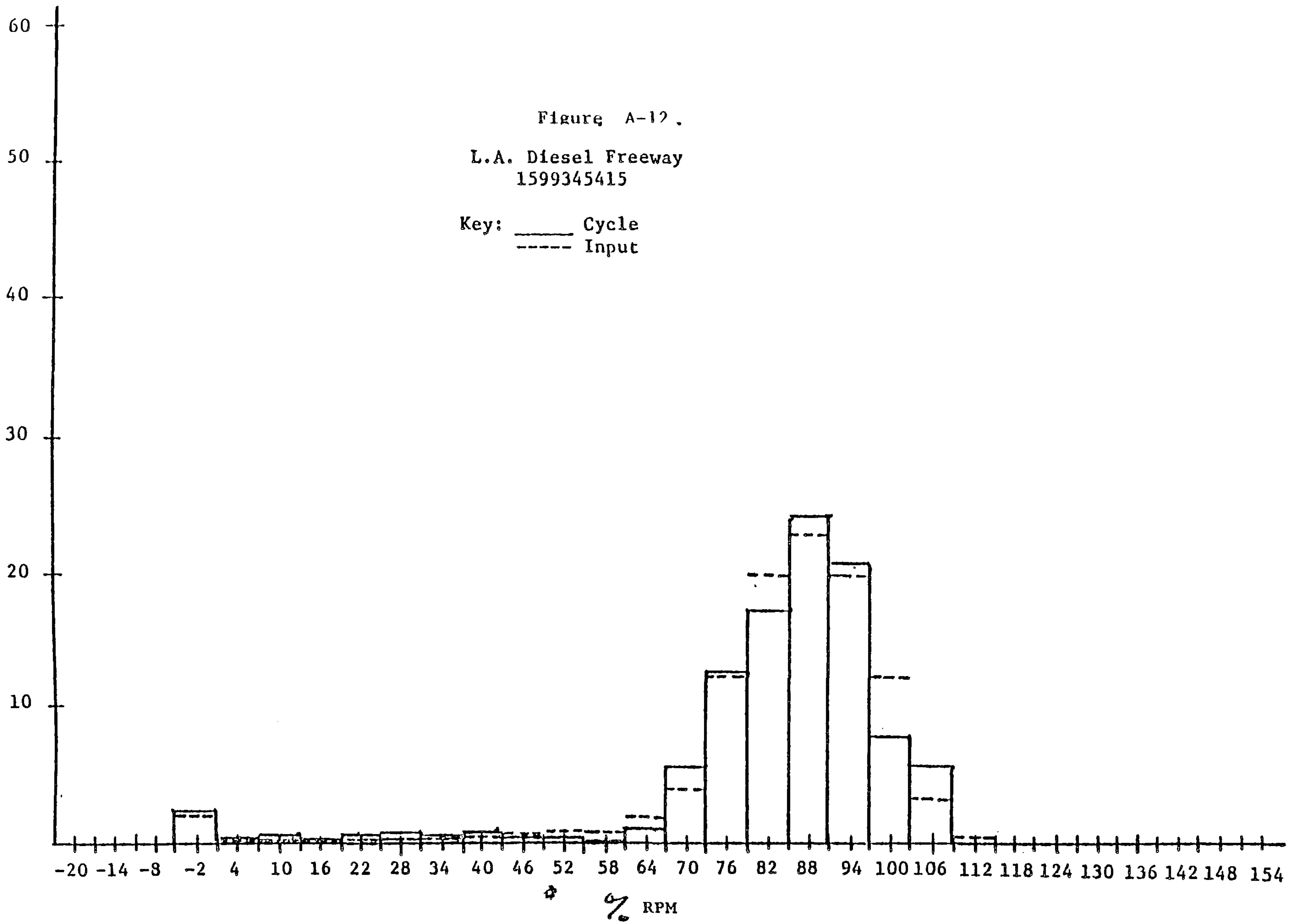


Figure A-12.
L.A. Diesel Freeway
1599345415
Key: _____ Cycle
----- Input
60
50
40
30
20
10
%
-20 -14 -8 -2 4 10 16 22 28 34 40 46 52 58 64 70 76 82 88 94 100 106 112 118 124 130 136 142 148 154
% RPM

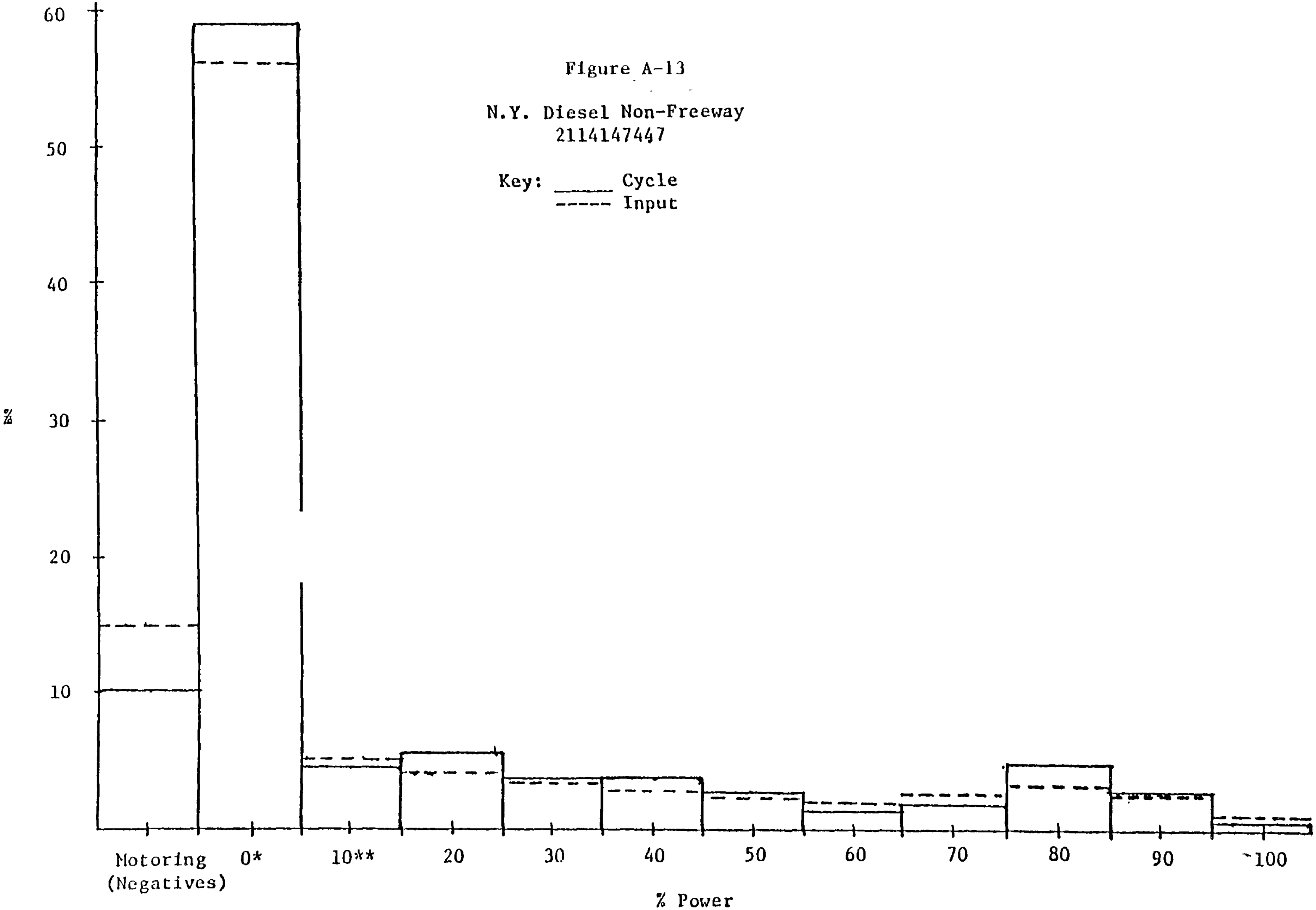


Figure A-13

N.Y. Diesel Non-Freeway
2114147447

* $0 \leq \% < 5$

$5 \leq \% < 15$

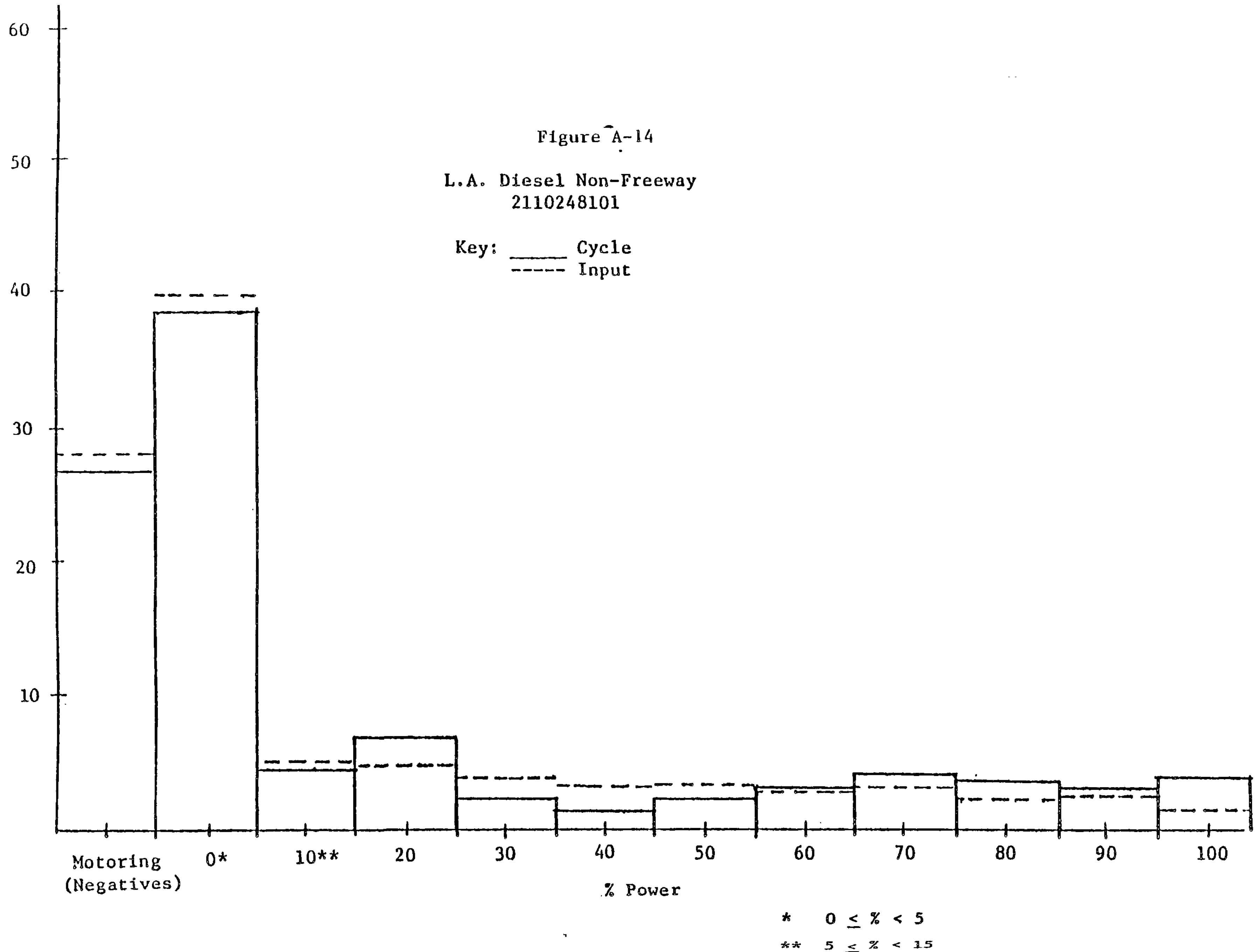


Figure A-14
L.A. Diesel Non-Freeway
2110248101
Key: ______ Cycle
----- Input
%
60
50
40
30
20
10
Motoring
(Negatives)
0*
10**
20
30
40
50
60
70
80
90
100
% Power
* 0 ≤ % < 5
** 5 ≤ % < 15

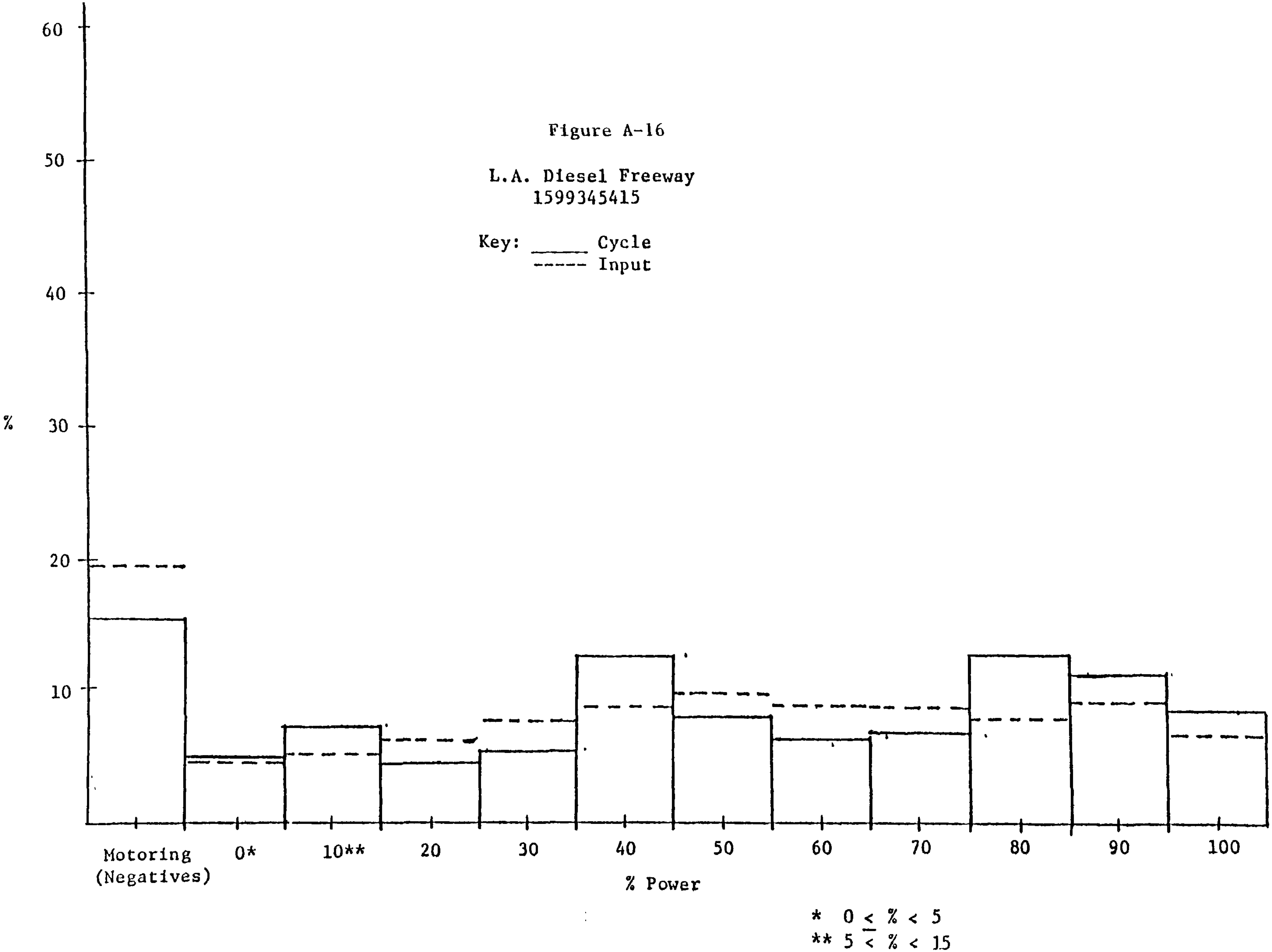


Figure A-16

L.A. Diesel Freeway
1599345415

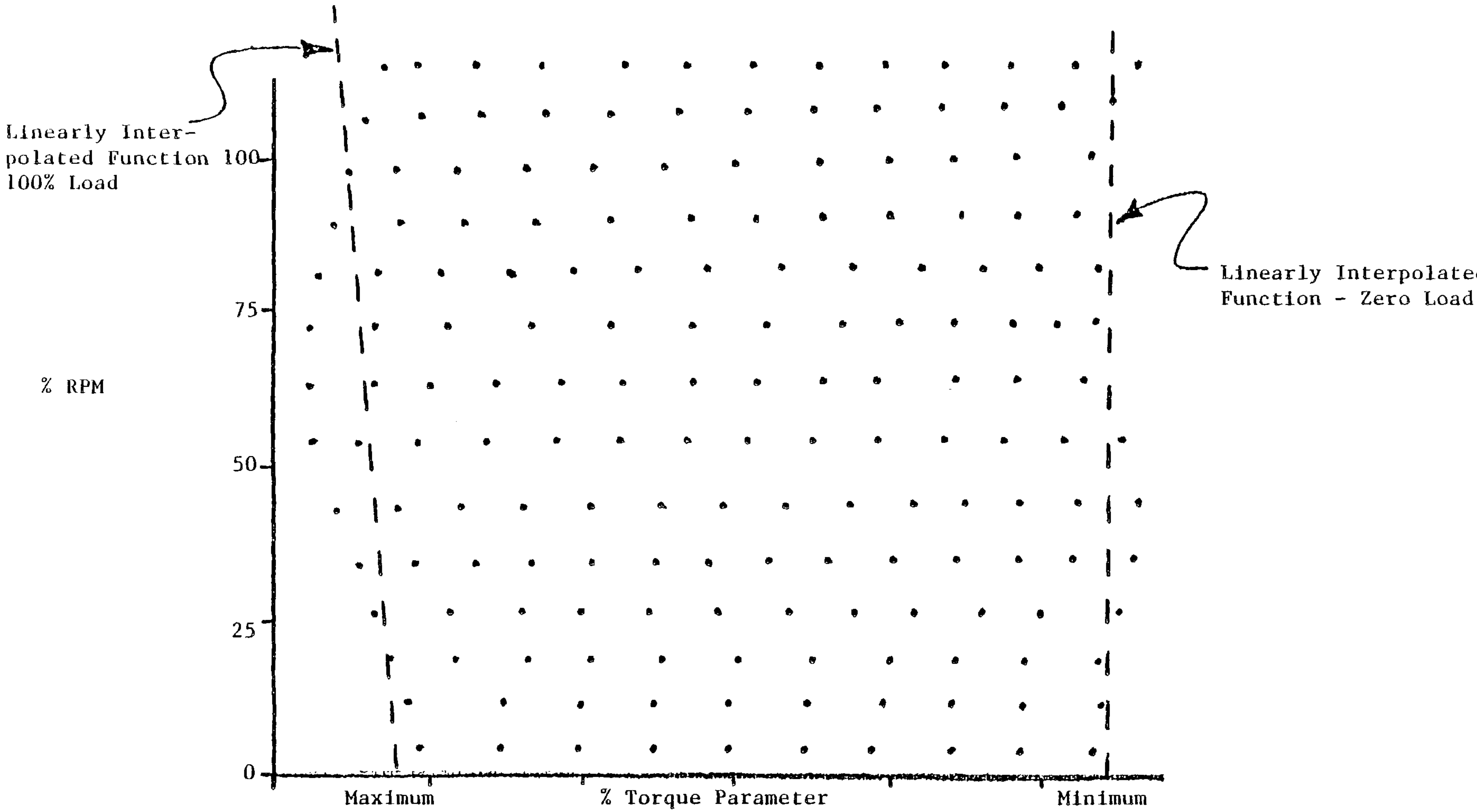


Figure A-16 Graphed EVSL Matrix

Figure A-17

Test Procedure Alternative Decision Flow Chart

Heavy-Duty Emission Test Procedure

Are old ones viable?

- San Antonio road route studies (1972-1975) said No!
- Ethyl Study (1967) said No!
- In-house and contracted testing of current and prototype engines (1978-1979) said No!
- No evidence or factual data has been found by EPA or presented to EPA by the industry which demonstrates the viability of current procedures for heavy-duty vehicles of the future.

Conclusion: The present 9- and 13-modes are not acceptable alternatives.

New steady-states?

- Experimental 23-mode test was evaluated (4/72); was determined to be no better than 9-mode or 13-mode.
- Sensitivity Study: no re-weighting of steady-state modes consistently correlated with any of several transient tests i.e., steady state tests in general are dubious predictors of transient emissions.
- Engineering judgements based upon light-duty experience.
- Concern: Can any steady-state remain valid through progressing technology?

Conclusion: The success of a new steady-state test is doubtful. If transient test is representative and cost-effective, then use it.

Chassis cycle?

- Chassis cycles were developed from CAPE-21 speed data. A certification procedure would be similar to LD-LA4.
- Certification on a chassis cycle, due to a large number of truck applications and component variations, would be impractical (See text-MVMA letter) and vehemently opposed by the industry.

Conclusion: Due to logistical problems of chassis certification, this is not a viable option for the present rulemaking.

Engine cycle?

- An engine cycle is the most practical of all alternatives. For this reason the CAPE-21 generated transient engine cycles were proposed in the NPRM.
- Further modifications to the proposed cycles? (See text)
- Further modifications to the proposed procedures? (See text)

Conclusion: An engine dynamometer test is the most practical; a transient test is the most representative. Modifications to the proposed cycles and procedures will be made where possible. (See recommendations and text.)

Figure A-18

CHANGES TO EPA PROPOSED CYCLE TO FORM THE CATERPILLAR MODIFIED CYCLE.
SEE TEXT FOR MEANING OF CHANGE SYMBOLS.

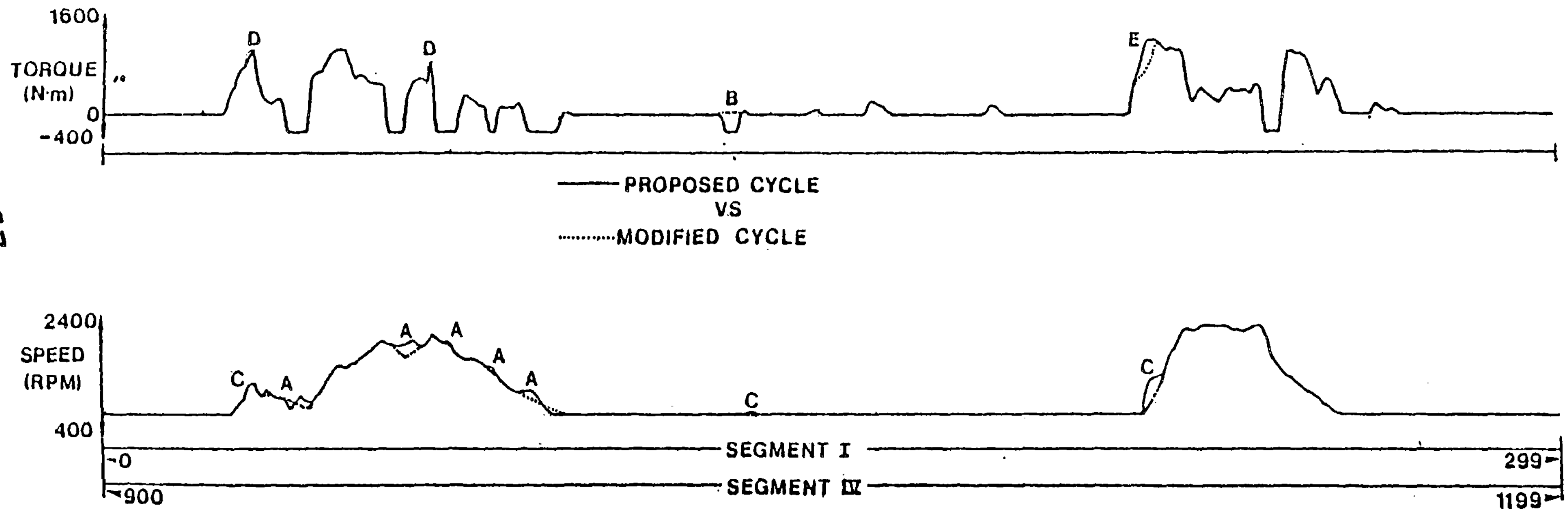


Figure A-18 (cont.)

CHANGES TO EPA PROPOSED CYCLE TO FORM THE CATERPILLAR MODIFIED CYCLE.
SEE TEXT FOR MEANING OF CHANGE SYMBOLS.

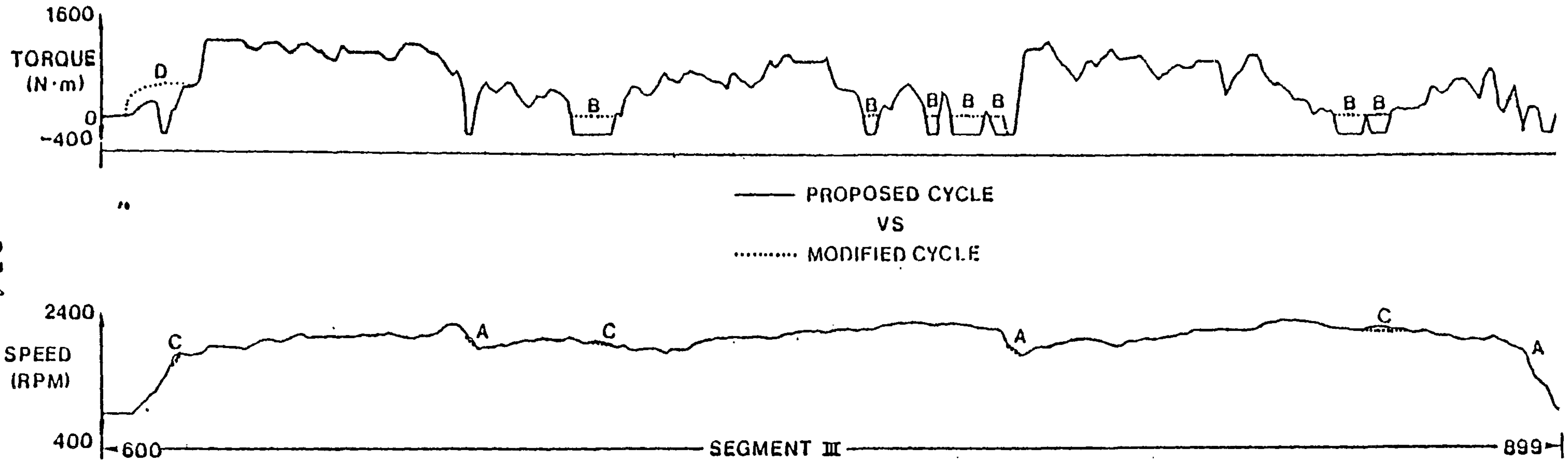


Figure A-18 (cont.)

CHANGES TO EPA PREPOSED CYCLE TO FORM THE CATERPILLAR MODIFIED CYCLE.
SEE TEXT FOR MEANING OF CHANGE SYMBOLS.**

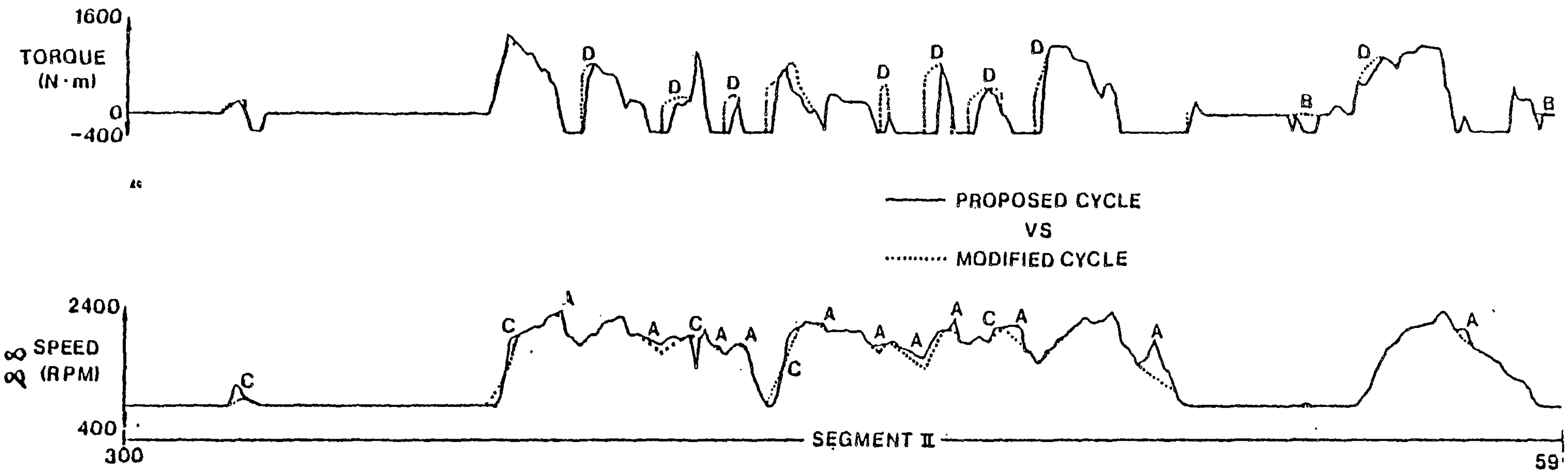


Exhibit A-1

Excerpt from Science Magazine

August 24, 1973

Auto Pollution: Research Group Charged with Conflict of Interest

One of the first issues that Russell Train, the nominee for administrator of the Environmental Protection Agency (EPA), will have to decide if and when he takes office, will be what to do about that agency's role in automotive pollution research. Train's predecessor, William Ruckelshaus, promised Congress that he would reassess some of the agency's close research ties with the auto and oil industries it regulates.

At issue is EPA's participation in a key research organization, called Coordinating Research Council–Air Pollution Research Advisory Committee (CRC-APRAC), which has sponsored much of the research that has been important to federal regulation in the battle to clean up the nation's air. CRC-APRAC is supported by the auto industry, the oil industry, and the EPA.

However, a few months ago Ruckelshaus promised Congress:

> If it [EPA participation in CRC-APRAC] gives the appearance to you and possibly to others that this has compromised our position, we will have to cease this association. . . .

An internal review is under way at EPA, and a report is due soon.

Because three-fourths of the $20 million that the group has spent to date has come from the American Petroleum Institute (API) and the Motor Vehicles Manufacturers' Association (MVMA), with only the remaining fourth from the government, CRC-APRAC has been accused by public interest lobbyists and members of Congress as having a pro-industry bias. Moreover, because it puts the regulated industries in bed with the agency that regulates them, the arrangement, says the pollution guru of Congress, Senator Edmund Muskie (D–Me.), poses a serious conflict of interest for EPA.

The APRAC group is one wing of CRC, a major trade organization which, for over half a century, has been a vehicle for getting the oil and engine suppliers together on some common problems. The APRAC group is unusual to CRC and to other trade research organizations in general because it receives large amounts of federal funding and routinely has federal officials participating in its decisions. The arrangement grew up in the late 1960's, when auto pollution was first becoming recognized as a national issue and when research funds for EPA's predecessor in the field, the National Air Pollution Control Administration (NAPCA), were scarce. Now, however, critics argue that EPA should be pursuing a "Caesar's wife" policy and keep itself above suspicion in its regulation of the auto industry, and that the CRC-APRAC tie is compromising.

The alleged conflict of interest which Muskie and others see in EPA's tie with CRC-APRAC, however, may be only the tip of the iceberg. Almost without exception, when a research scientist is funded by CRC-APRAC, he is already taking money from both the industry being regulated and the regulator. But this potential conflict is further tangled by the fact that many of CRC-APRAC's contractors, separately, depend on the auto or oil industry for a major share of their business. Some take money not only from the industry, but from EPA too. What emerges is not a clear-cut line between scientists working for EPA and those working for industry, but, instead, a murkier set of in-group relationships. Small wonder then, that, after 5 years of national effort, many apparently simple technical questions relating to auto emissions control remain hotly disputed.

Of CRC-APRAC's foes, the best-known is Muskie. In hearings last April on the EPA postponement of the 1975 emissions control deadline that was imposed by the 1970 Clean Air Act, the Maine Democrat challenged the objectivity of studies done by a researcher who has done much of CRC-APRAC's work on the health effects of carbon monoxide (CO), Richard D. Stewart of the Medical College of Wisconsin in Milwaukee. Stewart had found evidence that the average level of carboxyhemoglobin—an indicator of CO poisoning—in the blood of nonsmokers across the country was below 2 percent, which is the safe limit now used in federal regulation. (Stewart also found carboxyhemoglobin in the blood of smokers to be higher than that in nonsmokers.) Muskie, illustrating why CRC-APRAC researchers are accused of bias, pointed out that Stewart's work had been overseen by a typical CRC-APRAC panel, headed by a man from the General Motors Corp. (GM), with people from Phillips Petroleum Co., Marathon Oil Co., another GM man, and one EPA representative, who, Muskie added sarcastically, was "slightly outnumbered." Muskie also waved a full-page Chrysler Corp. ad publicizing Stewart's results, and he said, "Chrysler is the one automobile manufacturer which has attacked the health basis of the 1975 standards. It is that information which is going to be peddled around the country . . . for the purpose of attacking the basis of the 1970 Act."

(In fact, Stewart's findings, as written up by Associated Press and carried in newspapers across the country, were interpreted as evidence of the heavy influence of smoking in CO poisoning, a finding which other researchers on health effects—such as John Goldsmith of the California State Health Department—believe may be valid but nonetheless distracting from the main point: that susceptible people, involuntarily exposed to CO from auto exhaust, suffer adverse health effects.)

Muskie listed other panels of CRC-

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APRAC where big auto and oil companies are generously represented, while EPA employees are outnumbered—sometimes by 12 to 1. He argued that the auto companies take advantage of EPA's support of CRC-APRAC to give its work credibility, and then publicize their own interpretations of it.

> The shadow of EPA's involvement can be used and will be used to give the aura of credibility, official credibility, to statements made by Chrysler like this, challenging the health basis of the act. . . . I say the answer is to provide adequate funds and not lean upon industry to do the job.

Whether or not EPA is really an equal partner in CRC-APRAC hinges on the extent to which it exerts an influence on the group's deliberations. The CRC-APRAC's full-time officers, general manager Milton K. McLeod and project manager Alan Zengel stated in interviews that most of the group's decisions are made by the APRAC committee, which has 6 EPA representatives out of a total of 21 members.* The APRAC committee decides, without formal outside review, what work shall be undertaken, and who shall be appointed to the many subpanels, such as the one Muskie listed during the hearings, which supervise the research work itself. As to the government officials being outnumbered, McLeod and Zengel admitted (and EPA officials confirmed) that the panels often make decisions by voting, and that sometimes EPA people vote one way with the industry people voting the other.

However, not only do the oil and auto companies appear to dominate much of CRC-APRAC's decision-making, but the groups which CRC-APRAC selects to perform its research, in turn, depend for their livelihoods on business with these same industries. The most obvious example is that part of CRC-APRAC's work is funded by fuel companies and performed by fuel companies, and deals with matters in which they have a vital interest. CRC-APRAC has given a total of approximately $1 million to three oil companies: Esso Research and Engineering Co., a subsidiary of Standard Oil of New Jersey, which is studying the effectiveness of two well-known emission control devices, thermal reactors, and dual catalysts; Ethyl Corp., where changes in fuel volatility, a suggested means for lowering harmful emissions, are under study; and Phillips Petroleum Co. One of the major decisions EPA must make is whether short-term measures, such as altered fuels, and add-on gadgets, such as the dual catalyst, can be substituted by Detroit for a major switch to a new type of auto engine with new fueling requirements.

In addition to funding oil companies directly, CRC-APRAC supports other contractors who, in turn, depend on oil and auto companies for a major share of their business—a situation that again raises the question of their stake in the outcome of the research. The largest CRC-APRAC contractor is TRW Systems, which has gotten $3.3 million from that group. Despite its reputation among scientists as an aerospace firm, the parent company, TRW Inc., in fact does approximately 40 percent of its worldwide business (its annual sales are $1.6 billion) making and marketing vehicle parts. Thus, it is very much an interested party in federal regulations affecting the auto industry. TRW Systems, the research arm of this giant, has studied all aspects of vehicle maintenance and inspection for CRC-APRAC. The issue of vehicle maintenance and inspection has been a bone of contention between the industry and the government ever since the 1970 act passed Congress. According to Charles Heinen of Chrysler Corp., and CRC-APRAC's chairman, the auto manufacturers have been arguing that strict maintenance and inspection policies to keep existing auto antipollution equipment clean would serve to meet emission standards. But EPA standards setters have countered that such a policy, emphasizing maintenance, would de-emphasize the need to improve the quality of the original equipment installed in the car. They have said that this would therefore shift the burden of the clean car from the manufacturer to the owner or his garage mechanic.

The second largest recipient of CRC-APRAC money has been Scott Research Laboratories, Inc., one of the country's leading makers of air pollution measuring equipment. In the last 3 years, Scott has done about half its business, or about $3.8 million, with auto and fuel companies and their trade associations. Additionally, CRC-APRAC over the same period has spent an added $1.1 million at Scott.

One of Scott's major projects for CRC-APRAC has been studies of vehicle use patterns, or what EPA regulators term "driving cycles." A driving cycle is a package of information on when and where various types of vehicles—trucks, cabs, cars, and others—are used, at what speeds they are run, at what temperatures, and so forth. Data on actual vehicle use, which in turn go into making up the EPA driving cycle, has been a central issue to many ongoing disputes over emissions control, since one of EPA's standards setting jobs is to determine the driving cycles, which in turn determine the performance standards that manufacturers must make their engines meet. According to Malcolm Smith, one of Scott's principal investigators on the vehicle use studies, at the termination of the CRC-APRAC sponsored work, the auto industry took the data to EPA and used it to argue that existing federal "driving cycles" be reexamined, but EPA refused.

One of the largest contractors to CRC-APRAC has been the Stanford Research Institute at Menlo Park, California, which has received $1.3 million in the last 5 years. John Eikelman, SRI coordinator of environmental research says that a major portion of SRI's industrial environmental research has been with the petrochemical industry, including measuring pollutant damage to vegetation, identification of crude oil in spills, and other work. SRI has also worked on catalytic emission control systems and auto parts for various other industry sponsors. For CRC-APRAC one principal researcher, Harris Benedict worked on a nationwide assessment of damage to crops attributable to air pollution; but even this work illustrates how the thrust of CRC-APRAC research, despite its intrinsic interest and merit, keeps coming back to regulatory issues in which EPA is involved up to its ears.

The SRI researchers surveyed dollar value losses to corn, citrus, and other food crops and to ornamental plants, indexed them geographically, and came up with an overall annual loss estimate of $132 million, far less than a previous estimate of $500 million. The finding that air pollution doesn't do

* The APRAC group consists of: C. M. Heinen, Chrysler Corp., chairman; J. W. Blattenberger, Cities Service Oil Co.; D. L. Block of Ford Motor Co.; C. E. Burke of American Motor Corp.; R. A. Coit of Shell Oil Co.; R. E. Eckhardt of Esso Research and Engineering Co.; E. F. Fort of International Harvester Co.; D. G. Levine of Esso Research and Engineering Co.; E. D. Marande of Ford Motor Co.; C. E. Moser of Texaco Inc.; E. H. Scott of Standard Oil of Ohio; P. D. Strickler of Gulf Research and Development Co.; C. S. Tuesday of General Motors Corp.; R. B. Welly of Jeep Corp.; D. W. Innes of Ford Motor Co.; and, from the Environmental Protection Agency, A. P. Altshuller, J. F. Finklea, R. E. Harrington, Kay Jones, Eric Stork, and H. L. Wiser.

much damage to crops—which after [illegible] are mostly in rural parts of the country—as had been feared has proved useful in arguing against cleaning up every single automobile in the nation; it indirectly strengthens the hand of those who want a geographic national pollution control strategy limited to urban areas, where air pollution is worst. Another SRI-performed study found that soil is a natural "sink" or absorber of CO. This is a finding which clearly affects the debate over whether overall CO levels are increasing or decreasing, and, hence, over the urgency of man's need to reduce them. Both studies, then have a link, albeit indirect, to EPA's regulatory role.

CRC-APRAC's research program must be viewed in light of the fact that some of it is performed by the oil companies themselves, some by groups who depend or have depended heavily on oil and auto companies for their business—both of which have some stake in the regulatory game. A third pattern among CRC-APRAC contractors, and one that further muddles the issue of who works for whom, is that many of the smaller CRC-APRAC contractors also take money from the American Petroleum Institute and the Motor Vehicle Manufacturers' Association directly, from the oil and auto industries, and in some cases, from the government too. An all-in-the family pattern appears to characterize the winning and losing of pollution research contracts. For example, Smith at Scott Laboratories, noted that after EPA declined to accept the industry's interpretation of its surveys of vehicle use to reexamine the driving cycles, Scott was able to continue the work through MVMA sponsorship anyway. Another case was that of Wilbur Smith Associates, an international transportation consulting firm, which had research and development contracts simultaneously with EPA and with CRC-APRAC. According to one of the researchers there, Wilbur Smith Associates has subcontracted a part of its work to a Bedford, Mass., aerospace firm GCA Corp., which, oddly enough has in addition held its own contract directly with CRC-APRAC. Many of the principal investigators interviewed remarked that these overlapping, interlocking contract awards were typical of the auto emission research business, and some added that it was also a characteristic of the aerospace-defense department business in which many of these investigators previously worked. In fact, several major university centers for air pollution work are conspicuously absent from the list of 40-odd CRC-APRAC contractors, whereas about 14 of the contractors are firms prominent in the aerospace field. Many of the investigators interviewed said they personally had done aerospace work: "I got tired of making bomb calculations," said one. "Working on environmental problems seemed to be a good thing to do," said another. But an EPA official who sits on some CRC-APRAC panels offered a less sanguine view: "The only thing worse than an unemployed aerospace engineer," he quipped, "is an unemployed aerospace engineer who has gone to work on the environment."

Interviewed about the soundness of policies which appear to encourage researchers to take money from both EPA and the auto and oil industries, many of the investigators retorted, "How else would you do it?" Many pointed out that just giving more money to EPA—with a proviso that EPA get out of CRC-APRAC—which is what Muskie's staff is considering doing—would not solve the problem, since EPA has as much stake in the outcome of the research as the industry does. A California air pollution expert, however, made another suggestion which others echoed: that a separate government body, serving in effect as a third party to the controversy, become the prime sponsor of auto emissions research. "I'm amazed that parts of HEW [the Department of Health, Education, and Welfare] have been overlooked in all this. Why shouldn't they build up a capability in the NIEHS [National Institute of Environmental Health Sciences]? . . . They're good. They'd be ideal. . . . But they've been ignored."

—Deborah Shapley

Exhibit A-2

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

DATE: October 13, 1976

SUBJECT: Prediction of Heavy Duty Gasoline Trucks' Transient Emissions from Steady State or Sinusoidal Test Procedures

FROM: Janet Becker, CAB

TO: Gary Rossow, SDSB

THRU: Marcia Williams, Chief, CAB

The intent of this memo is to explore the possibility of predicting transient cycle emissions for heavy duty gasoline trucks from emissions as measured over a steady state or sinusoidal procedure. Of particular interest, of course, is the currently used 9-mode FTP composite, or some reweighted version of it.

Although it was not clear that analysis had been done to indicate that there is a difference between single-axle gas trucks and other gas trucks, SwRI included only the nine single-axle trucks in their analysis used to determine the predictability of transient emissions from the 9-mode FTP, or some reweighted version of it.

When the 15 mph and 20 mph average speed transient cycles were linearly regressed on the 9-mode FTP composite emissions, the best predictive relationships overall for HC, CO, and NOx were derived from the 15 mph cycle when the trucks were empty. For this case, as for the other speed-load combinations, prediction of HC transient emissions was fairly accurate (correlations between transient HC and 9-mode FTP emissions ranged from .93 to .96). Although NOx could be predicted fairly accurately for the 15 mph, empty truck case, prediction was not acceptable over any other speed-load combination. Transient CO could not be predicted accurately via the 9-mode FTP composite over any of the six speed-load transient cycles.

To determine a reweighted version of the 9-mode test which would hopefully achieve better predictability of transient emissions, a linear programming technique was used. This technique found the set of modal coefficients (weights for each of the none modes) which would best predict transient emissions. The method of least squares was applied. (At this point in time, SwRI and EPA are jointly evaluating the accuracy of this approach). The set of modal coefficients was subjected to the following constraints before the prediction relationship was developed.

1. All modal coefficients had to be non-negative.

2. The sum of the modal coefficients had to equal 1.

EPA Form 1320-6 (Rev. 3-76)

The magnitude of the various modal coefficients (weighting factors) used in the resulting prediction equations vary with pollutant, driving cycle (transient vs. sinusoidal), speed, and load. For example,

1. The closed throttle mode is significant in the prediction of transient HC at all speed-load combinations, but is insignificant in the prediction of transient CO and NOx at all speed-load combinations.

2. The idle mode generally is significant in the prediction of transient NOx, but is insignificant in the prediction of sinusoidal NOx.

3. The 19" mode is insignificant in the prediction of transient CO, but is highly significant in the prediction of transient NOx. (However, when the wide open throttle mode is substituted for the 3" mode, the 19" mode becomes the most significant mode for CO).

On the basis of examples such as these, it appears that a unique set of modal coefficients which will successfully predict transient HC, CO, and NOx does not exist. However, no formal anlaysis was done to support this statement.

SwRI's conclusion that the correlation between transient cycle emissions and the reweighted 9-mode emissions is generally higher than the correlation between transient cycle emissions and the 9-mode FTP composite could be fallacious for several technical reasons (including possible problems with the constraints applied to the system, possible correlation among the supposedly independent variables (the modes), and SwRI's using the same data used to determine the new weighting factors to decide whether correlation improved). Also, the fact that some of the reweighted correlations are smaller than the original correlations leaves the linear programming technique open to criticism.

Substituting a wide-open throttle mode for the 3" vacuum mode of the 9-mode FTP did not improve the ability to predict transient emissions for the 15 and 20 mph average speed cycles, according to SwRI's analysis.

With respect to the question as to whether percent change in emissions as measured over the 9-mode FTP composite can predict percent change in emissions as measured overa a fully transient cycle, four levels of emission control were defined: pre-1970, 1970-1973, 1974-1975 Federal, and 1975 California. The average pre-1970 gas truck emissions for HC, CO, and NOx were used as the bases for the percent changes calculated. The percent change in emission (by pollutant) for each of the 18 gasoline trucks was calculated. SwRI used the 10 mph and 20 mph average speed transient cycles with the trucks half full for this part of the analysis.

A linear regression of percent change in transient emissions on percent change in FTP emissions was performed. For the 1970-1973 level of emission control, the linear relationships at 20 mph average speed/cycle yielded better accuracy of prediction than did the 10 mph cycle. However, accuracy using the 10 mph cycle was significantly worse only for HC. The regression equations for the 20 mph average speed cycle are:

HC: $y = .95x - 17.11 \quad R^2 = .982,$

CO: $y = .92x + 6.92 \quad R^2 = .994$

NOx: $y = 1.82x - 84.30 \quad R^2 = 1.000$

where y = percent change as measured over the transient 20 mph cycle with trucks at half load,

and x = percent change as measured over the 9-mode FTP composite.

Although the R^2 values are high, suggesting that accurate prediction via these equations is possible, the practical use of the equations is limited by at least two considerations:

1. Only four trucks were used to determine this equation and a priori one would expect the R^2 to be high,

and

2. These equations could be used only over the limited range of x values covered by the four trucks in the sample. For example, one can not logically predict an 84.30% decrease in transient emissions, given that there was no change in FTP emissions. (This corresponds to setting x equal to zero and solving for y).

For the 1974 level of control, the linear regression relationships between the two transient cycles and the FTP for percent changes in emissions were accompanied by R^2 values below .5, which is unacceptable for prediction purposes. These relationships suggest however, that percent decrease as measured over either the 10 or 20 mph transient cycle is greater than percent decrease as measured over the 9-mode FTP.

It was of interest to determine if emissions measured over sinusoidal driving cycles could be used to predict emissions as measured over the fully transient cycles, the idea being that a sinusoidal test would be simpler and less expensive to operate than a fully transient test. Linear regression relationships of emissions as measured over the 20 mph average speed transient cycle on emissions as measured over the 20 ± 5 mph sinusoidal cycles were developed for HC, CO, and NOx. The trucks were at half load for this analysis. Accuracy of prediction was poor, with R^2 values ranging from .2 for HC and NOx to .3 for CO. For CO, emissions measured over the transient cycle are always greater than those measured over the sinusoidal cycle for the case studied. This implies that significant CO on-the-road emissions could occur even if a vehicle complied with a sinusoidal test for CO.

To determine if emissions on deceleration and acceleration can be predicted from a steady state test, emissions as measured over the sinusoidal cycles at 30 $\pm$ 5 mph and 40 $\pm$ 2 mph (at half payload) were linearly regressed on the corresponding steady state emissions. The 40 $\pm$ 2 mph equations yielded the better predictions:

HC: $y = .995x - .252 \quad R^2 = .885,$

CO: $y = .939x - 3.138 \quad R^2 = .812,$

NOx: $y = .940x + .615 \quad R^2 = .852,$

where y = emissions (gm/min) as measured over the sinusoidal cycle,

and x = emissions (gm/min) as measured over the steady-state cycle.

For this case, accuracy of prediction is fair for HC and NOx, but unacceptable for CO. The ability of the 30 mph steady-state cycle to predict the 30 $\pm$ 5 mph sinusoidal cycle emissions was poor for all three pollutants.

The sinusoidal tests produce lower HC and CO levels than the steady state tests for the 40 $\pm$ 2 mph case. This fact would indicate that there are not significant HC and CO emissions during transient maneuvers, provided that the 40 $\pm$ 2 mph cycle can be considered to contain transient maneuvers.

Exhibit A-3

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

SUBJECT: Transient vs. Steady-State Test Procedures for Measuring Emissions of Heavy Duty Diesel Trucks

DATE: September 28, 1976

FROM: Janet Becker, CAB *Janet Becker*

TO: Gary Rossow, SDSB

THRU: Marcia Williams, Chief, CAB *MW*

Currently, the Federal Test Procedure used to measure heavy duty diesel vehicle emissions is a 13-mode non-transient engine procedure. This non-transient engine procedure is being used to establish the initial compliance of new heavy duty vehicles with federal emission standards. Since heavy duty vehicles usually operate in transient cycles, the question immediately arises as to the comparability of emission factors obtained via a non-transient test procedure and those which might be obtained via a transient driving cycle which represents the driving patterns of a typical heavy duty truck. Olson Laboratories, under contract to EPA, is in the process of analyzing data which will be used to determine such a driving cycle.

Due to the unavailability of test data over the final driving cycle, it is clearly impossible to answer this comparability question precisely at the present time. However, it is possible to move ahead on the general question of the comparability of the 13-mode test results and test results derived from various transient tests; and thus to anticipate the degree of comparability between the 13-mode test and the forthcoming representative driving cycle. Since it appears from preliminary data collected by Olson Laboratories that a 15-20 mph average speed transient cycle will be selected as the representative driving cycle, the transient cycles at these average speeds are emphasized in the present memo. The transient driving cycles used in this analysis were developed by EPA on the basis of preliminary CAPE-21 data on a small sample of trucks.

Emissions data on 12 heavy duty diesel and 18 heavy duty gasoline trucks were collected and analyzed by Southwest Research Institute (under Contract Nos. 68-03-2147 and 68-03-2220). Data were collected for a variety of chassis dynamometer tests, including the 13-mode*, steady-state operation, sinusoidal driving patterns, and completely transient driving cycle operation. Each test was carried out when the trucks were empty, at 50% payload, and at GVW. Each test, except the 13-mode, was carried out at a variety of average speeds.

*It was assumed that the 13-mode test would give the same results on a chassis dynamometer as on an engine dynamometer.

EPA Form 1320-6 (Rev. 6-72)

The question as to whether or not the 13-mode FTP composite can be used to predict the emissions over the 15 mph transient or 20 mph transient cycle was addressed via regression analysis. Prediction equations of the form:

$$y = ax + b,$$

where y = emission (gm/min) over the transient driving cycle in question, and x = 13-mode FTP composite (gm/min) were developed for HC, CO, and NOx for empty trucks, half-full trucks, and full trucks. Associated with each such equation is a "coefficient of determination" (R^2), which is used to help decide the accuracy of the prediction equation. For the 15 mph and 20 mph transient cycles, equations for half-full and full trucks yielded larger R^2 values than did the equation based on empty trucks' emissions. The R^2 values are given below.

		Half-full trucks	Full trucks
15 mph transient cycle	HC	.440	.446
	CO	.537	.691
	NOx	.850	.843
20 mph transient cycle	HC	.493	.348
	CO	.513	.656
	NOx	.878	.841

The R^2 values associated with HC and CO indicate that prediction based on a linear equation of the form y = ax + b is not very accurate. For NOx, the R^2 value is large enough to use the prediction equations with more confidence. The two prediction equations for NOx which were provided by SwRI are:

Equation 1: $y = .674 + .641x, \; R^2 = .878,$

where:

y = emissions (gm/min) measured over 20 mph transient cycle (half load)

and

x = emissions (gm/min) measured via the 13-mode FTP composite

Equation 2: $y = .671 + .467x, \; R^2 = .850,$

where:

y = emissions (gm/min) measured over 15 mph transient cycle (full load) and

x = emissions (gm/min) measured via the FTP composite.

These equations indicate that prediction equations vary with different speed-load combinations. However, the contributions of speed and load can not be factored out without the other two equations (20 mph, full load and 15 mph, half-load), which SwRI did not provide.

Since a linear equation using the currently defined weighting of the 13 modes (resulting in the 13-mode FTP composite) does not predict transient emissions well for all three pollutants, the 13-modes were reweighted via a linear programming technique. The objective was, for each load-average speed transient cycle, to find a linear combination of the 11 modes, (although there are 13, 3 are idle and these modes were combined for this analysis so as to decrease the number of estimated parameters) which would equal the emissions measured over the given transient test. This objective was subjected to the constraints:

1) All modal coefficients must be non-negative,

and

2) The sum of the coefficients must equal one.

These constraints could prove to be very limiting if, for example, the emissions over the transient cycle were consistently higher than over any of the modes. Constraint 2 is particularly questionable from a mathematical viewpoint, although perhaps is supported from the engineering angle. Since all modes were included in the regression, another questionable assumption is the independence of the modal tests correlation among the independent variables affects the estimates of the modal coefficients.

The results of this linear programming technique were equations approximating a given transient cycle's emissions on the basis of the reweighted 13 modal values. The half-load equations provided the best overall prediction for all three pollutants.

<u>15 mph, half-loaded trucks</u> (modes are in parentheses and are explained below)

HC : y = .180 (1, 7, 13) + .507(2) + .170(5) + .144(6) + .002(8), R^2 = .845

CO : y = .271 (1,7,13) + .202(4) + .243(5) + .021(6) + .067(8) + .97(10), R^2 = .773

NOx: y = .351(1,7,13) + .433(2) + .164(5) + .010(8) + .042(9), R^2 = .917,

where:

y = emissions (gm/min) over the transient cycle at half-load, Explanation of modes

(1,7,13)	Idle
(2)	2% peak torque at peak torque speed
(3)	25% peak torque at peak torque speed
(4)	50% peak torque at peak torque speed
(5)	75% peak torque at peak torque speed
(6)	100% peak torque at peak torque speed
(8)	100% rated horsepower at rated speed
(9)	75% rated horsepower at rated speed
(10)	50% rated horsepower at rated speed
(11)	25% rated horsepower at rated speed
(12)	2% rated horsepower at rated speed

Keeping in mind the fact that 12 observations are being used to estimates 11 parameters, these R^2 values are surprisingly low. Undoubtedly the correlation among modes is influencing the R^2 values, as well as the constraints that were put on the system. Until further analysis is done, these equations are not recommended for use in predicting transient emissions.

SwRI considered the question of whether percent change in emissions over transient cycles can be predicted from the percent change in emissions over the 13-mode FTP composite by looking only at the 10 mph and 20 mph transient cycles. The diesel trucks were divided into two groups determined by method of emission control: pre-1974 models and 1974-1975 models. A pre-1974 average emission (gm/min) was calculated for each test cycle. For each of the five 1974 and 1975 model-year trucks, a percent change in emissions was calculated on the basis of the pre-1974 average level. The percent changes observed over the transient tests at 10 mph and 20 mph average speeds were linearly regressed on the percent changes observed in the 13-mode FTP composite, and the following relationships resulted:

Transient, 10 mph avg. speed

HC :	y =	.11x–16.52	R^2 = .012
CO :	y =	1.03x + 8.54	R^2 = .531
NOx:	y =	1.11x + 2.28	R^2 = .795,

where:

y = percent change over transient cycle,

and

x = percent change over 13-mode FTP composite.

<u>Transient, 20 mph avg. speed</u>

HC:	y =	-.04x - 17.89	R^2 = .002
CO:	y =	1.58x + 8.15	R^2 = .700
NOx:	y =	1.06x + 2.86	R^2 = .865,

where:

y = percent change over transient cycle,

and

x = percent change over 13-mode FTP composite

From a statistical viewpoint, only for NOx could the percent change in the 13-mode FTP be used to predict percent change over the transient cycles with any degree of accuracy. One caution is that from looking at a scatter plot for NOx, it appears that the relationship might be curvilinear as opposed to linear, so possibly the prediction equation needs a quadratic term.

A sinusoidal driving cycle is a compromise between a steady-state cycle and a fully transient cycle. One question of interest is how well the sinusoidal predicts the fully transient emissions. SwRI used 20$\pm$ 5 mph sinusoidal and 20 mph average speed fully transient half-load data to derive the following linear relationships.

HC :	y =	.519x + .368	R^2 = .686
CO :	y =	.635 + 5.465	R^2 = .118
NOx:	y =	.923x + 2.501	R^2 = .946

where:

y = emissions (gm/min) over 20$\pm$ 5 mph sinusoidal at half-load

and

x = emissions (gm/min) over 20 mph transient cycle at half-load.

For CO, sinusoidal emissions should not be used to predict transient cycle emissions. For HC, prediction of transient from sinusoidal is borderline, and for NOx, predictability looks good.

To see if the accelerations and decelerations that are missing from a steady-state cycle can be accounted for via a linear relationship, linear equations were developed to predict sinusoidal emissions (30$\pm$ 5mph and 40$\pm$ 2 mph from steady-state emissions at 30 and 40 mph at half-load. The prediction was better using the 40 mph cycle, and these equations are

HC: $y = 1.18x + .368$ $R^2 = .686$

CO: $y = 1.074x + .926$ $R^2 = .569$

NOx: $y = 1.791x + .665$ $R^2 = .971$,

Where:

y = emissions (gm/min) over 40$\pm$2 mph steady-state cycle at half-load,

and

x = emissions (gm/min) over 40 mph steady-state cycle at half-load.

Only for NOx is the prediction relationship good enough to use with confidence. The equations for HC and CO are poor-to-borderline predictors. Moreover, the steady-state emissions are less than the sinusoidal emission levels, indicating that significant emissions occur for all pollutants during transient maneuvers.

In conclusion, it appears that only for NOx can a version of the test (either the FTP composite or a reweighted version) be used to accurately predict transient cycle emissions. Also, sinusoidal emissions are greater than steady-state emissions for all three pollutants implying that significant emissions occur during acceleration or deceleration. Thus, it seems possible that manufacturers could design emission control systems which would satisfy a version of the 13-mode FTP (a composite of steady-states), but still would permit unacceptably high emission levels when trucks are on the highways in transient operation.

B. Issue - Redefinition of "Useful Life"

1. Summary of the Issue

In the February 13, 1979 NPRM, EPA proposed that the current definition of "useful life" be changed for heavy-duty engines. Currently in the regulations useful life is interpreted as approximately half of the service seen by a typical heavy-duty engine; specifically, for gasoline-fueled engines, 5 years, 50,000 miles, or 1,500 hours of use, whichever occurs first and for diesels, 5 years, 100,000 miles, or 3,000 hours.

The proposal extends this "useful life" period to the "average period of use up to engine retirement or rebuild, whichever occurs first." The manufacturers would themselves determine this average value for each engine line they manufacture. In no case, however, may the useful life of any heavy-duty engine be less than 50,000 miles or 5 years nor less than the basic mechanical warranty on the engine. For most engines, this change more than doubles the useful life period and thus has significant effects on durability testing and warranty obligation.

2. Summary of the Comments

A large number of comments dealt with EPA's justification for changing the useful life definition. Concern was expressed that Congressional intent was violated and that the divergence from past regulatory experience was unwarranted. Second, that inherent quality of a full-life useful life which requires lifetime emissions compliance was seen as an increase in the stringency of the emission standards. Third, commenters criticized the "average" aspect of the useful life definition for causing unnecessary problems. Finally, EPA received a range of comments that all revolved around difficulties in actually determining a useful life value for a given engine line. The following paragraphs briefly expand on these four areas of comment.

The comments that were directed at Congressional intent cite portions of the legislative histories of both the 1970 Clean Air Act (which first addressed "useful life") and the 1977 Amendments to that Act (which made modifications to the language of useful life provisions). Often quoted were the passages which made clear that the legislators indeed understood that the 50,000-mile "lifetime" they chose for durability and warranty purposes in 1970 approximated only half of the expected life of a light-duty vehicle. Thus, said the commenters, Congress explicitly wove the half-life concept into the Act. Also, an excerpt from a Senate report preceding the 1977 Amendments explains the rationale behind the wording of §202(d)(2) (which allows the Administrator to lengthen--but not shorten--the useful life for non-light-duty vehicles) as providing greater flexibility in defining the durability of trucks. Chrysler in particular saw in this excerpt "no intention to abolish the half-life concept." Finally, several comments contended that Congress had meant for there to be a "balance" between the treatment of light-duty vehicles (LDVs) and heavy-duty engines (HDEs) in useful life matters.

A related area of comments involved the implications for heavy-duty engines of the recently decided Court of Appeals action relating to motorcycle useful life.1/ This court proceeding was going on as Congress considered the 1977 CAA Amendments, and the record shows that the legislators knew of and responded to the useful life controversy. Their answer was to remove motorcycles from §202(d)(2) and create §202(d)(3) to specifically allow a shorter useful life than 50,000 miles/5 years for motorcyles. Some commenters argued that by leaving the language affecting other non-light-duty vehicles and engines (including HDEs) unchanged, Congress "implicitly continued to recognize the half-life concept" for these vehicles (MVMA). Additionally, Mercedes Benz pointed to the Court's opinion in which the court argues that, according to the legislative history of the Amendments, the approach used in the 1970 CAA for LDVs and HDEs was "reasonable."

Most of the commenters noted that the half-life concept has been a part of vehicle emissions regulations since the 1966 (HEW) rules applying to 1968 model year vehicles, preceding the earliest statutory mention of useful life. In that rulemaking, 100,000 miles was identified as the basis for "lifetime emissions." Under the assumption that emissions deteriorations would be linear, HEW established a procedure for calculating average lifetime emissions at the approximate half-life (50,000-mile) point. All subsequent regulations for light-duty vehicles, light-duty trucks, and heavy-duty engines have used half of the expected life as the useful life. The comments imply that the average lifetime emissions concept has embodied the intentions of Congress through the years and that for EPA to now change that concept for HDEs is unwarranted.

A final area of comments which strikes at the actual concept of a full-life useful life argued that it acts to increase the stringency of the emissions standards. As the heavy-duty regulations are presently constructed, manufacturers must design their engines so that during approximately the first half of their lifetime their emissions do not deteriorate past the level of the standards. This situation requires that the emissions of a new engine be somewhat below the standard in order that deterioration may be accommodated. The proposed full life concept would require lifelong emissions compliance and hence a still lower initial level of emissions. This is the "increased stringency" referred to in the comments. Some of the commenters went on to claim that EPA is in effect requiring a reduction in emissions in excess of the 90 percent minimum set by Congress.

The two remaining major areas of comment were not directed at the basis of the full-life concept so much as at specific problems which might be expected to arise from EPA's proposed application of the concept. The first of these is the language of the NPRM that requires the manufacturers to determine an "average" period of engine use for each engine line. The comments hinge on the implication that half of the engines subject to an average useful life will require rebuild or retirement before they reach that useful life. While some commenters implied that an emission warranty claim would result in each case, most said that a flurry of claims could be expected to result from decay in emission-related components toward the end of the useful life. Also, there was considerable concern that the emissions-related warranty would be confused with the engine warranty, sparking warranty conflicts, and that the full life warranty on emissions would require coverage of related parts beyond commercially-sound limits. Finally, Ford urged a labeling change that would make it clear that the useful life number was given "for the sole purpose of the emission-system warranties required by the Clean Air Act."

The last set of comments were procedural in thrust and revolve around the difficulties that the manufacturers would expect in defining a useful life number under the proposed full-life concept. First, data concerning actual engine usage periods is largely unavailable at this time. Additionally, the lack of specificity in the "retirement or rebuild" useful life limit drew comment since the decision of when to retire or rebuild is reached by the user on largely economic--as opposed to mechanical--grounds. Thus, manufacturers would find it difficult to arrive at an average period for this event for an engine. The problem would be further compounded by the wide range of vocational applications seen by many engine families which makes the rigor of duty a quite variable entity. Ford is probably a worst case example because over 65 percent of their gasoline trucks are sold as incomplete chassis; this, they claim, prevents them from knowing the end uses of their engines.

A treatment of comments relating to several additional useful life issues, more minor in scope than those above, may be found in Part II of this document.

3. <u>Analysis of the Comments</u>

The same order in which the issues were summarized in the previous section will be followed as the issues are discussed and analyzed below.

a. <u>Congressional Intent/Regulatory Precedent/Stringency</u>

The language and the legislative history of the Clean Air Act, as amended, support the proposed changes to a full-life useful life definition.

Nowhere does the Act place a half-life useful life restraint on heavy-duty useful lives. Quite to the contrary, Section 202(d)(2) clearly provides the Administrator with the discretion to set the useful life for a duration or mileage greater than that set by Congress for light-duty vehicles if he determines that a greater duration or mileage is appropriate. Given the need to create an incentive for manufacturers to build emission control components as durable as the rest of the traditionally long lasting engine parts and the significant air quality benefits that will be realized if the proposed definition of useful life is adopted (see discussion below), adoption of the proposed definition is certainly "appropriate" and well within the descretion explicitly granted to the Administrator by the Act.

Nor does the legislative history evidence a Congressional commitment to impose a half-life restraint on setting the useful life for heavy-duty vehicles. While the final outcome of the 1970 Clean Air Amendments was a conscious defining of light-duty useful life to be half of the expected actual life, it seems that decision was a result of forces that were present at that specific time and to that specific class of vehicles. A 100,000 mile/10-year requirement was seriously considered by a Senate committee 2/, but was halved largely as a compromise response to the light-duty vehicle industry reaction against any sort of performance warranty (versus "parts and labor" warranties).

There was no similar commitment to the half-life concept with respect to heavy-duty vehicles and engines; nor was there any indication that Congress intended to "balance" the treatment of LDVs and HDEs in the manner suggested by the commenters.

There is no reason to believe, as some commenters suggest, that when Congress removed motorcycles from the vehicles affected §202(d)(2) and created §202(d)(3), they meant to endorse the half-life concept that was then being applied by EPA to heavy-duty engines. Rather, in creating a separate provision for motorcycles, Congress was simply interested in retaining the 50,000 mile/5-year minimum for those "other motor vehicles," while at the same time expressly authorizing EPA to adopt a useful life of less than the 5 years/50,000 minimum set by §202(d)(2). Had there been a desire to place a half-life constraint on EPA, Congress could have easily inserted such language at that time.

The Court in Harley-Davidson v. EPA. 598 F.2d. 228 (D.C. Cir, 1979) did indeed agree with Congress that motorcycles should be treated differently from heavy-duty and light-duty vehicles, but not on the basis of half-life vs full-life useful life. Rather the Court concurred with Congress that a useful life of less than 5 years or 50,000 miles for motorcycles was appropriate, but the 5 year/50,000 mile minimum should be retained for other mobile sources.

Turning now to the comments which implied that past regulatory practice should constrain future rulemaking, the staff takes a somewhat different view. The regulations promulgated by EPA must be the best attempt possible at that time to fulfill the wishes of Congress within the context of feasibility, cost, and other factors. Indeed, in 1970, early in the history of vehicle emissions regulations, HEW established a useful life concept which allowed heavy-duty engines to exceed the standards for the greater part of their lives. This interpretation may be evidence of an uncertain regulatory climate during that time frame, but the provisions were clearly not mandated by Congress. Further, the only other regulations involving useful life since the 1970 CAA, those pertaining to motorcycles and aircraft, apply the full-life concept.

The final area of comment which affects the full-life concept itself is the stringency issue. This idea might be better treated in the broad context of how it fits into the total full-life useful life plan. If the Administrator has the discretion to adopt a full-life useful life, then a lower zero-mile emission level is simply a practical result of applying that requirement to the certification process. Thus, we agree that, in a narrow sense, the design-goal emission level is more stringent under a full-life useful life concept. But, in the larger perspective, the standards themselves are not more stringent; they are simply met for the lifetime of the engine. The staff cannot accept the stringency issue as an argument against the full-life useful life. In any event, Congress asked for standards representing a reduction of "at least 90 percent", provided they are technologically feasible (emphasis added).

The staff position on the idea of a full-life useful life as formulated before receipt of the comments remains largely unchanged. That position is summarized as the following:

Because of the extended periods of use seen by HDEs, continued functioning of emissions systems is vital. The present "half-life" useful lives in reality represent something less than half of the actual lifetimes of most engines. Thus, to assure the air quality benefits for this package are realized--and that the consumers get their money's worth--it is necessary for the emissions systems to function close to the full life. In no instance is this more clear than in the case of gasoline-fueled engines, which will be equipped with catalyst technology for the first time. Absent an incentive to design appropriate durability into these components, one would expect a congregation of catalyst failures around the minimum useful life point. Similar logic holds as well for diesel manufacturers as they improve the durability of their emission-related components. It is the incentive for durable design, then, that is the crux of the staff's argument for a full-life requirement.

In light of our previous discussions, concluding that neither the stringency issue, existing regulations, nor Congressional intent constrain EPA to a half-life policy, we continue to support the idea of a full-life useful life concept, subject to practical improvements in its application.

b. "Average" Useful Life and Problems in its Determination

The remaining discussion will deal with the practical difficulties associated with the full-life useful life concept. The first of those is the proposed requirement that the useful life value supplied by the manufacturer be the "average" for that engine family. The staff has considered alternative methods of establishing the useful life number, though no commenter offered a suggestion along these lines. For example, the alternative of allowing complete latitude in defining the useful life is likely to encourage unrepresentative values. Depending on whether a manufacturer places emphasis on quick durability programs and few warranty claims or rather would favor a lengthy durability program to delay the use of an in-use df, a manufacturer might either gravitate toward the lower useful life limit or place the useful life too high, respectively. (One present lower limit as proposed is the basic engine warranty, which is based on economic grounds and can be expected to undershoot the actual period the engines are on the road in most cases.) Another alternative could be for EPA to establish that some percentage of the period of use or some percentile of the retirement/rebuild distribution be used instead of a straight average. This option, however, suffers from a complete lack of data to support any specific numbers.

The staff must conclude that specifying that an "average" useful life be determined is the best way under a full-life useful life plan of balancing fairness to the industry with some measure of assurance for EPA that the chosen "period of use" is accurate.

Regarding the flood of warranty claims anticipated by the commenters, the staff disagrees that under the proposed rule half of the manufacturers' engines will require emissions warranty work. Although it is clear that half will reach their individual retirement/rebuild points, this does not necessarily mean an emissions violation will exist in every case. Certainly there will be a number of additional warranty claims attributable to the extension of the useful life period. The Agency does not, however, expect this number to be excessive. Additionally, the proposed regulations imply that the manufacturer would be responsible for post-rebuild emissions compliance.

The staff has recommended changes in the proposed rule which speak to each of these issues. First, new provisions are included which define the end of an engine's useful life as the average period of use or the point at which the engine needs rebuilding, whichever is reached first (provided that the 50,000 mile/5 year minimum has been passed). Thus, the cost of the rebuild, as well as all subsequent repairs, will be borne by the owner--not by the manufacturer. Similarly, the problem of warranty conflicts and misleading labels are answered, we think, by the recommended policy of allowing the manufacturer to define useful life values for separate service applications (again, see Conclusions and Recommendations). The last point made by manufacturers in the area of warranty was that a full-life emissions warranty will force emission-related parts to be guaranteed beyond the point of economic wisdom; i.e., for the full useful life of the engine. The staff can only respond that the purpose of an emissions warranty is to assure that emission control components on in-use vehicles and engines are operating. This necessarily requires manufacturers to design emission control components with adequate durability, even if the costs incurred might be considered too large by standard marketing criteria.

EPA does not believe that the costs associated with Section 207(a) warranties will increase significantly when the extended useful life is implemented. (As we stated under Issue F. - Idle Test and Standards, Section 207(b) warranty regulations have not yet been implemented; any costs associated with such regulations will be treated in future emission performance rulemaking packages.) Because costs have been included in our economic analysis to cover the increased durability of emission control components we have at least partially accounted for the costs which might be incurred if a manufacturer chooses not to work toward more durable components and as a result suffers warranty claims. Moreover, any effect on the aftermarket industry is likely to be minimal since we expect a comparatively small number of additional warranty claims to result from the redefinition of "useful life."

The final area of comment regarding useful life pertains to the anticipated problems with accurately specifying an average useful life value. While we do recommend that an average be required, we agree that such difficulties need to be considered in order to achieve the best design for a full-life policy.

Our agreement with the commenters does not in all cases extend to the severity of the problems. It is not surprising to us, for example, that a broad base of engine-life data does not exist in a convenient form. But since the regulations would give the manufacturers a reason to collect this kind of data, we believe that it could be obtained relatively easily once the effort is made (through telephone surveys, for example). The staff is convinced that such information would be accessible even for engines sold as incomplete vehicles. Also, it is the average lifetimes of the engines themselves, not their emission controls, that is of interest; so the comments about the data gathering being complicated by the advent of new control technology apply only for those engines whose basic mechanical deterioration is affected by the controls. We expect this to be a rare situation. The upshot is that useful life data is available now for all engines which are not to be radically changed for 1983 certification. Further, the staff believes that the acquisition of such information will facilitate the approximation of the useful lives of new engines as well.

The staff has been able to directly address the remaining problems (i.e, the lack of specific retirement/rebuild criteria and the variation in engine vocation within an engine family) through recommended changes in the regulations, as explained in the Conclusions and Recommendations section below.

4. Staff Recommendations

On the basis of the comments and their analysis above, the staff recommends that the useful-life provisions as proposed be retained largely intact. Three significant changes are offered, however, which respond to a wide range of comments.

As we concluded during the Discussion above, the staff believes that the full-life useful life concept should remain a part of this Rulemaking. Within this context, we advocate that the language "average period of use" be kept intact for the sake of practicality. Since the manufacturers will be setting the useful life values, EPA's requiring that value to be an average appears to be the most reasonable method of encouraging accurate useful lives.

Several of the difficulties associated with an "average" useful life, however, will be reduced or eliminated if certain staff recommendations are adopted. Specifically, we support 1) a set of more objective criteria for determining when rebuild is necessary, 2) a manufacturers' option to supply for the owner alternate expected useful lives depending on service application, and 3) modifying the "useful life" definition to be less restrictive of the manner in which the useful life is determined.

The first of these suggested changes is the most significant and would remove much of the uncertainty in defining an "average period of use up to engine retirement or rebuild." The major criterion for determining whether an engine is due for a rebuild would appear on the label and would be, for the purposes of this rulemaking, a compression test, along with a measure of oil consumption and of bearing failure. Those tests will cover nearly all mechanical situations which normally signal the need for a rebuild. Since the actual test values will be determined by the manufacturer for each engine family, establishing the average useful life should be easier and more accurate. Another implication is that an "actual useful life" will exist for each individual engine; there will be a measurable endpoint to the manufacturer's obligation for an engine with respect to both durability testing and the emissions warranty. Thus, the regulations clearly will not require post-rebuild emissions compliance.

The second recommendation amounts to allowing a qualifying statement on the label to indicate to the owner that the useful life of this particular engine can be expected to vary from the "average" due to a lighter or heavier service application. The label could also direct the reader to the operator's manual for information about vocation-specific average useful lives, about how the emissions-related warranty differs from the mechanical warranty, etc. The purpose of the label change is to promote user understanding of the "average useful life" concept and hence to reduce the threat of warranty conflicts.

The final staff recommendation is to remove from the definition of useful life the restriction that for new engines the useful life be determined from durability testing. We see this provision as an unnecessary complication of the process of establishing a useful life value.

Some of our recommendations, particularly the first two, will to a certain extent add to the complexity of portions of the regulations and the certification process as compared to the original proposal. However, the staff is firmly convinced that by making these adjustments to the proposal, EPA will not only answer a range of reasonable comments but will improve the workability, versatility, and fairness of the full-life useful life concept. We urge the adoption of these provisions.

References

1/ Harley-Davidson Motor Company, Inc. v. EPA, U.S. Court of Appeals, D.C. Circuit, No. 77-1104, March 9, 1979.

2/ Legislative History of the Clean Air Act Amendments of 1970, Senate Public Works Comm. Print No. 1, August 25, 1970, §207(c).

C. Issue - In-Use Durability Testing

In order to better respond to comments on the proposed in-use durability testing procedure and to optimize all components of the program, EPA is delaying the finalization of the in-use durability testing requirements. Further analysis of the design of the durability program will continue and finalization of the program is expected to occur on the same time line as the statutory NOx reduction. The summary and analysis of comments on this component of the proposal are not included in this document. Instead, they will be addressed when the in-use durability regulations are finalized.

Beginning in 1984, and continuing until finalization of a revised durability testing procedure, the burden of durability testing will be shifted to the manufacturers. Under this concept, the manufacturers will determine their deterioration factors in programs which they design. EPA will not approve the programs which the manufacturers design but will require that they: 1) describe their durability testing program in the certification application, 2) certify that their durability testing procedures account for deterioration of emission related components and other critical deterioration processes, and 3) adhere to the maintenance requirements as applicable specified in the allowable maintenance regulations. These requirements are the same as those proposed for the determination of the preliminary deterioration factor.

Manufacturers are encouraged to begin small-scale in-use durability programs in the near future so they can gain some meaningful experience with in-use durability testing. This will benefit the manufacturers and EPA in that they could generate in-use durability data which could verify the feasibility of and need for an in-use type durability testing program.

EPA has chosen to finalize its proposal of multiplicative deterioration factors for all heavy-duty engines. The comments received concerning this aspect of the proposal are summarized and analyzed below.

1. Summary of the Issue

EPA has proposed that multiplicative deterioration factors be used for both gasoline-fueled and diesel heavy-duty engines.

2. Summary of the Comments

Multiplicative Deterioration Factors

Diesel engine manufacturers commented that there is no support for the use of multiplicative DFs for diesel engines. The manufacturers further commented that the use of a multiplicative DF unduly penalizes engines with low initial emissions and makes the design goal standard more stringent regardless of the actual deterioration properties of the engine. Gasoline-fueled engine manufacturers provided no conclusive evidence that catalyst-based technology should not require a multiplicative DF. Only Ford Motor Company supplied data to support their claims, but this was based on Non-Methane Hydrocarbon data.

3. Analysis of the Comments

As stated in the regulatory analysis which supports this rulemaking action, the use of multiplicative DFs over additive DFs or vice-versa is not unequivocally supported by theoretical or empirical considerations. EPA's position on the multiplicative DF issues is discussed in three sections below: (a) the importance of using the correct type of DF, (b) multiplicative DFs for gasoline-fueled heavy-duty engines, and (c) multiplicative DFs for heavy-duty diesel engines.

(a) The importance of using the correct type of DF.

Given two durability fleets, one called "clean" and one "dirty":

+ = additive DF value; X = multiplicative DF value

Std.: emission standard

4K Point: emission level at the 4,000-mile (125 hr) emission test

UL: emission level at the end of the useful life

Case 1 -- "Clean Durability Fleet"

Std.: 1.3 g/Bhp-hr

4K Point: .5 g/Bhp-hr

UL: 1.0 g/Bhp-hr

+ = .5 g/Bhp-hr X=2

With these DFs, emission data engines can have 4K emissions as high as .8 g/Bhp-hr with an additive DF, but only .65 g/Bhp-hr with a multiplicative DF.

Case 2 -- "Dirty Durability Fleet"

Std: 1.3 g/Bhp-hr

4K Point: .5 g/Bhp-hr

UL: 1.2 g/Bhp-hr

+ = .7 g/Bhp-hr X = 2.4

With these DFs emission data engines can have 4K emissions as high as .6 g/Bhp-hr with an additive DF, but only .54 g/Bhp-hr with a multiplicative DF.

Thus, in either of the cases discussed above, the additive DF would give an emissions deterioration cushion for the manufacturers which would be more desirable for certification carryover and SEA.

EPA's concern is best understood by studying the impact of using the results of the durability testing for one family to apply to all calibrations within that family. Using the data provided in cases 1 and 2 shown above, the cases below show the impact when an additive DF is used when a multiplicative DF is appropriate and vice versa.

<u>Case 3</u> -- "Clean Durability Fleet"

+ = .5 g/Bhp-hr

X = 2

If an additive DF is allowed when a multiplicative DF is really appropriate, then the error could be: (1.3 g/Bhp-hr) computed - (1.6 g/Bhp-hr) actual = -.30 g/Bhp-hr, or actual deterioration to 1.6 g/Bhp-hr when the standard is 1.3 g/Bhp-hr.

If a multiplicative DF is allowed when an additive DF is really approprite, then the error could be:

(1.3 g/Bhp-hr) computed - (1.15 g/Bhp-hr) actual = .15 g/Bhp-hr, or actual deterioration to 1.15 g/Bhp-hr when the standard allows 1.3 g/Bhp-hr.

<u>Case 4</u> -- "Dirty Durability Fleet"

+ = .7 g/Bhp-hr

X = 2.4

If an additive DF is allowed when a multiplicative DF is really appropriate, then the error could be:

(1.3 g/Bhp-hr) computed - (1.44 g/Bhp-hr) = -0.14 g/Bhp-hr, or actual deterioration to 1.44 g/Bhp-hr when the standard is 1.3 g/Bhp-hr.

If a multiplictive DF is used when an additive DF is more appropriate, then the error could be:

(1.3 g/Bhp-hr) computed - (1.24 g/Bhp-hr) actual = +.06 g/Bhp-hr, or actual deterioration to only 1.24 g/Bhp-hr when the standard allows 1.3 g/Bhp-hr.

It can be seen from the cases shown above that:

1. a multiplicative DF allows the maximum air quality protection because it yields a buffer when applied in a situation and which may be additive and is the correct methodology in a multiplicative situation;

2. an additive DF in a multiplicative situation could allow an engine to exceed the emission standard, but has no effect, positive or negative, in a situation which is really additive;

3. the effects of interchanging DF determination methodologies decreases as the actual amount of deterioration from the same starting point increases.

(b) Multiplicative DFs for gasoline-fueled heavy-duty engines.

The catalyst-based technology anticipated in heavy-duty gasoline-fueled vehicles supports the use of multiplicative DFs because catalysts reduce the engine-out emisions by the same percent regardless of any slight variability in the engine-out emissions.

EPA's rationale for the use of multiplicative DFs for catlayst equipped engines is outlined below.

The condition that must be satisfied for the use of multiplicative deterioration factors, rather than additive factors, to be appropriate is that differently calibrated engines in the same engine family experience the same percentage increase in emissions over a given interval of service accumulation. This can be shown to be the case under suitable assumptions.

Let: E_{eo} (M) = engine-out emissions of a pollutant as a function of mileage M;

E_{tp} (M) = tailpipe emissions of the same pollutant as a function of mileage M;

$$e(M) = 1 - \frac{E_{tp}(M)}{E_{co}(M)}$$ = catalyst efficiency as a function of mileage M;

$M_i =$ initial reference mileage;

$M_f =$ final reference mileage;

(1) represent engine 1 of the family; and

(2) represent engine 2 of the family

Assume that engine 1 and engine 2 are calibrated differently and therefore have slightly different engine-out emissions, but that the efficiency of the catalyst as a function of mileage is the same for the two (i.e., that the catalysts are equivalent when new and that the slightly different engine-out emissions do not significantly affect catalyst deterioration). Then,

$$E_{tp}^{(1,2)}(M_i) = E_{eo}^{(1,2)}(M_i)(1 - e(M_i))$$

$$E_{tp}^{(1,2)}(M_f) = E_{eo}^{(1,2)}(M_f)(1 - e(M_f))$$

$$\frac{E_{tp}^{(1,2)}(M_f)}{E_{tp}^{(1,2)}(M_i)} = \frac{E_{eo}^{(1,2)}(M_f)(1 - e(M_f))}{E_{eo}^{(1,2)}(M_i)(1 - e(M_i))}$$

If it is further assumed that for both engines the deterioration in engine-out emissions is negligible, then

$$E_{eo}^{(1,2)}(M_f) = E_{eo}^{(1,2)}(M_i),$$

and

$$\frac{E_{tp}^{(1)}(M_f)}{E_{tp}^{(1)}(M_i)} = \frac{E_{tp}^{(2)}(M_f)}{E_{tp}^{(2)}(M_i)}$$

This is the condition which must be satisfied for a multiplicative deterioration factor to be appropriate.

This conclusion has been reached using three fairly reasonable assumptions: 1) engine-out emissions deteriorate very little; 2) catalysts on differently calibrated engines deteriorate identically, and 3) catalysts can be modeled as proportional reduction devices.

(c) Multiplicative DFs for heavy-duty diesel engines.

In order to unequivocally demonstrate that an additive DF is preferential to a multiplicative DF, one must first define the conditions which demonstrate these two situations.

Additive DF: like engines with different initial emission levels deteriorate the same absolute amount.

Multiplicative DF: like engines with different initial emission levels deteriorate in an amount directly proportional to their initial emission levels.

The best possible example to illustrate the deterioration nature of heavy-duty diesel engines would be to have emission results from two engines within the same family which have both been tested for emissions durability (1,000 hr). Unfortunately, the current durability testing program only requires one engine from each family to meet the durability requirements.

As a possible alternative to this approach, EPA has studied the emission results from 37 heavy-duty diesel engines which underwent emissions durability testing for 1979 certification. Figures C-1, C-2, C-3, and C-4 which follow this discussion are plots of 125 hr emission levels versus DF. Specifically they are:

Figure C-1: HC 125 hr vs. Additive DF
Figure C-2: CO 125 hr vs. Additive DF
Figure C-3: HC 125 hr vs. Multiplicative DF
Figure C-4: CO 125 hr vs. Multiplicative DF

The lines drawn on each of the figures represent the best fit straight line through the data points.

Although the best fit lines appear to adequately represent the data points, no statistical significance can be found. The R^2 values for these regressions were:

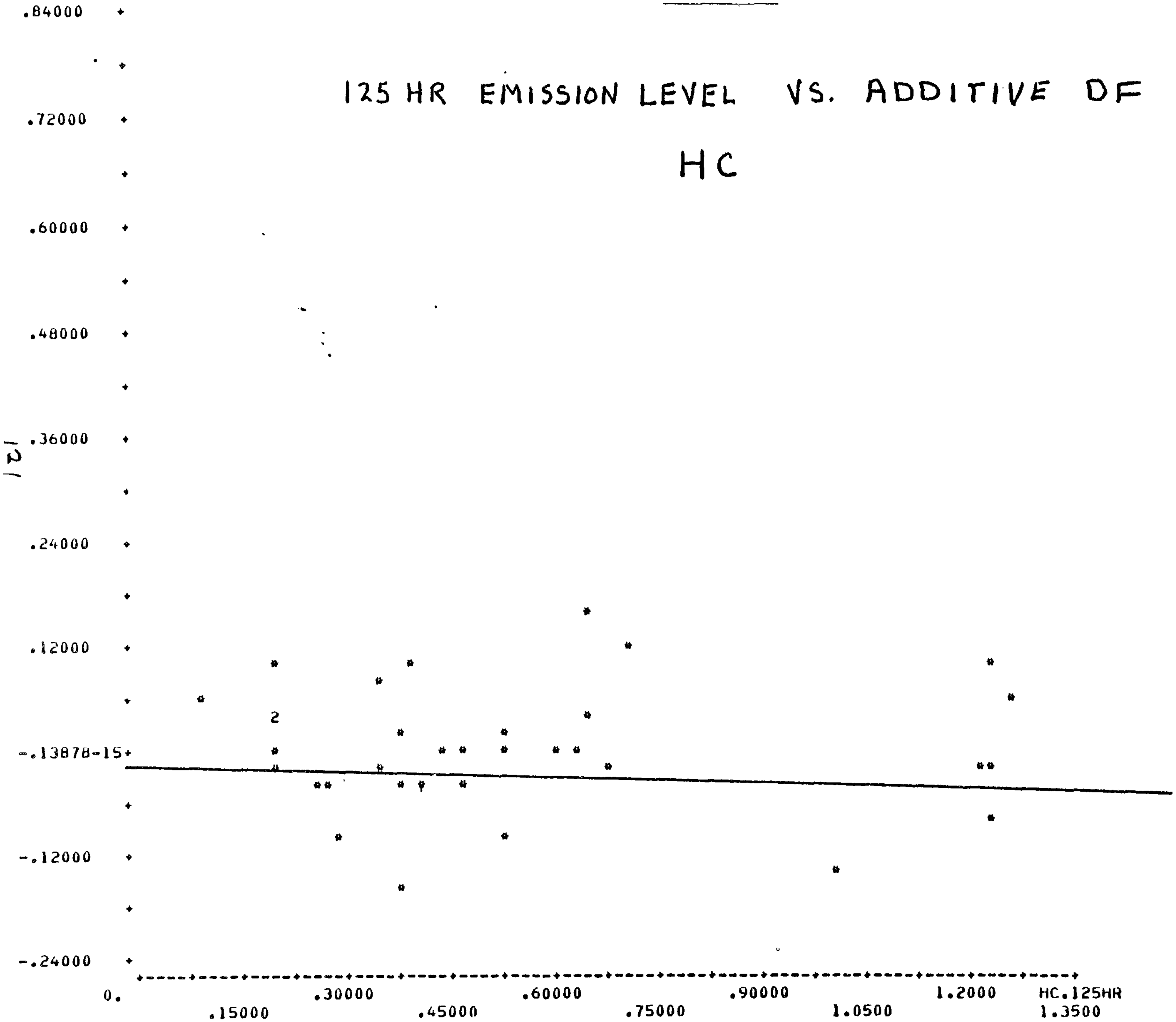
Figure C-1: 0.00190
Figure C-2: 0.04116
Figure C-3: 0.01410
Figure C-4: 0.01140

In addition, and perhaps more importantly, the data points as shown in the figures do not conclusively support an additive or multiplicative DF for HC or CO when compared to the definitions given earlier. In short, deterioration does not appear to be the same absolute amount when initial emission levels are different nor does deterioration appear to increase as the initial emission level increases. Thus, neither type of DF is conclusively supported.

<SCATTER VAR=2,1 CASES=ALL INTERVAL=(-.24,.84);(0,1.35) HEAD=10 HC.DF VS HC.125HR>

SCATTER PLOT HC.DF VS HC.125HR
N= 34 OUT OF 37 2.HC.DF VS. 1.HC.125HR

FIGURE C-1



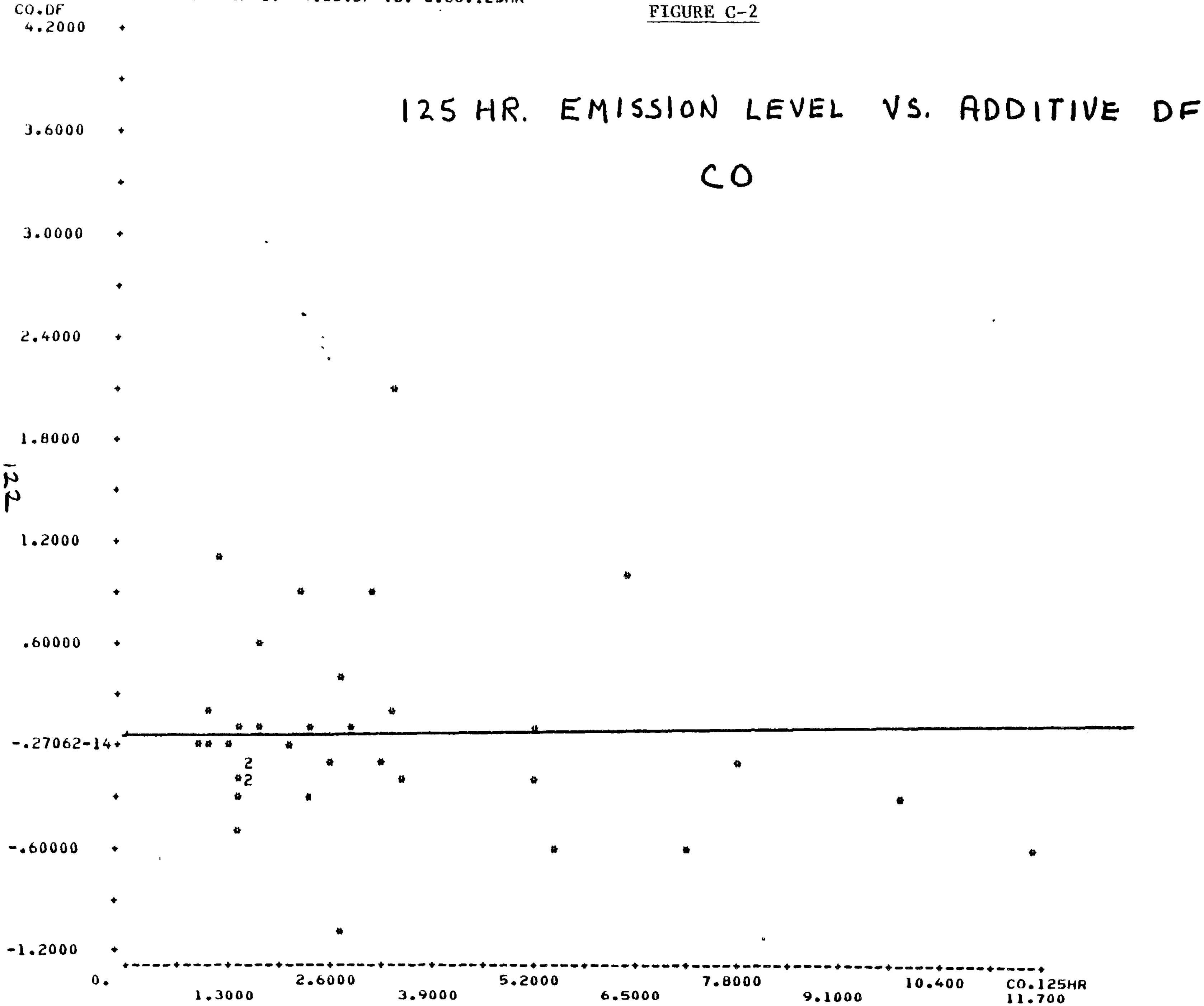
<SCATTER VAR=4,3 CASES=ALL INTERVAL=(-1.2,4.2)I(0,11.7) HEAD=10 CO.DF VS CO.125HR>

SCATTER PLOT CO.DF VS CO.125HR
N= 36 OUT OF 37 4.CO.DF VS. 3.CO.125HR

FIGURE C-2

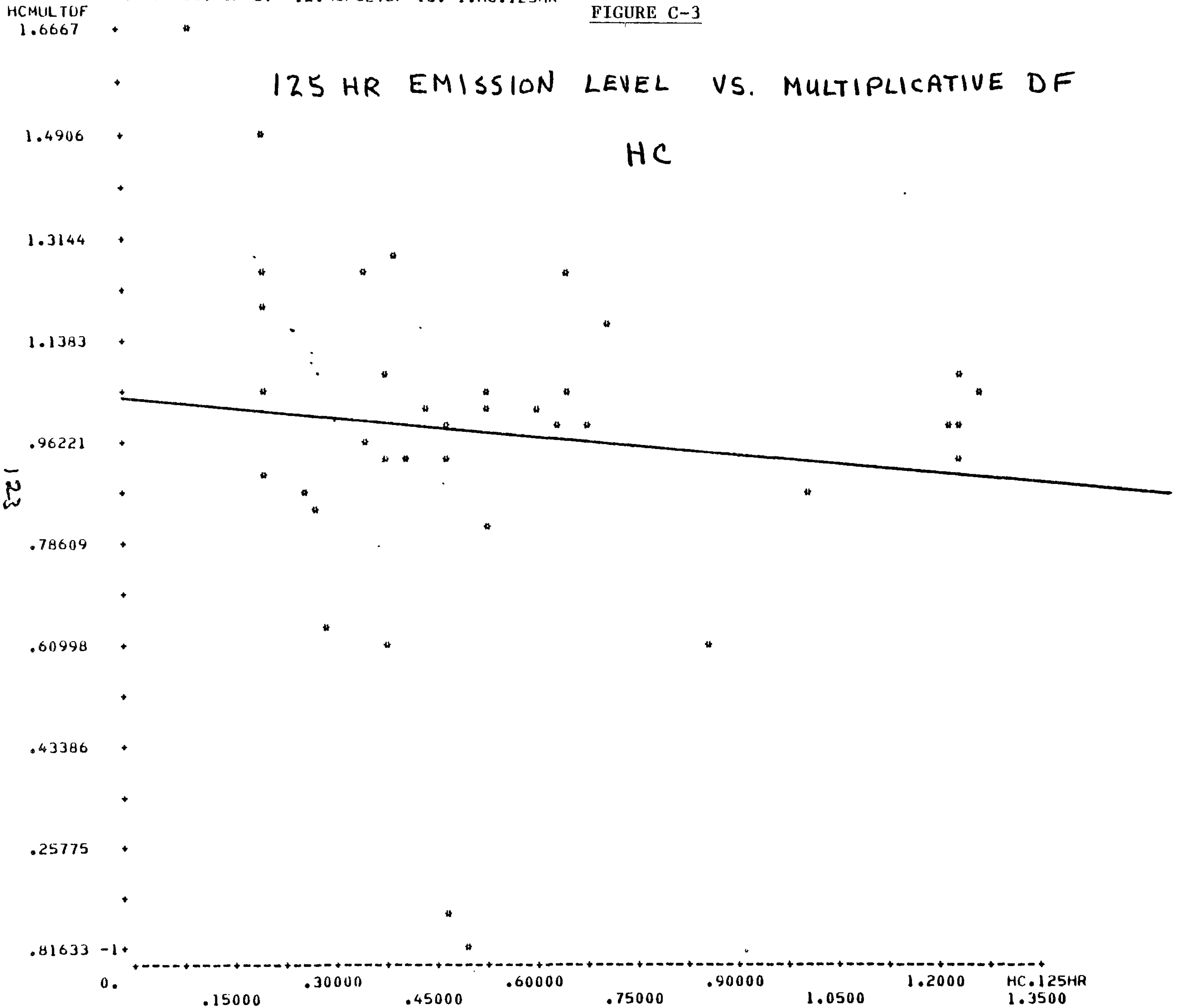
125 HR. EMISSION LEVEL VS. ADDITIVE DF

CO



SCATTER PLOT HC.MULTDF VS HC.125HR
N= 37 OUT OF 37 12.HCMULTDF VS. 1.HC.125HR

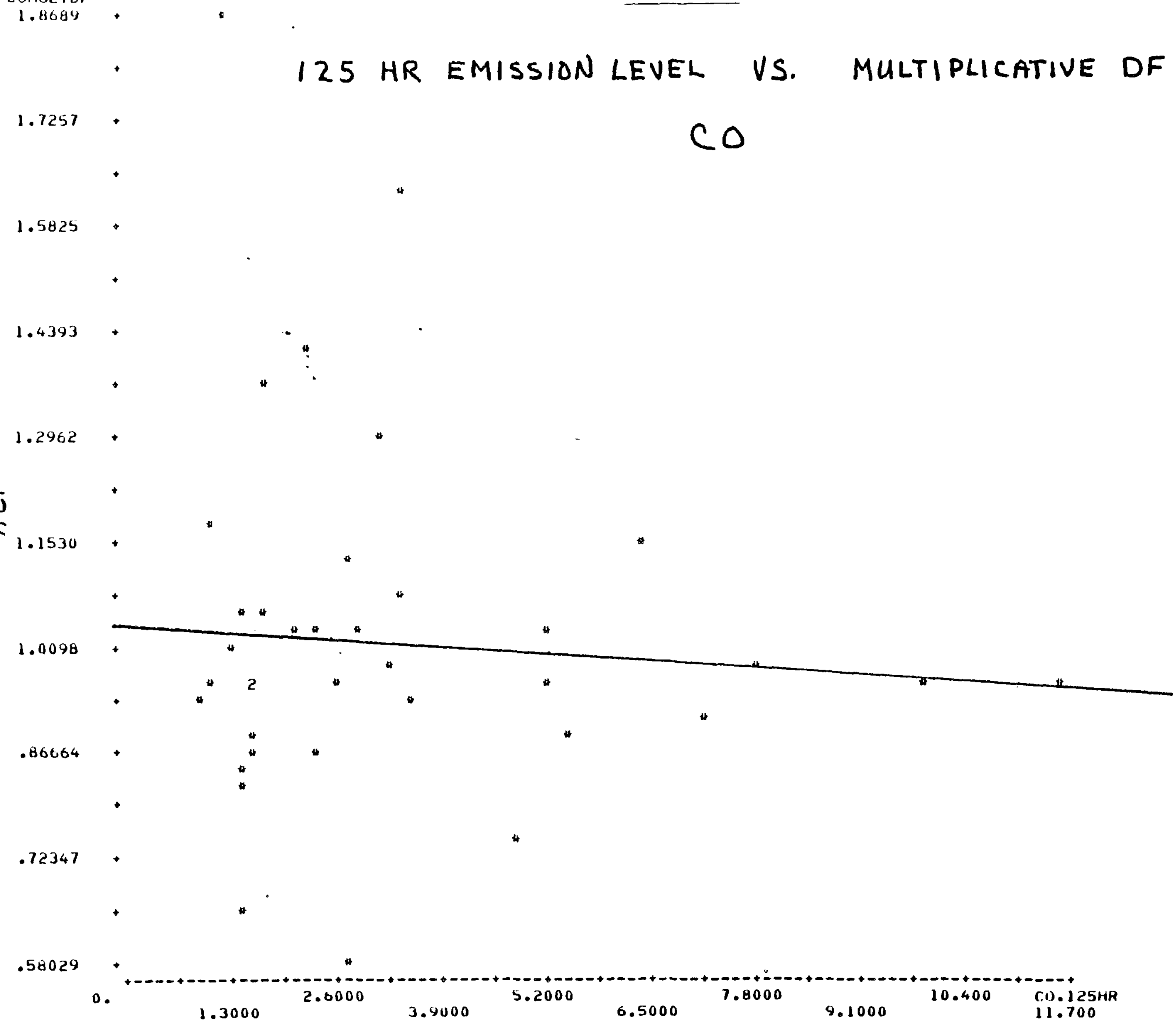
FIGURE C-3



SCATTER VAR=14,3 CASES=ALL INTERVAL=(0,11.7) HEAD=10 CO.MULTDF VS CO.125HR>

SCATTER PLOT CO.MULTDF VS CO.125HR
N= 37 OUT OF 37 14.COMULTDF VS. 3.CO.125HR

FIGURE C-4



As is well known to the manufacturers, EPA will soon propose particulate standards for heavy-duty diesel engines. Preliminary data available to EPA from both internal testing and manufacturers' comments indicate that the trap oxidizers expected to be used to meet this particulate standard also act as a proportional reduction device for gaseous emissions and would thus support a multiplicative DF.

In conclusion, since the data available to EPA does not conclusively support the use of an additive DF and since a multiplicative DF always provides greater air quality protection, EPA's technical staff concludes that a multiplicative DF is the more appropriate choice for diesel engines. This policy brings heavy-duty diesel engines under the same type of DF as is used for light-duty diesel vehicles.

4. Recommendations

Retain the multiplicative deterioration factor procedure as proposed for both gasoline-fueled and diesel heavy-duty engines.

D. Issue - Allowable Maintenance

1. Summary of the Issue

Included in the pending NPRM are newly-proposed provisions to limit the amount of maintenance which can be performed on heavy-duty durability-data engines. Emission-related maintenance must be technologically necesasry and must have a reasonable likelihood of being performed by owners in the field. specific minimum maintenance intervals are proposed which EPA has determiend to be technologically feasible. Additionally, "emission-related maintenance" and "non-emission-related maintenance" are defined. These provisions will help ensure that in-use engines do not exceed the emission standards as a result of control technology which requires more frequent maintenance than the users will actually perform.

2. Summary of the Comments

The most significant comments relating to allowable maintenance will be summarized and treated in Part I of this document: the remainder, in Part II. The three categories into which the major comments fall are 1) questions of EPA's justification, from both a legal and a logical standpoint, 2) criticism of certain of the proposed maintenance intervals, and 3) comments relating to the four criteria for assuring "a reasonable likelihood of maintenance being performed in-use."

Beginning with the legal issues, several commenters questioned EPA's authority to establish "technologically feasible" intervals for maintenance. Several commenters' interpretations of §§207(c)(3)(A) and 206(d) of the amended Clean Air Act (CAA) (cited in the NPRM as the basis of the provisions) differed from the interpretation of the Agency. Mack Trucks and International Harvester (IHC) believe the intent of the law is simply to require that the maintenance on certification engines is not more frequent than that specified in the operator's maintenance instructions and to assure that the instructions are "comprehensive and comprehensible."

A distinct legal issue forwarded by Caterpillar claimed that EPA is in violation of the company's First Amendment rights by requiring minimum maintenance intervals. The argument is based on the assumption that maintenance information is a form of "commercial speech" and as such cannot be limited or regulated. Caterpillar cites legal precedents to support the assertion that the "time, place or manner" of such communications may be regulated--but not the content.

In addition to these legal criticisms, commenters questioned the logical and factual basis of EPA's proposed revisions. First, the claim was made that the profit-making aspect of most heavy-duty applications has led to good in-service maintenance practices, but no supporting data was provided. Also, EPA was criticized for not adequately addressing the weaknesses of the current maintenance requirements. Second, if inspection/maintenance facilities for heavy-duty engines are established, said one commenter, they would provide the necessary stimulus for the owners to do the proper maintenance.

The final criticism along these lines centers around the tendency of the extended maintenance requirements to force some manufacturers to improve the durability of certain emission-related components. Specifically, the claim is that market pressures have the effect of extending the component durabilities to the maximum that the first-cost increases will allow. The decisions about how much durability and required maintenance should be designed into a component have traditionally rested in the hands of each manufacturer and have been based solely on economic criteria; the comments support a continuation of this state of affairs.

A substantial volume of comment material was directed at the more technical issue of the proposed intervals themselves. Only four maintenance intervals were singled out as being unreasonably long. For gasoline engines, comment concentrated on the intervals proposed for spark plug and catalyst replacement. For diesels, the comments addressed the turbocharger and injector maintenance intervals. These interval-related comments, in contrast with the comments summarized above, were often accompanied with supporting test data.

Generally, commenters expressed their concern that the proposed maintenance intervals are too long and that EPA's factual basis for the changes is inadequate or nonexistent. Also, the Motor and Equipment Manufacturers Association (MEMA) and Ford presented an argument that the proposed requirements would adversely affect competition among independent parts manufacturers and dealers. More emission-related warranty repairs will be required as a result of the extended intervals, say the commenters, and these repairs will take place at the engine manufacturer's repair outlets using the manufacturer's parts. In this scenario, the business of the independents would be expected to suffer. MEMA then suggests that, if EPA decided to follow through with the proposed intervals, manufacturers be permitted to recommend to the owners shorter maintenance intervals. The longer required intervals would be applied during durability testing to promote low-maintenance designs, but warranty claims would perhaps be less frequent among the presumably better-maintained in-use population.

Moving now to the specific intervals, the proposed maintenance requirements for gasoline engine spark plugs received considerable comment. EPA's apparent extrapolation from LDV spark plug experience is criticized for several reasons, all relating to the deterioration of the electrode gap.

First, because of the higher N/V ratios in HDV's compared to LDV's (i.e., HDV's are geared 1.5 to 2.5 times lower), a greater number of ignition events occur for a given distance traveled. Thus, on a mileage basis, spark plugs in HDE's would be expected to deteriorate more quickly than similar plugs in LDVs. Second, combustion temperatures are characteristically higher in heavy-duty gasoline engines than in light-duty engines. Both of these situations will tend to erode the spark plug gap in HDE's more rapidly than in LDV's. Additionally, IHC mentioned that oil consumption can contribute to combustion chamber deposits and spark plug fouling (as distinguished from gap erosion).

General Motors discussed at some length the several problems that might accompany erosion of the gap. Primarily, there is more probability of misfire. Faulty ignition will reduce power, worsen fuel economy, and greatly increase HC emissions with the accompanying threat of catalyst overheating. GM presented data showing catalyst bed temperatures reaching the critical range (above 1600°F, they say) in a heavy-duty vehicle with a 10% intermittent misfire. (The catalyst specifications were not included.) Also, gap erosion and increasing voltage requirements create greater dielectric stresses in ignition parts (as discussed below).

GM attempted to show that the effect of a shift to unleaded fuel on spark plug life is not as great as EPA implies. Delco Remy measured ignition voltage requirements of spark plugs in extended LDV service using lead-free gasoline. After 50,000 miles, service "less severe than 30,000 miles of heavy truck operation," the required ignition voltage had increased by 46%.

Finally, IHC attributes California's decision not to extend heavy-duty spark plug maintenance intervals to a lack of data upon which to base such an extension.

The comments reacting to the proposed 100,000 mile catalyst maintenance interval were more voluminous. For the most part, the criticism was of the limited data from which the extended interval was derived.

General Motors presented the most complete analysis of catalyst durability. Their discussion concentrated on the aspects of heavy-duty engine operation which they felt would cause more rapid catalyst deterioration than would be expected in light-duty usage. These characteristics are greater fuel and oil consumption, high exhaust gas temperatures, and the existence of high-speed closed-throttle motoring operating modes.

When compared to LDVs, HDEs burn more gasoline per mile traveled and consume more oil as well (the latter effect is partially due to the reduced oil viscosity at high temperatures which permits more leakage past the rings and valve seals). The lead in unleaded gasoline and the phosphorus in gasoline and motor oil are the primary causes of chronic catalyst poisoning. GM's analysis estimated the ratios of HD to LD poisoning rates from lead and phosphorus. By making assumptions of the contaminant concentrations in fuel and oil and of the relative poisoning effects of Pb and Ph, GM calculated an estimated catalyst deterioration ratio for trucks 3.42 times greater than passenger cars. Also, computer modeled 100,000 mile deterioration factors of 5.4 for HC and 35 for CO were projected from assumed fuel- and oil-economies for a 1979 Chevrolet 350 CID engine. Finally, projection of in-progress durability testing data yields a 100,000 mile deterioration factor for HC of 3.5.

Next, GM stated that EPA's conclusion that manufacturers will be able to solve overheating problems lacks support. They go on to report their experience with catalyst temperature during testing. Catalyst bed temperatures on a GM development engine have reached 1500°F to 1680°F during wide-open throttle, though CO limits were exceeded on the transient test. Since further control will be needed, GM anticipates that additional air injection will push the temperatures as high as 1800°F to 1900°F due to further catalysis of the CO. (Alumina substrates begin to experience phase changes above 1600°F, according to GM, and such temperatures can eventually destroy the structural integrity. Simultaneously, catalyzing efficiency suffers.)

The last issue discussed by GM is the catalyst temperature problem associated with high-speed closed throttle motoring. A GM on-the-road test showed catalyst bed temperatures which exceeded 1800°F after the truck climbed a hill and began down the other side.

Comments received from both GM and Ford bear on how the over-temperature problems might be addressed. Ford performed an EPA proposed transient test in which exhaust gas temperature was measured at four locations--4, 20, 42, and 63 inches from the exhaust manifold. Analysis of the data reveals the various times from test start to 600°F (representative of catalyst light-off), peak temperatures, and the distribution of time spent at various temperatures. Temperature traces were very similar in shape but progressively cooler the further back from the engine the thermocouples were. "Light-off" occurs during the cold-start test within 1 minute at 4 inches but takes more than two minutes at 63 inches. Peak temperatures varied from 1600°F (4") to 1400°F (63"). At 4 inches the exhaust gas spent 90% of the time above 600°F as opposed to 60% at 63 inches. Temperatures in the first three minutes were slightly higher during the hot-start portion of the test.

Ford pointed out that catalyst peak temperatures would be somewhat higher since additional air is added to the exhaust during the high-power/fuel-enrichment (high temperature) modes; temperatures "well in excess of 2000°F" are expected. Substrate melt temperature, according to Ford, is 2650°F. Ford expects there to be a high probability of substrate melting during severe vehicle operation. Finally, mention was made of the anticipated trade-off between moving the catalyst and achieving light-off in a reasonable amount of time.

General Motors suggested the use of "power-modulated air injection systems and high-speed-overrun converter bypass sytems" to address the anticipated catalyst temperature problems. Also, regarding the high-speed motoring difficulties, GM reported three attempts to develop carburetors and fuel-injection systems that could shut the fuel supply off during engine motoring. The attempts have heretofore failed because fuel that remains in the manifold evaporates and creates jump in emissions since it is too lean a mixture to ignite; violent backfires can also occur. Similarly, upon restoration of the fuel flow the manifold is wetted and combustion is intermittent for several seconds. GM states that they have begun new efforts to develop such fuel shut-off systems but are not hopeful that the combustion problems can be solved.

Moving now to the comments relating to diesel engine maintenance requirements, the intervals proposed for turbochargers and injectors received the most attention. The thrust of the comment was that the manufacturers should be permitted to recommend whatever maintenance they consider to be required on their engines. EPA's basis for requiring the proposed cleaning, rebuilding, and/or replacement intervals for injectors, injector tips, and catalysts was challenged.

Mack Trucks recommended turbocharger and injector cleaning at 50,000 mile intervals and their replacement as needed "to maintain representative performance." Thus, EPA's proposed intervals are double and quadruple those recommended by Mack for their present-technology equipment.

Caterpillar objected that the proposed intervals for diesel injector tips were the same as those for gasoline injector tips. Caterpillar went on to suggest that EPA assumed identical injector operating environments for both gasoline and diesel engines.

The final area of comment was directed at the four satisfaction criteria which were proposed to assure maintenance performance in the field. Criteria (A), (C), and (D) were criticized for vague or confusing language and criterion (B) for being illegal.

If the only option available to a manufacturer is criterion (B), then it would be required to pay for the maintenance. Ford suggests that such a requirement contradicts §207(g) of the CAA by placing the maintenance burden on the manufacturer rather than the owner.

Ford also commented on aspects of two other criteria (in addition to the use of vague terminology). Criterion (C), they say, will not be applicable to a situation where the only change in the recommended maintenance is to adjust the interval. Also, Ford reads criterion (D) to mean that when a signal is used to encourage maintenance performance, the signal must be removed after survey data has been collected. The data would be of "doubtful utility" in such a case.

3. Analysis of the Comments

This section presents the EPA staff's discussion and anlysis of the comments summarized above. The comments will be treated in the same order that they appear in the Summary of Comments. This section begins with an overview of EPA's position on allowable maintenance in general to provide a context for the discussion.

By restricing the amount of emission related maintenance allowable during durability testing, EPA is primarily trying to encourage an effort on the part of the manufacturers to reduce the amount of owner attention that their emission systems require. This encouragement fits into the larger strategy of sustaining the air quality benefits of regulatory actions as the vehicles/engines are actually used. Indeed, both the U.S. General Accounting Office and the Automobile Association of America have recently pointed to increased light-duty vehicle emission system durability as an approach to better in-use emission performance in those vehicles (1, 2).

Certainly a functioning network of inspection-and-maintenance programs would help achieve proper maintenance in the field, but such a network does not yet exist for heavy-duty engines. Likewise, the providing of clear maintenance instructions to the user will also help to some extent. Again, this in itself is not a total solution because the nature of emission control systems is often such that the operator is not aware that maintenance is due or that it is necessary. Thus, manufacturers have a real opportunity to help ensure in-use emission-system performance by pursuing long-lived designs that require little attention. EPA expects that once resources are directed toward these design goals, manufacturers will be able to reduce required maintenance well below that necessary for current technology components.

The staff analysis of the comments will begin with the issue of legal authority. Section 206(d) of the 1977 Clean Air Act Amendments (CAA) directs that "[t]he Administrator shall by regulation establish methods and procedures for making tests under this section," (i.e., tests to determine emission compliance). It is on the basis of Section 206 that EPA's entire certification and durability programs have been built, as well as the Selective Enforcement Auditing regulations.

The commenters are concerned that there is no specific Congressional mandate for EPA to establish minimum technologically feasible maintenance intervals for durability test engines. However, the proposed maintenance requirements easily fall within the rather broad wording of §206. (Even certification and durability testing as they appear in present regulations are not specifically described in §206, yet they have never been successfully challenged.) The requirement for the design of a certification program is that vehicles and engines be tested "in such a manner as he [the Administrator] deems appropriate". The "appropriateness" of the proposed changes is discussed later in the context of the "factual basis" comments.

Section 207(c)(3)(A) of the CAA requires vehicle and engine manufacturers to provide owners with maintenance instructions which "correspond to regulations which the Administrator shall promulgate." We challenge Mack's narrow interpretation that the manufacturer's responsibility consists solely of providing the owner with "comprehensive and comprehensible" maintenance instructions. The legislative history of §207(c)(3) supports a broader interpretation.

Among the responsibilities of the Agency under §207(c)(3), we believe, is to make certain that the maintenance provided to owners is no more than that necessary to assure emission compliance. A manufacturer should not be allowed to avoid its warranty obligations by requiring excessive maintenance that is not performed widely in the field. This would result in the voiding of many warranties because of a failure to properly perform the maintenance, even though such maintenance was not actually necessary to keep the vehicle or engine in compliance. Therefore, except under special circumstances, the maintenance required of the owners to retain their warranty should not be more than that performed during the certification testing. The conclusion, then, is that the maintenance instructions should be based on the maintenance done during §206 durability testing.

The logical and factual basis for establishing technologically feasible maintenance intervals was challenged from several directions, but little information to substantiate the claims was provided. The staff agrees that, to some extent, better maintenance habits should accompany the commercial aspects of heavy-duty engine usage. We are not convinced that the degree of maintenance required to maintain emission compliance is widely performed, especially when component designs require frequent attention and when performance of the maintenance does not improve driveability or fuel economy.

Clearly at the lower emission levels proposed in this package proper maintenance is a key part of an overall in-use emissions control plan. The weakness of the present regulations is the lack of incentives for the required maintenance to actually get done. The regulations address one facet of the problem by encouraging all manufacturers to use the best technology components possible from a low-maintenance requirement standpoint.

As we pointed out earlier, inspection-maintenance programs for heavy-duty vehicles/engines can provide another important part of an in-use control strategy. However, only a few localities have heavy-duty I/M programs in place and the suggestion that I/M might obviate the need for allowable maintenance seems premature. The staff believes that widespread implementation of I/M in the future will increase the relative importance of allowable maintenance requirements. By clarifying the warranty-related maintenance and improving its chance of being performed properly, these regulations will make it easier for the owner to obtain warranty repairs. Straightforward requirements and easy repairs are a prerequisites to public acceptance of I/M.

The staff views the argument regarding market pressures and component durabilities to be somewhat misdirected. If lower maintenance in some components indeed provides a powerful competitive advantage, then the market should be an important factor in encouraging reduced maintenance and longer lasting component designs <u>beyond</u> today's technology. Generally, however, we do not believe that the market pressures for improved durability in emission-related components is strong. (The durability of emission controls has not been widely stressed in advertising, for example). The staff is also concerned with the implication that manufacturers would be willing to trade off improved maintenance characteristics and durability (and hence, a degree of better maintenance in the field) for commercial purposes. We cannot accept the argument of the existence of market pressures as a rationale for allowing more frequent maintenance than present technology has been shown to require. Conversely we do hope that the pressures will, in the future be a strong factor in encouraging continuing reductions in the amount of maintenance required on emission-related components.

Several comments were directed in a general way at the proposed minimum maintenance intervals, both challenging EPA's factual basis and expressing concern about possible effects of EPA's actions. We will address these general comments before moving on to the technical treatment of the individual intervals.

The factual justification for the intervals proposed for spark plugs in gasoline engines and diesel turbochargers and injectors is sound. We present our technical rationale for these intervals later in this section. The case of catalysts for heavy-duty gasoline engines is unique in that the specific technology has not been completely developed. Neither EPA nor the industry can exactly predict the durability and the maintenance requirements of 1984 heavy-duty catalysts; a best estimate must be derived from the information available. EPA's response to this situation should not be, however, to provide no guidance or incentive for the design process regarding durability. In the absence of a requirement some manufacturers can be expected to devote less effort to durability considerations, resulting in unnecessarily short replacement intervals. Available data indicates that the specified interval for catalyst replacement has a very high probability of being achieved. Thus, we conclude that EPA is acting properly in encouraging the development of catalysts that will last to (or nearly to) the useful life of the engine.

The comments of MEMA and Ford that independent parts suppliers and manufacturers will suffer as a result of the proposed requirements is based, we believe, on a faulty assumption. That assumption is that the number of claims for emission-warranty repairs will necessarily increase because many owners will find that their emission-related equipment no longer functions properly, despite the performance of "recommended" maintenance. This assumption implies that Ford and MEMA do not expect that improvements will be made by manufacturers in the level of maintenance required in order to bring them into line with the best available technology. The purpose of the requirements is to encourage just such improvements. In the event that manufacturers choose not to work toward lowermaintenance components and the warranty claims do occur, the manufacturer should be liable. There might be a potential for a market shift in aftermarket parts replacement if EPA required unrealistically long maintenance intervals. Parts would fail more, requiring free manufacturer replacement under the emission warranty and depriving the independents of those sales. However, the maintenance intervals required here are realistic and represent a level of technology which will be reasonably easily achieved by the manufacturers (as we will discuss shortly). A market shift due to an increased number of warranty claims should not result from these regulations.

On the other hand, the very fact that maintenance intervals are being increased will mean that parts will be replaced less often and aftermarket parts sales may drop. We are convinced, however, that the benefits which will be seen by the consumer in vehicle durability and in cleaner air outweigh such an adverse economic impact on the aftermarket industry. The Clean Air Act certainly does not encourage manufacturers to design into their products a high degree of maintenance; rather, it simply requires that owners be allowed to perform all non-warranty maintenance at establishments of their choosing.

Emission-related maintenance (as defined in Subpart A, Section 86.084-2) on engines, subsystems, or components used to determine the deterioration of emission controls will be limited to that which is technologically necessary. EPA has established minimum technologically necessary intervals for a number of emission-related components. This maintenance is also that which will be recommended to the owner in the operator's manual. The manufacturer may recommend more frequent maintenance, as long as the instructions for such additional maintenance are clearly differentiated (in a format approved by the Administrator) from the emission-related maintenance approved under Section 86.084-25(c). Performance of this additional maintenance may not be made a prerequisite to emission warranty coverage. It may be appropriate for a manufacturer to require additional maintenance as a precondition to warranty coverage of such maintenance is necessary to offset the effect of severe and abnormal operating conditions. These issues are a proper subject to be considered in the course of developing performance warranty regulations under Section 207(b) of the Act. Permitting additional "recommended" maintenance addresses MEMA's concern that manufacturers be able to recommend maintenance in addition to that performed during durability testing. Also, the provisions should answer Caterpillar's concern about accurate communications with their customers.

The issue of spark plug maintenance intervals will now be addressed. The staff has reconsidered the analysis used in the report "Emission-Related Maintenance Intervals for Light-Duty Trucks and Heavy-Duty Engines". We feel that improvements in that methodology are possible and have adjusted the proposed 30,000-mile interval on the basis of the new analysis.

This analysis will calculate the improvement in light-duty vehicle spark plug change intervals between 1974 and 1978 due to the change to unleaded gasoline and then apply the percentage improvement to 1974 heavy-duty spark plug intervals. In 1974, domestic LDV intervals ranged between 12,000 and 15,000 miles. By 1978, the range was 22,500 to 30,000. Comparing the endpoints of the ranges yields increases of 188% and 200%; we will use the simple average of these increases, or a 194% increase in recommended LDV plug change intervals as a result of the fuel change. This is probably a conservative estimate since additional spark plug longevity is likely to result from design improvements as well.

Thus, we have constructed a basis on which to compare 1974 heavy-duty spark plug intervals (when leaded fuel was used) to anticipated 1984 intervals (following the introduction of unleaded fuel). By proceeding in this manner, it is possible to "cancel" the effects of differences between LDV and HDE operating characteristics and conditions, differences which drew much of the comment. Our analysis will assume that there will be no significant changes in N/V ratios, combustion temperatures, and oil consumption between 1974 and 1984 heavy-duty gasoline-powered vehicles and engines. Thus, the introduction of unleaded fuel will be the major variable affecting spark plug life.

Spark plug replacement intervals recommended for HDE's in 1974 were 12,000 miles for GM and IHC, 16,000 for Ford, and 18,000 for Chrysler. The high Chrysler number probably relates to the lighter vehicles which predominate their heavy-duty fleet; concentrating on Ford, GM, and IHC, a representative interval is 14,000 miles. Increasing this interval by the 194% we expect as a result of the fuel change, we arrive at 27,160 miles as a projected heavy-duty spark plug interval.

We have relied in this analysis on intervals specified for vehicles subject to a 50,000-mile useful life. Since later in their lives engines tend to burn more oil and hence deteriorate the gap more quickly, we should adjust our projected replacement interval to allow more frequent maintenance over a 114,000-mile useful life. To provide this additional cushion, we have rounded the interval down to 25,000 miles, which is very appropriate for heavy-duty engines employing unleaded gasoline.

As the preceding discussion suggested, a range of comments are addressed to some degree by the revised analysis. Certainly the higher N/V ratios and cylinder temperatures of HDEs might be expected to have a greater effect on HDE spark gap erosion as compared to that in LDVs. Yet, 1974 replacement intervals for spark plugs were in the same range for both HDEs and LDVs. This fact implies that the engine speed and combustion temperatures are not major contributors to gap deterioration, at least, during 12,000 to 15,000 miles of use with leaded gas. No comments suggested that after the introduction of unleaded fuel the relatively harsh conditions seen by heavy-duty plugs would have a greater effect on durability relative to light-duty plugs than before the fuel change. Therefore, there seems to be validity to the assumption in the preceeding analysis that both HDE and LDV spark plug intervals will experience similar relative improvements when the shift to unleaded fuel occurs.

Regarding the mention of oil comsumption as a contributor of the fouling of spark plugs, the staff see the use of "hot" and "cold" spark plugs as a means of addressing this problem, as well as the electrode erosion problem. For certain applications, manufacturers will certainly be able to recommend plugs using different alloys to either heat up quickly and burn off oil and carbon residues (from low-speed/idle operation) or stay cooler to reduce eroding of the gap (for high-load applications).

Next, while we understand that the effects of misfiring spark plugs on catalysts can be catastrophic, we do not agree that a large increase in the occurrence of misfiring due to plug deterioration will accompany these regulations. The technology for a 25,000-mile spark plug exists and hence gross misfiring should not be an issue.

The Delco Remy LDV data shows that even with unleaded fuel spark plug voltage requirements increased significantly after 50,000 miles (equivalent to 20,000 to 33,000 miles of truck operation from the standpoint of ignition events, according to GM). The data indicates that gap erosion will indeed occur in extended spark plug service even after the introduction of lead-free fuel into the heavy-duty gasoline fleet. The severity of the problem for heavy-duty is not as clear. Heavy-duty ignition systems often operate at higher voltages than do light-duty systems. Additionally, GM does not seem to imply that higher voltage requirements in the 50% range toward the end of a spark plug's life will necessarily be accompanied with frequent misfire. The staff interprets the data primarily to indicate a possible effect from dielectric wear on the ignition parts resulting from higher later-life voltage requirements or higher voltage systems. GM (and other commenters) did not provide any information to indicate that such problems would be difficult to overcome, if indeed they occur in heavy-duty engines.

The staff sees no reason to alter its previous analysis showing a 25,000-mile spark plug to be reasonable for 1984 heavy-duty gasoline engines.

Finally, a conversation with a representative of the California Air Resourses Board* seems to refute IHC's theory regarding the reasoning behind CARB's decision not to extend heavy-duty spark plug maintenance intervals. Their actions were not aimed at heavy-duty engines at all, and thus they had no reason to investigate heavy-duty spark plug life. It was not a lack of data that led to a continuation of the current heavy-duty maintenance interval but rather a complete lack of effort in that direction.

We now turn to an analysis of the comments relating to the 100,000-mile catalyst replacement interval proposed in the NPRM. The comments generally took issue with EPA's extrapolation of light-duty catalyst technology to heavy-duty applications.

General Motors presented a useful methodology for estimating the relative effects of lead and phosphorus catalyst poisioning in LDVs vs. HDEs. However, the staff disagrees with several numerical values which GM used in the analysis. First, they compared 100,000 miles of heavy-duty service to only 50,000 miles of light-duty service. Second, with regard to fuel economy, the staff believes that the analysis will be improved by the use of different miles-per-gallon numbers. GM uses a predicted 1983 fleet average light-duty value of 25 mpg. But since our interest here is to judge the difficulty in applying catalyst technology to HDE's it is more reasonable to observe a "worst case" light-duty application (i.e., one that would come closest to exposing a catalyst to heavy-duty

* Bob Weiss, Certification Department, August 7, 1974.

type treatment). We looked at data from several 1979 Cadillac certification vehicles with large, catalyst-equipped engines (425-CID) and found an average fuel economy of 13 mpg. This is the value we use in our analysis. Similarly, while we believe that 6.5 mpg is a better estimate of the average heavy-duty gasoline engine fuel economy, GM's 5 mpg figure will be used for our worst case analysis. The following table compares GM's numbers, adjusted for 100,000 miles of light-duty operation, with EPA's.

100,000 Mile Passenger Car			100,000 Miles Heavy-duty Truck
EPA	GM		GM and EPA
13	25	Fuel Economy (MPG)	5
7,692	4,000	Gallons of fuel	20,000
38.46	20	Grams Pb (.005 gr/gal)	100
.77	0.4	Grams Fuel Ph (.001 gr/gal)	2
2,500	2,500	Oil Economy (mi/qt)	1,250
40	40	Quarts of Oil	80
45.4	45.4	Grams Oil Ph (.16 wt%)	90.8
38.5	20	Total Pb - grams	100
46.2	45.8	Total Ph - grams	92.8
84.7	65.8	Total Pb & Ph Contaminants	192.8

Applying GM's estimated phosphorus-to-lead poisoning ratio of 9:1, one arrives at an expected rate of poisoning 2.16 times greater for heavy-duty than for light-duty (using 25 mpg) or 2.06 (using EPA'S 13 mpg). Then, making the adjustment for catalyst sizing, the factor for GM becomes 1.56 and for EPA becomes 1.49. Our analysis indicates that GM's comparison of 50,000 miles of LDV service to 100,000 miles of HDE service to arrive at a poisoning ratio of 3.42 somewhat exaggerated the poisoning problem. The effect of changing the LDV fuel economy in the analysis is relatively small.

GM went on to multiply their HD:LD poisoning ratio by an average 1980 light-duty deterioration factor (DF) to arrive at a high predicted heavy-duty DF. The EPA staff finds two aspects of this final step to be questionable. First, since 1979 average LDV DFs are around 1.2 for both HC and CO, GM's "average" of 1.35 seems high. This may be due to the introduction more three-way catalysts for 1980 or some other hidden factor; but since all but a handful of 1979 LDV's are equipped with oxidation catalysts we believe their DFs provide an adequate baseline. Second, the expected effect of poisoning on a catalyst is to affect the conversion efficiency. GM applied the poisoning ratio directly to the LDV DF, again exaggerating the results in their favor. The correct way to make this calculation is as follows, using the DF of 1.2 and the poisoning ratio of 1.49 from above.

A DF of 1.2 implies that, over the 50,000 miles of LDV extrapolation, emissions will deteriorate 20 percent. Assuming that continued deterioration to 100,000 miles is linear (although it usually levels off with time), one would expect that twice the deterioration, or 40 percent would occur. Beginning with a 100,000-mile LDV DF of 1.4, then, one can apply the HD-to-LD poisoning rate ratio to the percent deterioration. Thus, an expected heavy-duty DF of (1 + [(.4)(1.49)]) = 1.60. That is, the percent deterioration of a light-duty catalyst is increased by nearly 50 percent due to the increased poisoning expected in heavy-duty applications.

Since the DF calculated above only takes poisoning into account, we should make some adjustment for the loss of conversion efficiency occuring as a result of higher average temperatures to be expected in heavy-duty catalysts. Temperature excursions beyond 1800°F can begin to cause a phase change in alumina substrates or monolith washcoats, reducing their large surface areas with the resulting loss of active catalyst sites and hence conversion efficiency. The correlation between temperature exposure and loss of efficiency has never been established to our knowledge; a GM representative said, however, that they assume an effect on emission deterioration due to heat exposure of the same magnitude as the effect due to poisoning. With the higher noble metal loadings necessary for heavy-duty catalysts, more active sites are available and loss of some is not so crucial as in light-duty catalysts. This point, coupled with the catalyst cooling measures that we expect to be used for heavy-duty (these measures are discussed later in this section), lead the staff to the conclusion that a heat-related deterioration effect which is half the poisoning related effect is reasonable. We will adjust our heavy-duty DF calculation by using a combined poisoning-plus-heating ratio of 1 + [.49 + 1/2 (.49)] = 1.74. Then the revised heavy-duty DF to be expected with catalyst-equipped engines is (1 + [(.4)(1.74)]) or 1.70. It is clear that the difficulties which GM anticipated in achieving low enough 4,000-mile emission values are not so great as their high DFs had implied.

GM also submitted the results of a computer modeling program which also predicted very high rates of emission deterioration for heavy-duty catalyst-equipped engines. We suspect that the complex model may have incorporated some of the poor assumptions discussed above. In a conversation with an author of the model, we learned that only the poisoning mechanism was simulated with any real basis of information; heat effects were assumed. No post-50,000 mile data, of course, was available to include in the model, resulting in more judgements. The number of opportunities for error to be introduced into the model through both the inputs and the operations themselves is phenomenal; the staff has little faith in the results, especially when they vary so much from our reasoned analysis above.

The only durability data on heavy-duty catalyst-equipped engines that was provided appeared in GM's submission. On the basis of five test points ranging from 0 to 500 hours of dynamometer operation (equivalent to 0 to 15,000 miles), GM extrapolated a high HC DF. This data is too limited to be conclusive and is drawn from a current-technology catalyst system. GM's linear extrapolation directly contradicts their comment (regarding durability testing) that catalyst deterioration is not linear. And the expected improvements we expect in catalyst durability further reduce the strength of GM's conclusions.

We have discussed above the expected long-term effects of chronic poisoning and infrequent temperature excursions on catalyst efficiency. We wish to pursue now in more detail the problem of short-term high temperature transients--their effects on catalyst structure and methods of avoiding their occurence. GM and Ford provided limited data on various aspects of this issue, and tests recently performed by EPA provide a further base of information. In the next paragraphs, we will describe the EPA tests, analyze data resulting from both these and industry test programs, and draw conclusions about the threat of catalyst overheating. The discussion begins with a presentation of the staff position on the effects of high temperatures on catalysts.

The primary material used currently to support the noble metal catalyst in automotive converters is gamma alumina, in the form of either pellets or a washcoat on cordierite monoliths. At elevated temperatures, a phase change to alpha alumina begins which is accompanied by a reduction in the structural strength and surface area of the material. Active catalyst sites tend to diffuse and agglomerate as well as become unaccessible due to the loss of porosity; this process effectively reduces the number of sites available for catalysis and hence lowers the efficiency of conversion. Finally, the magnitude of the physical changes which occur in the alumina above the safe operating temperatures is a function of temperature, time of exposure, and the presence of certain ions which stabilize the gamma lattice.

The published "safe operating temperature" for gamma alumina substrates is approximately 1700°F (which contrasts with GM's "critical temperature" of 1600°F). Gamma-to-alpha phase change can be expected to occur between 1750°F and the alumina melt temperature of around 2900°F. The staff will assume that below 1700°F, no change in the structure of gamma alumina takes place.

The staff is unaware of any research which would indicate how substrate structure and loss of efficiency are affected by time and temperature. (A representative of Englehard Industries Division reported in a telephone conversation that when they have exposed a catalyst to 1800°F in a steady-state bench test, efficiency losses of 40-60% have been observed after twenty-four hours of exposure). It is known, however, that heavier noble-metal loadings, like those expected in heavy-duty catalysts, bolster the durability of the conversion efficiency. This is because more active sites are available initially, allowing a cushion if some are lost through agglomeration or reduced substrate surface area (or even poisoning).

We expect that any temperature excursion beyond 1700 or 1750°F will probably cause a limited amount of the alumina to change phase. Yet for a well-loaded catalyst (in the range of 40 g/ft^3), temperature excursions between 1750 and 2000°F lasting less than a minute should not cause major losses in conversion efficiency. However, because of the cumulative nature of the effects, the frequency of such events would have to be minimized, an issue which is addressed in detail below in the context of catalyst heat reduction. (The staff consulted Dr. Ray Ober of Englehard Industries Division and References 3, 4 and 5 in the formulation of the foregoing position).

EPA has recently conducted a test program which investigated catalyst temperatures during several types of engine operation. A GM 454-CID "tall block" heavy-duty engine with dual exhausts was equipped with two 260-CID GM catalysts. While the total volume if the two catalysts exceeded the displacement of the engine, the noble metal loading was only 10 g/ft^3 in each catalyst (compared to 40 g/ft^3 expected by the staff for heavy-duty catalysts).

The primary purpose of the tests was to observe the sensitivity of maximum catalyst temperatures to the distance between the exhaust manifold and the catalyst. Distances of 38, 68 and 116 inches were tried (nominally 3, 6 and 9 feet). For each catalyst position, we operated the engine over the proposed transient test, through a series of high-power, high-speed steady-state modes, and finally under closed throttle motoring conditions. We immediately followed each steady-state mode with a motoring mode, the motoring being done at the same speed as the preceding steady-state portion (the exception was that if the catalyst tempertures did not stabilze below 1700°F during the steady-state run, we omitted the motoring). Catalyst bed temperatures were recorded continuously.

The maximum catalyst bed temperatures reached during the transient portion of the EPA tests are presented below for each of the three catalyst positions. Hot-start-segment temperatures were not available for two of the eight tests, as indicated by dashes. Also, the estimated catalyst light-off times, taken as the time from the beginning of the test to the time at which the catalyst temperature reaches 575°F, appear in the table.

Transient Test Results

Distance from Exhaust Manifold	38" Cold Start	38" Hot Start	68" Cold Start	68" Hot Start	113" Cold Start	113" Hot Start
Maximum Catalyst Temp. (°F)	1592	1586	1519	1534	1455	----
	1597	1597	1539	1511	1451	1451
	1537	1534	1531	----		

Light-off Time (sec)	38"	68"	113"
1st Catalyst	140	196	285
	112	220	256
	164	181	---
2nd Catalyst	220	256	---
	192	315	300
	238	231	256

As the catalysts were placed further from the exhaust manifold, a progressive drop in maximum temperatures occurred. The magnitude of the effect was approximately 70°F for each additional distance of 3 feet (A possible explanation for the lower maximum temperatures seen in the third test at 38" is offered later in this discussion). This pattern compares with Ford's exhaust temperature investigation, which showed that three feet of travel in the exhaust pipe cooled the exhaust flow over 100° F. It follows, then, that while much of the heating of the catalyst is a result of the exothermic oxidation reactions, a significant portion of the heating results from the exhaust gas and hence is sensitive to catalyst placement.

The time required for the catalyst to reach the 575°F "light-off" temperature was increased each time the catalysts were placed further back from the manifold. We calculated the average light-off time for the catalyst pair during each test and then averaged all of these single test values for each catalyst distance.

The effect of each three-foot shift of the catalyst was shown to be a loss of 40 to 50 seconds in light-off time. Again, comparing Ford's data, the time for the exhaust gas to reach the 575°F catalyst threshold temperature varied by about 70 seconds over three feet of distance; this observation supports the EPA data regarding the effect of catalyst position on light-off time.

Turning to the steady-state runs which preceded the motoring tests, stabilized catalyst temperatures appear below. A temperature was defined to be "stabilized" when it was not changing by more than 1°F every 5 seconds. For reference, rated horsepower for the test engine was 225 hp.

Stabilized Steady-State Catalyst Temperatures (°F)

Catalyst Distance			38"	68"	113"
RPM	Torque	HP			
1500	330	94	1440	----	----
2500	205	98	1335	1243 *	1172*
3000	200	114	----	1318 *	1247*
2500	255	121	----	1317 *	----
2500	275	131	----	----	1347*
3500	200	133	1480	----	----
3000	250	143	1500	1385 *	1317*
3300	250	157	----	1438 *	1410*
3500	250	167	----	1530	----
3000	300	171	----	**	1525
3500	300	200	**	***	1575
3690	320	225	***	***	***

* Average of both catalyst temperatures.
** Temperature did not stabilize below 1600°F.
*** Staff assumed that temperature would not stabilize below

Despite the fact that each speed-torque combination was not attempted for each catalyst position, it is possible to see a trend in these data. It appears that, in general, the stabilized catalyst temperature at a given speed-torque setting becomes lower as the catalyst is moved back. This is most obvious in the instance of the higher power modes during which the temperature stabilized only in the 113" position. Thus, even during high-powered operation of extended duration, the effects of catalyst placement on catalyst temperature may be observed.

For several of the steady-state modes that reached a stable temperature, we closed the throttle and let the dynamometer drive the engine at the same speed. At the 38" catalyst distance, the motoring was unfortunately continued for only 1.5 minutes. However, at the 68" and 113" position, the engine was usually motored until the temperature peaked and began to fall. Figures D-1 plot the temperature profiles, beginning with the stabilized temperatures from the steady-state modes, for the three catalyst positions. Plotted values represent the average temperatures for the two catalyst for the 68" and 113" graphs. For 38", only one. catalyst is represented.

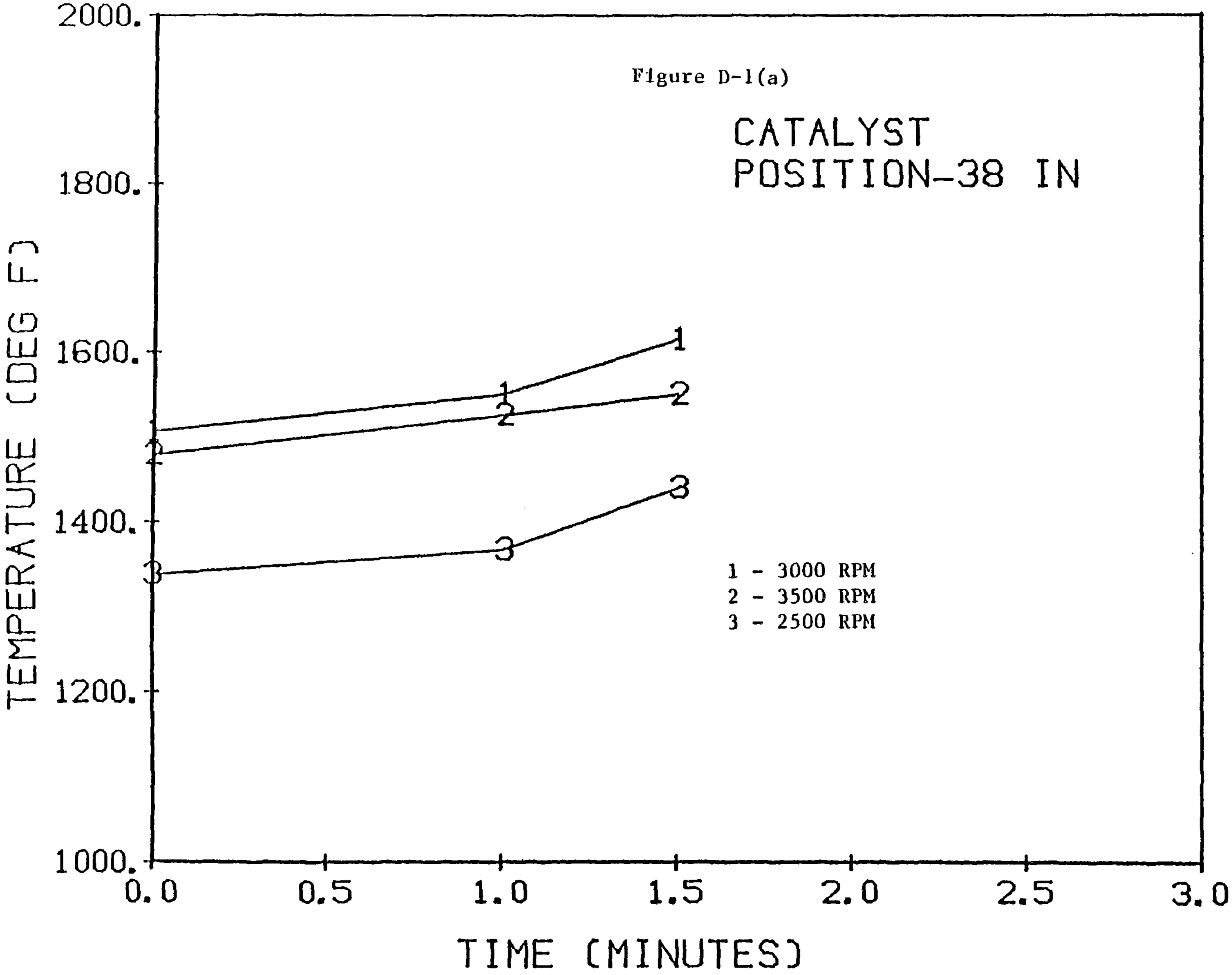

CATALYST
POSITION-38 IN
1 - 3000 RPM
2 - 3500 RPM
3 - 2500 RPM
TEMPERATURE (DEG F)
TIME (MINUTES)
2000.
1800.
1600.
1400.
1200.
1000.
0.0
0.5
1.0
1.5
2.0
2.5
3.0

Figure D-1(a)

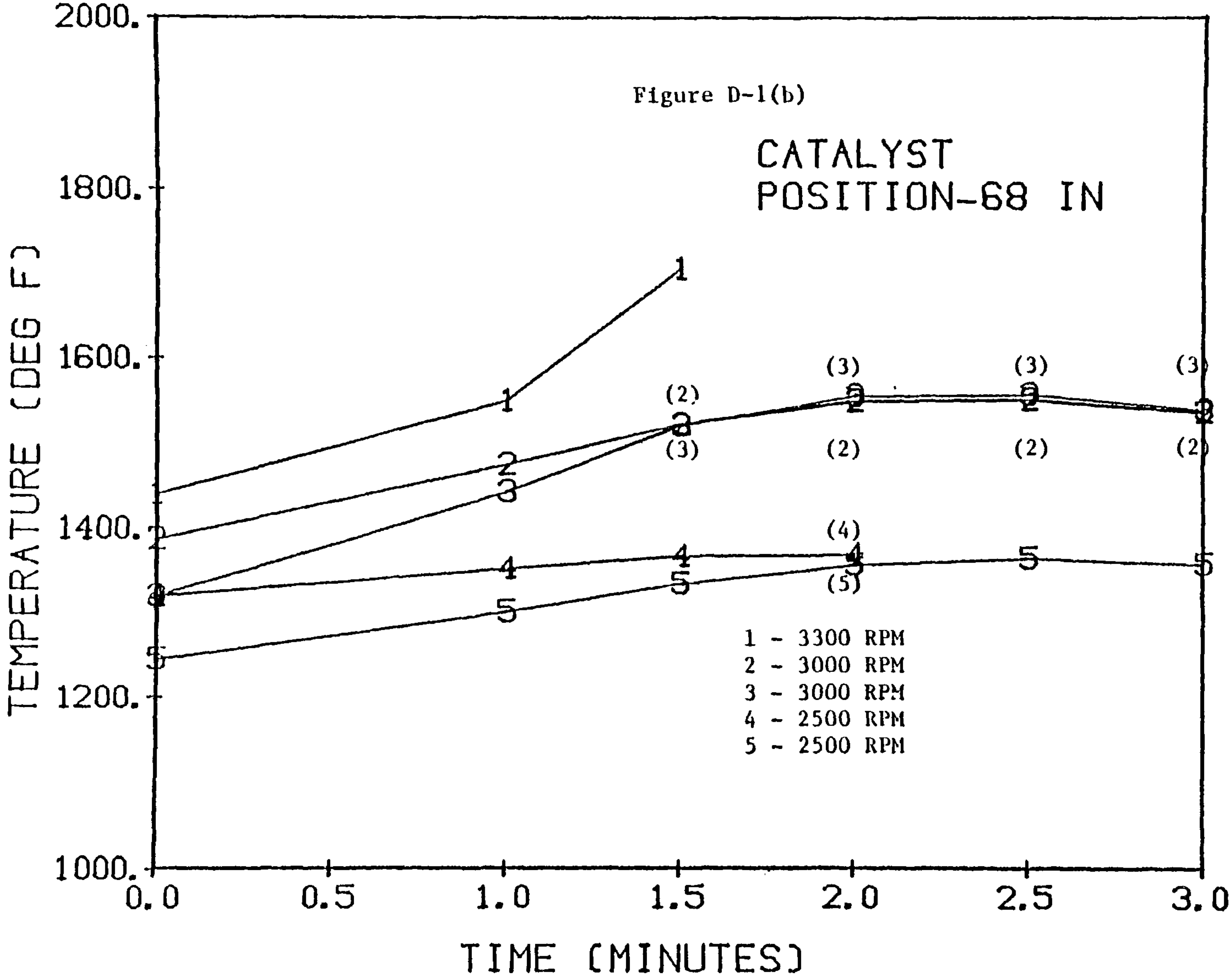


Figure D-1(b)
CATALYST
POSITION-68 IN
TEMPERATURE (DEG F)
TIME (MINUTES)
2000.
1800.
1600.
1400.
1200.
1000.
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1 - 3300 RPM
2 - 3000 RPM
3 - 3000 RPM
4 - 2500 RPM
5 - 2500 RPM

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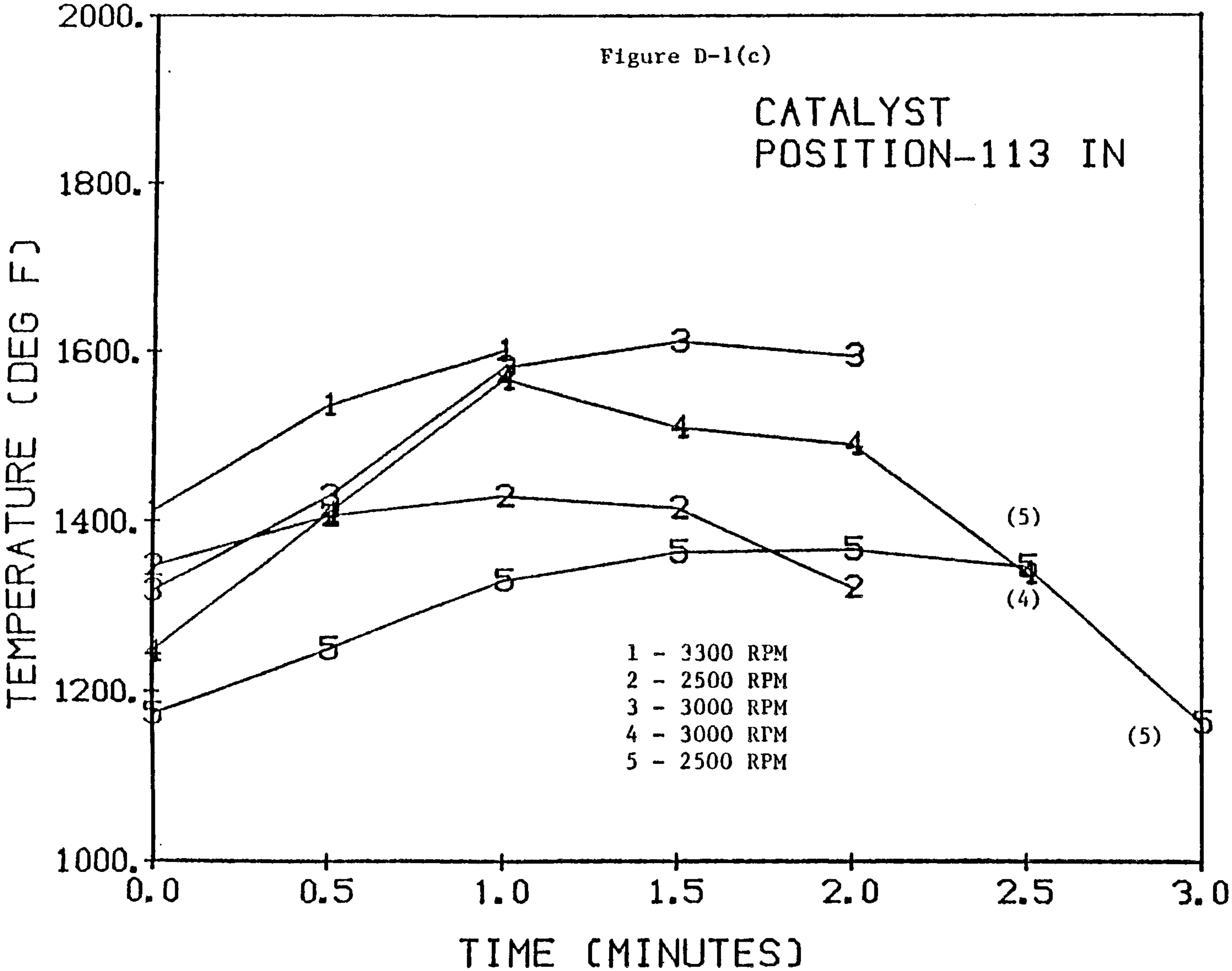


Figure D-1(c)
CATALYST
POSITION-113 IN
TEMPERATURE (DEG F)
2000.
1800.
1600.
1400.
1200.
1000.
0.0
0.5
1.0
1.5
2.0
2.5
3.0
TIME (MINUTES)
(5)
(4)
(5)
1 - 3300 RPM
2 - 2500 RPM
3 - 3000 RPM
4 - 3000 RPM
5 - 2500 RPM

The striking rise in temperature during the one motoring test at 68" which began at 1440°F was due to the stopping of the motoring in response to high temperatures. We assume that the initial burst of fuel when the throttle opened was not combusted and caused the catalyst temperature (primarily of one catalyst) to begin to rise very quickly. Thus the rapid rise did not actually occur during motoring as the figure suggests. In the way of further explanation of the data, the steady-state runs which resulted in stabilized temperatures greater than 1500°F were not followed by a motoring test. Finally, data at the 30 second point of motoring was taken only at the 113" position.

The general pattern illustrated in Figures D-1 is that the catalyst temperature rises rapidly at first, then peaks and begins to drop. Since the motoring speed and throughput of raw fuel should be constant, it seems that a short-lived event occurs soon after the closing of the throttle that pushes the temperature up for a minute or two. That event may be the result of the remaining mixture in the intake manifold burning poorly and subjecting the catalyst to a burst of hydrocrabons. This particular catalyst-heating situation would not persist because the remnant manifold mixture would be followed by a still leaner mixture from the motoring process itself. Thus an immediate but temporary rise in catalyst temperature would be expected. A conculsion of this reasoning is that it is probably not motoring itself but the <u>transition</u> to motoring that threatens the catalyst with overheating, even though the catalyst sees some raw fuel during motoring.

The effect of catalyst placement is less perceptible in the motoring data than in the transient and steady-state testing. There seems to be a pattern within the data at the 68" and 113" positions that indicates that higher stabilized starting temperatures result in greater temperature rises during motoring. So, to the extent that placing the catalyst further back reduces these starting temperatures, the motoring heat rise can perhaps be addressed simultaneously. Also, the data appear to indicate that more distant catalyst placement leads to a quicker arrival at the maximum temperature; we can presently offer no explanation for this pattern.

A final pattern that is discernable from the data is that lower speeds result in lower maximum temperatures. Reduced HC throughput is probably the explanation for this phenomenon. Because of the various torque levels that preceded the motoring runs, however, motoring speed and maximum temperature are not directly comparable.

An insight into the effects of heat spikes on the efficiency of a catalyst with a light noble metal loading is possible from the motoring investigation. An inadvertant excursion above 1800°F for cases peaks and reverses after 1 to 3 minutes. The magnitude of the temperature increase is such that if the motoring is begun while the catalyst is sufficiently hot, the substrate or washcoat can reach damaging temperatures (1750°F and above).

On the basis of the EPA and industry data discussed above and within the context of the previously described staff position, we are prepared to make several conclusions about the catalyst heating issue. We will separate from the discussion for the moment the special problems associated with closed throttle motoring.

The staff is convinced that several straightforward design approaches exist which individually or in combination can greatly reduce the threat of catalyst damage through overheating. The first approach is through catalyst placement, taking advantage of the relative freedom in catalyst positioning afforded by heavy-duty vehicles as compared to light-duty vehicles. Because of their size and construction, heavy-duty chassis usually make it possible to situate a catalyst rather far from the engine.

Similar approaches which could also reduce catalyst temperatures take advantage of heavy-duty chassis as well. Cooling fins on the catalyst and the exhaust pipe would improve heat transfer from the converter. Reducing or removing the insulation familiar to light-duty catalyst containers (and present on the catalyst used in the EPA tests) would facilitate further heat transfer. According to a representative of Engelhard Industries Division, removal of insulation can affect catalyst temperatures by as much as 100-200° F. The less space-restrictive and temperature sensitive characteristics of heavy-duty chassis (relative to light-duty) which reduce the need for insulation would also allow the use of screens, cages, or similar types of open shielding if such protection is necessary. Still another approach which might be useful in some applications is the installation of wind deflecters to improve the air flow across the catalyst during highway operation.

When such measures are taken to cool the catalyst, light-off time becomes more of an issue. More efficient removal of heat from the catalyst can be expected to compound the effects of catlayst positioning, which was demonstrated above to significantly increase light-off time. The tradeoff which Ford pointed to between lower catalyst temperatures and light-off clearly exists.

The magnitude of this tradeoff problem is somewhat exaggerated by the commenters. The cold-start/hot-start weighting applied to the results of the proposed transient test tend to minimize the impact of emissions during the early part of the cold start segment (The reader is urged to consult the Feasibility of Compliance chapter of this document for an in-depth discussion of this topic). We wish not to encourage manufacturers to forfeit cold-start emission control but rather to point out that some increase in light-off time should not be a determining factor in achieving a given design-goal emission level.

In addition, engine-out cold-start emissions can be reduced directly, diminishing the need for early conversion efficiency. The design of choke operation and carburetor flow characteristics to minimize cold-start HC and CO are two examples. A final approach is to use monolithic catalysts, which, because of their lower mass, heat up and light off more quickly than do pelleted designs.

The obvious exception that we have made in the discussion thus far is the motoring mode. While the catalyst-cooling approaches suggested above should greatly reduce the frequency of occurance of high-temperature excursions, the staff believes that their elimination is not likely. Because a relatively small number of such events will begin to degrade the structure and efficiency of current alumina substrates, we believe that some method of avoiding the temperature spikes will be necessary. A mechanism to shut off the fuel flow during closed-throttle motoring and an air-pump shut off to stop the oxidation process in the catalyst (or both) are suggested as ways of protecting the catalyst. (See the Staff Recommendations).

An underlying assumption of the entire catalyst heating discussion above is that gamma alumina will continue to be the only catalyst support material. In the event the new potential market for heavy-duty catalysts spawns the development of more temperature-resistant substrates, the conclusion of our analysis would change greatly. Conversations with Engelhard Industries representatives have indicated that such substrates are being developed and may well be available by 1984.

Substrates which could withstand greater temperatures without losing their surface area would reduce the need for distant catalyst placement and extensive cooling measures, making light-off less of a problem. Additionally, the temperature spikes associated with motoring would possibly no longer threaten the catalyst, eliminating the need for special protection during this mode.

Even if alumina remains as the primary substrate material, we conclude the technology exists for heavy-duty catalyst systems that will function for 100,000 miles. Deterioration of catalyst efficiency may be slightly more rapid than that seen in current light-duty systems, but not to such a degree that the feasibility is compromised. Additionally, since the deterioration curves of catalyst systems generally flatten out as time goes on, the significant loss in efficiency is expected to occur in the first half of the catalyst life. If catastrophic failure from gross heat effects or intentional poisoning is avoided, continued functioning beyond 100,000 miles is very possible, even to the estimated 114,000 miles average heavy-duty gasoline engine useful life.

several seconds during a motoring experiment seems to have resulted in a loss in efficiency. The experiment fell between the second and third transient tests at the 38" catalyst positions; on the basis of a comparison of the emission values from those two tests, a decrease in conversion efficiency of about 15% was observed. This loss may explain the lower maximum catalyst temperatures seen in the transient test following the temperature excursion.

The very light noble metal loading of these catalysts is probably most responsible for the loss of efficiency. Because of the relatively small number of active catalyst sites available, a small loss in subtrate surface area would be expected to appreciably reduce the conversion efficiency. The heavier loading of heavy-duty catalysts will improve this situation.

It is important to note that the value of the entire EPA temperature analysis is compromised to some degree by the inconsistant treatment of the dual catalyst system. The temperature characteristics of the two converters were appreciably different, but they were not always treated independently. For example, the transient test maximum catalyst temperatures as recorded represent only one catalyst, the one that was the hottest. Similarly, the temperatures during the steady-state and motoring study sometimes correspond to only one catalyst.

Although we assumed that the GM catalysts were equal in mass and in flow specifications, it appears that they differed to some degree; the temperatures sometimes differed by 100°F. Because the transient emission tests combined the exhaust flows for analysis, it is not possible to separate the emission components contributed by the individual banks of cylinders under the influence of the individual catalysts. Therefore, for instance, since one of the catalysts may for some reason have been more sensitive to heat effects, it alone may have caused the efficiency loss. Detailed conclusions drawn from the temperature analysis study, then, are of limited value.

However, the EPA data reveals several general trends which lead to the following conclusions:

1) Catalyst placement has a marked effect on the maximum converter temperatures reached during operation over the proposed transient cycle and in high-speed steady-state modes. Temperatures during motoring can possibly be controlled by lowering the initial temperatures through catalyst placement.

2) Catalyst light-off times progressively increase with catalyst distance from the exhaust manifold.

3) The transition to closed-throttle motoring is accompanied by an immediate catalyst temperature rise which in at least some-

The final area of comment regarding maintenance intervals is specific to diesel engines. (General comments not directed at specific intervals were treated previously.) Looking first at turbochargers, it is important to note that the introduction of crankcase emissions into the turbocharger inlet is no longer being considered by EPA. If EPA decides to require control of crankcase emissions from turbocharged diesels, a method will probably be recommended which allows the turbocharger to be bypassed.

Mack Truck's comments recommend turbocharger maintenance at 50,000 miles, their current practice. However, they submitted no information to indicate what differences exist between theirs and Caterpillar's 200,000-mile-interval turbocharger that would explain Mack's requirement of more frequent maintenance. The technology obviously exists for a more maintenance-free turbocharger. Mack is either presently using a design which requires more attention than technology would dictate or they are simply recommending more maintenance than their turbocharger requires. In either case Mack's objection is based not on technology but on a concern about EPA's justification for establishing required minimum intervals. The issue of justification was treated earlier in this section.

EPA's proposed intervals for cleaning diesel injector tips were not based on an assumption of similar operating environments for both gasoline and diesel injectors. The basis was simply the observation that 100,000-mile and greater cleaning intervals are recommended now on some engines. In the absence of any submitted information that would indicate that this low-maintenance technology is inappropriate to other heavy-duty diesels, we reaffirm the feasibility of the proposed intervals. This concludes the staff analysis of the interval-specific comments.

We recommend that EPA delay the requirment that manufacturers must demonstrate "a reasonable likelihood" that proper maintenance will be performed in-use. Our recommendation arises not from specific comments about these proposed provisions but from a belief that such a requirement is not necessary at this time. It appears to us that the manufacturers would reasonably easily be able to show that required maintenance was indeed being performed on the emission-related components which these regulations will require. With respect to the forthcoming NOx regulations, however, the situation is different. It is possible that three-way catalyst technology will be used, in which case oxygen sensors will control the feedback systems. It is for this type of component that the staff believes some sort of assaurance of in-use maintenance will be necessary.

At such a time that these provisions are reproposed, EPA will analyze the comments received with this package as well as any new comments.

4. Recommendations

The staff has concluded that the proposed maintenance requirements (Section 86.083-25 of Subpart A) should be retained in their proposed form with the following exceptions:

1. The technologically necessary spark plug change interval should be revised from 30,000 miles to 25,000 miles.

2. The technologically necessary catalyst replacement interval should remain 100,000 miles. The preamble of the final rule, however, should make it clear that for gamma alumina catalyst substrates, EPA expects that an air pump shutoff capability and/or a motoring mode fuel shutoff will be necessary for motoring conditions exceeding 15 seconds in duration in order to protect the catalyst. We further recommend that such a system be specifically exempted from being classified as a defeat device.

<u>References</u>

1/ "Better Enforcement of Car Emission Standards -- Away to Improve Air Quality", Report by the Comptroller General of the U.S. General Accounting Office, Report IICED-78-180, January 23, 1979.

2/ American Automobile Association letter to Rep. Henry Waxman, August 13, 1979 (EPA Central Docket Section #OMSAPC-78-4).

3/ "Comparison of Catalyst Substrates for Catalytic Converter Systems", J.L. Harned and D.L. Montgomery, General Motors Corporation, SAE Paper #730561.

4/ "Active Aluminas as Catalyst Supports for Treatment of Automotive Exhaust Emissions", Harry E. Osment, Kaiser Aluminum and Chemical Corp., SAE Paper #730276.

5/ "Ceramic Substrates Technology for Automotive Catalysts," Maxwell Teague, Chrysler Corp., SAE Paper #760310.

E. Issue - Parameter Adjustment

1. Summary of the Issue

Briefly stated. the issue is this: Does the available evidence justify the proposed regulation of heavy-duty parameter adjustment.

In the NPRM, EPA proposed to amend the certification process to permit the Administrator to adjust previously identified engine parameters (i.e., idle fuel-air mixture, idle speed, initial spark timing, and choke valve action) to settings anywhere within the physical limits of adjustment for the parameter(s) in question. The proposed requirements were identical to those recently promulgated for light-duty vehicles and will encourage manufacturers to design heavy-duty engines which are less susceptible to in-use maladjustment. Such maladjustment is capable of causing in-use emissions to be substantially higher than allowed by the standards.

2. Summary of the Comments

Many commenters expressed their concern that EPA had no data which showed that heavy-duty vehicles are being maladjusted in the field. They point out that EPA states in the preamble to the NPRM that "EPA does not have test data which indicate how serious (maladjustment) may become for heavy-duty vehicles with the use of advanced emission control technology. However, there is no reason to believe that the degree of heavy-duty in-use maladjustment will be much different than has been the case with catalyst equipped light-duty vehicles and light-duty trucks."

The commenters contend that since EPA admittedly has no data to support heavy-duty parameter adjustment, EPA is using the "crystal ball" approach which was struck down in court in International Harvester vs. Ruckelshaus.

Several commenters cited an Oregon Department of Environmental Quality inspection and maintenance program report which included 4600 gasoline powered trucks, all weighing more than 8500 lbs GVW. That report includes a paragraph stating that heavy-duty vehicles have less of a problem with the inspection and maintenance program than do light-duty vehicles. The report goes on to hypothesize that since heavy-duty vehicles are working (i.e., commercial) vehicles they probably receive better overall maintenance than general passenger vehicles.

Many commenters expressed their belief that since heavy-duty vehicles are primarily commercial vehicles, they are well maintained by professional mechanics and, therefore, maladjustment should not be a problem. However, no commenter provided any data to support this belief.

Diesel engine manufacturers stated that even if the available light-duty data on parameter maladjustment could be extrapolated to heavy-duty vehicles, resultant conclusions would have to be limited to gasoline-fueled heavy-duty vehicles because the light-duty data did not include any diesel engines. One commenter cited an EPA contract report1/ which involved the testing of 12 used heavy-duty diesel engines. He claimed that the "data certainly indicates little if any, deterioration or tampering with the emission control systems considering the normal possible spread in emission levels".

Diesel manufacturers also stated that since diesel engines are used in a wide variety of applications they require wide ranges of parameter adjustment. Specific examples of parameters which need a wide range of adjustment or the width of such ranges of adjustments were not given.

Some comments other than those summarized above were received. These additional comments are considered secondary in nature and are treated in Part II of this document.

3. Analysis of the Comments

The major issue raised by commenters was a lack of supporting data used by EPA to justify the need for parameter adjustment regulations for heavy-duty trucks. EPA's technical staff believes that available evidence is sufficient to demonstrate the need for heavy-duty parameter adjustment. That evidence is discussed in this section.

Light-duty in-use maladjustment studies2/,3/,4/,5/ have shown conclusively that parameter maladjustment is the source of significant in-use emissions which are above standard. Heavy-duty vehicles have the same engine parameters which perform the same functions as those parameters found to be most commonly maladjusted for light-duty vehicles. For example, both light-duty and heavy-duty gasoline-fueled engines have adjusting mechanisms on the carburetor which control the idle air-fuel mixture and the idle speed. Also, both heavy-duty and light-duty gasoline-fueled engines have chokes to facilitate cold start driveability and both have spark plugs whose firing must be properly timed. Maladjustment of these various parameters can arise from simple failure of the operator to have proper maintenance performed, improperly trained mechanics, or in some cases deliberate maladjustment in an attempt to improve performance (at the expense of emissions). All of these causes would exist for heavy-duty vehicles as well as for light-duty vehicles. Heavy-duty inspection and maintenance studies done in Oregon and New Jersey show that heavy-duty vehicles fail at rates essentially identical to those found in light-duty I/M programs. The light-duty I/M failures are primarily due to parameter maladjustment and there is no reason to believe that the majority of heavy-duty I/M failures are due to anything but parameter maladjustment.

EPA's Restorative Maintenance Program2/ showed that parameter maladjustment is a significant problem with light-duty vehicles less than 12 months old. Idle mixture maladjustment was found on 37.7% of the vehicles tested. Results also showed idle speed to be maladjusted 25% of the time, choke to be maladjusted 10.4% of the time and initial spark timing to be maladjusted 19.0% of the time. Table E-1 summarizes this study and shows the significant increases of in-use emissions due to the various maladjustments. Other studies,3/,4/,5/ have given similar results with the additional conclusion that the older vehicles become the more likely they are to be maladjusted. It is clear from these studies that parameter maladjustment is occuring to a wide extent on light-duty vehicles and the resultant increase in emissions is substantial.

Again, heavy-duty gasoline-fueled vehicles have the same engine parameters that were found most likely to be maladjusted on light-duty vehicles. These engine parameters serve the same function whether on light-duty vehicles or heavy-duty vehicles. It is reasonable to expect that heavy-duty maladjustment of these parameters will be similar to the light-duty experience.

However, several commenters expressed the belief that since heavy-duty vehicles are commercial vehicles they are better maintained than light-duty vehicles. They stated that better maintenance should mean that parameter maladjustment is not as big a problem for heavy-duty vehicles. No direct data was presented to substantiate this rationale. However, an Oregon Department of Environmenal Quality report6/ was cited as evidence. In that report 4600 heavy-duty gasoline vehicles had been tested as of February 1978 as part of the Oregon Inspection and Maintenance program. The preliminary conclusion reached was that heavy-duty vehicles were having less of a problem with I/M than light-duty. This was hypothesized to be due to the commercial nature of heavy-duty vehicles and the predicted better maintenance these vehicles might be receiving.

An examination of this report reveals that heavy-duty vehicles were failing the I/M test at a 37% rate while light-duty vehicles were failing at a rate of 40%. This difference of 3% is certainly not a major one. Since that report, an additional 7000 heavy-duty gasoline vehicles have been tested and the failure rate has risen to the 40% level. This means that heavy-duty gasoline-fueled vehicles are now failing Oregon's I/M test at almost exactly the same rate as light-duty vehicles.

Furthermore, a New Jersey Department of Environmental Protection study7/ showed that the degree of commerciality of heavy-duty gasoline vehicles has no effect on I/M test failure rates. The

Table E-1 -- Summary of Results from Restorative Maintenance Study

1975/76 Standards: 1.5/15/3.1

Parameter	Maladjustment Rate	Comparison Between Vehicles* With This Maladjustment and All Other Vehicles	HC	CO	NOx	Comparison Between Vehicles* with Only This Maladjustment and Properly Adjusted Vehicles	HC	CO	NOx	After Restorative Maintenance (Average of all vehicles)	HC	CO	NOx	After Selective Malperformance (Change from previous passing test)	HC	CO	NOx
Idle Mixture >0.5% CO	37.7%	All other	0.81	7.36	2.84	Properly Adjusted	0.75	7.16	2.76	As received	1.32	20.27	2.82	Enriched to classic lean best idle	+85%	+211%	-4%
		With Maladjustment	2.16	41.6	2.79	Maladjusted	2.02	39.22	2.66								
			+166%	+465%	-2%		+169%	+448%	-4%	Disablement timing and choke	1.25	18.44	2.65				
Idle Speed	25%	All other	1.26	19.77	2.77	Properly Adjusted	0.73	7.02	2.74					Not Available			
		With Maladjustment	1.48	21.7	2.97	Maladjusted	0.94	7.01	3.18								
			+17%	+10%	+7%		+29%	0	+16%	Idle mixture and idle speed	0.90	8.13	2.69				
>100 RPM fast	15%	Fast	1.42	22.62	3.10	Fast	0.84	7.15	3.38								
			+13%	+14%	+12%		+15%	+2%	+23%								
>100 RPM slow	10%	Slow	1.59	20.30	2.78	Slow	1.06	6.97	2.90								
			+26%	+3%	0		+45%	-1%	+6%	Complete Restoration	0.87	7.65	2.55				
Spark Timing	18%	All other	1.27	18.64	2.78	Properly Adjusted	0.73	6.95	2.75	Not Available				Advanced 5°	+24%	+6%	+19%
		With Maladjustment	1.58	27.61	3.01	Maladjusted	0.98	10.32	3.56								
			+24%	+48%	+8%		+34%	+48%	+29%								
>2° Advanced	8.3%	Advanced	1.88	35.33	3.50	Advanced	1.11	11.48	4.01								
			+48%	+90%	+29%		+52%	+65%	+46%								
>2° Retarded	9.7%	Retarded	1.25	18.46	2.35	Retarded	0.63	7.14	2.32								
			-2%	0	-15%		-14%	-3%	+3%								
Choke Rich Lean	10.4% 5.3% 4.3%	Not Available				Not Available: all vehicles with choke maladjustments also had other maladjustments.				Not Available				Enriched 3 notches	+23%	+80%	+15%

*Vehicles in as received condition.

study split the trucks into two groups; large fleet trucks (i.e., those fleets which had more than 29 trucks) and small fleet trucks (i.e., fleets having less than or equal to 29 trucks). It was expected that the large fleet trucks would have a smaller failure rate because the fixed costs of a periodic maintenance program can be spread over a larger volume. The results of the study showed no significant difference between the I/M test failure rate of the large fleet trucks versus the failure rate of the small fleet trucks. The actual failure rate achieved by both groups was about the same as the failure rate reported for heavy-duty gasoline-fueled vehicles in Oregon's I/M program.

In summary, for gasoline-fueled vehicles, the data from EPA's Restorative Maintenance program 1/ shows that parameter maladjustment is the biggest reason for in-use light-duty vehicles' failure to pass the FTP as well their failure to pass I/M tests. Heavy-duty gasoline-fueled vehicles have the same engine parameters which serve the same function as those engine parameters found most likely to be maladjusted on light-duty vehicles. The same basic causes for maladjustment of those parameters exist for heavy-duty vehicles as for light-duty. Since heavy-duty gasoline vehicles are failing I/M tests at rates identical to light-duty, it is reasonable to conclude that heavy-duty engine parameters are being maladjusted to a degree comparable to light-duty vehicles.

The heavy-duty diesel engine manufacturers' rationale that since EPA has no data on diesel parameter maladjustment, diesel engines should be excluded from this part of the regulation is not acceptable. The NPRM did not list any parameter that would be subject to adjustment by the Administrator for diesel engines because there is admittedly a lack of data concerning diesel maladjustment. EPA will not subject any diesel parameters to adjustment until such time as evidence shows that adjustability should be limited and the Administrator gives manufacturers sufficient lead time. The fact that EPA has no direct data which shows diesel engines to be maladjusted in the field does not mean that EPA does not have a legitimate concern regarding misadjustment of diesel parameters or that it does not have a sufficient basis to create the mechanism for evaluating and regulating parameters which at some later date are identified as being maladjusted in-use such that emissions are significantly affected. Certain diesel parameters such as fuel injector timing are adjustable and can affect fuel economy and driveability (as well as emissions) and could be maladjusted in-use.

Diesel engine manufacturers' were also concerned that these regulations would limit the adjustment of parameters to an extent whereby the range of adjustment would be so small that the engine could not be used in all of the applications in which it had been used previously. The proposed parameter adjustment regulations would not disallow an engine from having a wide range of adjustment for a parameter. It may be that wide ranges of adjustments are necessary because diesel engines are used in a wide variety of vehicles and applications. However, no matter what application the engine is used for that engine must still meet the emission standards. Whether the parameters of an engine are adjusted for urban delivery usage or line-haul usage makes no difference as to the applicability of the emission standards. EPA is not attempting to limit the number of different applications in which an engine can be used but rather EPA wishes to insure that the engine will meet emission standards in all its potential applications and that parameter settings which could cause excessive in-use emissions are eliminated. The question of the possible need for a wide range of adjustment for any particular engine parameter would be addressed at the time that parameter was identified by EPA as being subject to adjustment under the regulations.

4. Recommendations

EPA's technical staff recommends no major changes to the proposed heavy-duty parameter adjustment regulations. Minor changes to the NPRM, for clarification purposes, are addressed in Part II of this document.

References

1/ Study of Emissions From Heavy-Duty Vehicles; EPA-460/3-76-012, May 1976.

2/ An Evaluation of Restorative Maintenance on Exhaust Emissions of 1975-1976 Model Year In-Use Automobile, EPA 460/3-77-021, December, 1977.

3/ 76S-1975/76 Model Year Surveillance Test Program Report, Vehicle Surveillance Section, California Air Resources Board, June 1977, Preliminary Draft.

4/ Tune-up: Its Effect on Fuel Economy, Emissions and Performance - Results of the 1975/76 Test Program Conducted by Champion Spark Plug, Champion Spark Plug Company

5/ The Incidence of Tampering on Cars in New Jersey During 1975, Mobile Source Enforcement Division, June 22, 1976.

6/ See item IV.G. 27 in the Docket (Docket #OMSAPC-78-4).

7/ Summary Report on New Jersey Department of Environmental Protection Analysis of Heavy-Duty Gasoline-Fueled Truck Emissions, New Jersey Department of Environmental Quality, Trenton, New Jersey.

F. Issue - Idle Test and Standards

1. Summary of the Issue

EPA has proposed separate certification standards and test procedures for the idle mode for both gasoline and diesel engines.

2. Summary of the Comments

Manufacturers unanimously criticized the proposed idle test as redundant. The proposed transient test procedure, as do the current steady-state tests, already contains substantial portions of idle (approximately 25 percent), and was claimed will adequately characterize the contributory emissions of the idle mode.

Secondly, EPA was criticized for failure to document air quality benefit or needs associated with the idle standard. It was asserted that factual evidence has not been advanced by EPA to support the CO "hot spot" - "street canyon" problem referenced in the Draft Regulatory Analysis. It was also argued that the presumed need for a heavy-duty idle standard is diminishing over time with the increased stringency of light-duty standards, as evidenced by diminishing central city eight- and one-hour CO violations. The contributory effect of heavy-duty vehicles was characterized as negligible. In summary, the industry declared that the EPA is legally obligated under the Clean Air Act to quantify air quality needs and benefits associated with promulgated standards, and EPA has purportedly failed to do so for the idle test.

Third, diesel manufacturers complained that diesel engines have inherently low HC and CO idle emissions. Required idle certification testing would purportedly add to testing expense with no corresponding impact on air quality. Furthermore, Cummins submitted data showing that any diesel engine failing the idle test would certainly fail the transient test.

Finally, one manufacurer commented that an idle standard will act as an unnecessary design constraint; design flexibility is needed to "tradeoff" emissions between various operating modes.

3. Analysis of the Comments

The Cape-21 heavy-duty vehicle operational characterization study indicated that over 45 percent of truck operational time in the New York City urban area was spent at idle. Based upon this fact, it is reasonable to presume that some degree of ambient CO problems can be attributed to idling heavy-duty vehicles. Also, high CO ambient readings are commonly found associated with congested, rush-hour traffic. It is also well established that such congested traffic situations contain high percentages of idle operation.

Heavy-duty gasoline vehicles subject to certification on the transient procedure almost certainly will utilize catalyst technology. Based upon data collected from prototype, catalyst-equipped engines in the EPA laboratory, it has been observed that catalysts which are sized to adequately handle the high-power, high-speed portions of the transient cycle will be large enough to have the capacity to virtually eliminate idle emissions on a certification test. The idle standard will provide assurance that this capacity will be used to control idle emissions. They very argument made by one of the manufacturers that an idle standard will act as an unnecessary design constraint eliminating needed flexibility to "tradeoff" emissions between idle and other operating modes - is the prime reason the idle standard is needed. The idle standard would assume that idle emissions are not traded for emissions in other modes.

Positive air quality benefits can also be attributed to use of the idle standard in conjunction with the implementation of Section 207(b) of the 1977 Clean Air Act Amendments. The identification of failed in-use catalysts, air pumps, fuel metering and related components, and their subsequent replacement/repair would have the net effect of reducing the number of gross emitters in the heavy-duty class, and therefore would have the net effect of improving air quality. Furthermore, use of the idle standards would allow lower cut points for the Inspection/Maintenance program, and would make I/M more publicly acceptable since manufacturers' warranties may be invoked to pay for maintenance. The allowance of lower set points enables the test to better discriminate in identifying failed and properly-operating catalyst systems (more so than in the case of light-duty I/M engines). Overall, the idle test is quick, simple, cheap, and an effective indicator of failed catalytic converters.

The staff notes that although the existence of this short test will make it easier to implement the 207(b) warranty with respect to heavy-duty vehicles, it will not, of itself, implement that warranty. Rather final emission performance warranty regulations are required. The Agency has proposed emission performance warranty regulations on April 20, 1979 44 FR 23784. As proposed, heavy-duty vehicles could be subject to the warranty. However, because of comments received asserting that the warranty, as proposed, was inappropriate with respect to Heavy-Duty vehicles and engines, the Agency is considering omitting them from the final rule and reproposing new regulations to cover them.

In any case, it will be future warranty regulations that can actually implement this warranty for heavy-duty vehicles and engines. Therefore the staff has not calculated the cost that would be associated with implementation of the 207(b) warranty with respect to heavy-duty vehicles and engines. These costs will be figured in future rulemaking packages on the emission performance warranty. The staff would like to point out, however, that even if heavy-duty vehicles and engines are included in the soon to be promulgated emission performance warranty package, it believes that the warranty costs for heavy-duty vehicles and engines would be small. The economic analysis prepared in response to the 207(b) warranty (see Public Docket EN-79-6) concluded the additional cost to new light-duty vehicles and light-duty trucks would be less than $5.00 per vehicle. The Agency received no data from heavy-duty manufacturers or other parties demonstrating that the costs would be significantly different for heavy-duty vehicles and engines.

Furthermore, costs of compliance with the certification idle test are minimal. As discussed above, catalysts effective on the transient certification procedure can easily be made to meet the certificaton idle standard as a matter of course, therefore, requiring no additional development costs. The only attributable costs to the idle test procedure are those associated with performance of the actual test, (i.e., insignificant on a cost per engine basis).*

Diesel engines, however, emit minimal idle emissions (today's diesels are well under the proposed idle standards), will not be equipped with emissions sensitive catalyst systems, and evidence to date indicate virtually no deterioration. Use of an idle test procedure for diesels, with or without in-use compliance testing, is expected to have little or no effect.

In summary, the high percentage of time urban trucks spend at idle, the ease of an in-use idle procedure, the relative effectiveness of an in-use idle procedure in detecting failed catalyst systems, and the virtually nonexistent costs of a certification idle standard support its promulgation. No compelling data at this time, however support implementation of any idle standard for diesel engines, and a delay in its promulgation is warranted. This decision could be reconsidered in the future, should the need become more evident.

4. Recommendations

Retain the idle CO standard for gasoline engines. Delete the idle tests requirements for diesel engines; delete the idle HC standard for gasoline engines.

* Reference Chapter 5 of the Regulatory Analysis, "Economic Impact."

G. Issue - Leadtime

1. Summary of the Issue

In brief, this issue can be stated as follows: what is the earliest model year by which heavy-duty engine or vehicle manufacturers can comply with the proposed regulations? The Clean Air Act calls for the establishment of the 90 percent standards for heavy-duty engines in 1983.

In the NPRM, EPA indicated that manufacturers of both gasoline-powered and diesel engines would be able to comply with the proposed regulations in time for the 1983 model year. This belief was based upon an analysis of information then available concerning leadtime for test equipment procurement and checkout, control technology development, and engine certification. The EPA timetable for gasoline-fueled engines included 10 months for procurement of CVS systems and dynamometer modifications, 14 months for technology development, and 12 months for certification. For diesel, the procurement phase was extended an additional 10 months and development time was reduced to 4 months. Comments on these times were requested in the NPRM.

2. Summary of the Comments

All commentors who discussed leadtime claimed that there was insufficient leadtime to comply with the proposal by the 1983 model year. Responses varied as to when the proposal could actually be implemented. Most manufacturers' timetables indicated 1984 as an attainable goal. Some (IHC for gasoline and Mack) indicated that 1985 was the earliest attainable year, while others (Detroit Diesel, Caterpillar, and IHC for diesel) indicated that compliance was not possible before 1986.

Manufacturers estimated equipment procurement and checkout times extending into mid-1981 (as opposed to late 1980 under the EPA timetable). Gasoline-fueled engine manufacturers estimated development times of 3-6 months longer than EPA's original estimates (14 months). For diesel engine manufacturers, these development times ran from 1-1/2 to almost 3 years, as contrasted with the 4 months contained in the EPA proposal.

Commentors offered a wide variety of suggestions as to what EPA should do in response to these leadtime problems. They can be broadly categorized as those which advocated withdrawing most of the original proposal and substituting 90 percent reduction standards based upon the current test procedures, and those involving use of some form of a transient test procedure with leadtimes extended beyond 1983. These suggestions, and EPA's responses, are detailed in Part II of this Summary and Analysis of Comments.

The timetables developed by the individual manufacturers are presented in Figures G-1 (gasoline-fueled) and G-2 (diesel) and reviewed below. It should be noted that in the interest of clarity Figures G-1 and G-2 do not necessarily include all of the detail or keep the same terminology used by each manufacturer.

a. Gasoline-Fueled Engine Manufacturers

Ford

The Ford comments on leadtime analyzed the time required for what Ford considered the three main components of a compliance program: a) developing transient testing capability, b) engine development and certification, and c) catalyst development. Ford concluded that 1983 was not attainable because the required timing of these three elements was not compatible. To determine what model year would be feasible using Ford's timing, the Technical Staff has combined these elements into an overall schedule.

The Ford timetable shown in Figure G-1 indicates compliance for the 1984 model year. Ford has had limited transient test capability since March 1979 in one cell. Equipment for two full cells has been ordered, and they are expected to be operational by May 1980. The remaining cells to make up the full compliment of 12 cells which Ford feels it needs are projected for June 1981. These times are based upon 9-10 month leadtimes for equipment and 1-2 month installation and checkout. The schedule assumes that the catalyst design program will begin in January 1980 (after issuance of Final Rule). This program has been timed by Ford to allow a minimum of 44 months leadtime before start of vehicle assembly operations. The schedule also assumes the availability of a "forced-cooling" procedure for an accelerated testing rate (see "Test Procedure" issue and durability testing based upon a 50,000-mile useful life.

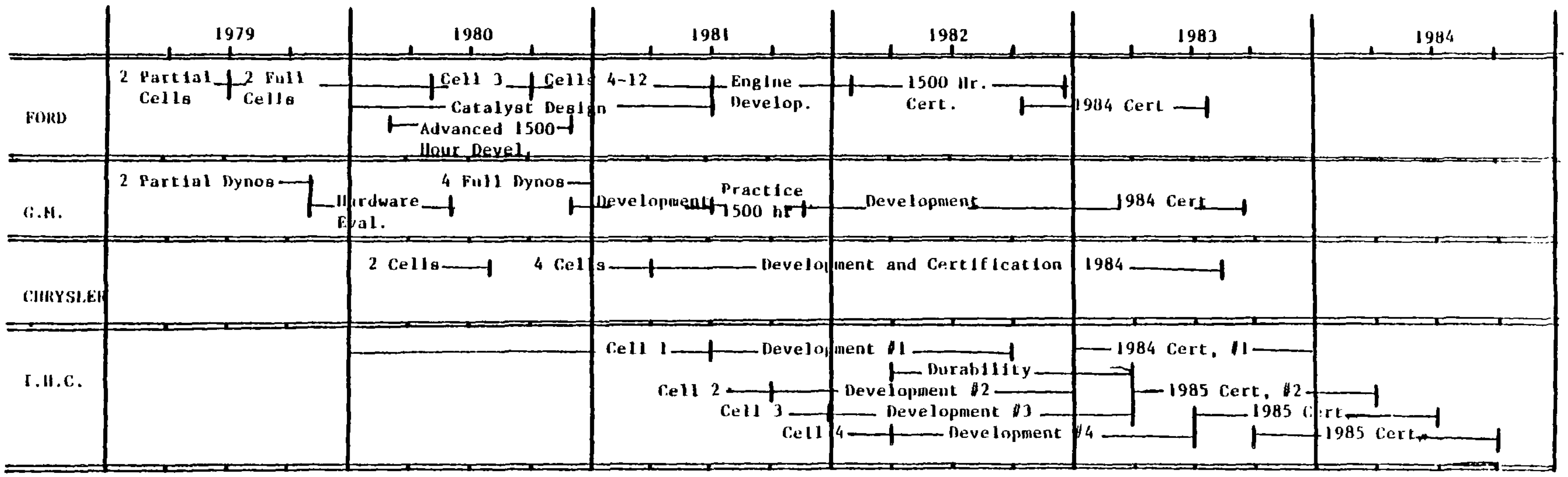
Ford's catalyst development program is based upon preliminary test data which "clearly indicates that existing light-duty catalyst technologies are inadequate..." Ford also states that the catalyst devleopment schedule "assumes that no major problems occur which would necessitate new catalyst designs during the catalyst development program."

General Motors

The timetable supplied by General Motors also indicates 1984 as an attainable model year. Partial testing capacity in two cells is expected by November 1979. Full testing capacity (with a CVS sampling system) in two cells is expected by December 1980. At that time, GM's engine development program would begin. Final certification would be in time for the 1984 model year. Combined delivery and checkout time is estimated by GM as one-

Figure G-1

Gasoline Fueled Engine Leadtimes



year. GM has allowed 6 months for equipment installation and checkout, for either dynamometer control systems or CVS systems.

Production tooling leadtimes in the GM schedule are based upon assumptions that could cause considerable delay if not borne out. Leadtime for catalysts is based upon use of cores already being tooled for "certain passenger car applications." As discussed elsewhere in the evaluation of feasibility, GM feels that there may be significant durability problems necessitating larger catalysts. If this were to occur, leadtime would be extended.

The GM timetable is also predicated upon the assumption that their quadrajet carburetor will not have to be redesigned or replaced. This carburetor, which uses air valve secondaries and is found on a majority of GM heavy-duty gasoline-fueled engines, has been identified on engines tested by EPA as a possible source of high transient emissions.

GM has indicated the potential for delay in this schedule in other areas as well. Their dynamometer equipment is a non-standard General Electric design featuring aluminum core armatures. While it appears that these dynamometers are suitable for transient operation, there is a possibility that the armatures may not be capable of handling peak field currents. That would necessitate the installation of new dynamometers and reduce available development time and tooling leadtime. GM's estimates are also based on the assumption that separate emission systems for California (requiring separate certification) will not be required.

Chrysler

Chrysler is in a distinct position among gasoline-fueled engine manufacturers in that current heavy-duty certification is being done using eddy current dynamometers. The leadtime to purchase new dynamometers is significantly longer than that to convert existing equipment. However, Chrysler has already begun construction of 2 new cells, which are expected to be fully operational by August 1980. Two existing electric dynamometer cells will be converted and will be operational by April 1981. In their submittal, Chrysler has indicated that their full development and certification process would have to begin 2-1/2 years prior to the first effective model year. This would require a minimum of 4 test cells. Thus, the first year for which Chrysler could certify engines under its proposed schedule would be 1984.

International Harvester

IH was the only gasoline manufacturer indicating more than four years of leadtime required to certify to the transient procedure. The schedule submitted by IH indicates completion of their first dynamometer system by June 1981, with the remaining three systems being staged at three-month intervals (based upon IH manpower limits). Allowing 18 months for development and 12 months for certification for each engine family results in a program stretching to September 1984 (in time for the 1985 model year).

As was the case with GM, the IH schedule is predicated on the assumption that IH will not have to develop engines to meet separate emission standards for California. This requirement would add additional time.

b. Diesel Engine Manufacturers

General Motors

An outline of the timetable submitted by GM and other diesel manufacturers is given in Figure G-2. GM projects one research test cell for September 1979. This would be used for some preliminary engine characterization and as a basis for developing specifications for the 12 cells needed for GM for engine development. These 12 cells would be procured in 1980 and installed by September 1981. They would be installed in a new diesel test laboratory which is now being built. This facility was already being built at the time of the proposal, and was initiated for product development independent of regulatory requirements.

Technology assessment would begin on the research cell. Upon completion of the installation of the 12 cells, a two-year and 9-month period of engine development and pre-certification testing would begin. Certification testing could begin in July 1984. As stated by GM, implementing the transient test would be "very ambitious for the 1985 model year."

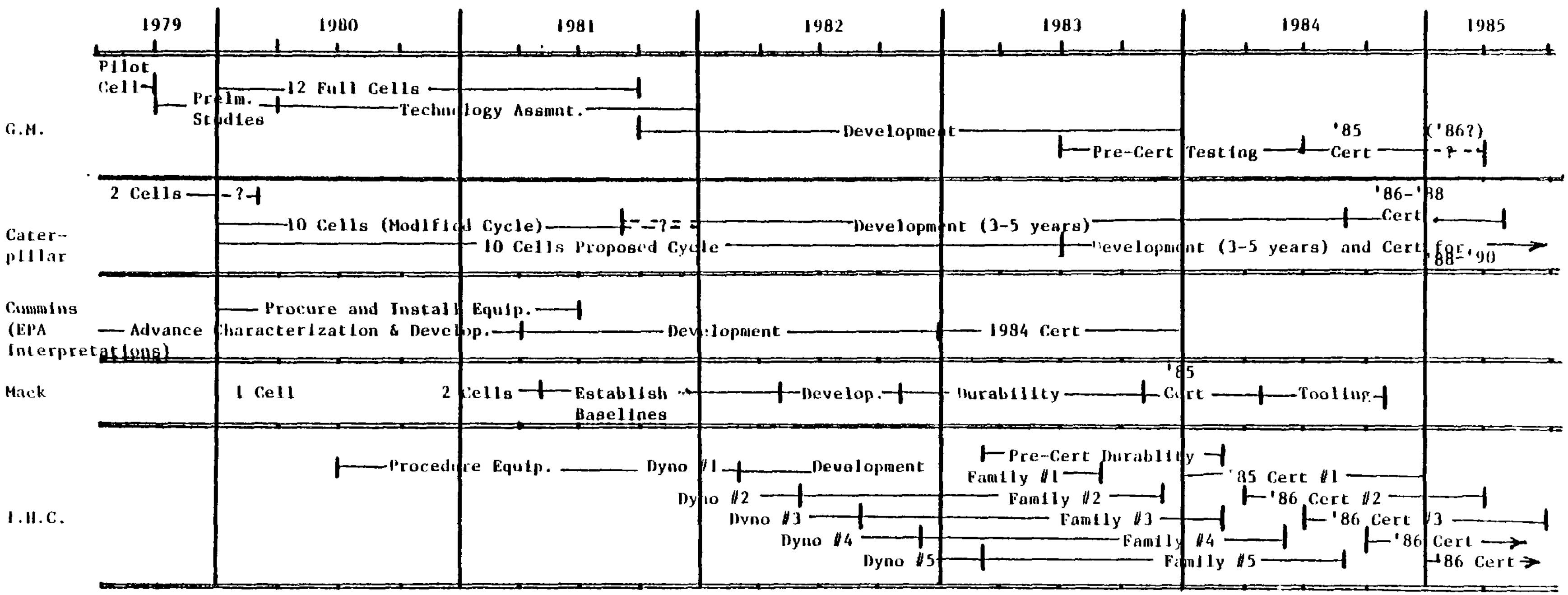
Caterpillar

The main emphasis of the Caterpillar leadtime comments concerned development and validation of a revised test procedure using eddy current dynamometers. Based upon the presumptions that a revised cycle could be easily "validated" and that emission standards would be set at or above the levels of current production engines, Caterpillar projected that a revised test procedure could be implemented for 1983. Delays in validation or the need to reduce engine emissions would extend the Caterpillar schedule 3-5 years. Further consideration of the Caterpillar timetable will be based upon the assumptions that the test procedure promulgated by EPA will not require a validation program and that reductions in engine emissions will be required.

The timetable which Caterpillar would follow under the above conditions is the longest of all manufacturers' estimates. Caterpillar estimates that compliance with the proposal might not be possible before as late as the 1990 model year. The earliest model

Figure G-2

Diesel Engine Leadtimes



year in which Caterpillar projected compliance with the proposal was 1986 (assuming it was possible to retain existing eddy current dynamometers and that an engine development program to meet the final standards would be required).

Caterpillar presented the various elements of their timetable at different stages of their testimony and did not tie them together into one overall schedule. In fact, the various aspects of the Caterpillar timetable, when assembled together in Figure G-2, reveal certain discrepancies regarding the development of transient test capability. During oral testimony at the May 14-15 Hearing, Caterpillar indicated that two transient test facilities were on order and would be operational by the end of 1979 (page 118 of transcript). Caterpillar further indicated that another 20 months would allow them to have their desired quota of ten facilities operational. This later time was expressly dependent upon the assumption that some modified cycle permitting the use of existing eddy current dynamometers would be acceptable to EPA. Caterpillar's written submission following the Hearing modified these times without explanation. On page 17, the "end of the year" from the oral presentation becomes "early 1980". Page 26 changes the 20 months needed to have 10 operating facilities which projects to September 1, 1981 to "the beginning of 1982". That presentation indicates that all ten cells would be obtained through modifications to existing cells, and does not appear to consider the two systems already on order. Since the testimony presented at the Public Hearing was more specific as to the timing of the availability of the 10 needed cells than the somewhat generalized phrasing of the written submission, the September 1981 projections will be used for this analysis.

The Caterpillar presentation relied heavily on the possibility of retaining existing eddy current dynamometers. Caterpillar indicated that a full 3-1/2 years would be required to add facilities capable of running the unmodified transient cycle. Telephone discussions with Mr. Joseph Haefele of Caterpillar revealed that this time was necessitated by the need to construct a new wing on their technical center to house the test cells. It included design of the facility as well as actual construction. Mr. Haefele indicated that construction of the facilities would be completed by January 1983. This would be followed by a six-month installation period for test equipment, and an anticipated three-month debugging period. The cells would then be fully operational by the fourth quarter of 1983. This time is three months longer than presented in the Caterpillar written submission (corresponding to the debugging period). Mr. Haefele indicated that Caterpillar's recent experience in constructing a new wing to its technical center confirms such a timetable. That project took over 3-1/2 years to complete.

Turning to engine development, Caterpillar presented a general outline for "any significant modification to a product line" which the company indicated would take from three to five years to successfully complete. The approach was not based upon considerations of particular technologies to be evaluated or engine design changes which might need to be made to reduce emissions.

Cummins

Cummins' presentation regarding leadtime was very brief. They estimated 1-1/2 years for equipment installation and followed that with the position that "we will not have time both to implement a transient test system and to develop new emission control technologies based on that system for the 1983 model year." Cummins did not indicate how much development time was appropriate, nor what model year they could first expect to certify to. However, coupled with Cummins' repeated call for a 4-year leadtime which they believe is required by the Clean Air Act, the preceding wording suggests the 1984 model year for Cummins. Cummins already possesses some transient testing capability and has generated substantial test data. Their current capability surpasses all other diesel manufacturers. The EPA technical staff interprets the materials supplied by Cummins as indicating the possibility of certifying for the 1984 model year. The associated schedule is given in Figure G-2. Cummins cautioned that CVS delivery times which they used could be delayed. They believe that equipment suppliers may not be able to meet industry demand. In addition, they feel that delays could result from equipment changes resulting from development of the EPA particulate procedure (e.g., heat exchangers).

Mack

The timetable proposed by Mack indicates that 1985 would be the earliest model year for which Mack could certify their engines. They expect to have two cells operational by May 1981. After that follows a 2-1/2 year period which is divided into three phases: one year to "establish baselines," six months for development of control technology, and 12 months to assure engine durability. EPA staff interprets the baseline phase as including current engine characterization and some assessment of technologies - a category corresponding approximately to what other manufacturers describe as advance development or technology assessment. The development and durability phases correspond to what other manufacturers generally have included in the single category of development. The Mack timetable concludes with six months to obtain certification and six months to introduce minor production tooling changes for the 1985 model year.

In separate testimony from that presenting the above timetable, (p. 18 of June 27, 1979 comments) Mack has indicated that they expect to have their first complete cell operational in "early 1980." This fact does not appear to be reflected in the above timetable.

International Harvester

The IH timetable calls for 66 months of leadtime for diesel engines to reach production. In presenting this schedule IH indicated that they "would be reluctant to invest in any extensive number of dynamometers and the control equipment for the proposed transient test cycle until the Final Rules for particulate measurement have been published in the Federal Register." Therefore, the "leadtime for diesel engines can begin no sooner than the Final Rule" for particulates, which they assumed would be June 1980. IH would not project certification of any engines before the 1985 model year; and it would not certify all engines before the 1986 model year.

IH used the 20-month leadtime for equipment acquisition which had been estimated by EPA in the NPRM. Stating an inability to project the required amount of engine development time pending knowledge of the yet-to-be proposed particulate standard, IH "assumed" a period of 18 months for this phase of its program. Near the end of the development program, durability testing would begin. This durability testing would also overlap the initial 2 months of certification, as shown in Figure G-2. Total time for acquisition of the first test cell to completion of certification of the first engine family is 34 months.

As was done with their gasoline engine program, IH would plan to stage the installation of test cells for its second through fifth engine families at 3-month intervals. IH would therefore certify its last engine line for the 1986 model year.

Others

The Engine Manufacturers Association commented that the 20-month period estimated by EPA for procurement and installation of test cells is "unrealistic and unsupported by the record" and that the 4-month development time for diesel engines is "totally insufficient." EPA's suggestion that equipment might be purchased in advance of Final Rule was also rejected. The Motor Vehicle Manufacturers Association similarly rejected the idea that manufacturers should already be working toward achieving the reductions specified in the Act.

Perkins Engines commented that the 20-month leadtime for equipment estimated by EPA was adequate. Because of insufficient development time after that period, Perkins recommended that the transient procedure remain optional for the first two years. Perkins presented no specific timetable for compliance.

IVECO Trucks of North America (importer of heavy-duty diesel vehicles) commented on the special hardship which they foresaw for smaller manufacturers. Shorter leadtime was seen by IVECO as forcing increased competition between manufacturers for limited supplies of test equipment. Being unable to afford to pay premium prices that larger manufacturers could absorb would put smaller manufacturers at a time disadvantage. In addition, smaller manufacturers could not readily afford to order equipment in advance of Final Rule because of the financial risk if substantial changes were made in the Final Rule requirements.

3. Analysis of the Comments

To provide a basis for comparing and analyzing the various schedules which have been submitted to EPA, the information will be used to revise the original timetable proposed by EPA in the NPRM. This will be done separately for gasoline-fueled and diesel engines.

a. Gasoline-Fueled Engines

The gasoline timetable proposed by EPA included ten months for procurement of test equipment, fourteen months for technology development and twelve months for certification. Each one of these areas can now be updated.

The limiting factor considered in EPA's procurement phase was the delivery of equipment. Gasoline-engine manufacturers (except for Chrysler which has advance ordered new dynamometers already) do not need to purchase new dynamometers, so that the time limiting factor becomes the emissions sampling system. EPA's original time estimate, as well as the estimates supplied by the manufacturers, was based upon use of a constant volume sampler (CVS) with critical flow venturi (CFV) flow regulation. This is the type of system now being used by EPA. One principal vendor of CVS systems has indicated to EPA that delivery times of 6-7 months are currently being quoted (including backlogs). Ford in its submission used 9-10 months, which is significantly longer than the above estimate. However, they used a correspondingly short time for installation and checkout as we shall see below.

An alternate approach employs a positive displacement pump (PDP) for flow measurement. Delivery times for PDP systems would be approximately 6 months as compared to the 7 months for CFV systems.

One possibility has been considered that has the potential of eliminating the delivery time problem to get an early start on perhaps one cell. This involves using two light-duty CVS systems in parallel. Assuming systems were already available from the manufacturers light-duty work means no delay awaiting system delivery. However, it must be noted that delivery times for dynamometer control systems to convert electric dynamometers to transient control are estimated by the techincal staff as approximately 6-7 months. In addition, all manufacturers indicated in their submittals that procurement for one or two advance cells had already begun, the latest of which would be available by the end of August, 1980. This would allow the early beginning of work, especially for items with long leadtimes. It also makes the attempt to use light-duty CVS systems in parallel unnecessary.

Following procurement, either of the alternate measurement systems (CFV or PDP based) would require a period for installation and checkout. Recent EPA experience indicates that 3-6 months is a reasonable estimate for this time. The 3000 CFM CVS delivered to EPA in January, 1979 took six months to be fully operational. However, this unit was developmental in nature and had several unique features that had to be checked out. It therefore represents maximum installation time. Ford estimated installation would take 1-2 months. In the case of multiple dynamometer installations, the EPA staff estimates that the first system could be operational in approximately 3 months, and all cells in 6 months. Ford estimated an installation time for 10 cells of approximately 10 months. GM used 7 months for 4 cells. These schedules probably contain time for unforseen delays.

The overall equipment acquisition and installation phase can be determined by combining the above estimates. The result is approximately January 1981 to have all cells operational. For comparison, manufacturers estimates of this time are as follows:

Manufacturers	Procurement and Installation Time	Number of Cells
Ford	July, 1981	12
GM	Jan., 1981	4
Chrysler	April, 1982	4
IH	April, 1982	4

GM's projections meet the EPA timetable. Chrysler presents no specific analysis of their procurement and installation activities, and it appears reasonable to believe Chrysler could accelerate their program sufficient to meet the January 1981 date. The additional time projected by Ford is due to extended delivery time estimates and the large number of test cells (12) Ford expects to have. While Ford may choose to have 12 transient cells, this does not appear to be necessary for their projected 8 engine families. EPA's staff estimate, based upon historical ratios of dynamometers to engine familes for heavy-duty manufacturers, indicates that 9 test cells should suffice for Ford (one cell per family plus one additional). The January 1981 date may be difficult for Ford, but should be feasible.

Amongst the manufacturers, IH stands out as departing in a major way from the EPA estimate. For this reason alone the figures might be considered as unnecessarily long. IH indicated during testimony at the May 14-15 Hearing (pages 573-574 of transcript) that one gasoline cell and one diesel cell had been ordered and would be installed "give or take about 11 or 12 months" from that time. In a telephone conversation with Mr. Bill Martin of the IH gasoline staff on July 20, 1979, Mr. Martin indicated that the new gasoline cell had not actually been ordered yet, but would be very soon thereafter. Mr. Martin indicated that this cell should be operational by September 1980.

If the equipment for the remaining three cells is ordered in January 1980, the second cell should be available by the end of September 1981. IH had planned to stage follow-on cells at 3-month intervals. This was to conserve manpower requirements. However, as the second and subsequent cells go through installation, it is reasonable to expect the installation time estimated for the first cell to be reduced through gained experience. Therefore, EPA believes that cells 3 and 4 could be brought on line by IH by January 1981.

The second phase of an overall timetable is control system and engine development, which, as was indicated in the NPRM, can be broken down into work involving use of vehicles (e.g., catalyst environmental factors and durability assessments) and work done in test cells. EPA is aware that manufacturers have already begun vehicle testing of catalyst systems to evaluate their ability to function in the heavy-duty environment. Dynamometer testing can begin with engine characterization and technology assessment after the advance procurement of 1 or 2 cells by the manufacturers, and be followed by engine development as later test cells become available. EPA had originally estimated that 14 months would be sufficient for development of gasoline-fueled engine control systems. This estimate was based largely on the assumption that "for the most part, the HD manufacturers will be able to utilize the catalyst control technology currently used on light-duty vehicles and light-duty trucks" (44 FR 9471, February 13, 1979). Testimony submitted during the comment period indicated that manufacturers were encountering significant durability related problems in applying these systems (see the analysis of feasibility). These problems have stemmed from the higher loads and higher power requirements for heavy-duty engines as well as from closed-throttle motoring. Larger, more heavily loaded catalyst systems protected during motoring by air-pump or fuel shutoffs will probably be needed.

EPA is aware that Chrysler has developed a catalyst based system for possible use in meeting the 1980 California standards for its 360 cubic inch engine. Chrysler had not actually certified this engine at the time of this analysis, but data has been submitted from testing under current test procedures for durability engines which indicates that the engine could be certified.

Durability 1500-hour data on the 9-mode procedure was as follows: HC = 0.64 g/BHP-hr, CO = 20 g/BHP-hr, HC + NOx = 3.9 g/BHP-hr. EPA has had the opportunity to test this same configuration as one of the current technology engines being evaluated on the transient procedure. Transient test results were as follows: HC = 1.39 g/BHP-hr, CO = 136 g/BHP-hr, NOx = 2.33 g/BHP-hr. This data indicates the impact of the change in test procedure on the catalyst system performance. The major contributors to the high transient emissions from this engine were the cold-start bag and the Los Angeles Freeway portion of the cycle.

In reviewing the test data submitted to EPA on the durability-data engine, it appeared that as the engine approached the 1500-hour point, the catalyst either failed, or was about to fail because the emission rates began to raise rapidly. Clearly, the system would not be applicable in meeting EPA requirements without significent changes.

EPA has also tested two heavy-duty engines in catalyst configurations certified for use in light-duty trucks. These two engines (a GM 400 and a Ford 351) both experienced very high CO levels, in excess of 100 g/BHP-hr, as had the Chrysler engine.

Based upon the data now available, the EPA technical staff believes that somewhat more development time than the 14 months originally estimated will be necessary. Although the durability problems are real, the EPA staff has already identified approaches which could be used to cope with them. In addition, EPA also recently demonstrated the feasibility of the target emission levels associated with these regulations. (For more discussion of these areas see issue D - Allowable Maintenance, and I - Technological Feasibility.) Therefore, only a modest increase in development time over that originally estimated will be required. Eighteen months of development time will be used as a conserative estimate for gasoline-fueled engines.

The final phase of EPA's overall timetable as proposed consisted of one year for the certification process. A review of the steps in this process indicates that less than twelve months is required for certification, but that it must be keyed to the start of production, which for gasoline-fueled engines (for those manufacturers who also make light-duty engines) is late summer or early fall. The current process consists of three steps: the Part I application review, testing of durability and emission data engines, and the Part II review. These steps take approximately 1 month, 5 months, and 1 month, respectively, for gasoline-fueled engines. An abbreviated certification process could eliminate the first step. However, with full-life useful life and the need to establish deterioration factors comparable to in-use values, it is likely that an increased amount of time will be needed by manufacturers to establish durability. Therefore, this analysis allows 7 months for certification. Based upon issuance of a certificate 30 days in advance of a September 1 production start date, the certification process would have to begin by January 1 of the model year previous to that being certified. This confirms the original EPA estimate for gasoline-fueled engines.

The elements of equipment procurement and installation, develoment, and certification can now be combined into an overall schedule, as shown in Figure G-3.

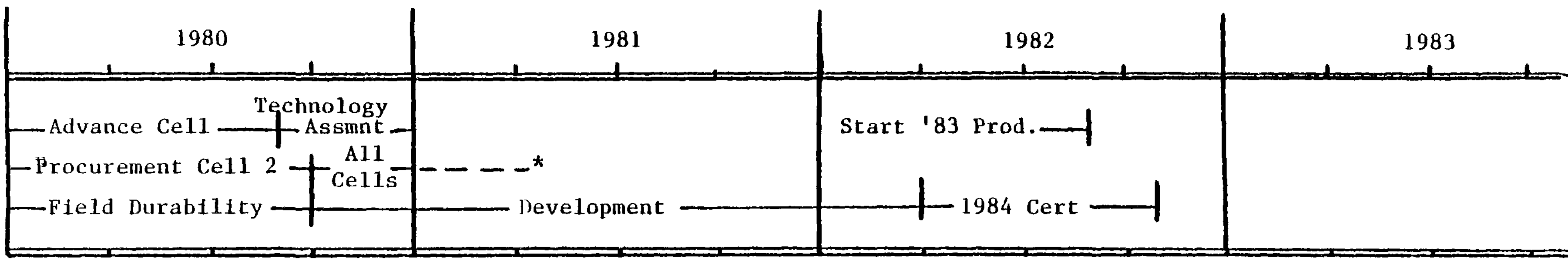
The timetable as given misses the deadline for start of 1983 engine production by approximately two months. It is concievable that if all went well, certification might be possible for 1983. Alternatively, start of 1983 production might be delayed a couple of months toward the end of 1982. However, the EPA schedule as developed above has already been based upon optimum timing estimates. No time was allowed to develop CVS specifications or negotiate sales contracts before ordering test equipment. Delays in delivery, installation, or in time for personnel training on the test equipment of several months, although they cannot be specifically identified by their nature, can be considered likely. If there were unusual problems in control system development they might also extend the development time. In addition, this schedule has not made any specific allowances for tooling time for catalysts and possibly other engine parts. Tooling leadtimes have been estimated by manufacturers as follows:

Manufacturer	Lead Time	Comments
Ford	26 months	Catalyst.
Ford	32 months	Major equipment parts.
GM	15 months	Catalyst. Based upon use of catalyst already being tooled for other applications.
GM	36 months	Redesigned carburetor.
IH	21 months	

Some of these times are probably longer than would actually be necessary. If we use the IH estimate of 21 months for redesigned

Figure G-3

EPA Projected Gasoline - Fueled Engine Compliance Schedule



*Note: Completion of installation for some cells could further overlap with development.

components, then catalyst and carburetor designs would have to be done by early 1981 in order to certify for 1983, which seems unlikely under the timetable of Figure G-3.

Both GM and IH indicated in their submissions that their projected timetables included the assumption that separate emission systems for California would not be required. At this time that is probably a reasonable assumption. If there were a potential for delay arising from separate California standards it could be raised at such time as California were to apply for a waiver from the Federal standards.

In support of their contention that EPA was underestimating leadtime, GM included a schedule projected by EPA in a memo of August 19, 1975, ("Scheduling of Final Heavy-Duty Vehicle Regulations", D.A. Finley to Ernest S. Rosenberg, Chief, Regulatory Management Staff). That schedule projected a total time of 5 years and 9 months from final rule to certification as compared to the 2 year 10 month leadtime developed above. There are many aspects of the 1975 projections that could be detailed to explain this discrepancy. However, it is more appropriate to realize that this memo is simply a very early projection of what was at that time a largely unknown future process. The memo itself states that "at the present time, scheduling for this program remains speculative" and indicates that the timetable developed should be considered an "outside estimate". Therefore, those early projections cannot be used to challenge current estimates.

b. Diesel

The timetable for diesel engines proposed by EPA included 20 months for equipment procurement and installation, 4 months for development, and 12 months for certification. Data now available to EPA indicates that some changes in those projections are in order.

The 20-month's leadtime for equipment acquisition was based upon the purchase and installation of electric motoring dynamometers to replace the eddy current dynamometers currently being used by diesel manufacturers. This time period remains accurate EPA contacts with dynamometer vendors and delivery times quoted by manufacturers in their submission indicate 12 months for equipment delivery. The EPA staff estimates that five months for installation and checkout is adequate. This 17-month period would correspond to the first cell being operational, with a three-month additional period for bringing multiple cells on-line. All major manufacturers have indicated that procurement of one or two advance cells with electric dynamometers is already underway. If the remaining number of required test cells were ordered in January 1980, they would become available for testing in June - August 1981. With the exception of Caterpillar and IH, all manufacturers' projections were within a couple of months of these estimates.

Caterpillar indicated in their testimony that conversion to electric dynamometers would require the addition of a new testing facility to house the equipment. Caterpillar further indicated the time to do this would be three years for construction of the facility and six months for equipment installation. The EPA technical staff believes that the construction period could be significantly reduced, but that availability of test cells would be delayed considerably even under the most optimistic assumptions. For example, if the new facility could be built in 1-1/2 years, test cell installation would not be completed before early 1982. Therefore, Caterpillar would probably have to house the new equipment, at least temporarily, in their existing test cells. While this might not be desirable from Caterpillar's viewpoint, it would be feasible. Caterpillar's intention to remodel if eddy current machines were retained indicates that the CVS systems can be accommodated in the current cells. New dynamometer systems should also be able to be accomodated. For example, one type, the regenerative brush type of electric motoring dynamometer, requires no more space than an eddy current dynamometer. There would be extra expense associated with installing the test equipment in remodeled cells and later moving it to a new facitlity, but this might be necessary for Caterpillar to keep pace with the rest of the industry.

IH has indicated their intention to delay the aqcuisition of new test equipment pending the issuance by EPA of final particulate standards. Although the concern raised by IH is understandable, it is clearly unreasonable to delay a current compliance program for the sake of an as yet undefined future rule. Rather at such time as a particulate standard were proposed, that proposal would have to consider the impact of new standards or possible test procedure changes on any ongoing programs as one effect of the proposal. If there were any need to establish new timetables, it would be determined at that time. The impact of changes in test procedure upon equipment investments already made would also be evaluated at that time.

In addition to the issue of the starting date, the EPA technical staff believes that the timetable presented by IH is longer than necessary. In the IH verbal testimony at both the May 14-15 Hearing and the June 16-17 Hearing, IH indicated that a single diesel cell was ordered. The May 14-15 testimony indicated that the system would be operational in approximately one year. Based upon this information, availability of the first IH dynamometer system can be accelerated from September 1, 1981 to June, 1980. In addition the installation of the second and subsequent systems can be accelerated. The 20-month leadtime for equipment acquisition used by IH was based upon the EPA estimate used in the NPRM. However, as indicated above, that time is considered sufficient for installation of multiple dynamometers, rather than just the first dynamometer as used by IH. The EPA staff estimates that the second

IH system (in addition to its advance ordered system) should be available by June 1981 and the remaining three systems by September 1981.

Data submitted during the comment period (principally by Caterpillar) on alternate transient cycles indicates the possibility that an eddy current dynamometer-based system may be capable of reproducing the transient cycle, or a somewhat smoother version of that cycle, close enough to produce comparable emission results to those obtained on an electric motoring dynamometer. However, there is insufficient data at this time to resolve the question of how close it may be able to come. A principle cause for caution arises from the fact that the torque and speed response relationships on an eddy current dynamometer (which operates basically in what is called "torque control" mode) are different from those of an electric dynamometer (operating in a "speed control" mode). These different system characteristics could give somewhat different emission results, even if the same cycle tolerance specificaions were met. Small differences could become important for an engine whose emissions were close to the standard. Therefore, any manufacturer wishing to retain his eddy current dynamometers rather than purchase new electric dynamometers may feel it necessary to first undertake a pilot program to establish test correlation with EPA results. If this were successfully accomplished, the manufacturer would then be able to use eddy current dynamometers.

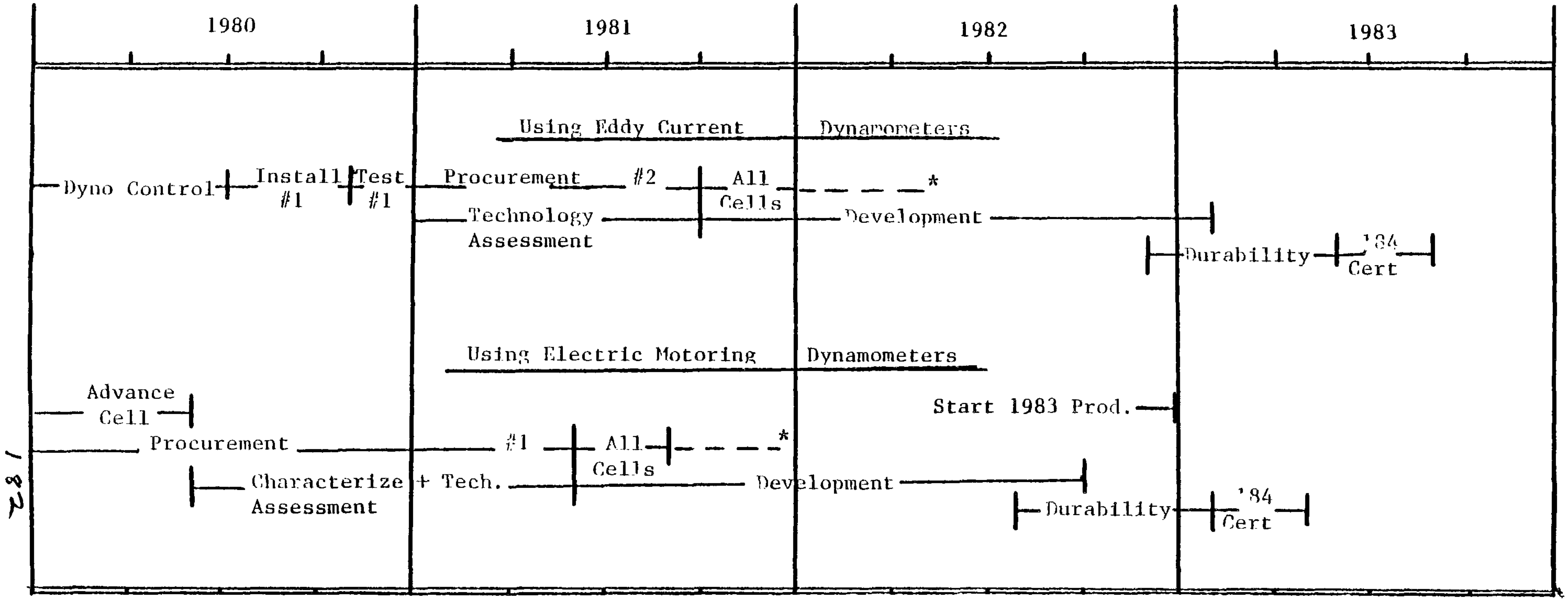
The EPA staff estimates that it would take approximately six months to obtain the dynamometer control system to convert an eddy current dynamometer to transient operation. If the CVS system from the manufacturer's advance cell could be used for sampling, the cell might be on line in an additional four months. Two months of testing to establish correlation would then follow, making a total of approximately one year. If correlation were successful, the manufacturer could then proceed to convert his remaining eddy current machines. This could be done on the same timetable as developed previously for gasoline-fueled engines (9 months for the first cell to become available plus three months for remaining cells).

The net result of this process would be a timetable some four months longer than the timetable for replacement of eddy current machines with electric machines (both alternative timetables are given in Figure G-4). This delay, coupled with the risk that eddy current dynamometer-based measurements may not in fact correlate well enough to be usable, would make it unlikely that any manufacturer would try that approach.

Because of the potential cost savings involved if eddy current machines could in fact be used, it seems desirable to the EPA staff to attempt to reduce the risk facing manufacturers wishing to explore this option. Since the program to establish correlation

Figure G-4

EPA Projected Diesel Engine Compliance Schedule



*Note: Completion of installation for some cells could further overlap with development.

would require approximating one year, this goal could be accomplished by allowing some form of optional certification on the 13-mode procedure for the first year of implementation of the new standards. The optional standard would be derived from comparison of transient and 13-mode emission levels. It would be established with the intent of approximating as closely as possible the benefits to be realized from the transient test. This might involve some loss of air quality benefits for that year because of the fact that 13-mode emissions cannot accurately quantify in-use transient emissions. However, the fact that manufacturers would have to certify to the transient procedure in the second year should preclude any significant loss of benefits. Manufacturers will avoid the need to modify engine lines twice in such a short period of time.

As test cells become available, engine testing will begin. In contrast to the situation with gasoline-fueled engines, little diesel work can be done before acquisition of transient testing capability. This is because the problem facing diesel manufacturers is not so much one of in-use durability of systems as one of determining the transient performance of various technologies or engine changes which might be used to reduce emissions. Advance cells would be used for initial engine characterization plus some technlogy assessment. As more cells become available, engine family development would begin. Engine development time was limited to four months in the EPA proposal. Manufacturers have made a valid case that this time is insufficient. In another section of this document (see the "Test Procedure" issue), estimates have been made of those engine families which would exceed the 1983 standards, based upon the target values supplied by manufacturers in their submissions. These estimates indicate that approximately 70% of diesel engine families will need development work. For some manufacturers (GM and IH), all families may need emission reductions. However, many of these families will exceed target values by relatively small amounts, and should be easily brought into compliance. The EPA technical staff estimates that diesel engines should require less development time than gasoline engines. Fourteen to 16 months should be sufficient.

Development times submitted by manufacturers exceeded these estimates considerably in some cases:

Manufacturer	Estimated Development Time
GM	27 Months
Caterpillar	3-5 Years
Cummins	No specific estimate
Mack	18 Months (after characterization)
IH	18 Months

GM presented no basis for its estimate of 27 months. In fact, their testimony indicated a lack of information on which engine families would need correction or by how much. The EPA staff estimates of reductions needed for GM diesel engines (see Table-6 of analysis of "Test Procedure" comments)indicates that several GM families will probably need only small reductions. It is also unlikely that GM would require more time to develop its diesel engines than its gasoline engines, which GM has indicated would consume 19 months (excluding 5 months of durability).

In its testimony concerning feasibility, Caterpillar estimated that 4 of its 11 currently certified engine families fail to meet the standards. This agrees with the EPA staff estimates which also indicates that only one of thse families would require what could be considered a large reduction. The development time of 3-5 years proposed by Caterpillar was not related to the estimates of engine families needing work and appears inconsistent with those estimates. With one complete test cell expected to be available by the end of 1979 or early 1980, work on the single family needing the most work could begin. Work on remaining engine lines could be done within the time frame estimated above by the EPA staff.

Near the end of the development process, the manufacturers will be able to begin durability testing. Since engine useful lives will be approximately double the values currently being used, it will be important to assess emissions durability. The current accelerated diesel durability testing takes an average of 3 months to complete, so an estimate of 6 months will be used to assess the extended useful life. Manufacturers may well desire more time than this to adequately assess the in-use performance of engines for long useful lives.

The current certification process for diesel engines is similar to that for gasoline-fueled engines. The three steps and required time intervals are as follows: the Part I application review, 1 month; testing of durability and emission data engines, 4 months; the Part II application review and issuance of certification, 1 month. An abbreviated certification process such as is now being implemented for light-duty and heavy-duty certification could eliminate the Part I review. Durability testing has already been accounted for in the previous paragraph. Since manufacturers will establish their own preliminary deterioration factors, there will be no "official" durability testing as part of certification. Emission-data engine testing should take approximately 1 month at the maximum of two emission data engines per family. Allowing for issuance of certification 30 days before the beginning of production, which for diesel engines is the beginning of the calendar year, this means that certification must begin by October 1 of the year prior to the applicable model year.

All the elements of a diesel engine compliance schedule are combined in Figure G-4. Shown in that Figure are two timetables. The first is based upon establishing test correlation on eddy current dynamometers, while the second is based upon the procurement of electric motoring dynamometers. The first schedule shows that if adequate correlation were demonstrated, certification to the transient procedure should be possible for model year 1984 using eddy current dynamometers. However, if the attempt to correlate were not successful, the manufacturer would have incurred an approximate 1 year delay and would then have to follow the schedule for procurement of electric dynamometers. That would delay certification until 1985. Therefore, the EPA technical staff does not believe any manufacturer would choose this course. If a situation should arise where the need to estabish correlation was elimated, then one year would be gained on this schedule and certification for 1983 would be possible.

The second timetable, that for procurement of electric motoring dynamometers, indicates that certification for model year 1984 would be feasible with an approximately 7-month "cushion." This time could be used by the manufacturer to increase development time or cover unforseen delays. The second timetable also allows leadtime for tooling of any major engine changes before start of production. Estimates for tooling leadtimes were given by GM and IH as 24 and 22 months, respectively. The timetable of Figure G-4 would allow at least six months of development before long leadtime tooling commitments would be required. Additional time would be available through use of the advance purchased cell. For those engine families requiring little or no development work, certification for 1983 would be possible.

4. Staff Recommendations

The EPA technical staff recommends delaying implementation of these regulations until 1984. For the first year of implementation the staff also recommends the use of an optional 13-mode standard for diesel engines.

This analysis has revised the EPA projected compliance timetable based upon manufacturers comments and other new data available to the EPA staff. The results indicate that for gasoline-engines there is some possibility that certification could be accomplished for the 1983 model year, but that the risk of missing that deadline would be high. For diesel engines, some engine families could meet a 1983 certification deadline, but those requiring significant emission reductions could not. For diesel engines there is a possibility that eddy-current type dynamometers might be retained, at considerable cost savings. This possibility is most likely to be realized if diesel manufacturers were allowed to certify to an optional 13-mode standard for 1984. This standard would be derived to, as far as it is possible, give similar reductions to those required by the transient procedure.

H. Issue - Economic Impact

1. Summary of the Issue

The U.S. EPA has proposed a comprehensive control strategy for 1983 and later model year heavy-duty engines.

For both gasoline-fueled and diesel heavy-duty engines, this strategy includes a new test procedure, more stringent HC and CO emission standards, a new useful life definition, a revised durability testing program, allowable maintenance provisions, parameter adjustment, selective enforcement auditing at a 10% AQL, and an idle test with idle emission standards for HC and CO.

In addition, the control strategy also includes a diesel crankcase emission standard for heavy-duty diesel engines.

In the proposal, the EPA technical staff estimated a per engine cost of $204 for a gasoline-fueled heavy-duty engine with discounted operating costs of $1,016.

For diesels, the average per engine cost will be $185, with no expected increase in operating costs.

The rulemaking strategy as a whole was estimated to cost $2.54 billion dollars with $2.382 billion for gasoline-fueled heavy-duty engines, and $158 million for heavy-duty diesel engines over the first five-year period.

2. Summary of the Comments

The comments will be summarized according to the major components of the rulemaking strategy. For both types of engines, the costs of the following will be directly addressed: test procedures, development and emission control hardware, certification, allowable maintenance, useful life definition, parameter adjustment and selective enforcement auditing. The cost of diesel crankcase emission hardware will also be addressed separately.

To the extent possible, the comments in the costs area will be addressed on a manufacturer-by-manufacturer basis, but flexibility in format is a necessity.

A. Test Procedures

1. Gasoline-Fueled Engines

Comments on test procedure related costs were received only from General Motors and Chrysler Corporation.

General Motors

General Motors Heavy-Duty Gasoline Engine Transient Emission Test Facility Detail of Estimated Cost

Description	Cost
Dynamometer Room No. 1 (Four Single-Ended Dynos)	
Constant Volume Sampler (2) and Installation	$ 436,000
Dual Bag Emission Bench (2) and Installation	277,000
Additional Computer Facilities (HP-21 MXF) and Installation	295,000
Computer Interface Modification	78,000
Dynamometer and Controls Rework (Improved response and heaters)	18,000
Miscellaneous Transducers, Propshafts and Dynamometer Room Equipment	91,000
Rearrangement (Control Room Revisions, Equipment Room Revisions, Dynamometer Room Revisions, Relocate Equipment, etc.)	222,000
Subtotal	$1,417,000
Dynamometer Room No. 2 (One Double-Ended Dyno)	
Constant Volume Sampler (1) and Installation	218,000
Dual Bag Emission Bench (1) and Installation	133,000
Additional Computer Facilities (HP-21 MXF) and Installation	100,000
Computer Interface Modifications	42,000
New 300 H.P. Dynamometer (includes controls, MG set, installation)	390,000
Miscellaneous Transducers and Propshafts and Dynamometer Room Equipment	33,000
Rearrangement (remove existing dynamometer, MG set, misc. rework)	42,000
Subtotal	$ 958,000
Dynamometer Room No. 3 (Two Single-Ended Dynos)	
Dynamometer and Controls Rework (to allow computer control)	$ 18,000
Computer Interface Modifications	36,000
Miscellaneous Transducers, Propshafts and Dyanmometer Room Equipment	57,000
Test Cell Rearrangement and Rework	41,000
Subtotal	$ 152,000

Building Revisions for Additional Space Requirements

Remove and Construct New Walls	150,000
Rearrangement	60,000
New Mezzanine	125,000
Mezzanine Lift	10,000
Environmental Control for Engine Cold Soak	40,000
Subtotal	$ 385,000
Outside Engineering Fees	$ 100,000
Total	$3,012,000

Chrysler Corporation

	Total Cost	Unit Cost
Two new test cells	$2,320,000	$1,160,000
Two cells modified	314,000	157,000
Renovate development cells	140,000	70,000
Develop controller	30,000	7,500
Emission Test Equipment:		
CVS systems	500,000	125,000
Emission carts	335,000	83,750
Bag carts	280,000	70,000
TOTAL	$3,919,000	

2. Diesel

Detailed cost estiamtes were received only from General Motors. Caterpillar gave a percent error comment without revealing specific figures. Cummins gave only a cost per engine range for the test procedure and certification. Mack submitted a total cost figure.

General Motors

	Total Cost	Unit Cost
Building Shell	$ 5.2 M	$ —
Building - service equipment	7.49 M	—
Test Cell Support Systems		
Dynmometers and Controllers:		
Electric	2.1 M	300,000
Eddy Current	350 K	50,000
Equipment		
CVS	2.1 M	150,000
Emission Instruments	2.1 M	150,000
Data Acquisition Systems	700 K	50,000
Quick Change Engine Mounts	350 K	25,000
Misc. Test Instruments and Equip.	420 K	—
Special Contingency	5.2 M	—
TOTAL	$26,010,000	

Caterpillar's comments on certification testing facilities stated that these would be 23.41% of their total expected expenditure. Mack commented that their total test procedure costs were expected to be about $5,216,000.

B. Development and Emission Control Hardware

1. Gasoline-Fueled Engines

Comments were received from General Motors, International Harvester, and Chrysler.

General Motors

Component	Cost	Tooling Cost
Dual Monolithic Converters	$220.00	$ 2M
Pipe Insulation and Chassis Shields	30.00	?
Large AIR Pump	25.67	11M
AIR Modulation System	7.00	?
Decel Fuel Shut-off and Electronics	10.90	1.85M
Temp Compensated Accelerator Pump	2.09	1.2M
Mechanical/Vacuum Power Enrichment	1.95	25 K
Electric Choke	4.50	250 K
Adjustable WOT Fuel Curve	.70	7.75M
Tamper Resistant Idle	.50	204 K
Tamper Resistant Choking Valve	6.50	6.1M
Cold Start Ignition Modifier	4.00	200 K
Engine Modifications	13.00	10.211M
Filler Neck, Gas Cap, Labels	2.50	?
Tamper Resistant Distributor	.61	—
Assembly Tools		600 K
Assembly Labor	10.00	—
TOTAL	$340.00	$45 M*

* Total estimated.

Chrysler

Component	Cost Estimate
Underbody 3-Way Monolithic Catalyst	$160.00
Close Couple Twin Monolithic Catalyst	165.00
Electronic Spark Advance and Feedback Carburetor	95.00
Increased Thermal Protection, 2.0g SHED Test Hardware, and Air Switching	75.00
EGR Maintenance Warning and OSAC Valve	-30.00
TOTAL	$465.00

IHC

Component	Cost Estimate
Catalytic Converters, Dual Stainless Steel Mufflers and Pipes	$250.00
Filler Neck Restrictions and Decals	50.00
EGR and Converter Warning Systems	40.00
Wiring, Brake Piping, Choke and Heat Shields	60.00
Capital and Engineering Development	70.00
TOTAL	$470.00

2. Diesel

Diesel engine manufacturers as a group were unable or chose not to comment specifically on the emission control hardware necessary to meet the HC and CO emission standards.

General Motors - could not comment.

Cummins Engine Co. - range of costs from $0-$600 (variable injection timing).

Caterpillar - 59% of their total cost is approximately $275 per engine.

International Harvester - no comments received.

Perkins - no specific comment.

Mack - no specific comment.

Iveco - no specific comments.

Daimler-Benz - no specific comment.

C. Certification

Estimates of actual increases in certification costs were received from only two manufacturers, GM and Chrysler.

1. Gasoline

General Motors - GM provided cost estimates for the following components of certification:

125-hour emission data engine test	$23,000
Pre-production durability testing	122,400
125-hour test prior to durability fleet use	24,000
Emission testing during durability testing	43,000 (6 tests)

From this data GM detrmined a certification cost of $4.00 per engine.

Chrysler - Estimated total cost at $2 million because they would run twice as many durability data engines and emission data engines prior to certification. Chryslers estimate also included in-use durability testing costs.

2. Diesel

Only General Motors commented, and gave specific estimates for each phase of the certification.

General Motors -

125-hour emission data engine test	$24,000
Pre-production durability testing	124,400
125-hour test prior to durability fleet use	15,000
Emission testing during durability testing	24,000 (6 tests)

Caterpillar - stated that certification would be 2.35% of the total cost.

Cummins - estimated preliminary deterioration factor testing costs at $62,000 per engine family.

D. Useful Life Redefinition

All manufacturers stated that they would incur substantial warranty cost increases with the new useful life definition. Although these costs were not detailed, some commenters gave a rough cost based on their interpretation of the regulations.

General Motors - $100 per engine.

Caterpillar - $89 per engine.

International Harvester - $150 per engine.

Chrysler - $200-400 per engine.

These increased costs arise primarily from expected warranty claims associated with engine rebuild, catalyst failure, turbochargers, injectors, carburetors, etc.

E. Parameter Adjustment

Only Ford, Chrysler, and General Motors commented specifically on the costs of parameter adjustment.

Ford - commented that they envisioned tamper resistant idle speed, spark timing, air/fuel ratio and choke bimetal adjustment. Costs were estimated at $90 for electronic idle speed controllers and $5-10 for a timing "lock."

Chrysler - stated costs would be similar to those for light-duty vehicles.

General Motors - expected to use tamper resistant idle, choking valve, and distributor at a cost of about $7.50, with tooling costs of $6.3 million.

F. Selective Enforcement Auditing (SEA)

Comments on the costs of SEA were divided into three major areas; facilities and equipment, formal SEA testing costs, and production line audit costs. In general, all manufacturers thought EPA had underestimated these costs.

1. Test Facilities and Equipment

General Motors - GM presented an elaborate analysis of SEA facility costs based on four possible configurations and a set of assumptions. Of the four configurations presented, the second seems to be the closest to what EPA envisioned, so this configuration will be discussed. The facility costed as Configuration 2 in the GM comments assumes the following:

a) Service accumulation can be expected to need up to 125 hours and would take about six days to complete.

b) Service accumulation can be done on absorbing only dynamometers and the test cells would need temperature control.

c) Emission testing would be done on d-c dynamometers and the test cells would need temperature and humidity control.

d) The 12-36 hour cold soak would occur in the emission testing test cell.

e) The facility would not be connected to an existing exhaust emission test facility.

The facility costed includes:

a) Control room for dynamometer control consoles and emission equipment.

b) Electrical equipment rooms for m-g sets and constant volume samplers (CVS).

c) Fire protection system for the test cells, control rooms and electrical equipment rooms.

d) Fuel tank farm, fuel cells, and a distribution system.

e) Engine and pallet storage area.

f) Parts and equipment storage area.

g) Shipping and receiving area.

h) Span gas storage, liquid nitrogen supply, and distribution system.

i) Master gas storage area.

j) Particulate filter weighing room.

k) Equipment maintenance and calibration room and standards laboratory.

l) Technician laboratory.

m) Machine shop.

n) Engine prep and build area.

o) Offices.

p) Conference room.

q) Restrooms.

r) Locker rooms.

s) Lunch rooms.

A building of this type has been estimated to cost about $200 per square foot....The size of each area is estimated as follows:

a)	Test Area (includes penthouse)	85,000 sq. ft.
b)	Support area (includes penthouse)	36,000 sq. ft.
c)	Office area	15,000 sq. ft.
	Total (building only)	135,000 sq. ft. ($27.2 million)

Test Equipment Configuration 2:

a)	14 dynamometers (with control consoles)	$5,000,000
b)	6 emission benches and CVSs	3,000,000
c)	10 computers	1,000,000
d)	Miscellaneous equipment	1,100,000
	Total (equipment only)	$10,100,000

All of these costs are summarized below:

Building costs	$27,200,000
Equipment costs	$10,100,000
	$37.3 million

Chrysler - Chrysler estimated that the SEA regulations would cost about $1.8 million in additional new facilities and equipment.

1 Dynamometer	$190,000
2 Collectors	140,000
2 Diagnostic carts	240,000
2 Control consoles & software	200,000
1 Dynamometer cart receiver	60,000
8 Transporters	72,000
4 Gopower receivers	120,000
4 Gopower dynamometers	80,000
1 Gopower test cell	400,000
1 Main dynamometer cell renovation	100,000
1 Soak room (20' x 20')	140,000
	$1,742,000

International Harvester - IHC estimated only that two additional cells would be necessary in addition to those considered by EPA for a total of six cells. The two additional cells would be required with a 40% AQL. With a 10% AQL IHC stated they would need a total of 11 emission cells plus 5 "run-in" cells at a total building and equipment cost of $22,535,000.

Caterpillar - Caterpillar estimates SEA facility costs would be 5.29% of their total expenditures.

2. SEA Testing

The comments and cost estimates below cover the actual costs expected with SEA testing. These are based on the number of audits per manufacturer outlined in the draft regulatory analysis.

General Motors - GM estimated annual costs of $3.3 million for personnel related expenses and $130,000 for expenses to ship engines and components to the test facility. These costs can be broken down as:

66 employees at $50,000 per annum;
$30,000 per year to ship diesel engines;
$100,000 per year to ship gasoline-fueled engines and components.

Chrysler - Chrysler estimated manpower and testing costs at $320,000 per year.

Mack - Mack Trucks estimated that actual SEA audit costs would be near $25,000 for manpower, supplies and spare parts.

Caterpillar - Caterpillar estimated SEA testing would be 2.94% of their total cost.

3. Production Line Audits

The production line audit costs are those associated with a 10% AQL. These costs cover primarily additional testing of production engines.

Mack - Mack Trucks estimated self auditing costs of $225,000 per year, but gave no additional estimate for new facilities or breakdown of the cost of the audit tests.

Chrysler - Chrysler estimated that production audits would cost $320,000 per year, but this figure includes formal EPA audits.

International Harvester - IHC estimated they would audit 6.6% of each years production at $1000 per test. In addition, they stated they would require 11 audit cells plus five run-in cells to perform an audit test program.

Cummins - Cummins Engine Co. stated that production testing at a moderate rate would cost $60 per engine produced but gave no cost breakdown.

G. Diesel Crankcase Emissions

Although most commenters discussed the impact of the diesel crankcase emission proposal, only two manufacturers gave any cost estimates.

General Motors - GM estimated that $200,000 would be required to develop a closed crankcase system.

Caterpillar - Caterpillar Tractor Co. estimated costs of $10 for their 3208T, $135 for their 3306 and 3408 engines. No further cost breakdown was included.

H. Allowable Maintenance

No comments were received on the specific costs of the allowable maintenance provisions, except for the warning systems mentioned under hardware.

3. Analysis of the Comments

The EPA technical staff was disappointed in the quality and quantity of the comments received on the economic impact of the proposed regulations. Few commenters replied in the detail requested in the NPRM and only minimal supporting cost breakdowns were given by those who provided specific cost comments.

For those manufacturers who chose not to comment on a specific item in the proposal the EPA technical staff has no option but to assume that the cost estimates in the draft regulatory analysis were correct for that manufacturer.

The costs which EPA will ultimately consider chargeable to these regulations are only those which are necessary to meet the requirements imposed by these rules and not necessarily the total which the manufacturers stated they might spend.

This discussion section will be formatted in a manner similar to that of the Summary of Comments section with flexibility in format being used when appropriate.

A. Test Procedure

1. Gasoline-Fueled Engines

Since only General Motors and Chrysler gave specific comments, only their cost figures will be addressed.

General Motors - The General Motors test procedure cost estimate is outlined below with the EPA technical staff's analysis.

As can be seen from the description below, GM's cost estimates can be divided into hardware expenditures, computer and computer-related costs, and miscellaneous equipment, rearrangement, rework, and construction. A discussion of these costs for each of the four dynamometer rooms together with EPA's estimate of the cost is shown below.

	Cost	
Dynamometer Room No. 1 (Four Single-Ended Dynos)	GM Estimate	EPA Revision
Constant Volume Sampler (2) and installation	$ 436,000	300,000 1/
Dual Bag Emission Bench (2) and installation	277,000	133,000 2/
Additional Computer Facilities (HP-21 MXF) and installation	295,000	0 3/
Computer Interface Modifications	78,000	--

Dynamometer and Controls Rework (Improved response and heaters)	18,000	--
Miscellaneous Transducers, Propshafts and Dynamometer Room Equipment	$ 91,000	0 4/
Rearrangement (Control Room Revisions, Equipment Room Revisions, Dynamometer Room Revisions, Relocate Equipment, etc.)	222,000	-- 5/
Subtotal	$1,417,000	$751,000

1/ Based on EPA and Chrysler data
2/ GM should not require more than one emission bench per CVS.
3/ A realtime computer system not required by these regulations.
4/ GM probably has this equipment already.
5/ An absolute maximum, probably more than required by these regulations.

Dynamometer Room No. 2 (One Double Ended Dyno)	Cost: GM Estimate	Cost: EPA Revision
Constant Volume Sampler (1) and installation	218,000	150,000 1/
Dual Bag Emission Bench (1) and installation	133,000	--
Additional Computer Facilities (HP-21 MXF) and installation	100,000	0 2/
Computer Interface Modifications	42,000	--
New 300 H.P. Dynamometer (includes controls, MG set, installation)	390,000	175,000 3/
Miscellaneous Transducers and Propshafts and Dynamometer Room Equipment	33,000	0 4/
Rearrangement (remove existing dynamometer, MG set, misc. rework)	42,000	--
Subtotal	$ 958,000	$542,000

1/ Based on EPA and Chrysler data.
2/ A real-time system not required by these regulations.
3/ Hawker Siddley Electric Dynamometer and Ultra Electronics Controller.
4/ It is likely GM already has most of this equipment.

Dynamometer Room No. 3 (Two Single-Ended Dynos)	Cost: GM Estimate	Cost: EPA Revision
Dynamometer Control Rework (to allow computer control)	$ 18,000	--
Computer Interface Modifications	36,000	--

Miscellaneous Transducers, Propshafts and Dynamometer Room Equipment	57,000	0 1/
Test Cell Rearrangement and Rework	41,000	--
Subtotal	$ 152,000	$95,000

1/ It is likely GM already has this equipment.

Building Revision for Additional Space Requirements	Cost GM Estimate	Cost EPA Revision
Remove and Construct New Walls	$ 150,000	--
Rearrangement	60,000	0 1/
New Mezzanine	125,000	--
Mezzanine Lift	10,000	--
Environmental Control for Engine Cold Soak	40,000	0 2/
Subtotal	$ 385,000	$285,000
Outside Engineering Fees	$ 100,000	0 3/
Total	$3,012,000	$1,673,000 4/

1/ This cost is probably already included in rearrangement costs above.
2/ Not required, due to forced cool down provisions.
3/ This cost is probably already included in construction cost above.
4/ EPA considers this the absolute maximum GM would spend.

Based on the analysis above EPA liberally estimates GM's facility costs due to these regulations to be about $1,673,000. This exceeds EPA's original estimate by $421,000 due primarily to unanticipated construction costs. If these construction costs can be minimized then the two costs estimates should be reasonably close.

Chrysler Corporation - Chrysler estimated their total test procedure related costs at $3,919,000. A breakdown of these costs shows the purchase of two new test cells, the modification and renovation of two development cells, and other test equipment.

In 1979 dollars, most of Chrysler test procedure related costs seem reasonable. The $2.32 million for new test cells is higher than anticipated by EPA, but Chrysler's comments indicated that this was the actual cost of two new test cells which were commandeered from light-duty testing for use in heavy-duty development.

The cell renovations and modifications expected are estimated by Chrysler to cost $454,000 as compared to EPA's estimate of $435,000.

Since Chrysler will certify only 2-3 engine families and will use only two emission test dynamomters only two CVS systems, at a cost of $250,000 will be necessary.

Assuming Chrysler's other emission test equipment costs are necessary, Chryslers actual expected costs should be near $3,419,000.

2. Diesel

General Motors estimated diesel test facility costs at $26,010,000. The breakdown for this figure is provided again below for the sake of the discussion. EPA originally estimated a total cost of $11,928,000. The analysis below will assume nine engine families.

	Unit Cost	Total Cost
Building Shell	-	5.2M
Building - service equipment	-	7.49M
Test Cell support systems		
Dynamometers and Controllers		
Electric (7)	300,000	2.1M
Eddy Current (7)	50,000	350K
Equipment		
CVS	150,000	2.1M
Emissions Instruments	150,000	2.1M
Data Acquisition Systems	50,000	700K
Quick Change Engine Mount	25,000	350K
Misc. Test Instruments & Equipment	-	420K
Special Contingency	-	5.2M
		$26,010,000

General Motors began construction of a new diesel test lab back in 1975, long before these regulations were proposed. EPA cannot accept GM's estimate of any costs associated with new building structures or cell support systems nor can EPA accept GM's cost estimates for new eddy current dynamometers. As stated previously, any economic impact analysis should consider only incremental cost increases and most certainly not past expenditures.

With nine engine families the EPA technical staff believes GM will require five to seven remodeled eddy current dynamometers, motors, and controllers, for development. EPA concurs with GM's estimate of seven new DC electric dynamometers and controllers for emission testing.

EPA believes that GM will need only one CVS system for every two of its emission certification cells and thus will require only four CVS systems. GM may require some minor facility modifications in association with CVS installation and some minor modifications to the pre-production development dynamometers (eddy current).

EPA Revision of General Motors Cost Estimates

Item	Cost Per Cell	Total
Building Shell	0	0
Building Cell Support Systems	0	0
- Dynamometers & Controllers		
Electric (7)	300K	2.1M (7)
Eddy Current (7)	0	0
Eddy Current Motors and Controllers (7) 1/	85K	595K (7)
- Equipment		
CVS	150.000	600K (4)
Minor Facility Modifications 1/	80,000	320K
Emissions Instruments 2/	150,000	1.8M
Data Acquisition Systems	50,000	600K
Quick Change Engine Mount 3/	--	0
Misc. Test Instruments and Equipment 4/	--	0
Special Contingency 5/	—	0
TOTAL		6.015M

1/ EPA estimate.

2/ GM probably already has this equipment, but lacking other data the EPA technical staff will assume these are necessary.

3/ Not necessary to comply with these regulations due to forced cool down provisions.

4/ It is very likely that General Motors already has most of this equipment.

5/ Not supported in the manufacturers comments.

Since no other diesel manufacturer commented in a detailed enough manner to allow an analysis the EPA technical staff assumes that the cost estimaes in the draft regulatory analysis were correct.

b. Development and Emission Control Hardware

1 Gasoline Engines

The EPA technical staff appreciates the manufacturers comments on the emission control hardware which they believe will be required to meet the standards. EPA is not in the business of dictating what emission control strategy manufacturers may use or what they may charge for their development and hardware, but is interested in determining the approximate cost and nature of the hardware which will be required to meet the revised standards.

Type of Hardware - Based on EPA's own technical analysis and the information provided by the commenters, the following emission control hardware seems to be necessary to meet the revised emission standards and other provisions of the proposal.

Dual Monolithic Oxidation Catalysts
Chassis Heat Shields (2)
Stainless Steel Exhaust (2)
Engine Modifications to allow Unleaded Fuel Usage
Catalyst Durability Hardware
Unleaded Filler Restriction and Decal
Parameter Adjustment Modifications
Air Pump Improvements
Air Modulation
Electronic Ignition
EGR

This system is similar to that outlined by General Motors except for exhaust pipe "insulation" and minor carburetor modifications which may be required.

In comparison to Chrysler's submittal, the major differences lie in the catalysts and the evaporative emissions hardware which Chrysler included. The EPA technical staff does not foresee the feasability or need for start catalysts to handle cold start emissions, nor does it see the need for the use of a 3-way catalyst and feedback carburetor over an oxidation catalyst. The proposed NOx standard is not stringent enough to require a 3-way catalyst. The evaporative emissions hardware should not have been included in a system to meet the exhaust emission standards.

International Harvester foresees the need for EGR and converter warning systems which EPA does not believe will be necessary even with the longer useful life expected.

The cost of a system which the EPA technical staff believes will be necessary to meet the emission standards is outlined in the regulatory analysis which supports this rulemaking action. The control strategy ultimately chosen by each manufacturer and the price which it will ultimately charge for this hardware is controlled by each manufacturer.

2. Diesel

The fact that most diesel manufacturers chose not to comment on the cost of meeting the emission standards indicates that they could not comment meaningfully because of their lack of transient testing capability and, thus, they could not be certain of the magnitude of the task.

An EPA analysis of the diesel transient test data currently available to EPA (see Test Procedure Issue) shows that 14 of the current engine families already meet the target emission levels for HC and CO. These engine families represent 36.3 percent of 1979 projected sales.

An additional 14 of the families (38 percent of sales) are within easy range of meeting the target reductions with only minimal changes to injectors or other calibrations.

The final ten engine families will require some work to meet the target emission levels. This would include the minor changes to injectors and calibrations discussed above plus possibly combustion changer redesign, turbocharging and after cooling, pre-chamber injection, variable injection timing, and the addition of EGR on some diesel models.

The engines which appear to require the largest emission reductions seem to have one or more of the following characteristics:

- High-rated speed, low-rated BHP.
- Naturally aspirated.
- Two-stroke engines.
- High surface-to-volume ratio.
- Larger than average sac volume.
- Turbocharged but not intercooled or aftercooled

The actual average per engine cost which EPA estimates for diesel engines can be found in the regulatory analysis. This cost will primarily be applied toward the ten families which will need the most work since 74 percent will be able to meet the target emission levels with little or no development work.

C. Certification Costs

1. Gasoline

General Motors provided certification cost estimates in the same category as EPA's but these were unsupported by any further breakdown in detail. Chrysler provided no detail in their cost estimate.

EPA has identified two major areas in certification:

a) Pre-production durability testing (Deterioration Factor Assessment)
b) 125-hour emission data engine test

(a) <u>Pre-Production Durability Testing (Preliminary Deterioration Factor Assessment)</u>

Assume the current EPA procedure is used, and allow 10 percent of the manpower cost to cover overhead and miscellaneous.

Thus, the costs of this program would be:

Set up	16 phr	
Map	8	
Test	6	
Remove	4	
	34 x 14 = 476 person hours	
Service Accumulation	+3000 person hours	
	3476 phr x $30/hr	= $104,280

$\frac{20\ \#}{hr.} \times 1500\ hr. \times \frac{1\ gal.}{6.08\#} \times \frac{\$1.00}{gal.}$ = $ 4,934

Engine Cost Estimate	= $ 2,000
Certification Overhead and Miscellaneous	= $ 10,000
Total	= $122,000

(b) <u>125-hour Emission Data Engine Test</u>

Set up	16 phr	
Map	8	
Test	6	
Remove	4	
Service Accumulation	250	
	284 phr at $30/hr.	= $ 8,520

$\frac{20\ \#}{hr.} \times 125\ hr. \times \frac{1\ gal.}{6.08\#} \times \frac{\$1.00}{gal.}$ = $ 411

Engine Cost Estimate	= $ 2,000
Certification Overhead and Miscellaneous	= $ 2,000
Total	= $ 13,000

Using these figures, EPA concludes that the following are reasonable costs for certification testing.

Pre-production durability testing	$122,000
125-hour emission data engine test	$ 13,000

2. Diesel

General Motors estimated diesel certification costs in the same categories as EPA. The categories are the same as stated above for gasoline-fueled engines. EPA's estimates for these costs are different than those cited by General Motors.

General Motors' cost estimates are not supported with any detailed breakdown but EPA expects GM anticipated higher manpower costs during service accumulation. EPA's cost breakdown for each category is given below.

(a) Pre-Production Durabilty Testing (Deterioration Factor Assess.)

Assume the current EPA procedure is followed, and allow 10 percent of the manpower costs to cover overhead and miscellaneous.

The costs of this program would be:

Set up	20 phr	
Map	10	
Test	8	
Remove	6	
	44 phr per test	
10 Tests	440 phr	
Service Accumulation	+2000 phr	
	2440 phr at $30/hr.	= $ 73,200

$$\frac{140\ \#}{\text{hr.}} \times 1000\ \text{hr.} \times \frac{1\ \text{gal.}}{7.09\#} \times \frac{\$.90}{\text{gal.}} = \$\ 17,772$$

Estimated Engine Cost	= $ 7,000
Certification Overhead and Miscellaneous	= $ 7,300
Total	= $106,000

(b) 125 hour Emission Data Engine Test

Set up	20 phr	
Map	10	
Test	8	
Remove	6	
Service Accumulation	250	
	294 phr at $30/hr.	= $ 8,820

$$\frac{140\ \#}{\text{hr.}} \times 125\ \text{hr} \times \frac{1\ \text{gal.}}{7.09\#} \times \frac{\$.90}{\text{gal.}} = \$\ 2,220$$

Estimated Engine Cost	= $ 7,000
Certification Overhead and Miscellaneous	= $ 1,800
Total	= $ 20,000

Using these figures, EPA concludes that the following are reasonable costs for certification testing for diesel engines.

Pre-production durability testing	$123,000
125-hour emission-data engine tests	20,000

D. Useful Life Redefinition

The EPA technical staff has no basis by which to analyze the manufacturers' comments on their costs associated with the redefinition of useful life. The manufacturers all expected most if not all of these costs to be associated with warranty claims but did not provide any detailed analysis of where these costs would be incurred. Since the proposed regulations are not warranty regulations, warranty related costs cannot be included in this analysis.

The EPA technical staff does expect the useful life redefinition to affect two other components of this proposal: emission standards and hardware.

With a longer useful life, the target levels for HC, CO, and NOx will have to be lower thus requiring more research and development to meet the target levels.

Since the emission standards must be achieved for the full useful life, the hardware which is required to meet the standard must be more durable in addition to being more efficient. This will require increased costs.

E. Parameter Adjustment

Ford stated that the parameter adjustment provisions would cost $90-$100 per engine. General Motors stated costs which sum to $7.50 in hardware plus $6.3 million in tooling costs. Assuming 5 year sales of 2 million GM costs become $10-$11 per engine. An interpretation of Chryslers statement that "...the impact on Chrysler's heavy-duty vehicles will be the same as for our light-duty vehicles," would give costs of about $3-$8* per engine.

* Parameter Adjustment Regulations - Summary and Analysis of Comments, October 2, 1978.

Based on the comments from GM and Chrysler, the cost of the minor changes necessary to adopt the parameter adjustment regulations is in the range of $3-$11.

Practically all light-duty truck engines are also available as heavy-duty engines. Since light-duty truck parameter adjustment regulations are already in place, the cost of implementing heavy-duty parameter adjustment should be limited to making the necessary hardware modifications to all engines produced for heavy-duty vehicles.

This cost, with profit, would surely not exceed $5.00 per engine and without profit would probably be nearer $3.00 - $4.00. Only the incremental changed hardware would be required. The engineering and production development will already be done in association with light-duty trucks.

G. Selective Enforcement Auditing (SEA)

When analyzing comments on the costs of SEA it is important to remember the goal which the industry must achieve. In the case of SEA this goal is to pass a formal EPA audit at or below the established Acceptable Quality Level (AQL).

The goal of passing these audits can be achieved through at least three means: 1) research and development aimed at reaching lower target emission levels; 2) production line quality control procedures, and; 3) post production emissions testing (self audits). The degree to which these three methods must be implemented depends on the stringency of the standard, the stringency of the AQL, and the degree of confidence the manufacturer desires in it ability to pass a formal EPA audit.

EPA's analysis of the comments on this issue will be based on the factors described above.

1. Test Facilities and Equipment

The number of test facicilites and the amount of accompanying test equipment necessary for SEA will be dictated by either the formal EPA SEA audit rate or the manufacturers own production line auditing program.

a. Facilities and Equipment for Formal EPA SEA

EPA's formal SEA testing requirement is two actual audit tests per day. If the manufacturer's sales are less than 30,000 per year only one test per day is required. Based on a statistical analysis, an average sample size of twelve engines per audit is expected.* This assumes a 10 percent non-compliance rate in the configuration being audited.

The analysis to determine the number of facilities required will assume the following:

1. Engine installation and removal takes 4 hours each time (2 hours to install and 2 hours to remove).

2. Engine "break-in" will be conducted on eddy current dynamometers but the engines will undergo emissions testing on a DC electric dyanmometer.

3. Forced cool down would take 2 hours, in place of a natural soak of 12-36 hours and would occur in the "emission testing" cell after engine mapping.

4. Once formal SEA emissions testing has begun 2 tests per day must be completed if sales exceed 30,000 per year, otherwise, only one test per day is required.

5. Engine break-in, including installation, service accumulation, and removal uses 48 hours in a "break-in" cell.

6. Engine break-in takes 24 hours but is not conducted for more than 16 hours per day.

7. Emissions testing, including installation, mapping, and removal takes 11 hours.

Under these assumptions 1 "break-in" cell could provide 3 engines per week, and 2 cells could provide an average of 6 engines per week for emissions testing. Therefore 4 break-in cells would provide the average of 2 engines per day which would be necessary to comply with EPA's formal audit requirements. For smaller volume manufacturers only 2 break-in cells will be necessary.

a. <u>Test Facilities for Self Audits</u>

Production line auditing test facility and equipment needs would depend on the self-audit rate chosen by the manufacturer and the manufacturers annual production volume.

The current industry-wide light-duty vehicle self-audit rate at a 40 percent AQL is approximately 0.2 percent. A self-audit rate of 0.6 percent seems reasonable at a 10 percent AQL for

* Analytical Development of Sampling Plans for Selective Enforcement Auditing, Sylvia G. Leaver, MSED, December, 1978.

heavy-duty engines with new emission standards and a new SEA program. The self audit rate is completely at the manufacturers discretion, so the 0.6 percent figure assumed by EPA is admittedly subjective but probably a little high. It is very likely that the self audit rate will drop quite substantially in future years as the manufacturers gain more confidence in their SEA compliance efforts and produce engines to meet the same emission standards for several years.

A self-audit rate of 0.6 percent means that 3 engines in every 500 will be tested. Using the facilities required for formal SEA audits and a total break-in period of 16 hours, large-volume manufacturers could test as many as 1000 engines per year and small-volume manufacturers could test as many as 500 per year. At a 0.6 percent audit rate, 1000 engines would support production of 166,000 per annum and 500 engines would support production of as many as 83,000 per year.

The tables below give EPA's estimates for manufacturer's facility needs based on the analysis presented above and the sales projections prepared by EPA for the regulatory analysis:

SEA Facilities - HD Gasoline-Fueled

	Break-in Cells	Emission Cells
GM*	4	2
Ford*	4	2
IHC*	4	2
Chrysler*	4	2

SEA Facilities - HD Diesel

	Break-in Cells	Emission Cells
GM*	4	2
Caterpillar*	4	2
Cummins*	4	2
Mack*	4	2
IHC*	2	1
Others(9)*	2 each	1 each

* Facility needs dictated by formal EPA audit requirements.

As shown in the tables above, none of the heavy-duty manufacturers would require more test cells than those necessary for the formal EPA SEA audits.

The number of test cells estimated for each manufacturer is very dependent on the assumptions used in this analysis. If the break-in period or self audit rate were changed then each manufacturer's facility needs would also change. The EPA technical believes the facility estimates presented above to be reasonable and very close to the actual manufacturer needs.

c. Facility Costs

Having now estimated the number of complete facilities required by each manufacturer the task becomes to estimate the cost of these facilities.

These costs will be estimated by assuming heavy-duty gasoline-fueled engine manufacturers buy all new equipment and test facilities. This assumption is extremely conservative.

For heavy-duty diesel manufacturers, EPA assumes that all new facilities and equipment will be purchased with the following exceptions. EPA assumes that all of the larger volume manufacturers will use the eddy current dynamometers removed from their certification facilities as the break-in dynamometers for SEA. Secondly, EPA believes that no small volume manufacturer would buy SEA facilities but would use certification facilities if an audit were conducted. Thus, EPA assumes one half the costs of the certification facilities would be attributable to SEA.

In all cases, it will be assumed that these facilities would be placed near the production facilities to minimize production self audit costs and to allow the common use of other support facilities.

This analysis will assume one CVS per emission test cell and uses estimates provided by vendors, manufacturers, and EPA experience. Manufacturers would probably buy one CVS per emission test cell to assure their ability to meet formal audit requirements.

Cost per Complete Emission Test Site with CVS:
Gas & Diesel

	Diesel	Gas
D.C. electric dynamometer 1/	$120K	
Dynamometer installation 2/	20K	
Computer control 3/	35K	
CVS and installation 2/	180K	(150K)
Analytical system 4/	150K	
Computer interface 4/	40K	
Structure and other support functions and hardware (2500 sq.ft. at $200 4/ per sq.ft.) 2/	500K	
	$1.045M	$1.015M

1/ Hawker Siddeley Electric Dynamometer.
2/ EPA estimate.
3/ Ultra Electronics Incorporated.
4/ GM estimate.

Cost per Break-in Site: Diesel - Large Volume Manufacturer

	Diesel
Dynamometer installation 1/	$ 5K
Receiver 2/	30K
Transporters 2/	25K
Dynamometer Control 3/	20K
Structure and Other Support Functions (2000 sq.ft. at $200 per sq.ft.) 3/	400K
	$480K
	$530K (if new dynamometer required)

1/ Conversation with Eaton Inc.
2/ Chrysler estimate.
3/ EPA estimate.

Cost per Break-in Site: Gasoline-Fueled

The cost per break-in site for gasoline-fueled engine manufacturers would be the same as for diesels except a dynmometer estimated by GM and EPA to cost at most $50K would also be necessary. So the cost per break-in site would be $530K.

Small volume heavy-duty diesel manufacturers would use certification facilities for SEA and the only costs incurred would be one half the certification facility costs. These certification costs are based on a worst case assumption that each manufacturer would have to purchase or modify all equipment.

In closing this discussion of facility and equipment costs, a discussion of the manufacturers estimates in this area would be useful.

General Motors

GM estimated total equipment and facility costs of $37.3 million dollars and EPA estimated a cost of about $8.4 million dollars. The basic difference between the two estimates lies in the underlying assumptions in three areas: break-in period length, cold soak requirements, and support facilities. The EPA technical staff believes that a 16-hour "break-in" period is much more realistic than a 125-hour "break-in" period. Manufacturers will try to minimize their "break-in" periods to protect the resale value of these engines. A forced cool down would negate the need for a long soak period and facilities for this soak. Finally, EPA believes that support facilities GM claims are necessary would, in fact, be already available in other co-located facilities. Support facilities which are necessary should be available in the cost for 32,500 square feet allowed in this analysis ($6.5 million).

Chrysler

The estimate of Chrysler and EPA differ because Chrysler assumed the use of current facilities with some additions and modifications. EPA accepts all of Chryslers cost estimates except the soak room at $140,000. A forced cool down would eliminate the need for this soak room. Therefore, EPA modifies Chryslers estimate to $1.602 million dollars.

International Harvester

IHC estimated they would need 11 audit cells plus five run-in cells to perform an audit test program at a 10 percent AQL. EPA estimates IHC could meet their needs with two emission testing cells and four "run in" cells. The apparent discrepancy between these figures is due to a very high self audit rate anticipated by IHC (6.6%) plus only a 232 day per year work period. If IHC were to assume a 300 day work period they would require seven emission cells and 14 run-in sites cells to audit their production at 6.6 percent. At a 0.6 percent audit rate, which EPA assumed and believes is probably high , the number of extra facilities would decrease to zero. Therefore, based on EPA's analysis the number of audit cells required by IHC could ultimately be dictated by the formal EPA SEA test rate.

2. Formal SEA Testing

The actual formal SEA testing costs are a function of a number of different elements which will be discussed below. Costs will be computed on a cost per formal audit basis.

a. Selection and Transport - For gasoline-fueled heavy-duty engines both the engines and the dressup components must be shipped to the point where formal SEA testing occurs. In some cases this will be at the vehicle assembly point but it may not be in all cases. The EPA technical staff assumes that a round trip cost of $400 would amply cover these items on a per engine basis. On a per manufacturer basis this is conservatively high.

   For diesel engines, no dress up components are necessary for shipment in addition to the engines, so only $30 round trip selection and transport costs is necessary.

In the majority of the cases EPA believes that SEA testing will occur at the engine plant because many diesel manufacturers do not also make vehicles for their engines.

b. <u>Break-in Costs</u> - For this analysis we have assumed that manufacturers will use a 24 hour break-in period in a procedure similar to that used on an durability or emission data engine.

For gasoline fueled engines this assumes an average fuel usage of:

$$24 \text{ hr.} \times \frac{20^{\#}}{\text{hr.}} \times \frac{1 \text{ gal}}{6.08^{\#}} \times \frac{\$1.00}{\text{gal.}} = \$79$$

For diesel engines this assumes a fuel usage on the average of:

$$24 \text{ hr.} \times \frac{140^{\#}}{\text{hr.}} \times \frac{1 \text{ gal.}}{7.09^{\#}} \times \frac{\$.90}{\text{gal.}} = \$427$$

In addition to the fuel, each engine would incur break-in costs of about $600 in association with manpower. These costs are attributable to break-in (24 hr), set-up (6 hr) and removal (2 hr). The $600 figure assumes one technician per every two engines during break-in. So final break-in costs become $679 for gasoline-fueled engines and $1,027 for diesel engines.

<u>Emission Testing Cost</u>

The emissions testing costs are primarily associated with manpower. The manpower required can be roughly divided as shown below:

	Gasoline*	Diesel*
Set up	6 phr	6 phr
Map	4	4
Test	6	7
Remove	2	2
Cool Down	0	0
	18 person hours	(diesel 19)

* These figures assume more experienced technicians and a more efficient procedure than that used initially during certification.

At thirty dollars per hour, the manpower cost is $540 for gasoline engines and $570 for diesel engines. Fuel cost is $5 for diesels and $10 for gasoline.

Engines Per Audit

Based on the statistical analysis by Sylvia Leaver of MSED the average sample number would be 12 engines until a pass/fail decision is made. This assumes 10 percent of the engines are in noncompliance.

Miscellaneous

Some small cost per test expenses for overhead, supervision, electricity. water, air conditioning and other items are inevitable but the actual amount is difficult to assess. EPA shall assume a per test cost of 10 percent of the manpower costs or about $115 per test.

To summarize:

$$\frac{\text{Cost}}{\text{Engine}} = \frac{\text{Selection \& Transport}}{\text{Engine}} + \frac{\text{Break-in}}{\text{Engine}} + \frac{\text{Emission Testing}}{\text{Engine}} + \frac{\text{Miscellaneous Cost}}{\text{Engine}}$$

HD Gas = $400 + $679 + $550 + $115 = $1745

HD Diesel = $30 + $1027 + $575 + $115 = $1745

Finally:

$$\frac{\text{Cost}}{\text{Audit}} = \frac{\text{Cost}}{\text{Engine}} \times \frac{\text{Engines}}{\text{Audit}} = \$1745 \times 12 = \$21{,}000 \text{ per audit}$$

In closing this discussion of SEA testing costs, a comparison of these cost estimates with those of the commenters would be appropriate. However, most of the manufacturers, except Mack Trucks, estimated total costs of both self audits and SEA so direct comparison is not possible.

Using EPA's estimate of Mack sales in the mid 1980's and an audit rate of one audit per 30,000 engines sold, Mack would be subject to 1 to 2 formal EPA SEA audits per year. This cost would be $21,000 to 42,000 per year. Mack estimated costs of $25,000 per year.

3. Production Line Audits (Self Audits)

Production line audit costs on a manufacturer-to-manufacturer basis are very difficult to estimate. Some manufacturers may audit as much as 1 percent of their production and some may do little more than spot checking.

The EPA technical staff believes that on an industry-wide basis a self-audit rate of about 0.6 percent will prevail in the first year of production. However, as the manufacturers gain more experience with SEA and produce engines to meet the same standards for several years, the audit rate should drop to 0.4 percent in three years for HD gasoline and 0.4 percent or less for HD diesel.

In addition. because self-audits may be conducted on new or existing facilities at engine or vehicle assembly points and are a manufacturer's tool designed primarily to meet the manufacturers' needs, the costs of self-audits should be substantially less than those for formal audits.

Because self-audits will be conducted near engine or vehicle assembly points, shipping and handling costs for engines and components should be small, say $30 (one person-hour). The other major difference in cost would be a decreased "break-in" period. EPA believes the manufacturers would minimize their "break-in" periods to protect the engine's resale value.

A reasonable criteria would be that each "break-in" dynamometer provide one engine each 16-hour "day." Thus, using a set-up and removal time of 4 cell hours, the break-in period becomes 12 hours.

Using these assumptions, the cost per engine of a self-audit can be computed at $1,072 for gasoline-fueled engines and $1,274 for diesel engines. These computations are shown below. For comparison, IHC expected self-audit costs of $1,000 per engine for either gasoline-fueled or diesel engines.

Gasoline-Fueled Self-Audit Costs

Category		Cost
Selection and Transport 1/		$ 30
Break-In Manpower:		
Set-up and remove	6 phr.	
Break-in	6 phr. 2/	
	12 phr. x $30/phr =	360
Fuel:		
$12 \text{ hr} \times \frac{20\#}{\text{hr}} \times \frac{1 \text{ gal}}{6.08\#} \times \frac{\$1.00}{\text{gal}} =$		39
Emissions Testing: 3/		
Manpower		540
Fuel		10
Miscellaneous: 10 percent of manpower		93
	TOTAL	$1,072

1/ Assumes one person-hour.
2/ Assumes one person to monitor two engines.
3/ Same as for formal SEA testing.

Diesel Self-Audit Costs

Category			Cost
Selection and Transport 1/			$ 30
Break-In Manpower:			
Set-Up and Removal	6 phr.		
Break-In	6 phr. 2/		
	12 phr x $30/phr		360
Fuel: 12 hr x 140#/hr x 1 gal/7.09 # x $0.90/gal =		213	
Emissions Testing 3/			
Manpower			570
Fuel			5
Miscellaneous; 10 percent of manpower			96
		TOTAL	$1274

1/ Assumes one person-hour.
2/ Assumes one person to monitor two engines.
3/ Same as for formal SEA testing.

G. Diesel Crankcase Emissions

Although few comments were received on the cost of controlling diesel crankcase emissions the comments from Caterpillar and General Motors can be used to make a gross estimate of the costs of a system.

First and foremost, the EPA technical staff agrees with Caterpillars estimate of $10 to control diesel crankcase emissions from non-turbocharged engines.

For turbocharged engines, the issue becomes more complex because of the high maintenance interval for turbochargers and the tendency of "oily" crankcase emissions to foul the turbocharger. Based on the fact that GM estimated R&D costs to close the diesel crankcase at $200,000 and Caterpillar estimated the actual cost at $135-$145, it seems likely that at least in the view of GM and Caterpillar, controlling diesel crankcase emissions is technologically feasible. Indeed, diesel crankcase emissions have been controlled in marine engines for years.

The question is not one of technological feasibility but one of technolgical practicality. The system used on marine diesel engines is not practical for diesel truck and bus engines.

The system envisioned by EPA would include a large pump, pressure regulator, oil separator and some tubing which would remove the crankcase emissions and reintroduce them after the turbocharger. In addition to these two modifications EPA foresees obvious engine redesign and assembly costs which would be necessary. The EPA technical staff is convinced that controlling crankcase emissions from turbocharged diesel engines is technically feasible.

In total, EPA envisions a system costing $75 - $100 which would cover materials, labor and recovery of engineering and development costs.

H. Allowable Maintenance

Although no specific comments were received on the costs of the allowable maintenance provisions, it is obvious that some work will be necessary by vendors of catalysts, etc. to assure the durability of their product. It is quite difficult to estimate these costs, but in most, if not all cases, an approximation is possible.

1) 100,000-mile catalyst - cost of increased noble metal loading and larger catalyst volume plus engineering development.

2) 30,000-mile spark plug - may be technologically feasible using current technology and unleaded gasoline.*

3) 200,000-mile turbocharger - technologically feasible with little or no cost; already available from Caterpillar.*

4. Recommendations

The final cost figures used to compute the economic impact of these regulations should be reevaluated based on the manufacturers' comment. The cost ultimately included should be that which is required by these regulations and not necessarily that which the manufacturer might spend. In some cases, more money may be spent than is required, but this would not be done if there was not an overall benefit to be derived, such as greater operating efficiency or manpower savings.

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* See Allowable Maintenance Issue.

I. Issue - Technological Feasibility

1. Summary of the Issue

EPA has proposed HC and CO emission standards representing 90 percent reductions from the uncontrolled baseline level as measured on the transient test procedure. Assuming certification on the transient procedure, are the proposed standards technically feasible?

2. Summary of the Comments

The comments received can be broken down into two areas of primary relevancy: the feasability of diesel engines complying with the proposed HC standard of 1.30 grams/BHP-hr, and the feasability of a catalytic converter for gasoline engines maintaining effectiveness throughout 100,000 miles.

a. Diesel Engines

Diesel manufacturer's took issue with EPA's assertion in the Draft Regulatory Analysis that no significant development work would be required to allow diesels to comply with the proposed HC standard.

Caterpillar claimed that 4 of their 11 currently certified engine families would require "significant" design modifications. Cummins also submitted data substantiating the fact that several of their engine families were above the proposed standard. It was argued that the majority of diesel engine families on the market today would require some work to attain production emission targets attributable to the stringency of the 10 percent AQL. Caterpillar claimed that compliance for at least one engine family was impossible. Cummins claimed that new and unproven control technologies would be necessary.

Diesel manufacturer's also claimed that their ability to evaluate technical feasibility was severely hampered by lack of transient experience. All but Cummins (which has limited transient capability) relied upon an assumed 13-mode/transient ratio derived from SWRI's limited diesel baseline work in their feasibility analyses. Mack declined to comment at all, however, claiming inadequate experience and deprivation of due process.

Furthermore, Diesel manufacturers complained that facility modifications necessitated by adoption of the transient procedure would curtail already critically short leadtime, further aggravating the technical difficulties of compliance.

Future and unknown NOx and particulate standards were cited by diesel manufacturers as limiting factors on future hydrocarbon control. As yet unknown, these factors contributed to the high degree of uncertainty over eventual compliance.

Finally, no diesel manufacturers expressed concern over compliance with the proposed CO and interim NOx standards. Cummins flatly declared that CO and NOx compliance would be no problem.

b. Gasoline Engines

Gasoline engine manufacturers' harshly criticized any standard requiring use of catalytic converters on heavy-duty trucks, claiming it represented a "disservice to our customers", and unanimously denied the feasibility of a 100,000-mile catalyst under heavy-duty conditions. Use of lead-free fuel has the impact of decreasing valve and engine durability. Data was submitted purportedly illustrating state-of-the-art catalyst technology and alleging that present catalyst technology is inadequate for assuring the proposed emission reductions over the full useful life of the engine.

The major problem was characterized as one of catalyst durability in the heavy-duty environment. Light-duty catalysts operate in less extreme thermal and vibrational environments, and are required to last only half as long. Sustained exposure to the high temperatures in the heavy-duty environment and exposure to prolonged motoring during engine-braking were characterized as frequent and probable causes of cataclysmic catalyst system failure; it was claimed that present technology catalysts cannot survive under the full range of heavy-duty environments.

General Motors suggested on upward revision of the standards to levels achievable by non-catalyst technology, and also claimed EPA had no factual evidence that the proposed standard can be met for the entire life of the engine.

In summary, all gasoline manufacturers except Chrysler declared that a durable catalyst was impossible. Chrysler, however, maintained that a single catalyst system was indeed possible, and in fact, under development and in production for sale in California in 1980.

Like the diesel manufacturers, the gasoline engine industry cited future NOx standards as contributory factors on limitations on achievable reductions.

Ford maintained, aside from the durability question, that attainment of a 15.5 g/BHP-hr CO standard on the proposed transient test would be impossible, even with the best catalyst efficiences observed to date.

3. Analysis of the Comments

a. Diesel Engines

It would be useful at this point to analyze the level of technology present in today's diesel, and the magnitude of emission reductions required by the proposed rules.

Table I-1 presents actual and extrapolated transient emission data for all heavy-duty diesel engines certified in 1979. Table I-2 presents various engine design parameters and applied emission control equipment. Table I-3 presents a breakdown by manufacturer of the percentage of total engine sales extrapolated to meet the low mileage emission targets.

Extrapolated transient emissions for diesel engines for which no transient data exist were derived using a transient/13-mode HC ratio of 2.40. This ratio was derived in the Summary and Analysis of Comments pertaining to the Test Procedure Issue, and represents the average ratio of all engines tested on the transient procedure to date. It cannot be emphasized too strongly, however, that no predictive correlation between the two test procedures has been found by any of the laboratories running transient tests. It was testified by Caterpillar that this ratio tends to increase as 13-mode HC emissions decrease, i.e., the predictive value of the 13-mode, already dubious at HC levels around and above the standard, becomes worse at lower emission levels. Furthermore, it has been demonstrated that the attainment of emission standards entails designing to a given test procedure; for this reason steady-state test procedures have been historically invalidated by the application of technology to certify upon them. It should not be construed that the use of an average ratio relating HC emissions observed on both procedures constitutes admission of a correlation existing today with current technologies. More importantly, the application of future technologies to certify on the steady-state test would result in emission results observed on future engines exhibiting even less correlation. Lack of comprehensive transient data is the sole rationale for use of an average ratio; that such a ratio is the observed average of all engines actually tested is the justification for its use. It is conceded that extrapolation of transient emissions from certification 13-mode results on an engine by engine basis entails some error, in some areas perhaps significant. For the purposes of this technology assessment, however, it is believed that use of the 2.40 ratio constitutes a reasonable guess at the level of emissions observable on today's diesels. For certification to stringent emission standards, however, a "guesstimate" of representative emissions - as would be done if the 13-mode were retained - is technically unacceptable.

Using this 2.40 transient/13-mode ratio as an estimation technique, examination of Table I-1 indicates that many engine

Table I-1

Anticipated Diesel BSHC Reductions

Mfr.	Engine Family	1979 13-Mode Certification HC Emission 1/	Transient HC Emission 2/	Anticipated HC Reduction Necessary 3/	Percent of Company Sales
GM	4L-53T	0.83	1.99	1.10	5.9%
GM	6L-71N	0.84	2.02	1.13	13.4%
GM	8V-71N	0.82	1.97	1.08	5.0%
GM	6V-71NC	1.27	3.05	2.16	3.5%
GM	8V-71NC	0.80	1.49*	0.60*	9.0%
GM	6V-92TA	0.58	1.17*	0.28*	31.8%
GM	8V-71TA	0.51	1.22	0.33	7.5%
GM	8V-92TA	0.50	1.20	0.31	19.2%
GM	6L-71T	0.55	1.32	0.43	4.7%
CEC	091	0.38	0.91	0.02	0.5%
CEC	092A	0.32	0.77	0	35.3%
CEC	092C	0.26	0.62	0	15.7%
CEC	093E	0.26	0.86*	0*	42.1%
CEC	172A	1.20	2.88	1.99	1.1%
CEC	172C	0.53	1.27	0.38	0.9%
CEC	192B	0.30	0.72	0	0.1%
CEC	193	0.38	0.91	0.02	1.9%
CEC	221	0.79	1.90	1.01	0.1%
CEC	222	0.69	1.66	0.77	2.3%
IHC	DT-466	0.64	1.54	0.65	85.7%
IHC	9.0 Liter	1.38	3.31	2.42	8.6%
IHC	DTI-466B	0.56	0.81*	0*	5.7%
Mack	8	0.31	0.74	0	2.7%
Mack	9	0.76	1.82	0.93	53.9%
Mack	10	0.12	0.29	0	0.3%
Mack	11	0.58	1.39	0.50	41.6%
Mack	S1B	0.87	2.09	1.20	1.5%
Cat	3	1.20	1.97*	1.08*	57.4%
Cat	4	0.21	0.50	0	1.0%
Cat	9	0.23	0.55	0	0.0%
Cat	10	0.34	0.82	0	11.7%
Cat	11	0.53	1.27	0.39	5.2%
Cat	12	0.15	0.36	0	1.6%
Cat	13	0.68	1.63	0.74	8.0%
Cat	14	0.22	0.53	0	1.5%
Cat	15	0.63	1.51	0.62	1.1%
Cat	16	0.30	0.72	0	10.3%
Cat	17	0.37	0.89	0	1.9%

* Actual transient results.

1/ Includes deterioration factors (determined per 1979 procedure).

2/ Using transient/13-mode ratio of 2.40 (see Text), or actual transient data when available.

3/ Based upon a transient production target of 0.89 g/BHP-HR.

Table I-2

1979 Diesel Engine Family Certification Data

Mfr.	Engine Engine Family	Engine Cycle	Turbo-Charger	Inter-Cooled	After-Cooled	Inj. Timing	Compression Ratio	Sac Volume	CID	No. of Cylinders	Rated Speed	Rated BHP	Surface/ Volume Ratio	ECS*
GM	4L-53T	2	X			8°,10°	18.7	0.7mm³	212	4	2500	155-170	9.0	FM
GM	6L-71N	2				13°,15°	18.7	0.5mm³	426	6	2300	184-239	8.6	--
GM	8V-71N	2				12°,13°	18.7	0.7mm³	568	8	2300	248-316	8.6	--
GM	6V-71NC	2				10°,13°	18.7	0.7mm³	426	6	2100	160-190	8.6	TD, SPL
GM	8V-71NC	2				12°,13°	18.7	0.7mm³	568	8	2100	230-270	8.6	TD, SPL
GM	6V-92TA	2	X		X	10°,14°	17.0	0.7mm³	552	6	2100	300- 35	7.2	TD, SPL
GM	8V-71TA	2	X		X	12°,14°	17.0	0.7mm³	568	8	2100	350	8.0	TD, SPL
GM	8V-92TA	2	X		X	11°,13°	17.0	0.7mm³	736	8	2100	435	7.2	TD, SPL
GM	6L-71T	2	X			11°,14°	17.0	0.7mm³	426	6	2100	260-275	8.0	TD, SPL
CEC	091 (NH 230,250)	4				19°	15.8		855	6	2100	220- 40	11.2	--
CEC	092A	4	X			19°	15.0	0.9mm³	855	6	1900	293	10.8	AFC, SPL
CEC	092C	4												
CEC	093E(NTC 350,400)	4	X		X	19°	14.3	0.9mm³	855	6	2100	400	9.9	SPL, AFC
CEC	172A(VTB 903,350)	4	X						903			350		SPL
CEC	172C(" " ")	4	X			21°	16.6	0.6mm³	903	8	2100	275	15.1	AFC, SPL
CEC	192B (NT 450)	4	X			18.5°	15.5	0.6mm³	1150	6	2100	450	10.7	AFC, SPL
CEC	193 (KTB 600)	4	X		X	18.5°	14.5	0.6mm³	1150	6	2100	600	9.9	AFC, SPL
CEC	221 (V555)	4				22°	17.0	0.6mm³	555	8	3300	216	13.7	--
CEC	222 (VT225)	4	X			22°	16.2	0.6mm³	555	8	3000	225	15.4	--
IHC	DT-466	4	X			16°	16.3	0.32mm³	466	6	24-2600	210	2.5	FM, SPL
IHC	9.0-Liter	4				16°	19.1	0.32mm³	551	8	2800	180	16.33	PCV
IHC	DTI 466B	4	X	X		15°	16.3	0.32mm³	466	6	2600	210	12.5	FM, SPL

Table 1-2 (Cont'd)

1979 Diesel Engine Family Certification Data

Mfr.	Engine Engine Family	Engine Cycle	Turbo-Charger	Inter-cooled	After-cooled	Inj. Timing	Compression Ratio	Sac Volume	CID	# Cycle	Rated Speed	Rated BHP	Surface/ Volume Ratio	ECS*
Mack	8 (ETZ 1005)	4	X			18°	15.0	0.32mm^3	998	8	2100	354	10.66	SPL
Mack	9 (ENDT 676)	4	X		X	19°	14.99	0.35mm^3	672	6	18-2100	283-315	8.825	SPL
Mack	10 (ETAZ(B)1005A)	4	X		X	17°	17.0	0.32mm^3	998	8	2100	392	11.84	SPL
Mack	11 (ETZ 675)	4	X			18°	17.0	0.35mm^3	672	6	2100	235	10.178	SPL
Mack	S1B (ETZ 4T7B)	4	X			15°	15.5	0.5mm^3	475	6	2400	210	6.528	SPL
Cat	3 (3208)	4				16°	16.5	0.24mm^3	636	8	2800	160-210	11.2	--
Cat	4 (3306)	4	X			12°	17.5	25.4mm^3	638	6	2200	250	9.6	AFRC, SPL
Cat	9 (3406)	4	X			10°	16.5	25.4mm^3	893	6	2100	325	9.6	AFRC, SPL
Cat	10 (3406)	4	X		X	10°	16.5	22.1mm^3	893	6	2100	375	9.6	AFRC, SPL
Cat	11 (3406)	4	X			28°	14.5	1.1mm^3	893	6	2100	300- 25	9.3	AFRC, SPL
Cat	12 (3408)	4	X		X	11°	15.3	22.1mm^3	1099	8	2100	450	11.0	AFRC, SPL
Cat	13 (3208)	4				16°	16.5	0.24mm^3	636	8	2800	200	11.2	EGR
Cat	14 (3306)	4	X		X	8.5°	17.5	25.4mm^3	638	6	2200	245	9.6	AFRC, SPL
Cat	15 (3408)	4	X			28°	14.5	1.1mm^3	1099	8	2100	400	9.4	AFRC, SPL
Cat	16 (3406)	4	X		X	26.5°	14.5	1.1mm^3	893	6	19-2100	350- 80	9.3	AFRC, SPL
Cat	17 (3408)	4	X		X	28°	14.5	1.1mm^3	1099	8	2100	450	9.4	AFRC, SPL

* EGR = Exhaust Gas Recirculation
FM = Fuel Modulator
TD = Throttle Delay
AFC = Air Fuel Control
AFRC = Air Fuel Ratio Control
PCV = Positive Crankcase Ventilation
SPL = Smoke Puff Limiter
ECS = Emisson Control System

Table I-3

Percent of Total Company Sales (# Engines Sold) Expected to Meet Proposed HC Standard Target*

Company	Percent of Engine Sales
Caterpillar	28.1%**
Cummins	95.5%
Mack	3.0%
IHC	5.7%
Detroit Diesel	0%

* Based upon data from Table I-1.

** This percentage jumps to 66 percent when Caterpillar engine family 3, the high volume 3208, is discounted.

families will require varying degrees of modifications to achieve compliance. It also becomes apparent that greater than a third of both 1979 engines (36%) and 1979 engine families (37%) should already meet the 1984 production transient target levels (10% AQL). Actual transient data presented in Table I-4 more than substantiate this claim. 72% of all Diesels tested on the transient procedure exhibited BSHC levels below the standard; 44% had HC levels below the production targets.

The degree of present compliance is manufacturer specific, as illustrated in Table I-3. Cummins Engine Company is well ahead of the rest of the diesel industry in terms of emission control. Sixty percent of their engine families and 95.5 percent of their projected 1979 unit sales should meet the 10 percent AQL production target level (0.89 g/BHP-hr)* associated with the 1.3 g/BHP-hr transient HC standard. In their written submission, Cummins claimed that some development work was necessary on several of their families to achieve total compliance; specifically noted were efforts to develop a new technology, variable injector timing. Of the four engine families needing work (see Table I-1), the grossest HC emitter - family 172A - has already been dropped for 1980. Furthermore, Cummins identified several control strategies in their written submission (Table I-5) and included each strategy's known effects on emissions.** However, Cummins' declined to submit detailed data using the explanation that "detailed data on the emissions capability of future technologies are of a proprietary nature...." ECTD interprets this to mean that Cummins believes it has technological and competitive advantages over the rest of the industry; this interpretation is substantiated by Cummins' distinct predominance in the field of emission control. Cummins major new technology, variable injector timing, has already been incorporated on at least one test engine (identified as engine D on Table I-4);, transient HC emission data for this engine (.86 g/BHP-hr) met the production target emission level. In summary, Cummins is quite close today to 100 percent compliance, has identified and is familiar with several control strategies for the future, and is capable today of transient testing and development work. Cummins has testified that their avowed corporate policy for the last several years has been to develop low emission engines; the facts substantiate this claim, and imply that a consistent application of technology can effectively reduce engine emission levels.

Caterpillar Tractor Company is a distant second in terms of HC

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* See Chapter 7 of the Regulatory Analysis, "Cost Effectiveness."

** Cummins qualified this submission, due primarily to the fact that the test data were acquired on the 13-mode test, and not necessarily relatable to the transient procedure.

*** For which actual transient data is available.

Table I-4

Actual Transient Diesel HC Emissions

Engine	BSHC	Lab	Below Standard?	Below 10% AQL Target?
1978 Caterpillar 3208	3.37	SwRI	No	No
1976 Cummins NTC-350	0.68	SwRI	Yes	Yes
1978 DDA 6V92T	0.78	SwRI	Yes	Yes
1979 Cummins NTCC-350	0.86	SwRI	Yes	Yes
1978 DDA 8V-71N (#2 Fuel)	1.30	SwRI	Yes	No
1978 DDA 8V-71N (#1 Fuel)	1.49	SwRI	No	No
1979 DDA 6V92TA (#1 Fuel)	1.17	SwRI	Yes	No
1979 DDA 6V92TA (#2 Fuel)	1.09	SwRI	Yes	No
1979 IHC DTI-466B	0.81	SwRI	Yes	Yes
A*	0.99	Cummins	Yes	No
B	0.76	Cummins	Yes	Yes
C	0.72	Cummins	Yes	Yes
D (w/variable injector timing)	0.86	Cummins	Yes	Yes
E	1.83	Cummins	No	No
F	2.22	Cummins	No	No
G	1.25	Cummins	Yes	No
H	0.55	Cummins	Yes	Yes
1979 Caterpillar 3208	1.96	Caterpillar	No	No

Total Percent Below Standard: 72%

Total Percent Below 10% AQL Target: 44%

* Cummins' and Caterpillar data extracted from comments submitted.

Table I-5

Trends in Emissions with Design Changes as Submitted by Cummins (Based on 13-Mode Data)

Injection System Changes	BSHC
Increase # Spray Hole	?
Increase Spray Hole Area	?
Increase Spray Hole Angle	-
Advance Injection Timing	decrease
Tighter Injector Setting	decrease
Higher Clearance Injectors	?
Faster Injection Profile	decrease
Piston Changes	
Increase CR	decrease
Increase Piston to Head Clearance	increase
Increase Bowl Diameter	increase
Deeper Bowl Piston	decrease
Miscellaneous	
Smaller Turbine Casing	decrease
Aftercooling	decrease
Increase Intake Restriction	-
Increase Coolant Temp.	decrease
Increase Fuel Temp.	-

Key: - No Change
? Indeterminate Change

emission control, due primarily to the high HC emissions of their high-sales volume 3208 (DINA Family 3) (representing 57.4 percent of Caterpillar's 1979 projected unit sales). Caterpillar's lengthy supplemental written submission on the technological feasibility of the proposed HC standard addressed only the 3208 - Family 3 engine. Caterpillar bluntly stated that "...the current version of the 3208 does not comply with the proposed HC standard ...[and] available technology would not bring this engine into compliance." ECTD takes issue with the latter assertion, primarily on the basis of certification data from Caterpillar Family 13 - also a 3208. Referring to Tables I-1 and I-2 and to all data presented in the 1979 Part I submission to EPA's Certification Division, the only difference between Families 3 and 13 is the presence of EGR on 13. Note that 13-mode HC (on which the extrapolated transient emissions are based) on Family 13 is almost 50 percent less than that on Family 3. Caterpillar, however, made no mention of this fact in their written submission. Yet telephone conversations with Caterpillar representatives revealed that the EGR, traditionally employed for NOx control, was added to Family 13 also for the hydrocarbon control required by more stringent California standards. (In Part I, Volume I of 1979 Certification Records, p. 1A-IX, 6-1.0, Caterpillar states, "... Family 13 is intended to comply with a standard more stringent than the... (1979)...Federal Standard.") It should be noted, however, that Family 13 also does not meet the 1984 production targets, but is substantially closer, based upon the assumed transient/13-mode ratio of 2.4. (Actual transient data for Family 3 reveals this ratio to be only 1.48; were this to be consistent on the almost identical Family 13 - for which no transient data is available - then Family 13 would have transient HC emissions of 1.00 g/BHP-hr, well under the proposed standard and only marginally exceeding the production targets. This marginal difference could be eliminated by the several techniques Caterpillar did mention.)* Given the additional fact that neither 3208 Family is turbocharged or aftercooled (the two major methods of HC control), ECTD can only conclude that the current version of the Family 3 3208 incorporates little emission control technology. (Table I-2 reveals that the 3208 is also the only Caterpillar engine which does not utilize an air fuel ratio control system).** Nonapplication of technology in the past is by no means a persuasive argument that technology is inapplicable for the future, especially with several proven options available, one of which - EGR, has already been applied on a production basis (Family 13, 3500 unit projected 1979 sales). ECTD concludes that the Family 3 3208 can achieve compliance; the excessive emissions on the current version arise primarily from the absence of control technology.

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* Decrease in sac volume, increased compression ratio, timing advance.

** AFRC limits the injection of fuel during accelerations to that for which enough combustion air is present, thereby reducing smoke and most likely transient HC emissions.

Aside from the Family 3 3208, 70 percent of Caterpillar's remaining engine families are anticipated to meet the production targets.

Of the remaining engines which do not comply, highly informative comparisons can be made with those which do. For example, compare Family 15 and Family 17 - both 3408 engines - on Table I-2. Family 15 is anticipated to exceed the production targets (Table I-1), while 17 complies; Family 17, however, is virtually identical to 15. The manifolds, valves, and injection systems are the same. Different model turbochargers and air fuel ratio control systems are used, but most importantly, Family 17 is equipped with an aftercooler. Furthermore, both engines have sac volumes considerably larger than those achieved on other engines, the reduction of which facilitates HC control. Therefore, no compelling reason exists to presume the future noncompliance of Family 15. Family 11, which does not comply, and Family 16, which does, are also identical except for the fact that 16 is aftercooled.* Both engines also have high sac volumes.

In summary, with the exceptions of Families 3 and 13, for every Caterpillar engine family which is observed to emit high HC, there is a virtually identical engine which does not. It is construed to be significant that Caterpillar declined to comment on any engine family except Family 3. As discussed above, Families 3 and 13 both exceed the targets, while addition of EGR to the virtually identical 13 achieved a significant HC reduction. Furthermore, both engines lack turbochargers and aftercoolers. ECTD cannot dispute the contention that some redesign and development work will be necessary for Caterpillar, and it is recognized that Caterpillar is in a less than optimal situation by virtue of the fact that their highest sales engine is probably their dirtiest. Yet it is also one of the least controlled engines on the market, viable technologies exist today, and four years leadtime for development is available.

International Harvester produces three diesel engine families, one of which (DTI 466B) has been tested at SwRI over the proposed transient test and easily complied with the production targets. The 466B** is a higher technology (i.e., intercooled) version of the DT 466 high-volume engine, and is primarily manufactured for

* Injector timing on Family 16 is more retarded than on Family 11 (26.5° BTC vs. 28° BTC). Since injection timing retard tends to increase HC, ECTD must conclude that HC control on Family 16 is even higher than that presumed at first glance. ** IHC has declared that the DTI 466B is being modified for 1980 sales in California, reflecting an increase in the stringency of the California HC standard. Design changes will occur primarily in the injector system and combustion chamber, and indicate that even tighter HC control is achievable.

sale in California. It is readily apparent, however, that the application of this additional control technology to the 466 has already been accomplished on a production basis. IHC's remaining engine, the low-sales volume 9.0-liter version, is the engine on which the greatest HC reductions will be required. It is also neither turbocharged nor intercooled, and has a number of characteristics common to high HC engines (high rated speed, low rated horsepower, very high surface/volume ratio).

Mack's product line has yet to be tested over the transient cycle, but extrapolated transient emissions in Table 1 predict three of five engine families will exceed both the target and the standard. Family 9 is one of these although already turbocharged and aftercooled. Mack declined to comment on technological feasibility claiming lack of data; this lack of data also constrains this analysis. Furthermore, each of Mack's engine families are different; this precludes comparison of emissions and applied technologies between comparable engines. ECTD can only draw inferences from the degree of compliance of other manufacturers, the effectiveness of control strategies as evidenced by engines on the market today, and the lack of evidence that Mack's engines are fundamentally different in some way from other diesel engines. Based upon this and the fact that two out of five* of their engine families presently comply, no compelling evidence exists to indicate that Mack's engines cannot be brought into compliance given four years to do so.

Detroit Diesel is the only major diesel manufacturer whose entire product line exceeds the HC target levels. Particularly dirty are those engine families which are naturally aspirated. DDA has indicated that families 4L-53T, 8V-71NC, 6L-71N, 8V-71N, and 6V-71NC will not be produced after 1982, however, and need not be addressed in this analysis. Of the four remaining engines, all are relatively close to the standard. Data submitted by Caterpillar** indicated that a decrease in injector sac volume will decrease hydrocarbon emissions. Figure I-1 depicts this Caterpillar data and corresponding sac volumes and emission levels for the four DDA engines. Presuming a comparable emission trend with sac volume reduction, three of the four DDA's can be brought below the target level with a reduction in sac volume from the present .7mm^3 to .24 mm^3. The 6L-71T can be brought relatively close by sac volume reduction. Addition of an aftercooler, as already done on the 6L-71TA, easily brings it within the low mileage targets. When coupled with other injector optimizations presented in Table I-5, achieving compliance with these four families should be relatively easy and inexpensive.

* This represents only 3 percent of their unit engine sales, however.

** Table VI, "Effect of Nozzle Sac Volume...," of Supplementary Statement to July 16, 1976 Public Hearings.

In summary, a large percentage of diesel engines on the market today meet the 1984 target HC levels for a 10 percent AQL. Furthermore, proven strategies have been identified which will allow the vast majority of the remaining engine families to comply; many of these strategies have already been incorporated on production engines already on the market. Compliance with the transient HC standard with the 10 percent AQL for diesel engines can be accomplished by all manufacturers by 1984.

All diesel engines will easily comply with the 15.5 g/BHP-hr CO standard; no engine tested at SwRI has exceeded 5.0 g/BHP-hr, and none are anticipated to do so. This is due to the diesel engine's inherently low levels of CO emissions.

Several manufacturers claimed that the 10.7 g/BHP-hr interim NOx standard would be difficult to achieve in conjunction with the reduction in HC. ECTD takes issue with this claim, primarily on the basis of:

i) The highest NOx observed at SwRI on any 1979 engine has been 5.91 g/BHP-hr,* only 55 percent of the proposed standard; HC emissions for this engine were below the production target. Data from Cummins was somewhat higher (due somewhat to a different measurement technique); Cummins flatly stated, however, that compliance would be no problem. Several manufacturers did comment, however, that NOx measurements at SWRI were technically suspect. Investigation of the equipment at SWRI revealed deficient water traps in the 13-mode NOx analyzer, yet SWRI's 13-mode NOx measurements were never used for regulatory action and standard setting. The 13-mode tests were used both for assuring the operational integrity of the engine and for comparitive purposes with transient tests. Errors in SWRI's 13-mode NOx measurements therefore have no impact whatsoever on this regulatory action.

ii) Manufacturers based their estimates on 13-mode data. The transient test procedure generates less NOx than the 13-mode. Therefore, the industry's projections are overly pessimistic (see Table 6.)

iii) Discrepancies have arisen between NOx measurements using the CVS-bag technique and a dilute integration technique. Up to 25% lower NOx is measured on the bag technique due to unexplained chemical reactions in the bag itself. Yet even a 25 percent increase in SWRI's bagged NOx (Cummins utilizes the integration technique) fails to come close to the 10.7 g/BHP-hr standard for any of the engines tested. The difference between measured transient NOx at SwRI and the proposed NOx standard is so great that it renders the issue of bagged vs. integrated NOx an academic question for the purposes of this technology analysis.

* 1979 IHC DTI-466B (California calibration).

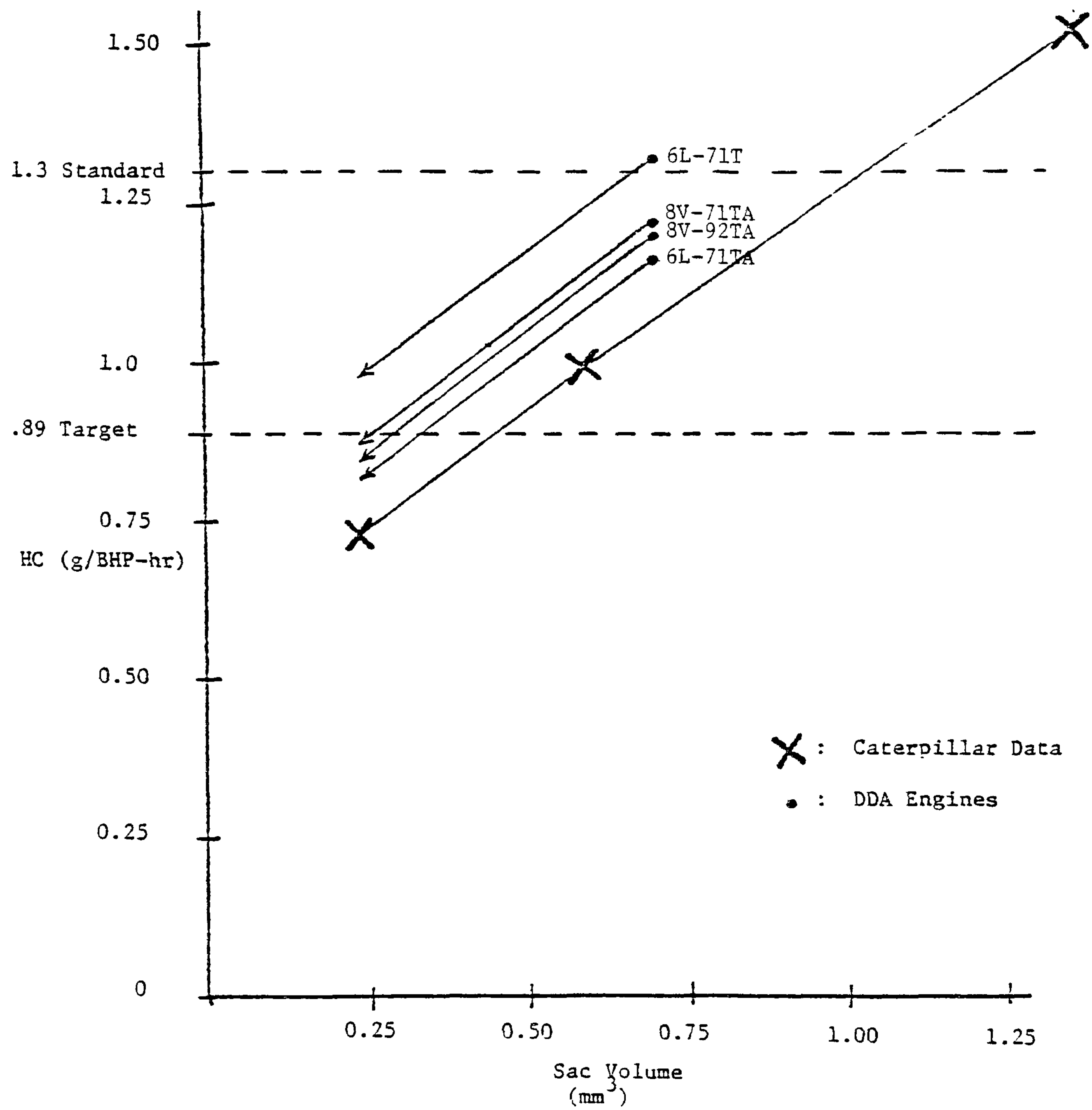

Figure I-1 Projected Effects of Sac Volume Reduction on DDA Engines.

Table I-6

Transient vs. 13-Mode NOx

Engine	Transient NOx g/BHP-hr	Transient Sampling System	13-Mode NOx g/BHP-hr	Lab
1979 Cummins NTCC-350	4.91	Bagged	8.7*	SwRI
1978 DDA 8V-71N				
#1 Fuel	5.40	Bagged	7.10	SwRI
#2 Fuel	5.69	Bagged	7.03	SwRI
1979 DDA 6V-92TA				
#1 Fuel	5.83	Bagged	7.28	SwRI
#2 Fuel	5.91	Bagged	7.58	SwRI
1979 IHC DTI 466B	5.56	Bagged	5.70	SwRI
A (Cummins data)	8.94	Integrated	9.12	Cummins
B "	8.45	Integrated	8.66	Cummins
C "	7.82	Integrated	7.98	Cummins
D "	5.07	Integrated	4.59	Cummins
E "	6.99	Integrated	7.58	Cummins
F "	5.69	Integrated	6.30	Cummins
G "	6.94	Integrated	8.20	Cummins
H "	7.24	Integrated	8.14	Cummins

* EPA Certification Data.

In short, the NOx standard is so lax that compliance will be easily achievable. There is enough slack between measured levels and the standard that tradeoff with hydrocarbons is possible (i.e., incorporate HC control techniques which result in higher NOx.)

Finally, to allow an HC + NOx standard would be tantamount to decontrolling HC simply because of the laxity of the NOx standard; this option is not recommended.

b. Gasoline Engines

We now turn to gasoline engines and the issue of catalyst feasibility which is comprised of two questions: is the durability of 100,000 miles achievable, and will future catalysts be sufficiently efficient to allow compliance with the proposed standards?

Detailed discussion of the issue of catalyst durability is presented in the Summary and Annalysis of Comments pertaining to Allowable Maintenance intervals - the 100,00 mile catalyst. It will suffice here to summarize those arguments and conclusions.

First of all, in-use catalyst durability data is limited to 50,000 miles, light-duty applications. Evidence was presented by the manufacturers showing that a viable, 100,000 mile heavy-duty catalyst would be difficult to design, primarily because of higher poisoning rates and higher temperatures experienced in the heavy-duty environment. ECTD's technical analysis*, however, points out several viable strategies and finds no compelling arguments to suggest that the full life catalyst would not be feasible.

The issue of catalyst efficiencies is impacted primarily by the production target levels required by deterioration factors and AQL level. Furthermore, the very mechanisms by which catalyst overheating is precluded tend to delay catalyst light-off, thereby increasing the impact of cold start emissions.

Discussions pertaining to projected catalyst deterioration factors and reductions necessitated by a 10 percent AQL can be found in the Allowable Maintenance and the Cost Effectiveness Analyses, respectively. Based upon these analyses, the probable target emission levels for catalyst - equipped engine are 0.5 grams/BHP-hr HC and 5.9 g/BHP-hr CO**. (NOx has been effectively decontrolled and should not impact catalyst feasibility in any way.) It is based upon these levels that the feasibility of compliance will be evaluated.

Oxidation catalyst efficiencies are functions of catalyst

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* Regulatory Analysis, "Allowable Maintenance - Summary and Analysis of Comments".

** Several manufacturers concurred with these projected targets.

sizing (i.e. cubic inch displacement), substrate and noble materials, catalyst density (i.e. the internal surface area available for catalysis), noble metal loadings (i.e., grams/ft^3 of catalytically active metals within the catalyst), catalyst temperature, and the amount of residual oxygen present in the raw exhaust (usually introduced into rich running engines by means of air injection.)

It has been observed during catalyst testing at the EPA laboratory that the Los Angeles Freeway segment of the transient test will dictate the final catalyst design. High speed, high power performance during this segment creates the highest flow of exhaust gases and a richer fuel/air mixture due to power enrichment devices operating at the higher loads. Here the catalyst is subjected to a combination of higher exhaust volumes, shorter residence times, and higher concentrations of pollutants due to power enrichment. Any catalyst capable of cleaning LA Freeway emissions will easily eradicate the emissions over the remainder of the cycle (with the notable exception of cold start emissions.)

It has also been observed in experiments with catalyst-retrofit engines that HC control is a by-product of CO control, i.e. if CO emissions are adequately controlled by a catalyst, then HC control follows as a matter of course. Any catalyst designed to handle CO over the LA Freeway should control HC over the entire test despite the high cold start HC emissions. CO control is therefore an reasonable measure of compliance capability.

Tables I-7, I-8, and I-9 present emission data from two heavy-duty engines retrofit with catalysts and tested at the EPA lab.

Table I-7 present data taken from a 1979 GM292 I-6 engine retrofit with dual Englehardt catalysts 50 grams/ft^3, 2:1 ratio of platinum/pollidium), and in standard, non-catalyst configuration. The 292 represents one of the smallest truck engines and was a logical choice on which to first test the effectiveness of currently available catalysts. Note that while hydrocarbons were reduced to a level close to the target of .50 g/BHP-hr, CO was reduced to under the standard but not to the target levels of 5.9 g/BHP-hr. (This substantiates the claim that HC is easily controlled, despite the preponderance of cold start HC emissions*.) It should be noted that no additional air injection was used, for optimal performance on the transient test. General Motors recognized the need for greater air injection in their written

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* Cold start emission impact on composite test results were calculated according to the following equation:

$$\%\ \text{Cold Start} = \frac{1/7\ (\text{grams : Bag 1}) \qquad x\ 100\ \%}{1/7\ (\text{Total grams: cold cycle}) + 6/7\ (\text{Total grams: hot cycle})}$$

Table I-7

Emission Data: 1979 GM 292

		BSHC			BSCO		
Cycle	Segment	Standard Configuration	with Catalyst	Conversion Efficiency	Standard Configuration	with Catalyst	Conversion Efficiency
1.	NYNF	65.65	36.76	44%	437.09	285.30	35%
2.	LANF	2.62	0.35	87%	69.90	4.55	93%
3.	LAF	0.39	0.02	95%	30.23	6.27	79%
4.	NYNF	2.08	0.03	99%	81.94	15.57	80%
5.	NYNF	6.17	1.33	78%	133.68	37.98	72%
6.	LANF	2.20	0.21	90%	65.85	4.79	93%
7.	LAF	0.37	0.03	92%	30.50	6.57	78%
8.	NYNF	2.33	0.08	97%	89.14	15.13	83%
Cold Cycle:		6.56	3.01	54%	77.59	29.01	63%
Hot Cycle :		1.38	0.18	87%	51.21	9.50	81%
Test Composite:		2.12	0.58	73%	54.98	12.25	78%

	Test Total* Integrated BHP-hr	Test BSFC
Standard Configuration:	16.95	.655
Catalyst Version .	16.72	.638

Cold Start emissions as a percentage of the test composite**

	BSHC	BSCO
Standard Configuration:	38%	9.7%
Catalyst Version :	72%	26 %

* Sum of Cold start and Hot start.

** See footnote in text for derivation.

Table I-8

Emission Data: 1978 IHC 404 - Dual Air Pumps

		BSHC			BSCO		
Cycle	Segment	Standard Configuration	with Catalyst	Conversion Efficiency	Standard Configuration	with Catalyst	Conversion Efficiency
1.	NYNF	36.32	9.22	75%	253.31	103.18	59%
2.	LANF	9.31	0.66	93%	90.87	4.45	95%
3.	LAF	0.80	0.07	91%	58.30	12.86	78%
4.	NYNF	6.69	0.12	98%	69.06	3.13	95%
5.	NYNF	17.15	1.33	92%	92.62	2.00	98%
6.	LANF	4.80	0.25	95%	62.68	0.0	100%
7.	LAF	0.75	0.07	91%	59.85	10.63	82%
8.	NYNF	5.73	0.14	98%	64.70	3.39	95%
Cold Cycle:		5.42	0.83	85%	79.59	17.05	79%
Hot Cycle :		2.90	0.18	94%	62.80	7.64	88%
Test Composite:		3.26	0.28	91%	65.22	8.98	86%

	Test Total Integrated BHP-hr	Test BSFC
Standard Configuration:	23.784	.689
Catalyst Version :	23.055	.708

Cold Start Emissions as a Percentage of the Test Composite

	BSHC	BSCO
Standard Configuration:	12%	4.2%
Catalyst Version :	33%	12 %

Table I-9

Extrapolated Emissions From IHC 404:
Fourfold Increase In Air Injection Volume Over Certified Configuration

		BSHC		BSCO	
Cycle	Segment	Air Pump Catalyst	Conversion Efficiency Over Standard Configuration	Air Pump Catalyst	Conversion Efficiency Over Standard Configuration
1.	NYNF	6.63	82%	81.07	68%
2.	LANF	0.41	96%	0.26	99%
3.	LAF	0.05	94%	2.72	95%
4.	NYNF	0.37	94%	0	100%
5.	NYNF	2.74	84%	12.02	87%
6.	LANF	0.36	93%	0	100%
7.	LAF	0.05	93%	3.43	94%
8.	NYNF	0.25	96%	0	100%
Cold Cycle:		0.60	89%	7.55	91%
Hot Cycle :		0.28	90%	3.10	95%
Test Composite:		0.32	90%	3.74	94%

Cold Start emissions as a percentage of the test composite

	BSHC	BSCO
Standard Configuration :	12%	4.2%
Air Catalyst Configuration:	26%	28 %

submission, claiming a need for "power modulated air injection systems" (i.e. air injection which could increase with loads, and not merely engine speed.) With regard to overall efficiences, several manufacturers claimed that catalyst efficiences observed to date have been too low to effect the required reductions. The most significant conclusion which can be drawn from Table I-6 is the fact that observed catalyst efficiencies over the transient test were 73-78 percent despite small air injection volumes and engine calibrations optimized for a radically different test procedure and non-catalyst emission control.

Tables I-8 and I-9 present data taken from a 1978 IHC 404 V-8 engine. The certified configuration included a single air pump; ECTD personnel retrofit the engine with a second air pump supplied by IHC (pump capacities are shown in Figure I-2). Vacuum fittings for the pumps' air divert valves were blocked off. The engine was then retrofit* with four 113 CID Englehardt monolithic catalysts (50 grams/ft^3 platinum-palladium, 4:1 ratio).

Test data presented in Table I-7 represent a standard transient emission test with the engine in the above configuration. (The left air pump delivered air to the left exhaust manifold, the right pump to the right manifold.) The emission reductions achieved in this configuration are striking. Transient CO was reduced 86 percent from the certified configuration level; transient HC was virtually eliminated. A transient CO level of 8.98 g/BHP-hr is well below the standard, but still not quite at the target emission level. At this point a valuable clue is found in the catalyst efficiences for the LA Freeway; aside from the cold start, catalyst efficiencies on the LA Freeway are the lowest observed over the entire test. This implies a need for leaner power enrichment or increased air injection.

In an attempt to provide this additional air injection, the outputs from both air pumps were diverted into the right manifold and only emissions from the right cylinder bank were measured. To derive a total emission measurement for the engine, an additional test was run with both air pumps diverted into the left bank from which emission were measured. Total emissions were then approximated based upon the sum of emissions measured from each bank.

Emissions derived from this configuration are presented in Table I-9. As is readily apparent, emissions generated over the transient cycle were virtually eliminated; transient BSCO was reduced well below the target levels. Cold start emissions were not great enough to threaten compliance.

* Two catalysts per cylinder bank; catalysts for a single bank were mounted in parallel. Catalysts were mounted approximately four feet from exhaust manifold, two feet ahead of the two dually-mounted mufflers.

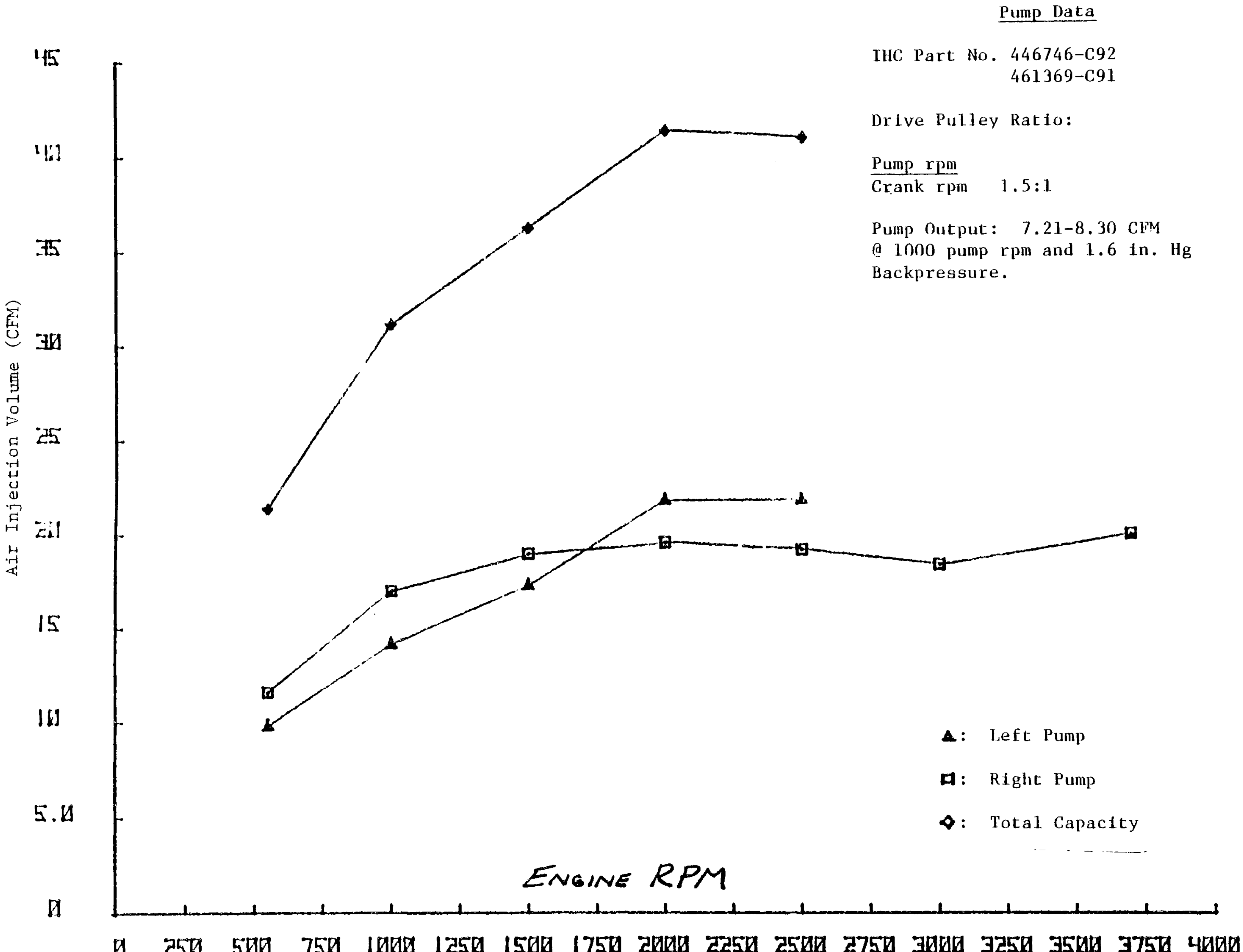

Figure 1-2 IHC 404: Air Injection Capacity.

Some additional observatons can now be made with respect to engine brake horsepower, fuel economy, and catalyst temperatures. Figure I-3 presents the maximum horsepower curve for the IHC 404 when equipped with a varying number of air pumps. Based upon the above emission data, this particular engine requires between two to four times the air injection volume of the certified configurtion to achieve the low mileage emission targets. With double the air injection producing 8.98 g/BHP-hr of CO and four times the air producing 3.74 g/BHP-hr, a tripled air injection volume (approximately 60 CFM) could be reasonably presumed to allow emission target compliance for this engine. Based upon the horsepower curves presented in Figure I-3 and the fuel consumption curves in Figure I-4, tripling the air injection volume can be presumed to increase engine BSFC by 8.4 percent. It cannot be emphasized too stongly, however, that this engine was calibrated to achieve emission reductions on a radically different test procedure without catalysts, i.e. performance and fuel economy were sacrificed to a certain extent as the combustion process itself was altered to achieve lower emissions. Emission reductions with catalysts, however, require less engine calibrations and combustion modifications, i.e., catalyst technology allows engine optimization for both fuel economy and performance while also reducing emissions.

The proof of this lies in observations made of the light-duty fleet between model years 1974 and 1975. A switch to catalyst technology between these model years resulted in a fleet-wide 16.7 percent increase in fuel economy. There is no reason to believe that the heavy-duty fleet will behave differently. Therefore the increase in fuel consumption necessitated by the increased air injection will be more than offset by decreases in fuel consumption due to the combustion process optimizations permitted by catalyst technology*. Furthermore, a single air pump delivering 60 CFM is certainly more efficient than three air pumps each delivering 20 CFM. Smaller pumps exhibit efficienty lcsses due to boundary lays effect on the smaller blades. Conversion to a single pump would certainly decrease the increaded fuel consumption to some extent. In short, it is the Technical Staff's firm belief that no fuel economy penalty will be experienced. In all likelhood, or discussed in the Fuel Economy Summary and Analysis of Comments, a net fuel economy benefit will result.

The final consideration relating to increased air injection is the catalyst operating temperature. Temperature data for emission test presented in Table I-7 (dual air pumps) are presented in Figure I-5, for the test in Table I-8 (the equivalent of four air pumps) in Figure I-6. Temperatures for catalyst on both the

* For a more detailed discussion of fuel economy effects, including comparisons with the light-duty fleet, see "Fuel Economy," Regulatory Analysis, Summary and Analysis of Comments.

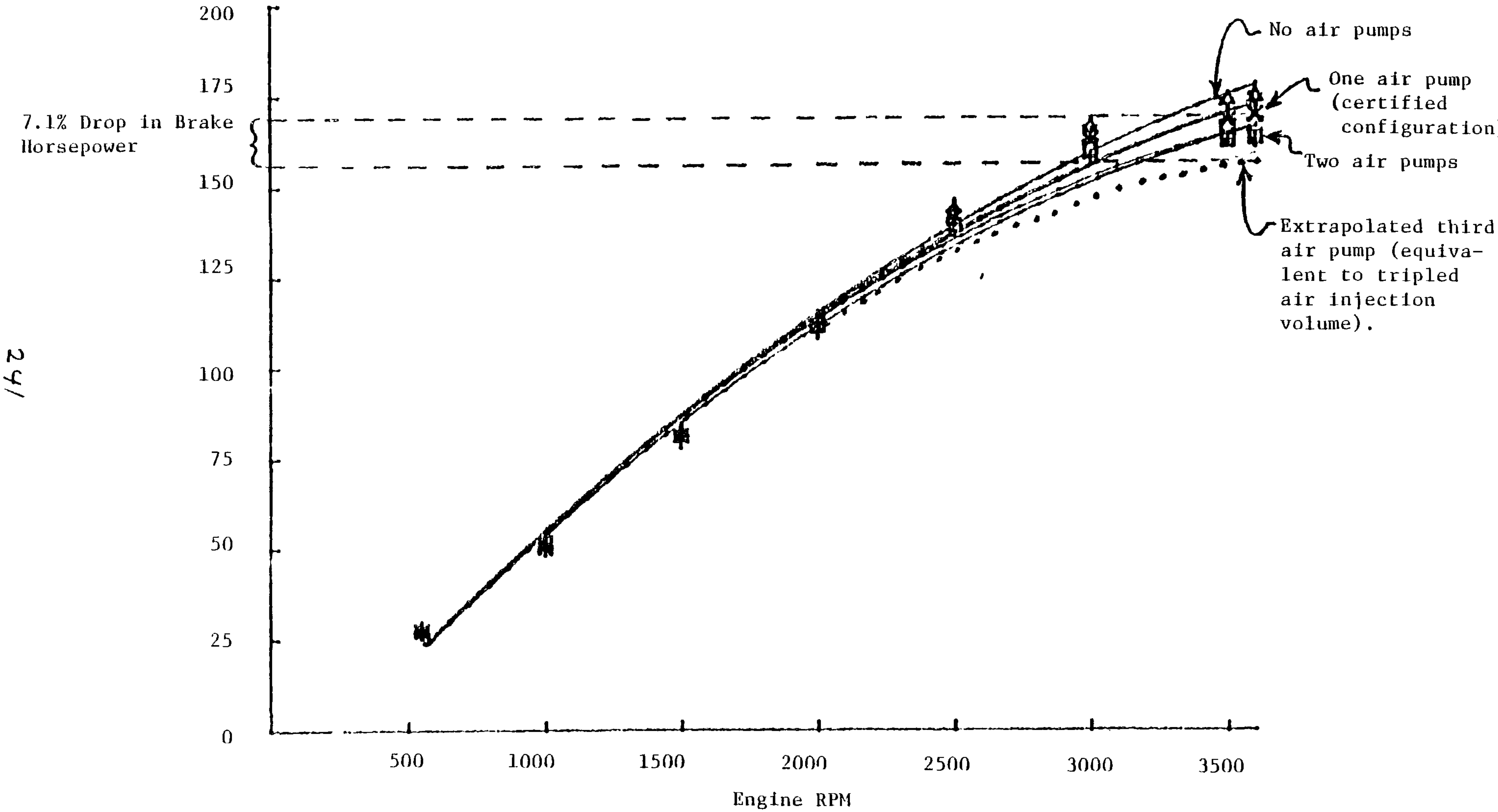

Figure I-3 WOT Horsepower. Curve for IHC 404 (no catalysts) Showing Horsepower Losses Due to Increased Air Injection.

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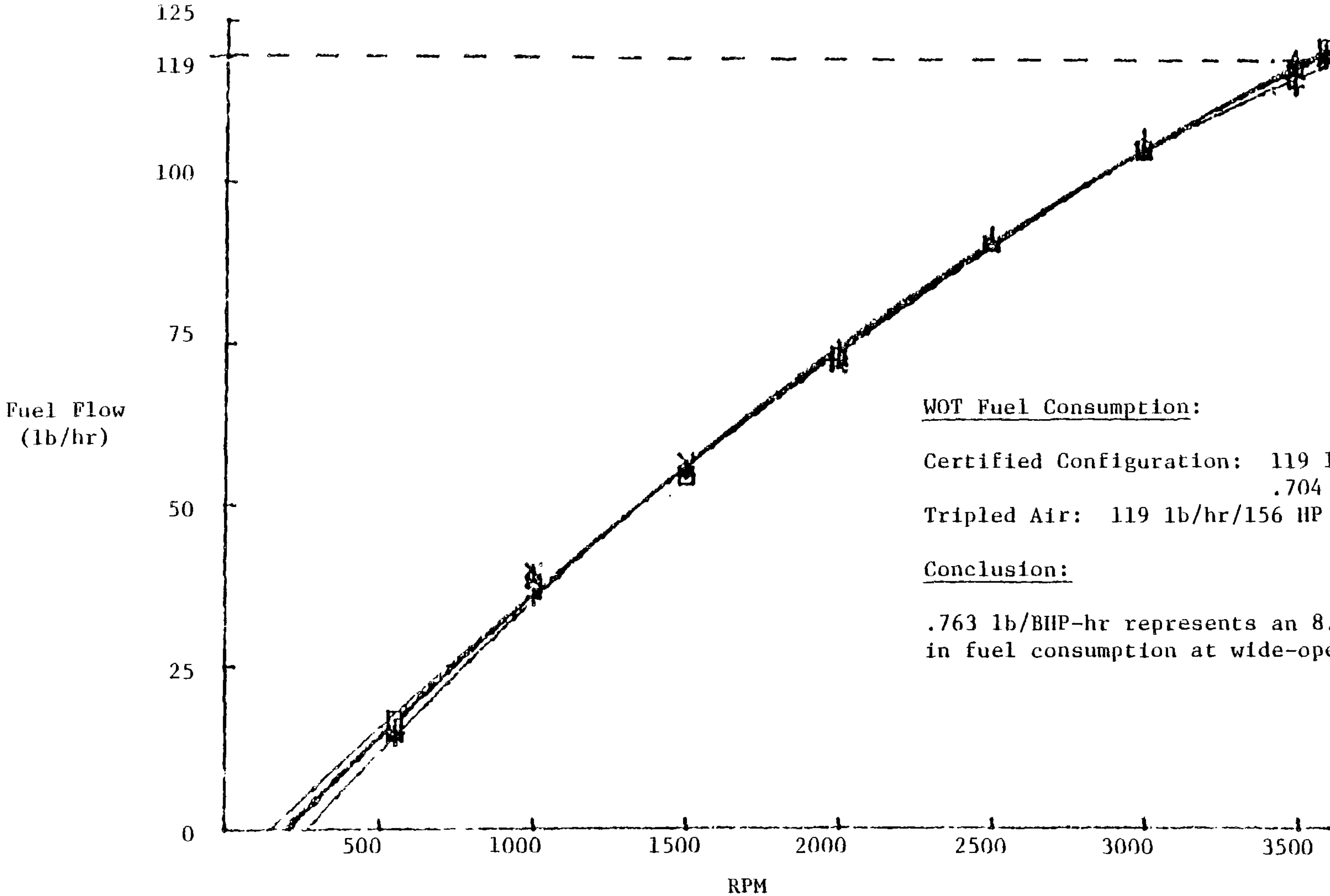


WOT Fuel Consumption:

Certified Configuration: 119 lb/hr/169 HP = .704 lb/HP-hr.

Tripled Air: 119 lb/hr/156 HP = .763 lb/HP-hr.

Conclusion:

.763 lb/BHP-hr represents an 8.4 percent increase in fuel consumption at wide-open throttle.

Figure 1-4 WOT Fuel Flow, IHC 404 (none, one and two air pumps).

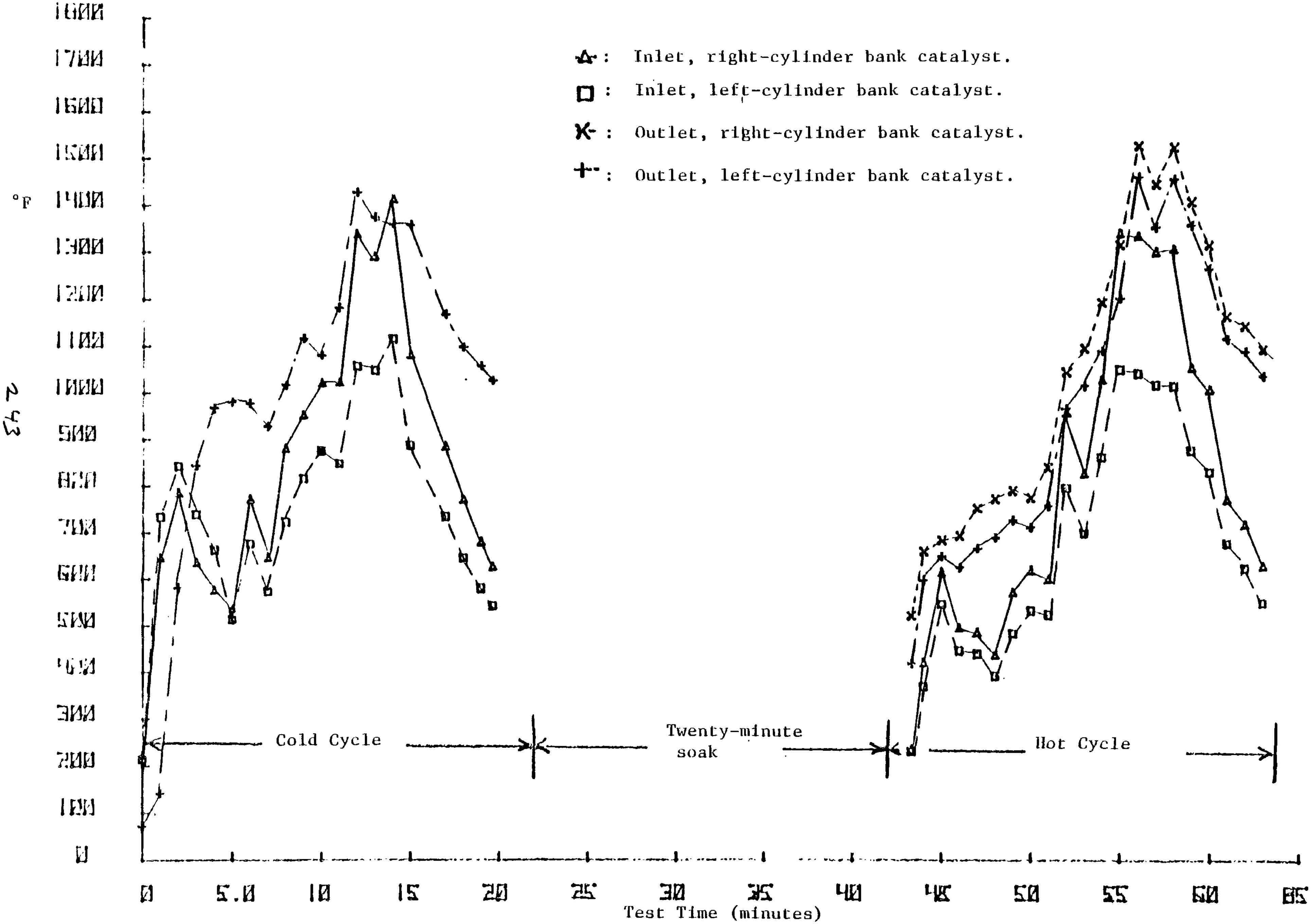
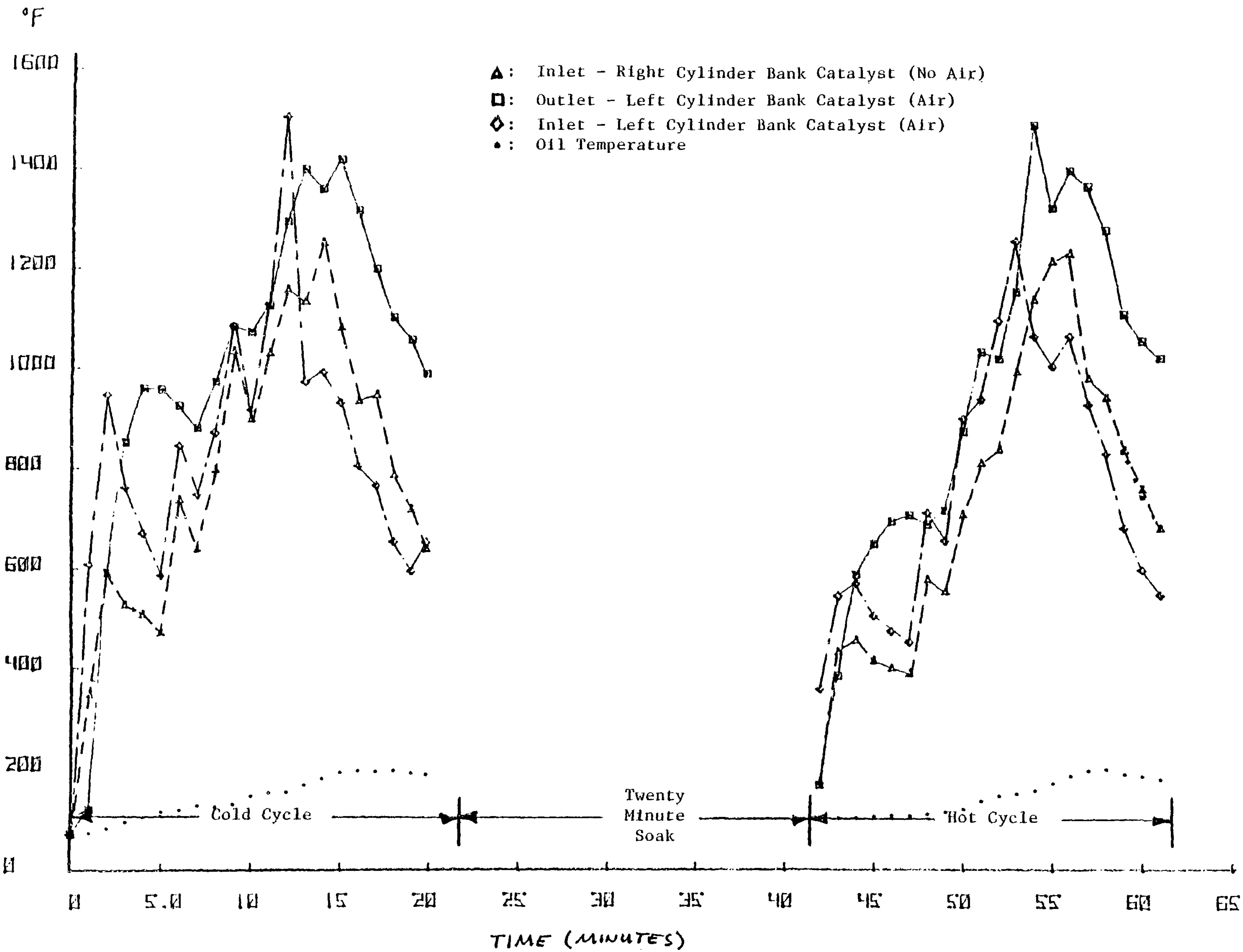


Figure I-5 Catalyst Temperature Data: 20 CFM AIR per Cylinder Bank


°F
1600
1400
1200
1000
800
600
400
200
0
▲: Inlet - Right Cylinder Bank Catalyst (No Air)
◘: Outlet - Left Cylinder Bank Catalyst (Air)
◊: Inlet - Left Cylinder Bank Catalyst (Air)
•: Oil Temperature
Cold Cycle
Twenty Minute Soak
Hot Cycle
0
5.0
10
15
20
25
30
35
40
45
50
55
60
65
TIME (MINUTES)

right and left cylinder banks are presented. Catalyst temperatures on the high power, hot cycle LA Freeway barely exceeded 1500°F, regardless of the air injection volume. At least for this engine, additional air injection did not raise the catalyst operating temperature to a critical level.

In summary, a limited test program conducted at EPA's Motor Vehicle Laboratory achieved emission reductions exceeding those required by the proposed standards on one of the larger gasoline engines in less than two weeks time. The industry, on the other hand, has four years. Based upon this experience, we can only conclude that technology is available to allow compliance with the low-mileage emission targets. As discussed in the "Allowable Maintenance," section of the Regulatory Analysis, a full life, 100,000-mile catalyst is presumed achievable.

4. Recommendations

The proposed standards are attainable for both gasoline and diesel engines.

Retain the proposed standards for Final Rulemaking.

J. Issue - Selective Enforcement Auditing

1. Summary of the Issue

In brief, this issue can be stated as follows: What Acceptable Quality Level (AQL) should be promulgated in the final rule? The AQL represents the percentage of heavy-duty engines (HDE) within a given population which will be allowed to exceed the emission requirements. The Clean Air Act does not specify the AQL to be applied to an assembly-line testing program like SEA.

A 10% AQL reflects EPA's view that the statute requires every engine to be warranted to meet the emission standards while allowing 10% for measurement error and inevitable quality aberrations. A 40% AQL assures that, for an engine population assumed to have a skewed-normal distribution, engines within this population will comply with standards on the average.

EPA promulgated a 40% AQL for its light-duty vehicle (LDV) SEA program because at the time the regulation went into effect, the LDV industry was building vehicles to meet previously established standards on the average. In order to have brought the light-duty vehicle engine families into compliance with a 10% AQL, manufacturers would have had to add additional emission control equipment to retain their certificates of conformity. EPA's intent in promulgating a 40 percent AQL for its light-duty vehicle SEA program was to provide light-duty vehicle manufacturers the time and flexibility to bring all their vehicles into conformance with the standards on a reasonable schedule. This schedule is to parallel efforts to improve fuel economy.

In the HDE Notice of Proposed Rulemaking (NPRM), the Agency proposed a 10 percent AQL as part of the total compliance strategy outlined in the proposal. EPA indicated that the 10 percent AQL could be met within costs not unreasoanbly burdensome to the manufacturers. Comments on costs associated with meeting a 10 percent AQL were requested in the proposal.

2. Summary of the Comments

The manufacturers, and other organizations which responded, were practically unanimous in their opposition to the implementation of a 10 percent AQL. Most of the comments concerned reasons why a 10 percent AQL should not be promulgated. Very little data were provided relating to the actual technological and economic considerations associated with meeting this AQL level or, in many cases, even the much preferred 40 percent AQL. Many manufacturers attributed this lack of data to their inability to run the newly-proposed transient test procedure for heavy-duty engines.

All commentors made one or more of the following three major points: The 10% AQL is contrary to the "Congressional intent of averaging", the 10% AQL effectively makes the standards more stringent than a 90% reduction from baseline, and the 10% AQL is inconsistent with the 40% AQL currently in effect for the light-duty vehicle SEA program. In addition, commentors gave various other reasons why a 10% AQL should not be put into effect: it will cause penalties in fuel economy; it will cause increased costs in the areas of test facilities, production testing, emissions hardware, and fuel consumption; it provides no important air quality impact: and it conflicts with certification requirements which imply "averaging". One commentor suggested that a 40% AQL should be promulgated, after which it could be lowered in the future as was suggested for the LDV SEA program. Another commentor stated that various combinations of emissions standards and AQL should be investigated for cost-effectiveness.

Most manufacturers stated that, due to the above reasons, the AQL should be revised to 40% in the final rule. Some gave examples of a 40% AQL or "averaging" sampling plan that EPA could adopt for the final rule.

a. Gasoline - Fueled Engine Manufacturers

General Motors (also manufactures diesel engines)

GM stated that it is opposed to a 10% AQL sampling plan for SEA. GM believed that Congress did not intend, in the 1977 Clean Air Act Amendments, to impose a more stringent AQL than that required for the LDV program (40%). G.M. asserted that Congress intended averaging for production line testing.

In its SEA discussion, GM directed most of its arguments towards supporting the concept of averaging for production line testing. These arguments included statutory language ("...regulations shall contain standards which require a reduction of a least 90 percent ...from the average of the actually measured emissions..."in Section 202(a)(3)(A)(ii) of the Act); the Draft Regulatory Analysis discussion which GM claims to be based on averaging; ambient air quality considerations; various past Congressional Committee reports and statements of EPA Administrators; consistency with certification requirements; and the analysis of the baseline testing program.

GM also stated that the emissions design target necessitated by the 10% AQL would have to be more than 50% below the target necessary to satisfy the "90%" reduction from baseline. No analysis was provided to support this statement.

Ford Motor Company

Ford stated that it favored a 40% AQL for SEA because that AQL is consistent with Clean Air Act requirements, with certification requirements, and with the current LDV SEA program. Ford also stated that a 40% AQL was needed because of the many new HDE compliance strategies contained in other parts of the NPRM.

This manufacturer believes that technology is not currently available and will not be available by 1983 to enable it to design its engines to comply with a 10% AQL. Ford stated that the 10% AQL SEA is more stringent than certification, which is based on averaging, and that Congressional action and environmental studies have not demonstrated a need for a 10% AQL. Finally, Ford contended that an SEA program in any form would not result in an air quality improvement; however, if such a program was to be conducted, Ford felt that the 40% AQL is the only logical cost-effective alternative.

Ford developed an AQL sampling plan similar to the one proposed by EPA and incorporating a 40% AQL. It suggested that this plan be adopted in the final rule. In the area of economic impact of the SEA regulation, Ford stated that the 10% AQL would require 100% production testing "to ensure an adequate probability of meeting an SEA test order," although Ford did not analyze the relationship between AQL, production testing rate, and the probability of passing an SEA. Ford contended that the 100% production testing would in turn impose additional test facilities, equipment, and plant modifications. The manufacturer stated that a 10% AQL may also reduce assembly line speeds and require more emissions hardware. No analysis of the extent of these effects was provided by Ford.

Chrysler

Chrysler commented that the 10% AQL represents a "considerable increase in stringency" over the 40% AQL and would result in a greater than 90% reduction from baseline. This manufacturer stated that the Clean Air Act does not require every engine to meet emission standards throughout its useful life. Rather, Chrysler believed the Act "compels" averaging because of the Section 202(a)(3)(A)(ii) statement requiring reductions "...from the average of the actually measured emissions...". It stated that deterioration factors are determined through an averaging methodology. Chrysler also pointed out that several statements in the NPRM documents suggest that EPA itself was viewing emissions on an average basis.

The HDE NPRM Preamble stated that a 40% AQL was instituted for LDV SEA "...to avoid an unreasonable economic impact on the industry." Chrysler stated that the "several SEA failures and many close calls" at the 40% AQL level in the LDV SEA program were evidence that the industry is not advanced enough in its production practices to contend with a 10% AQL and that the 10% AQL was therefore unwarranted and unsubstantiated.

In the area of cost impact, Chrysler mentioned two factors associated with a 10% AQL: additional emissions hardware (possibly an expensive 3-way catalyst) and additional manpower for compliance surveillance. No analysis was presented to support these cost increments.

Chrysler advocated adopting a 40% AQL because of economic and technological considerations and because it would satisfy the Congressional intent of averaging.

International Harvester Company (also manufactures diesel engines)

IHC stated that the 10% AQL proposal should be withdrawn until properly evaluated on a cost-benefit basis because of the enormous cost involved. It estimated an SEA at 10% AQL would cost $180 per IHC engine audited for SEA purposes.

IHC believed that Congress did not intend that a 10% AQL be promulgated because that AQL imposes emission standards more stringent than those required by certification. IHC stated that the legislative history of the Clean Air Act indicates that vehicles need only meet standards on the average. In addition, IHC felt that the imposition of a 10% AQL would have an adverse economic impact on the heavy-duty industry, so it should be relaxed as it was in the light-duty vehicle SEA regulations. Specifically, IHC envisioned that the 10% AQL would impose a large in-house quality audit program that would dwarf the costs for test facilities and EPA audit testing. IHC provided estimates of the costs of a building, equipment, and testing.

b. Diesel Engine Manufacturers

Cummins Engine Company

Cummins advocated a 40% AQL because of what it claimed to be the significant variation (possibly 20%) in test-to-test and engine-to-engine variability shown on the current steady-state test procedure. With the proposed decrease in standards, Cummins felt that variability will increase. (Cummins stated that it had done analyses of these variabilities, but they were not provided. It did cite two studies on NOx instrument error and did suspect that varibility could be 60% or more of the proposed standards.) This manufacturer stated that the 40% AQL would allow for this increased variability, which is presumed to also show up on the transient test. Cummins suggested that the AQL could be reevaluated after the new standards go into effect.

Caterpillar Tractor Company

Caterpillar stated that the 10% AQL is not consistent with the previously established concept that heavy-duty engines must meet emission standards on the average during their useful lives. Caterpiller believed the proposed 10% AQL would now require that almost all engines comply with standards. Caterpillar recommended that a 40% AQL be adopted to approximate averaging and thereby retain the original compliance concept. Caterpiller felt that to adopt the 10% AQL would be to require emissions reductions in excess of the 90% from baseline required by Congress in the 1977 Clean Air Act Amendments. This commentor suggested a methodology that could be used to establish a revised standard such that this standard, in conjunction with a 10% AQL, would give average engine emissions representing a 90% reduction from baseline.

Mack Trucks, Inc.

Mack stated that the 10% AQL is not consistent with Congressional intent and with past EPA policy of requiring SEA test vehicles to meet standards on the average (in the LDV SEA program). Mack asserted that a 40% AQL is more representative of annual production and more cost-beneficial. In addition, Mack argued that there is a substantial fuel economy penalty incurred in going from a 40% to a 10% AQL because of lower NOx design targets. Mack did not explain why the change in the NOx design target would be required.

Mercedes-Benz of North America

Mercedes-Benz, a subsidiary company of Daimler-Benz AG, stated that the 10% AQL proposal is without merit. In view of the statement about "...the average of the actually measured emissions.." in Section 202(a)(3) (A)(ii) of the Clean Air Act, Mercedes-Benz considered the 10% AQL to be contrary to Congressional intent, which is that standards are to be met on the average. In the LDV area, Mercedes-Benz noted, EPA has recognized that a 40% AQL corresponds to an averaging concept and, therefore, Mercedes-Benz felt that the 40% AQL should be adopted to determine compliance with heavy-duty engine emission standards.

The Perkins Engines Group (England)

Perkins stated that Clean Air Act enforcement provisions are the same for both the LDV and HDE categories. To impose a 10% AQL for the HDE class when a 40% AQL is currently in effect for the LDV SEA program represents a double standard, in Perkins view, which is all the more arbitrary in view of the fact that LDVs are a greater source of overall ambient emissions than HDEs. This commentor stated that a 40% AQL should be adopted to ensure compliance on the average and to ensure comparability with the LDV SEA program. Perkins suggested that the AQL could then be tightened in the future for both classes.

c. Other Commenters

Motor Vehicle Manufacturers Association

MVMA's main comment was that the 10% AQL is not consistent with an averaging concept for determining compliance with standards. Its arguments were based on the legislative history of the Clean Air Act, statements of past EPA Administrators, the averaging concept embodied in certification regulations, ambient air quality studies based on averages, the statutory language in Section 202(a)(3)(A)(ii), and the inclusion of averaging concepts in the Regulatory Analysis for the NPRM.

Engine Manufacturers Association

EMA stated that the intent of Congress was that production engines should meet standards on the average. EMA contended that the present 40% AQL for the LDV SEA program approximates averaging and thus conforms to Congressional intent. EMA indicated that EPA has shown no rational basis for imposing the much more stringent 10% AQL and urged adoption of the 40% AQL.

U.S. Department of Commerce

The Department of Commerce (DOC) commented that there is no rationale in the NPRM for a 10% AQL. DOC stated that the 10% AQL is "exceedingly stringent" relative to the 40% AQL in the LDV SEA program. The 10% AQL will cause a drastic increase, DOC believed, in the stringency of the standard to account for unavoidable production variations. DOC stated that a 10% AQL may not be technologically feasible, would adversely affect fuel economy, and would cause substantial cost increases. DOC did not, however, provide any data or analysis to support these claims. A 40% AQL should be adopted, DOC concluded, to ensure meeting standards on the average.

U.S. Council on Wage and Price Stability

COWPS recommended that a cost-effectiveness study of the 10% AQL be performed to evaluate its economic and social worth as part of the NPRM. COWPS suggested that an estimate of the emission reduction in going from a 40% AQL to a 10% AQL can be made, given the statistical distribution of assembly-line engine emissions.

COWPS also asserted that the average emission levels necessitated by the 10% AQL would be appreciably lower than those required by the 90% reduction, i.e., than the 40% AQL levels which approximate average emissions, but they provided no analysis to support this conclusion. If EPA desires only a 90% reduction in average emissions, COWPS suggested that the numerical standards be raised so that the average emission level with a 10 percent AQL coincides with a 90 percent reduction from the baseline average. Regardless of the combination of numerical standards and AQL that is ultimately promulgated, COWPS felt that combination should have satisfied the test of cost effectiveness.

3. Analysis of the Comments

Since many of the manufacturers and organizations responding made similar comments on the AQL issue, each of the major comments will be discussed under a separate heading in this section for purposes of clarity. For further information relating to the 10% AQL issue, reference is also made to the cost-effectiveness studies in Chapter VII of the Regulatory Analysis and to the discussion of the technological feasibility of the emission standards in the Summary and Analysis of Comments.

a. The 10% AQL is Not Contrary to Congressional Intent

When reviewing the comments to the NPRM on SEA for light-duty vehicles in 1976, the EPA Office of General Counsel (OGC) reached a finding that "...Congress intended that, eventually, every car coming off the assembly line should meet the emission standards established under Section 202." A copy of the memorandum containing this finding is available in the Public Docket for this Rulemaking. OGC acknowledged that a phasing in of this requirement was appropriate to avoid implementing SEA in an unreasonably burdensome manner, so long as the ultimate goal of full compliance is not abandoned. As explained in the LDV SEA preamble (41 FR 31474, July 28, 1976), auto manufacturers argued that implementation of a 10% AQL would have a disastrous economic impact on the industry, since it would result in a loss of certification for a majority of engine families. A 40% AQL was therefore established to implement SEA in a manner not unreasonably burdensome to the affected manufactures. This approach was designed to "provide manufacturers the time and flexibility to bring all their vehicles into conformance with the standards on a reasonable schedule" (41 FR 31475).

Authority for SEA testing of heavy-duty engines is the same as for LDVs (Section 206(b) of CAA). EPA maintains the position that there is a specific legal basis for requiring every HDE coming off the assembly line to meet standards. The full text of the EPA General Counsel memorandum, mentioned above, explains how, in fact, the language of the Clean Air Act and the relevant legislative history support an "every car" approach to compliance with emission standards.

The ultimate goal of every vehicle and engine complying with emission standards is also supported by the U.S. General Accounting

Office (GAO). The GAO did not take issue with EPA's legal interpretation of the Clean Air Act on this matter and recommended that the current LDV SEA program be revised to "...require a Federal emission standard compliance rate more indicative of the current rate for car configurations tested, which is well in excess of the 60% passing rate required." (GAO Report CED 78-180, p. 28).

b. The Relationship Between the Standards and a 10 Percent AQL

Section 202(a)(3)(A)(ii) of the CAA states, in pertinent part, "...regulations... applicable to emissions from vehicles or engines manufactured during and after model year 1983, in the case of HC and CO, shall contain standards which require a reduction of at least 90%... from the average of the actually measured emissions... during the baseline model year." Pursuant to this requirement, EPA conducted a test program on 1969 model year heavy-duty gasoline engines (the last model year before imposition of HC/CO standards for heavy-duty engines). Using the sales-weighted average emission levels obtained during this program, the standards were then set by multiplying these levels by 10 percent, i.e., a 90 percent reduction. These numbers once identified, then became the required standards. The 10 percent AQL does not change the values of the standards; it merely requires that every production engine must comply with the established standards. This is consistent with EPA's finding as discussed in Section 3(a), that every production engine must comply with standards established under Section 202 of the Clean Air Act.

EPA has performed an analysis which indicates that a 10% AQL can cause a manufacturer to design to lower target emission levels than those required by a 40% AQL. However, the magnitude of the difference between the target levels depends on several factors, some of which are within the manufacturer's control. One of the most important of these factors is the variability of identical production engines ("width" of emissions distribution) at each design level. By increasing quality control and minimizing other variations in the manufacturing and assembly process, the manufacturer may reduce variability and raise the target emission levels which he needs to be meet. In practice, the Agency believes that each manufacturer will trade off to one degree or another lower design targets vs. stepped-up quality control to obtain the most cost-effective approach towards the 10% AQL goal.

c. The Consistency of the 10% AQL With the 40% AQL Currently In Effect for the Light-Duty Vehicle SEA Program

The 40% AQL was established for the LDV SEA program to implement the program in a manner not unreasonably burdensome to the affected manufacturers. At the time LDV SEA was proposed, several auto manufacturers stated that they built the average production vehicle to meet the standards. It is important to note that the situation regarding LDVs and the 10 percent AQL is different from that relating to heavy-duty engines. As discussed in the Preamble to the LDV SEA regulations:

> "The approach taken here, then, of not setting the AQL at 10% will provide manufacturers the time and flexibility to bring all their vehicles into conformance with the standards on a reasonable schedule. Such a schedule can be compatible with their parallel efforts to improve fuel economy and which does not expose them unduly to the risk of loss of certification while they are learning to bring their production vehicles into compliance with the law." (41 FR 31475, July 28, 1976)

The circumstances under which the HDE SEA program is being promulgated are significantly different than those in the LDV case. Within the constraints of the CAA, EPA is authorized to set the standards for the HDE industry. The Agency can, therefore, take the effect of a 10% AQL into account when considering whether revised standards or more stringent statutory standards should be set. Moreover, the affected industry has 4 years leadtime before the standards and the SEA program go into effect, so that manufacturers can plan their design targets so as to have all production engines in compliance with the law starting in 1984. EPA's approach in both the LDV and HDE cases is a consistent one: The Agency has endeavored to implement an SEA program consistent with its legal interpretation that every vehicle or engine must meet standards and in a practical manner that does not place an unfair or unreasonable economic or technological burden on the affected industry. In the HDE case, the Agency has determined that the final standards, in combination with a 10% AQL, are not unreasonably costly to the affected manufacturers and are technologically attainable within the 4-year timeframe.

d. The Effect of the 10 Percent AQL on Fuel Economy

Based on assessments of technological feasibility by EPA's Office of Mobile Source Air Pollution Control (OMSAPC), there will be no fuel economy penalty in designing to meet the 10% AQL emissions targets. The 10% AQL imposes a NOx target level already being bettered by most heavy-duty diesel engines, so EPA does not accept Mack's contention that a lower NOx design target would be required that would in turn result in a substantial fuel economy penalty. In fact, EPA analysis indicates no loss in HDD engine fuel economy and a 4-9% benefit in fuel economy for HDG engines.

In the case of heavy-duty diesel engines, no fuel economy penalty is expected due to modifications to meet the required design targets. The slight penalty resulting from use of exhaust gas recirculation controls are expected to be offset by more fuel efficient emission control techniques, such as aftercooling and improved injector design.

For heavy-duty gasoline engines, OMSAPC anticipates that high-efficiency catalysts will be developed to comply with the regulatory requirements. The use of catalysts allows engines to be tuned for fuel economy, as opposed to non-catalyst equipped engines, where the engine must be tuned to comply with the emission standards which could cause possible fuel economy penalties.

e. <u>If a 40% AQL is Promulgated, It Could Be Lowered in Future Model Years As Was Suggested in the LDV SEA Program</u>

As discussed in 3.a., the Act has an established legal basis for promulgating a 10% AQL. As discussed in 3.c, the Agency has the opportunity, in this rulemaking, to set standards and an AQL such that no unreasonable burden will be placed on the HDE manufacturers in terms of their ability to comply with all aspects of the total regulatory strategy. Perkins Engines Group stated that the AQL should be the same for both the HD and LD classes. It is not EPA's intention to ensure absolute comparability between the two classes, but rather to set an AQL consistent with its legal interpretation of the Clean Air Act and the production capabilities of the affected industry at the time that both emission standards and AQL go into effect.

EPA has determined, based on available information and analysis of its own and manufacturers' data, that a 10% AQL can be implemented in 1984 on a cost-effective basis. Therefore, EPA does not see the need to first promulgate a 40% AQL and then lower it in future model years to the legally required 10% level.

f. <u>Air Quality Impact of a 10 Percent AQL</u>

EPA has performed an analysis of the reduction in emissions to be obtained in going from a 40% AQL to a 10% AQL in the SEA program. This analysis appears in Chapter VII of the Regulatory Analysis. The findings of this analysis indicate that by implementing a 10% AQL, HDG HC emissions will be reduced an average of 0.04 tons per vehicle over the vehicle's lifetime, HDG CO emissions will be reduced 0.5 tons, and HDD HC emissions will be reduced 0.24 tons.

As shown on Tables VII-1 and VII-2 in the Regulatory Analysis, there reductions represent a positive reduction in HC and CO for HDG and HDD engines which EPA analyses have shown can be achieved in a cost-effective manner. On the basis of dollars spent per ton of emissions removed the 10% AQL compares favorably with other emission control strategies.

g. Relationship of a 10 Percent AQL Program to Certification Requirements

Several commenters indicated that they felt the present certification program embodied an averaging concept which conflicted with the concept of a 10 percent AQL. They argued that consistency required use of a 40 percent AQL so that essentially the average engine emission level would meet the standards.

The staff does not agree with this contention. The purpose of the certification program and an SEA progam are complementary and do not conflict. Section 206 of the Clean Air Act, "Motor Vehicle and Motor Vehicle Engine Compliance Testing and Certification", authorizes a certification program (206(a)) and an assembly line testing program (206(b)). If a new motor vehicle or engine design demonstrates compliance with Section 202 standards throughout its useful life, a certificate of conformity will be issued under 206(a) regulations. The certificate is issued with respect to Section 202 regulations, i.e., regulations establishing emission standards. Since the function of the assembly line testing program is "to determine whether new motor vehicles or engines being manufactured do in fact conform with regulations with respect to which the certificate of conformity was issued" the program will determine compliance with emission standards.

In summary, the EPA certification and SEA programs attempt to accomplish different but related objectives. Through certification, a manufacturer demonstrates that it has the capability to design a vehicle or engine that will comply with standards throughout its useful life under conditions simulating actual use. Once these prototype vehicles or engines demonstrate compliance, EPA issues the manufacturer a certificate of conformity allowing it to actually manufacture vehicles or engines similar to the prototypes for distribution into commerce. Then SEA requires the manufacturer to demonstrate that newly manufactured vehicles or engines will also comply with standards thoughout their useful lives.

h. Cost Impact of the 10 Percent AQL on Heavy-Duty Engine Manufacturers

There is a cost component attributable to the 10% AQL, as there is to all other compliance options in the regulatory package. A heavy-duty engine manufacturer will actually incur a "10% AQL" cost in those cases where it experiences difficulty in attaining the target emission levels, i.e., when the manufacturer must spend more money in going to the 10 percent AQL target level from some other (higher) level, and where it decides to step up its in-house quality control programs in response to a 10 percent AQL.

A cost-effectiveness analysis has been performed in conjunction with the evaluation of this regulation. One option examined was the cost of the proposed SEA program at a 40 percent AQL versus its cost at a 10 percent AQL. The analysis indicated that the 10 percent AQL SEA program is the more expensive option, but that the cost of moving to the 10 percent AQL is small relative to other options in the regulation, and also, in view of the benefit in air quality, the 10 percent AQL has a favorable cost effectiveness ratio that is in line with the other compliance strategies in this regulation.

4. Staff Recommendations

It is recommended that a 10 percent AQL be promulgated in the Final Rule. An SEA program with a 10 percent AQL is consistent with EPA's legal interpretation of the Clean Air Act, does not place unreasonable cost burdens on heavy-duty engine manufacturers, results in a positive reduction in emissions, has no impact on fuel economy, and is technologically feasible, given the emission standards to be promulgated.

K. Issue - Nonconformance Penalty

1. Summary of the Issue

This issue concerns the system for production compliance auditing (PCA) and nonconformance penalties (NCP) proposed in the NPRM. Since the proposed emission standards were considered feasible for all manufacturers to meet, nonconformance penalties were not made available in the NPRM.

As described elsewhere in this Summary and Analysis of Comments (see I. "Technological Feasibility"), the EPA staff still believes that the standards are attainable by all manufacturers. However, to provide for isolated instances when compliance may not be attained due to unforeseen circumstances, the staff recommends that the PCA/NCP system be made available. Since the NPRM did not contain either a proposed "upper limit" different from the standards, or the marginal cost component of the general penalty formula, reproposal will be required. Therefore, the PCA/NCP system should proceed as a seperate rulemaking and no detailed analysis of the comments received will be done at this time.

2. Recommendations

The PCA/NCP portion of the original proposal should be separated from the final rulemaking and reproposed. It should be reproposed with the addition of upper limits on certification and the marginal cost component of the general penalty formula. An opportunity for comments will be provided for all aspects of the reproposed PCA/NCP regulations.

The preamble to the final rulemaking, in describing the removal of PCA/NCP from the package, should make it clear that EPA's intent is for all manufacturers to comply with the standards, and that manufacturers should proceed in that fashion. It should be explained that the availability of a nonconformance penalty is more of a "safety valve" for unforeseen complications than a route to a less stringent emission standard (via designing for a higher emission rate and planning on paying a penalty for all engines). Reproposal and finalization of PCA/NCP at a later date does not relate in any way to any statutory leadtime requirements for finalizing the heavy-duty engine emission standards.

L. Issue - Diesel Crankcase Emissions Control

1 Summary of the Issue

The proposed regulations require that "[n]o crankcase emissions shall be discharged into the ambient atmosphere" from 1983 model year (and later) heavy-duty diesel engines. A similar requirement has been in effect for gasoline engines for a number of years; this is the first time EPA has proposed to regulate diesel crankcase blowby.

2. Summary of the Comments

The proposed crankcase controls for diesel HDE's drew considerable adverse reaction. Both EPA's justification and feasibility issues were addressed by most of the commentors.

Several comments pointed to the low brake-specific hydrocarbon and carbon monoxide emissions from HD diesel crankcases as evidence of a lack of need for controls. Additionally, the information quoted in the NPRM is inconclusive in establishing the presence of nitrosamines in diesel blowby emissions.

The feasibility of controlling the crankcase emissions was challenged on the basis that most HD diesel engines will be equipped with turbochargers and intercoolers/aftercoolers by 1983. The anticipated technical problems arise from the oily nature of the blowby emissions which in a simple system would be introduced into the inlet air supply. Although in a naturally-aspirated engine the slight negative pressure of the manifold can draw crankcase fumes into the combustion chamber, the manifold of a turbocharged engine is under greater pressure than the crankcase. Thus, unless it is pressurized, the blowby must enter the stream on the inlet side of the turbocharger, allowing the oily emissions to become deposited on the compressor wheel. Similarly, the heat transfer surfaces of the heat exchangers can become coated with the residues. Several of the commenters indicate that such events can hamper the efficiency of both of these components. Loss of turbo efficiency can detrimentally affect performance, fuel consumption, and emissions. The commenters also expressed a concern that turbo durability will suffer and increased maintenance will be necessary.

Mack Trucks has tested a turbocharged engine equipped with crankcase gas recirculation and observed a decrease in performance and an increase in fuel consumption and smoke opacity. The intercooler also became plugged appreciably.

Finally, Cummins Engine Company mentioned four means of crankcase control which may have potential, none are developed to the extent of assessing their feasibility. These four alternatives follow:

1) Duct gases to turbo-inlet by way of a pressure regulator and oil separator (this method has resulted in severe loss of turbo efficiency).

2) Draw gases through the regulator and separator and a pump to the manifold, downstream of the turbo (an expensive alternative; still requires much development work to ascertain whether it is satisfactory).

3) Aspirate and mix gases into the exhaust flow.

4) Pump the gases through the regulator and a separator into the exhaust stream.

3. Analysis of the Comments

The heavy-duty diesel crankcase emissions data reported in "Diesel Crankcase Emissions Characterization, Final Report of Task No. 4, Contract No. 68-03-2196," referenced in the NPRM, have been updated with one Cummins engine. The additional engine showed HC, CO, and NOx crankcase emissions (g/BHP-hr) which were very comparable to thse reported previously and lend creedence to the earlier, limited data.

Estimates of the cost effectiveness of requiring control of the major crankcase pollutants may be calculated by dividing the anticipated control system costs by the expected lifetime emissions, in tons. Since all four major pollutants are controlled by the system, it is appropriate to distribute the system cost equally among the four pollutants. So for each pollutant one-quarter of the system cost is divided by the tonnage of lifetime emissions, as represented by the product of the emission rate and the total time of engine operation. The resulting cost-effectiveness numbers can be compared to those associated with other control strategies for a measure of the acceptability of the costs.

The following crankcase emission rates are taken from the "Final Report" referenced above:

	Emission Rate (grams per hour)*			
	HC	CO	NOx	Part.
Cummins NTC-350	0.63	2.48	1.15	1.02
DDA 6V-71 #1	0.77	0.06	0.04	0.75
DDA 6V-71 #2 (Std. Speeds)	0.69	0.45	0.39	2.11
DDA 6V-71 #2 (Low Speeds)	0.39	0.44	0.22	--
Mean	0.62	0.86	0.45	1.30

* Grams/hour numbers were not available for the Cumins engine.

These estimated rates of emissions would be seen over an average lifetime for HD diesels of approximately 475,000 miles. Using 3,000 hours of operation to represent each 100,000 miles, the expected lifetime is 14,250 hours. (As a rough check, 475,000 miles at 40 mph yields 11,850 hours).

Finally, a control system cost estimate is needed. We have very little information on which to base such an estimate, but Caterpillar quoted in their comments the following anticipated costs for PCV systems:

Engine	Estimated System Cost
3208T (Naturally aspirated)	$ 10
3306 (Turbocharged and aftercooled)	135
3406 (Turbocharged)	145
3408 (Turbocharged and aftercooled)	145

For the purposes of this cost-effectiveness calculation, we will use $10 for naturally-aspirated engines and $100 for turbocharged engines. The $100 figure assumes a turbocharger-bypassing system as described below (Caterpillar provided no information to support their higher numbers).

Distributing these costs among the pollutants and coverting grams to tons, we created the following table:

	Cost Effectiveness of Control ($/Ton)	
Pollutant	Naturally Aspirated	Turbocharged
HC	$257/Ton HC	2,570/Ton HC
CO	185/Ton CO	1,850/Ton CO
NOx	354/Ton NOx	3,540/Ton NOx
Particulate	123/Ton Part.	1,225/Ton Part.

To have meaning, these cost-effectiveness numbers must be compared with the cost effectiveness of other emission control programs. Listed below are ranges of cost effectiveness covering most of EPA's stationary and mobile source control programs:

Pollutant	Cost-Effectiveness Range ($/Ton)
HC	70 - 800
CO	10 - 40
NOx	100 - 2500
Particulate	10 - 1000

It is clear that crankcase control on turbocharged engines is not as cost effective as other control programs for any of the four pollutants. However, controls on naturally-aspirated engines fall in the "acceptable range" for HC, NOx and particulates. Since the costs were allocated equally among four pollutants, we could now re-compute the cost effectiveness when the costs are distributed only among HC, NOx, and particulate. Performing this calculation yields the table below:

Pollutant	Cost Effectiveness of Control ($/Ton)	
	Naturally Aspirated	Turbocharged
HC	342	3,420
NOx	472	4,715
Particulate	163	1,630

These final cost-effectiveness numbers are still in the acceptable range, and the staff concludes from this analysis that crankcase controls on naturally-aspirated engines are justified on the basis of HC, NOx and particulate control. (Routing crankcase NOx emissions through the combustion chamber will not actually eliminate them. However, controls on naturally-aspirated engines remain cost effective even when credited to HC and particulate control alone).

On the other hand, if nitrosamines are found to be a significant component in crankcase emissions, a considerably more costly control system might be acceptable. Preliminary data from current heavy-duty diesels indicates that nitrosamines may indeed be present. The complete and reduced data will not be available to EPA until late in 1979.

Finally, the staff has explored the feasibility question, which to a large extent revolves around the compatibility of crankcase controls with turbochargers and associated heat exchangers (intercoolers and/or aftercoolers). Of course, these components are not present on naturally-aspirated engines and hence there are no major technical problems with crankcase control on these engines. Naturally-aspirated engines in 1979 comprise 23 percent of the heavy-duty diesel market*, a fraction that is expected to rapidly drop even further as manufacturers use turbocharger technology to respond to fuel economy pressures. Still, the ease of application and low cost of controls on naturally-aspirated engines make controlling this portion of the market a reasonable option.

Alternative #2 suggested by Cummins in their comments (Summary of Comments above) seems very worthy of pursuit for turbocharged engines. By allowing the turbocharger and heat exchangers to be bypassed, the oil separator/ pump/pressure regulator configuration would eliminate the excessive deterioration of the component efficiencies. (The pump itself might be affected to some degree by the oily emissions.) While it is clear that such a system has yet

* Based on 1979 certification data.

to be developed for diesel engines, the staff perceives no major technical obstacles to impede the design; pump technology in general is highly advanced. Notwithstanding the cost, which will probably exceed $75, the staff is convinced that a pumped system is a technologically-feasible option for 1984. (It is interesting to note that a 1980 GM turbocharged engine is already equipped with crankcase controls, though probably the turbocharger is not by-passed).

4. Recommendations

We conclude from the foregoing analysis that a crankcase control system for naturally-aspirated engines is feasible and may be justified on the basis of HC, NOx, and particulate control. However, controls for turbocharged HD diesels are not expected to be cost effective for HC, CO, NOx or particulate control. We do expect that the forthcoming nitrosamine emission data will warrant a serious reconsideration of the need for controls. Further, we conclude that a system using a pump to bypass the turbocharger can be developed, if necessary, for 1984 model year engines.

Our recommendation is that diesel crankcase control requirements be retained for naturally-aspirated diesels but that the finalizing of control requirements be postponed for turbocharged engines pending the completion of the nitrosamine research now in progress. Significantly, we urge that the Preamble of the HD Gaseous Final Rulemaking clearly make the following points:

1. EPA anticipates that crankcase controls on turbocharged diesels will be necessary for the control of nitrosamine emissions. The proposed requirements for these engines are not being finalized at his time and will remain proposed until such a time that new nitrosamine emissions data is available (probably in late 1979). In the event that EPA decides to pursue a final rulemaking for these provisions on the basis of the new data, the Public Docket will be reopened for comment specific to this topic. A public hearing will be held if requested.

2. EPA is convinced that a control system employing a pump can overcome turbocharger and heat exchanger efficiency and durability problems and can be developed for the 1984 model year.

M. Issue - Numerical Standards/Standards Derivation

1. Summary of the Issue

EPA has proposed new emission standards for heavy-duty engines:

1.3 g/BHP-hr HC
15.5 g/BHP-hr CO
10.7 g/BHP-hr NOx

The HC and CO standards are based upon a 90 percent reduction from an actually measured uncontrolled baseline; the NOx standard was derived to reflect no greater stringency than today's standards. All standards were based upon the transient test procedure.

2. Summary of the Comments

a. Inability to Comment

All manufacturers claimed a distinct inability to comment on the proposed standards derived from the transient procedure. First of all, the industry argued that lack of experience with the transient test and lack of equipment to gain this experience essentially deprived them of their opportunity to meaningfully comment. EPA purportedly restricted the industry even moreso by failure to propose actual standards with the 2/13/79 NPRM. In Mack's words, this delay in announcing standards until May 1979, plus overall inexperience with the transient test, effectively resulted in a "deprivation of due process."

b. Standard Stringency

The industry also argued that the proposed standards, both above and in the context of the remainder of the proposed rules, were substantially more stringent than Congress intended. The 90 percent HC and CO reductions called for in the Clean Air Act Amendments were characterized as "merely targets." Yet in context with a 10 percent AQL and a full useful life, HC and CO reductions in excess of 90 percent will be required. Several manufacturers also characterized the 10.7 g/BHP-hr NOx standard, intended to reflect equivalent stringency with today's standard, as more stringent than required.

c. Standard Derivation

The methods of standard derivation were also criticized, both in concept and in implementation. Cummins argued that EPA has done no health effects study to support these proposed standards and advocated standard setting based upon health effects, and not simply percentage reductions.

HC and CO standards were actually derived by a 90 percent reduction from a baseline of in-use 1969 gasoline engines. Specific criticism of this Baseline Program and the resulting standards derivation were:

(i) Twenty-three engines were too small a sample.

(ii) The engines tested were unrepresentative, based upon inconsistent accumulated mileages, too small displacements, inappropriate pre-test tune-up procedures, and unrepresentative in-use applications.

(iii) No deterioration factors were computed into the measured baseline emission levels, nor were the allowable maintenance criteria required by the proposed rules followed in the Baseline Program.

(iv) Test validation criteria were relaxed to such an extent that unrepresentative and unrepeatable emission results were generated. EPA's inability to stay within tolerances is indicative of flaws in the test procedure.

(v) Proposed humidity tolerances were consistently exceeded in the baseline program. The need for these tolerances was questioned.

(vi) Motoring at -10 percent of maximum torque in place of closed throttle resulted in a significant underestimation of emissions, thereby lowering the baseline levels and the resulting standards.

(vii) A sales-weighted emissions average by definition is lower than some of the emissions used to generate the average. Therefore, a standard based upon a 90 percent reduction from this average represents more than a 90 percent reduction for many of the engines tested. It was suggested that a 90 percent reduction from the 90 percentile be used in deriving the standards.

Finally, EPA's derivation of the interim NOx standard was also criticized. Industry argued that EPA's derivation resulted in too stringent a standard.

3. Analysis

a. Inability to Comment

A detailed discussion of the industry's ability to comment on the proposed rules and standards is contained in the Test Procedure section of the Summary and Analysis of Comments. In short, the industry has been regularly advised and informed throughout the seven years that the transient test was being developed. EPA has openly broadcast its intention to promulgate a transient procedure for several years. Data from the 1969 Baseline Program was regularly disseminated; manufacturer's representatives personally witnessed transient tests at the EPA lab in eary 1978. An MVMA task force with participation by EPA representatives initiated prototype transient testing at Cummins in the summer of 1977. Since then the majority of the heavy-duty industry has done little to acquire transient capability. The industry's inability to comment is largely self-imposed. EPA can only reiterate the fact that all data available to the Agency was freely and openly disseminated.

Furthermore, EPA believes that sufficient technical information was made available to allow well reasoned and accurate analyses on the part of the manufacturers. Second-by-second cycle listings were provided in the NPRM, allowing exact computation of the engine's required operational modes. Gasoline engine manufacturers acknowledged unanimously that catalyst technology would be necessary; in-use catalyst durability is the most difficult technical hurdle for the industry to clear, yet assessments of on the road catalyst temperature sensitivity are not dependent upon the ability to run the transient emissions test. Two diesel manufacturers were able to submit actual transient data on their engines (Cummins and Caterpillar); transient diesel emission data collected at SwRI on several engines was distributed to the industry for their analyses - data from over thirty baseline and current technology gasoline engines was made available. In general, a given manufacturer's inability to run a given engine over the transient cycle did not preclude the industry's ability to comment. Sufficient data was available to allow characterization of the present state of the art of emission control and to allow a reasonable judgement as to the viability of compliance technologies.

EPA is well aware that final numerical standards were not proposed with the 2/13/79 NPRM because the 1969 Baseline Program was still underway. Upon publication of the final numerical standards and the technical report outlining baseline testing methodology and results in May of 1979, EPA fulfilled its legal obligation by allowing an additional two and one-half month comment period and an additional Public Hearing. Furthermore, the finalized standards were extremely close to the NPRM's "best estimate" of 1.4 g/BHP-hr HC and 14.7 g/BHP-hr CO. The NPRM also explained that EPA would not finalize standards less than .76 g/BHP-hr HC and 11.4 g/BHP-hr CO without reproposing, in the unlikely event that baseline emissions would end up that low. In short, the industry had six full months and two Public Hearings to submit their comments and opinions on the Proposed Rules. For the first three months of this comment period, EPA published a lower limit of emission levels below which the standards would not fall. For the last two and one-half months the final numerical standard were available and open to public comments and hearings. In summary, EPA has more than discharged its legal obligation to allow comment on both the proposed rules and standards.

. Standard Stringency

Section 202(a)(3)(A)(ii) of the Clean Air Act Amendment of 1977 empowered EPA to establish HC and CO emission standards which represent a reduction of "at least 90 percent" from uncontrolled levels, provided such reductions are technologically and economically feasible. The interim NOx standard is intended to be no more stringent than today's standard.

It is EPA's position that the 90 percent reductions of HC and CO represent the laxest standards desired by Congress, providing the resulting reductions were proven to be technologically feasible, cost effective, and directly relatable to improvements of the public health* and welfare. The standards in themselves are no more stringent than those required. Furthermore, these minimum reductions are feasible at reasonable cost, and result in concrete air quality benefits.**

In the context of the rest of the proposed rules, ECTD recognizes that additional emission control will be required, but only to insure that the mandated reductions will actually be achieved on the road.

Most commenters argued that adoption of the transient test procedure resulted in significantly more stringent standards. There is no doubt that more effective emission control is required at the levels of the proposed standards for the transient procedure. This is not indicative of greater stringency on the part of the transient procedure, however, but rather an indication of the laxity and inadequacy of the current steady-state procedures at lower emission levels. Note that both procedures yielded comparable HC and CO emission levels for uncontrolled engines in the 1969 baseline, yet at the lower levels of current technology engines the steady-state procedures seriously underestimate emissions expected to be seen in-use. That the transient procedure appears more stringent is due solely to the defeatability and laxity of the current procedures.

The 10 percent AQL requirement allows no more than 10 percent of the engines rolling off the assembly lines to exceed the standards as opposed to the 40 percent allowed for light-duty vehicles. Furthermore, the full useful life concept requires increased durability of emission-related equipment. The manufacturer has the

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* See below, Section, "Standard Derivation" - health effects.
** See Regulatory Analysis and Summary and Analysis of Comments for the particular issue.

option in both cases to select a lower low-mileage emission target to compensate for production variability and for higher deterioration factors. The manufacturer has other options, however: to enhance the durability of the emission control equipment and to reduce production variability. Either of these options relaxes the need for reducing low mileage targets and will be used to some degree. ECTD recognizes however, that the predominantly used option will most likely be lower target levels. In effect, this is not an increase in the stringency of the actual standards, however. These additional restrictions on compliance represent stringency over and above the numerical standards, and assure in-use compliance. (See the pertinent analyses on the Summary and Analysis of Comments - Selective Enforcement Auditing and the Redefinition of Useful Life, for arguments pertaining to justification.)

With regard to the stringency of the numerical HC and CO standards, ECTD can only claim that they represent a true 90 percent reduction from the uncontrolled baseline, as specified by Congress. Furthermore, as discussed in the Summary and Analysis of Comments relating to Technological Feasibility, the standards are achievable within reasonable cost. Finally, concrete air quality improvements have been proven to be directly relateable to these standards. The remainder of the package is designed to insure that the 90 percent reductions will actually be achieved in-use.

c. Standards Derivation

Cummins took issue with EPA's concept of standard derivation, claiming that EPA's concentration on strict percentage reductions from a baseline was narrow minded and not cognizant of the true basis of any pollutant standard, i.e., the protection of public health and welfare. Cummins argued that EPA should have assessed the health effects of HC and CO arising only from the heavy-duty source, and set standards for heavy-duty based upon the impact on public health of this single source. Cummins argued that use of the National Ambient Air Quality (NAAQ) standards was not an adequate substitution for the Congressionally mandated pollutant-specific study. In short, Cummins claimed that standards should have been derived per Section 202(a)(3)(E) of the Clean Air Act Amendment, and not per 202(a)(3)(A) as was done by EPA. Beyond this broad, philosophical interpretation of the derivation procedure, however, Cummins did not identify specific details and methodologies of practical implementation. Furthermore, Cummins did not quantify nor try to quantify the specific impact of this philosophical approach upon the actual 1.3 g/BHP-hr HC and 15.5 g/BHP-hr CO standards.

EPA takes strong issue with Cummins assertion that the Agency has "resisted a mandated regulatory process"* by purportedly

* Cummins' August 14, 1979 Supplemental Submission, p. 11.

ignoring health effects during the standard derivation process. While no single document with the specific title "Pollutant Specific Study - Heavy-Duty Vehicle Sources" was published prior to this rulemaking all information which would have appeared in such a document, however, was published with the Draft Regulatory Analysis accompanying the proposed rules, or referred to therein.* The adverse health effects of overexposure to HC, CO, and NOx are well documented in the literature and well known throughout the Congress and the industry. It is EPA's present intent to submit the information contained in the Regulatory Analysis to Congress to satisfy this reporting requirement.

Contrary to Cummins' assertions, the driving force behind the proposed standard is the health issue, defined by EPA in terms of the NAAQ standards. The standards were derived specifically to define the maximum level of pollutant concentration that people could be exposed to without experiencing adverse consequences to their health. It was shown in the Draft Regulatory Analysis that 103 out of 105 urban areas of population in excess of 200,000 were in violation of the NAAQ standards and therefore represent a potential health risk to over 100 million people.

The 1980's will be a decade in which no given source of pollution will be singled out as the major polluter. Any improvement in air quality will not be accomplished by eliminating a single source (e.g., light-duty vehicle standards represent the lowest achieveable with current technology), but through a concerted effort directed at all contributing sources. The contributing source addressed here are heavy-duty vehicles. Based upon EPA's analysis, heavy-duty emissions could be reduced by 100 percent and still not bring most urban areas into compliance with the NAAQ's. Given the health derivation of the NAAQ's, this implies that any percentage reduction of heavy-duty emissions, even 100 percent, would be "health effective."

This is the basis for EPA's approach: given the fact that violation of the NAAQ's are commonplace, any standard with which compliance is feasible and cost effective cannot help but be "health-effective" if it results in a tangible air quality improvement. EPA recognizes the fact that a reduction of 90 percent is not immutable and has extensively reviewed the standards for feasability and economic impact. In the context of the rest of the proposed rules, however, a 90 percent reduction from the uncontrolled baseline is close to the maximum reasonably achieveable with current and future technology at reasonable cost. It is significant to note that Cummins could not identify a difference

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* See Chapter IV OF Draft Regulatory Analysis, "Environmental Impact." Also see Chapter III of "Air Quality, Noise and Health," Report of a Panel of the Interagency Task Force on Motor Vehicle Goals Beyond 1980, March 1976.

between EPA's proposed standards and standards derived per their suggested approach. The ECTD staff believes that any incremental standard reduction is health effective, and the level of standards are impacted solely by the question of technological feasibility. The support documentation for this regulatory action adequately outlines the health-based rationale for the proposed standards and satisfies the Congressional intent that such an analysis predicate any standard derivation.

The standards derivation process embodied within the 1969 Baseline Program* received several procedural criticisms.

(i) Twenty-three engines comprised the data base from which the standards were derived. Many commenters argued that more engines were necessary to adequately characterize uncontrolled emissions.

ECTD disputes this claim on the basis of Figures M-1 and M-2. Here the sales-weighted average emissions are presented as they evolved with each additional engine added to the baseline, along with the percent change of the average with each additional engine. The last seven engines tested changed the baseline HC and CO averages by no more than ±1.6 percent. The last two engines changed the HC average by $\overline{0}.0$ percent. Testing of more than 23 engines for baseline purposes would have been redundant and would have delayed promulgation for no valid reason.

(ii) The engines tested in the 1969 Baseline were characterized by the industry as an unrepresentative sample. ECTD takes issue with this assertion.

The 1969 baseline sample was designed to incorporate all gasoline engines marketed in 1969 except those of very small sales (less than 1-2 percent). The data used in deriving this sampling plan was submitted by the manufacturers. Table M-1 presents the sampling plan, including 1969 market shares and actual engines tested. No significant engine families were neglected. Weighting and averaging of the elements of a sample to represent the relative proportions of those elements in the population is a standard statistical technique for estimating population means. This was done by sales-weighting the emission data in order to place higher weight on the larger sellers, i.e., those engines whose emissions would contribute more to the overall average. In short, the sampling plan includes all significant engine families, appropriately weights their emission according to their relative contributions to the whole and represents an adequately sized sample from

* Refer to the EPA Technical Report "1969 Heavy-Duty Engine Baseline Program and 1983 Emission Standards Development," by T. Cox, et. al., May 1979, in which the actual standards derivation was explained.

which the average emission level of all engines sold in 1969 could be estimated.

Commenters also criticized EPA's pre-test tune-up procedures, along with the purportedly unrepresentative applications from which the baseline engines was drawn. A review of the regulatory methodology and the degree of problems encountered in its implementation will serve to counter this criticism.

EPA was required by the Clean Air Act Amendments to derive standards "from the average of the actually measured emissions from heavy-duty gasoline-fueled vehicles or engines, or any class or category thereof, manufactured during the baseline model year."* (Emphasis ours.) This was interpreted to require actual emission testing of 1969 (the baseline model year) engines. It was debated within EPA whether to use in-use engines, or to seek cooperation from the manufacturers so that essentially new engines, identical in design and components to 1969 engines, could be built from scratch.

This latter option was rejected because strict reading of the Clean Air Act requires the test engines to have been manufactured in 1969. Furthermore, the chances of adequately representing 1969 engines by remanufacturing per 1969 specifications were slim, and the program would have been prohibitively expensive. Original equipment for 1969 engines would in many cases have been unavailable, as would the manufacturing facilities themselves (retooled to meet present needs). Special manufacture of individual engines would have been time consuming and expensive. Manufacturers stated that build-up and delivery of representative engines could not be guaranteed, i.e., EPA's test schedule would have been at the mercy of the regulated industry and have proceeded at their convenience. This was unacceptable.

The only remaining alternative was to test in-use 1969 engines, i.e., engines which by the time the baseline began had been on the road in continuous use for nearly 9 years. The average gasoline truck on the road in 1973 (when the 1969 engines were entering middle age) averaged about 11,300 miles per year.** Assuming no major changes in trend, after 9 years of service the average 1969 engine traveled over 100,000 miles and wasn't much good for either commercial work or emission testing. EPA restricted its selection of engines to those which were in original configuration, i.e., engines which had not been rebuilt in the block, shafts, and valves, which were equipped with original

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* Clean Air Act Amendment 1977, Title II, Part A, Section 202(a)(3)(A)(ii).

** Derived from data presented within the "Draft Interagency Study of Post-1980 Goals for Commercial Motor Vehicles" by a Federal Interagency Task Force, June 1976.

carburetors and distributors, and which passed basic checks of mechanical integrity. These selection criteria were essential if representativeness with the original 1969 fleet was to be maintained. Given the 9 years of continued use, however, engines meeting these criteria were understandably rare. Over two thousand inquiries were made and three hundred engines were inspected in the field, resulting in the selection of the 23 engines. (The field inspection was performed only if the engine met the original screening criteria.) In short, the greatest care was exercised throughout the procurement process to obtain the best engines possible for testing, recognizing of course that "perfect" engines were impossible to obtain. Futhermore, should deterioration be application specific, only at gross levels of deterioration should significant impact on emissions occur, and at those levels the selection criteria should have precluded inclusion in the baseline. In summary, all efforts were made to insure that only mechanically sound original engines were used in the baseline to accurately reflect 1969 engines per Congressional intent. Practical limitations resulted in low-mileage applications being preferentially selected. No data whatsoever was submitted to imply that application-related errors were incurred.

To ensure that Congressional intent was complied with as fully as possible, the philosophy of the pre-test engine preparation procedures was to assure that the engine met all operation specifications as prescribed by the manufacturer for the 1969 version. Only in this way could the Agency be certain that 9 years on-the-road had not produced uncharacteristic and improperly adjusted engines whose emissions would be unrepresentative of the 1969 Fleet. ECTD even went so far as to personally deliver several emission related components (carburetor, distributors) to individual manufacturers for check-out and restoration. When replacement parts were needed, only OEM parts were used. The end result of this philosophy was a complete tune-up and check-out of all operational engine components; all adjustments were made exactly as the manufacturers recommended to their customers in The applicable service manuals. To do otherwise could have allowed maladjusted and unrepresentative engines into the baseline.

To summarize EPA's position on the representativeness of the baseline engines, within the realm of the possible, EPA took those steps and actions which minimized errors and maximized both compliance with Congressional intent and the technical validity of the data.

(iii) EPA was criticized for purported failure to include deterioration factors and failure to comply with allowable maintenance procedures, as outlined in the Proposed Rules, during the baseline program.

Due to the elaborate tune-up procedures and checks on mechanical integrity, it has been assumed by ECTD that the baseline engines were restored to an effectively "as new" condition and deterioration factors were effectively zero. Furthermore, certification data for non-catalyst gasoline engines reveal that these engines have inherently low deterioration factors, and support the zero D.F. assumption.

The question of allowable maintenance procedures is an insignificant point with regard to the baseline. For durability testing, allowable maintenance provisions preclude unrepresentative maintenance to permit accurate characterization of deterioration, i.e., to allow deterioration to occur and be measured. For baseline purposes, however, the objective was to eliminate deterioration by engine tune-up so that "as new" emissions could be measured.

In short, the engines tested in the baseline were characterized as new engines, and therefore required no computation of deterioration factors. The Baseline was not a durability test program and required no allowable maintenance constraints.

(iv) EPA's relaxation of the transient test validation criteria by no means implies flaws in the test procedure, and by no means guarantees unrepeatable and unrepresentative results. The vailidation criteria set forth in the NPRM were derived from limited transient experience acquired very early in the Baseline Program. It must be stressed that the EPA transient facility was the first of its kind in the entire motor vehicle industry and test procedure developments and refinements occured throughout the entire baseline program. The validation criteria were relaxed based upon a recognition of the limitations of current dynamometer/engine control system technology.

Furthermore, all data acquired in the Baseline Program and in subsequent test programs at both EPA and the Southwest Research Institute indicate that the revised tolerances more than guarantee test repeatability and lab to lab correlation. (See "Test Procedure" Summary and Analysis of Comments for further discussion on the technical validity of the procedure.) EPA does recognize, however, that a deliberate attempt to optimize emissions by running a certain cycle up to the limits of the revised criteria could defeat the intent of the procedure. With this in mind, EPA fully intends to tighten the validation criteria in the future as experience is gained and technical improvements are made in the transient control capabilities of engine dynamometers. This is anticipated to happen well before certification testing of 1984 engines if necessary.

(v) EPA acknowledges that humidity specifications proposed in the 2/13/79 NPRM were consistently violated during the 1969 Baseline Program. Humidity effects on HC and CO emissions, however, are generally regarded to be minimal, as evidenced by the fact that no humidity corrections are required for light- or heavy-duty for HC or CO. Yet the difficulty experienced in humidity control along with the high cost of such control, lead ECTD to the conclusion that the humidity requirements be dropped for the Final Rules. In its place will be an appropriate NOx correction factor.

(vi) Motoring at -10 percent maximum torque was chosen by EPA for those portions of the transient gasoline procedure where negative torques are desired.

The EPA gasoline dynamometer facility incorporates several safety features which prevent injury to personnel and damage to equipment. These include continual monitoring of system operation by the support software, which in the cases of overspeed (e.g., engine runaways) and overload (e.g., a greater torque than the engine driveshaft and dynamometer can withstand safely), will automatically shut the facility down. These shutdowns occur both when the command signal asks for greater than maximum permitted speeds and load excursions, and when the system actually experiences such excursions. The maximum possible torque excursion permitted was ±400 ft-lbs; this was the maximum safe load on the driveshafts, the in-line torquemeters, and the General Electric motoring dynamometer. At several times during the transient gasoline test, the engine is commanded to deliver wide open throttle torque followed almost immediately by a motoring condition. For an engine capable of delivery 360 ft-lbs at wide open throttle (normally observed in the larger gasoline gengines), a torque excursion from wide open throttle to a motoring command of greater than -10 percent (i.e., 360 + 0.1 x 360 = 396 ft-lbs) would result in both a commanded and actual torque excursion greater than the 400 ft-lbs allowable on the test equipment, at which point safety overrides would stop the test.

It was in recognition of this fact that the original decision was made to use -10 percent as the motoring command, as opposed to a completely closed throttle.

The level of motoring to be used during the transient test can only be based upon judgement. The only practical instrumentation available for measurement of load factor parameters during the CAPE-21 project could detect the fact that motoring was occuring, but not its absolute level. Data is available, however, which indicates that part-throttle and completely closed throttle both occured frequently in normal use.

The use of -10 percent for motoring essentially recognized equipment limitations of EPA's laboratory. General Motors submitted much discussion and theoretical analyses showing differences in hydrocarbon measurements between part- and completely closed throttle operation at higher engine speeds. ECTD cannot dispute these claims; restricting complete closure of the throttle is a recognized technique for controlling hydrocarbons during the motoring portion of the simplistic 9-mode test. It can be argued, however, that changing the torque level of any mode will influence emissions. As mentioned above, part-throttle motoring was observed frequently in the CAPE-21 data base and its inclusion in the test procedure is hardly unrepresentative. Baseline levels are defined by the test procedure used; the 1969 Baseline used in standards derivation incorporated both part-throttle and closed-throttle motoring. (At lower speeds, -10 percent is sufficient to close the throttle.) The certification procedure for 1984 gasoline engines will also incorporate -10 percent motoring; the gasoline industry will be required to test in a manner completely consistent with how the standards were derived. In short, the standards are defined in terms of -10 percent motoring. (Motoring in diesel engines, however, is a different case. Whereas motoring emission in gasoline engines arise from air/fuel mixtures too lean to burn, the fuel in diesel engines is shut off during motoring at closed rack. Therefore, motoring emissions of diesel engines are relatively insignificant. The diesel test facility at SWRI has been capable of running at closed rack at all speeds. There are no compelling reasons not to run diesel engine at completely closed throttle if its possible to do so; running diesels at partly closed rack may even overstate emissions by a small amount.)

(vii) Comments were received questioning the derivation of standards from a sales-weighted average, claiming that 90 percent reduction from on average is actually greater than a 90 percent reduction for those engines in the baseline with emissions greater than average. ECTD can't dispute this. ECTD does note, however, that the suggestion to derive standards from the 90 percentile of the baseline is contrary to all regulatory history and the exact wording of the Clean Air Act Amendment, which precisely stated the standards were to be derived from an "average of the actually measured emissions."

Aside from the 1969 Baseline, ECTD's derivation of the NOx standard was criticized as resulting in too stringent a standard. In this particular instance, ECTD disputes the contention of stringency. As discussed in the Analysis of Comments pertaining to Technological Feasibility, a transient NOx standard of 10.7 g/BHP-hr is so lax as to represent a decontrol of the pollutant. No gasoline or diesel engine tested at EPA, SwRI, or any other laboratory on the transient test procedure has ever exceeded 10.7 g/BHP-hr. Only one gasoline engine has shown NOx as high as 9.7 g/BHP-hr. In the case of diesels, if all engines certified in 1979 can comply with an HC + NOx standard of 10.0 g/BHP-hr on the current procedures, which measures higher NOx relative to the transient, it is a misrepresentation of the facts to claim that a transient NOx only standard of 10.7 g/BHP-hr is more stringent.

4. Recommendation

EPA's derivation of the proposed standards was technically complete, competently performed, and within the express direction of Congressional intent.

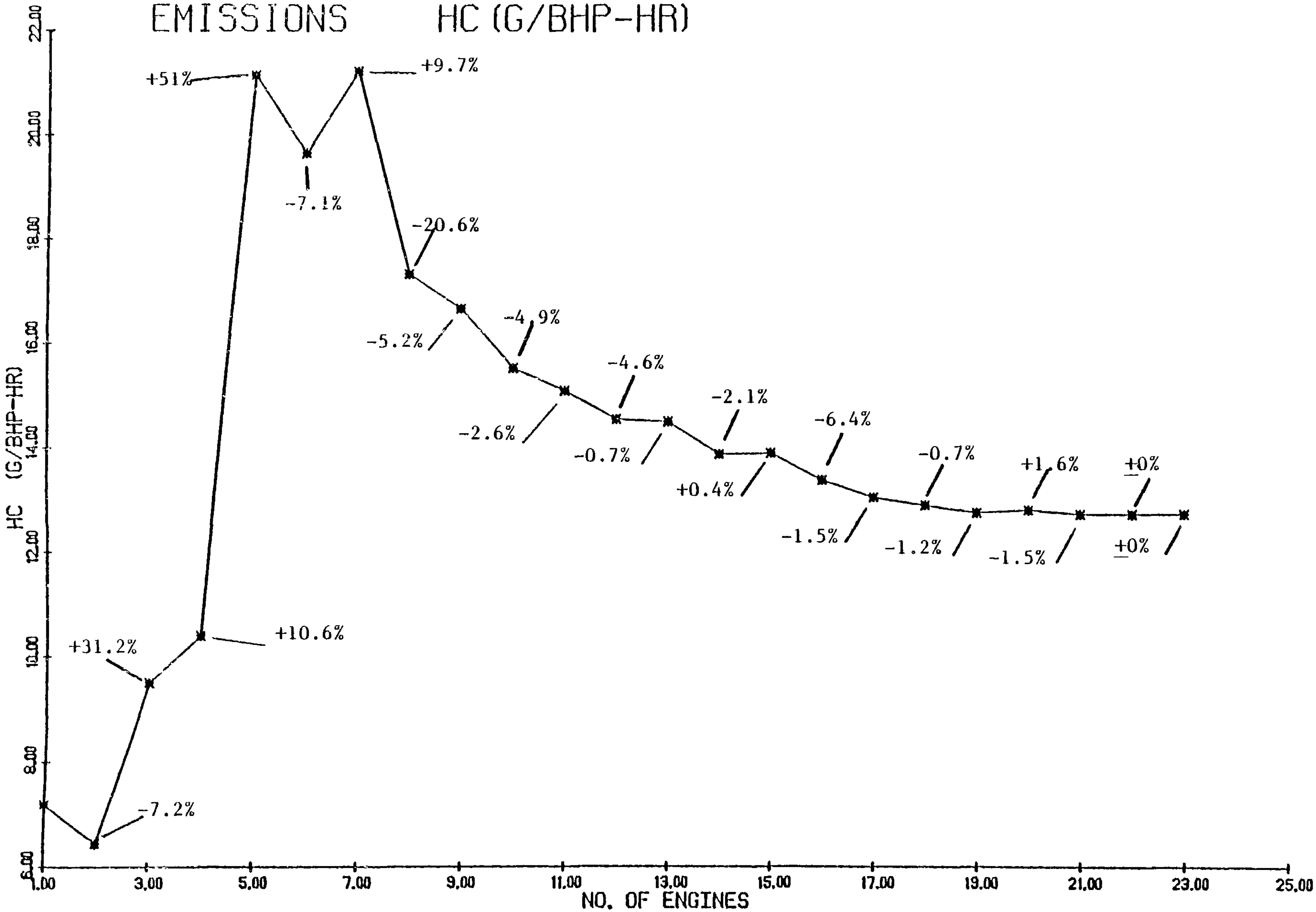
Retain the proposed standards.

Table M-1

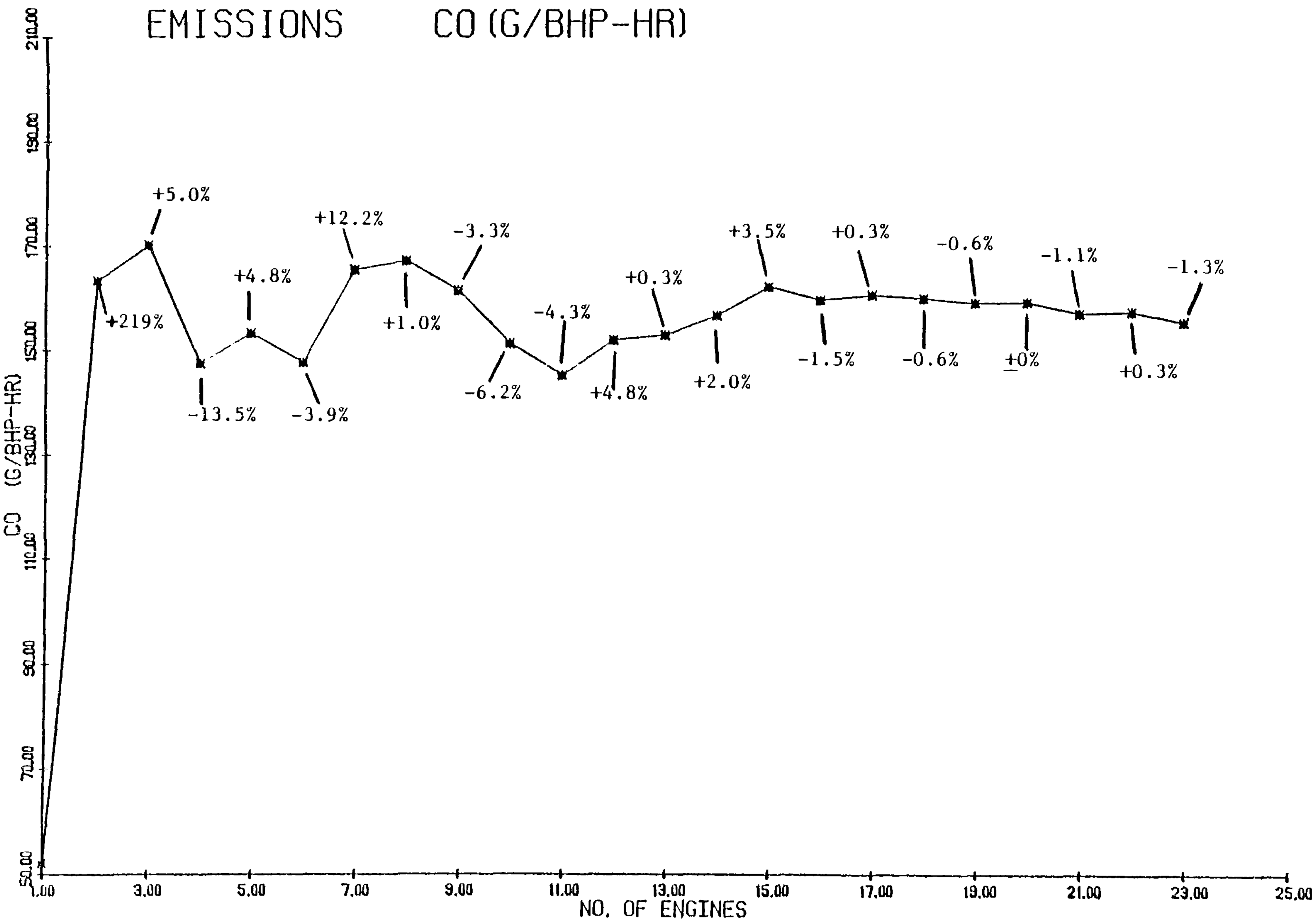
Baseline Sampling Plan

Manufacturer	Engine	Sales	% of Market	Sampling Target Range	Actual Procurement
Chrysler	318-3	10,850	3.1	0-1	1
(9.3%)	318-1	10,150	2.9	0-1	1
	361	7,000	2.0	0-1	1
	383	2,000	0.6	0-1	0
	413	1,500	0.4	0-1	0
	225	1,000	0.3	0-1	1
			Total	(2-3)	4
Ford	330	50,200	14.4	3-4	2
(33.5%)	360	21,300	6.1	1-2	2
	361	17,300	5.0	1-2	2
	300	14,200	4.1	1-2	1
	391	6,700	1.9	0-1	1
	477	2,600	0.7	0-1	0
	390	2,300	0.7	0-1	0
	534	2,000	0.6	0-1	0
			Total	(8-9)	8
GM	350-2	47,000	13.5	3-4	3
(39.3%)	366	22,000	6.3	1-2	2
	292	18,000	5.2	1-2	1
	351C	12,000	3.6	0-1	1
	250	10,000	2.9	0-1	0
	307	9,000	2.6	0-1	0
	305C	6,600	1.9	0-1	0
	477	6,300	1.8	0-1	0
	350-4	3,000	0.9	0-1	0
	396	2,000	0.6	0-1	0
			Total	(9-10)	7
IHC	V345	20,500	5.9	1-2	2
(14.7%)	V304	17,300	5.0	1-2	1
	V392	7,600	2.2	0-1	1
	RD450	3,350	1.0	0-1	0
	VS478	2,000	0.6	0-1	0
			Total	(3-4)	4

SALES-WEIGHTED BASELINE TRANSIENT
EMISSIONS HC (G/BHP-HR)



SALES-WEIGHTED BASELINE TRANSIENT EMISSIONS CO (G/BHP-HR)



N. Issue - Fuel Economy

1. Summary of the Issue

EPA has proposed more stringent HC and CO standards for heavy-duty vehicles. The proposed NOx standard is not considered any more stringent than the current NOx standard. The issue is: What effect will these new standards and associated procedures have on fuel economy of heavy-duty vehicles?

2. Summary of the Comments

Relative to other issues proposed in the NPRM, the volume of comments about the effects of the provisions in the NPRM on HD fuel economy were rather meager. The focus of these comments can be summarized into five categories: (1) The effect of the regulations will prevent fuel economy improvements that could potentially be obtained if the proposed regulations were not in effect; (2) The proposed regulations will cause a fuel economy loss (no specific cause ever cited); 3) The proposed regulation will cause a fuel economy loss due to the NOx standard; 4) The proposed regulations will cause a fuel economy loss due to a more stringent AQL (10% over 40%); and 5) The proposed crankcase regulations will cause a fuel economy loss on turbocharged diesel engines.

Comments that discussed fuel economy foregone most notably the Council of Wage and Price Stability claimed past LDV data would indicate a 5-10% fuel economy loss. Caterpillar predicts the proposed emission regulations " . . . could have . . . " around a 2.6% per year fuel economy improvement forgone due to shifting resources from fuel economy improvement to emission control.

Ford estimate a 10-15% outright loss in fuel economy, and Chrysler simply stated " . . . that the adverse effects on fuel economy will be sufficiently great to also provide grounds for a revision of the standards."

Both GM and Cummins discussed fuel economy impacts in relation to California NOx standards, but not in relation to the proposed provisions in the NPRM.

Mack provided an analysis based on the current 13-mode diesel test procedure indicating a 0.98% improvement in brake specific fuel consumption by selecting a 40% AQL over a 10% AQL.

Caterpillar predicted a 1-3% fuel economy loss on turbocharged diesel engines due to crankcase emission controls.

3. Analysis of the Comments

The comments on fuel economy cover both gasoline-fueled and diesel engines. Because of the different control strategies anticipated, it will be easier to discuss these engines separately.

a. Gasoline-Fueled Engines

The comments on gasoline-fueled engine fuel economy could generally be characterized as statements expressing opinion but lacking supporting data. The Council on Wage and Price Stability did provide some reference material to support their claim of a 5-10% fuel economy penalty. The documents cited include an out of date 1974 CRC study, and manufacturers comments during public hearings held in early 1977 and late 1978.

The Council of Wage and Price Stability claim that the light-duty data cited would indicate "non-trivial" fuel economy penalties of 5-10%. In making the transfer between light-duty vehicles (LDV) and heavy-duty gasoline-fueled (HDG) vehicles the Council of Wage and Price Stability apparently failed to look at the relative differences in current emission control systems (between LDV and HDG).

An analysis of more recent data indicates that it will be entirely possible for the fuel economy from HDG vehicles to increase as much as 17% with the application of catalyst technology. A more conservative estimate would be a fuel economy increase between 4 and 9%.

Since these statements are directly contradictory to the comments submitted by the interested parties, a review of the historical facts involving fuel economy effects of emission controls on LDV fuel economy will be given. One of the most recent papers on that subject (SAE Paper 790225) presents test data on over 6,000 cars ranging from pre-controlled model year vehicles through 1979 model year vehicles. The fuel economy data was taken on the same test procedure (75 FTP) for all vehicles. Table N-1 tabulates this data.

Before discussing this data two assumptions should be discussed. One, the LDV city fuel economy values will be used to compare to HDG transient test values. The reason behind this assumption is that the city cycle exercises the LDV in a transient manner more than the highway cycle, and therefore, would provide a better comparison (of the two cycles) to the transient HDG cycle.

The second assumption is not necessarily an assumption, but a selection of a reference point for analyzing the data. The 1974 LDV model year is selected as a point for initial comparison. For light-duty vehicles, the 1974 model year represents the last model year prior to wide spread oxidation catalyst (OC) usage. The 1974 model year could be characterized as "just before catalyst control era". If it can be assumed that wide spread catalyst usage will

Table N-1

Trends in Sales - Weighted
Fleet Fuel Economy, Passenger Cars 1/

	Each Year's Weight Mix:				1974 Weight Mix:*		
	City	Hwy.	55/45	Avg. Test Wt.	City	Hwy.	55/45
Pre-Control	12.9	18.5	14.9	3812	12.5	17.4	14.3
1968	12.6	18.4	14.7	3863	12.4	17.6	14.3
1969	12.6	18.6	14.7	3942	12.7	18.8	14.9
1970	12.6	19.0	14.8	3877	12.3	18.5	14.5
1971	12.3	18.2	14.4	3887	12.1	17.9	14.1
1972	12.2	18.9	14.5	3942	12.2	18.9	14.5
1973	12.0	18.1	14.2	3969	12.0	18.1	14.1
1974	12.0	18.2	14.2	3968	12.0	18.2	14.2
1975	13.7	19.5	15.8	4057	14.0	19.9	16.1
1976	15.2	21.3	17.5	4060	15.5	21.8	17.8
1977	16.0	22.3	18.3	3943	15.6	22.1	18.0
1978	17.0	24.1	19.6	3649	15.4	22.4	18.0
1979	17.6	24.3	20.1	3508	15.3	21.2	17.5

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* Average Test Weight = 3968 lb.

occur on HDGs with the proposed standards, then the 1979 HD interim standards and associated emission control technology is analogous to the 1974 LDV model year technology.

Table N-2 provides a comparison of historical fuel economy data. The city fuel economy data for LDVs comes from the 1974 weight-mix category in Table N-1. The 1974 weight-mix category compares the fuel economy from all LDV model years on a constant weight basis. The comparison of LDV fuel economy on a constant weight basis is considered more representative of heavy-duty vehicles since reducing vehicle weight would not generally be an option for heavy-duty vehicles. It would be assumed that any HD vehicle weight reduction would be taken up by increased payload.

In addition to the LDV-HDG comparison, light-duty truck (LDT) data shows similar fuel economy improvement trends. Data from recently completed LDT baseline testing (1969 and 1973 model years) is presented in Table N-3 along with LDT data from SAE Paper 790225. 1/ The SAE Paper does not calculate a constant weight mix for LDT's as the paper did for LDV's (Table N-1). Therefore, the baseline fuel economy is presented as the baseline sales-weighted inertia weight (IW) versus the same specific weight class for the later model LDT's presented in reference 1/. Inspection of Tables N-4 3/ and N-5 4/ indicates that this is a reasonable assumption.

Returning to the LDV-HDG comparison, it is evident that by going from pre-emission control technology to pre-catalyst control technology (pre-'68 to 1974), a fuel economy penalty of 4% was incurred by LDVs (Table N-2). Test data from pre-controlled 1969 HD engines (Table N-6)5/ and pre-catalyst 1979 engines (Table N-7)6/ indicate approximately the same order of fuel economy penalty was incurred by HDVs. It should be pointed out here that the fuel economy penalty incurred by HDGs is over estimated and should be somewhat smaller than that indicated. This overestimation occurs due to the fact that contrary to popular opinion, vehicle fuel consumption improves with age (see references 1 and 2). Since the pre-controlled 1969 engines were tested at significantly higher mileages than the pre-catalyst 1979 engines, correcting the fuel economy of the pre-controlled engines to the pre-catalyst mileage values would increase the brake specific fuel consumption (BSFC) of the pre-controlled engines, and thereby, decrease the difference between the two categories. It should be pointed out that all the LDV test data was corrected to a 4,000-mile fuel economy value.

After 1974, and once LDV catalyst technology was introduced, the fuel economy of light-duty vehicles increased rapidly. Table N-1 does show some fluctuation in the increase. However, during these years ('76, '77, and '78) certain automobile manufacturers used ambiguities in the test procedure in order to obtain higher fuel economy results. The somewhat lower mileage values for the

Table N-2

Fuel Economy Comparison*

LDV			HDG		
Model Year	City MPG**	% Change	Model Year	BSFC+	% Change
Pre-control	12.5	—	Pre-Control++	.688	—
1974	12.0	-4.0%	1979+++	.721	-4.8%
1975	14.0	+16.7%***	1984	( )	( )
1979	15.3	+27.5%***			

* Sales Weighted Average.
** Constant Vehicle Weight Basis, 1975 LDV FTP.
*** Based on 1974 mpg.
\+ Transient Engine Test (lb/hp-hr) constant HP/weight basis.
++ 1969 Baseline.5/
+++ 1979 Baseline.6/

Table N-3

Trends in Light-Duty Truck
Fuel Economy (LDT) vs Emission Standards

Weight Class	Fuel Economy (75 FTP) a/ 4000	4500	5000+	Standards (75 FTP) f/ HC	CO	NOx
Model Year						
1969	-	11.89 b/	-			
1973	-	-	11.04 c/			
1975	13.83	12.01	10.02 d/	2.0	20	3.1
1976	15.86	12.81	11.17	2.0	20	3.1
1977	16.70	14.85	10.73	2.0	20	3.1
1978	16.01	13.91	15.96 d/	2.0	20	3.1
1979	15.42	13.58	16.85 e/	1.7	18	2.3

a/ MPG 1975-1979 values from reference 1/.
b/ 1969 Baseline, sales-weighted IW = 4680.3/
c/ 1973 Baseline, sales-weighted IW = 4917.4/
d/ 1975-1978 LDT class excludes vehicles greater than 6000 lbs. GVW, 1978 mpg reflects some dieselization.
e/ 1979 LDT class includes vehicles up to 8500 lbs. GVW, 5000+ class reflects some dieselization.
f/ g/mi.

Table N-4

1969 Light-Duty Fuel Economy Baseline 3/

Vehicle Number	Sales Weighting Factor (%)	Inertia Class	Weighted Inertia Class	Fuel Economy (mpg)	Weighted Fuel Economy (mpg)
404	1.32	5500	66.00	12.03	0.1587
428	1.32	5500	66.00	13.68	0.1806
441	11.31	4500	508.95	13.22	1.4952
618	8.54	5000	427.00	11.17	0.9539
607	34.18	4500	1538.10	12.76	4.3614
418	1.99	4500	89.55	11.81	0.2350
444	1.99	4500	89.55	13.26	0.2639
601	0.84	5000	42.00	10.93	0.0918
419	2.35	4500	105.75	12.00	0.2820
427	2.35	4500	105.75	12.03	0.2827
450	2.35	4500	105.75	10.84	0.2547
602	2.35	4500	105.75	11.21	0.2634
421	4.85	5000	242.50	12.39	0.6009
425	4.85	4500	218.25	7.61	0.3691
473	4.85	5000	242.50	11.73	0.5689
491	4.85	5000	242.50	11.08	0.5374
610	4.85	5000	242.50	9.65	0.4680
613	4.85	5000	242.50	10.80	0.5238
			4680.90		11.8914

Table N-5

1973 Light-Duty Fuel Economy Baseline 4/

Vehicle Number	Sales Weighting Factor (%)	Inertia Class	Weighted Inertia Class	Fuel Economy (mpg)	Weighted Fuel Economy (mpg)
612	6.51	5000	325.5	10.93	0.7116
637	6.51	5000	325.5	11.49	0.7480
634	6.51	5000	325.5	11.58	0.7539
631	6.51	5000	325.5	11.58	0.7539
629	6.51	5000	325.5	10.75	0.6998
628	2.93	5000	146.5	12.15	0.3560
632	1.52	5000	76.0	14.17	0.2154
608	8.03	5000	401.5	9.28	0.7452
486	3.76	4500	169.2	11.76	0.4422
609	3.76	5500	206.8	9.43	0.3546
627	3.76	5500	206.8	10.45	0.3929
605	3.80	4500	171.0	10.66	0.4051
630	8.00	5000	400.0	11.94	0.9552
620	8.00	4500	360.0	11.06	0.8848
624	8.00	4500	360.0	11.08	0.8864
625	5.75	5000	287.5	11.45	0.6584
635	8.90	5000	445.0	10.71	0.9532
611	1.19	5000	59.5	10.15	0.1207
			4917.3		11.0373

TABLE N6: SALFS-WEIGHTEU TRANSIENT ENGINE EMISSIONS(G/BHP-HR) REFERENCE 57

1969 BASELINE ENGINE(S)

ENGINE		WTG. FACTOR	SIZE	GRAMS / BHP-HR HC	CO	NOX	PART	WEIGHTED G/BHP-HR HC	CO	NOX	PART	BSFC	<- WEIGHTED -> BSFC
01 FW 225R 2994 032 225 1	0	0.00368	2	7.20	52.20	8.46		0.026	0.192	0.031		0.6390	0.00235
02 V392 658417 392 1	0	0.02699	3	6.35	178.47	4.24		0.171	4.818	0.114		0.7777	0.02099
03 391-JW 391 1	0	0.02331	2	13.55	179.34	5.83		0.316	4.181	0.136		0.6465	0.01507
04 V304 648048 304 1	0	0.06135	5	11.21	127.76	6.70		0.688	7.838	0.411		0.6828	0.04189
05 F330 9AN505S 330 1	0	0.08834	5	28.13	157.15	7.89		2.485	13.883	0.697		0.7272	0.06424
06 GM351 2483434 351 1	0	0.04417	2	9.72	111.51	8.80		0.430	4.926	0.389		0.6520	0.02880
07 F330 9BN505S 330 1	0	0.08834	3	34.16	224.37	6.25		3.018	19.822	0.553		0.7503	0.06629
08 GM350 V0512XI 350 2G	0	0.05521	2	9.40	170.77	4.82		0.519	9.429	0.266		0.6680	0.03688
09 D318 PM 318R 318 3	0	0.03804	3	7.9)	86.97	7.60		0.303	3.308	0.289		0.5993	0.02280
10 V345 31980C 345 1	0	0.03620	2	7.12	76.53	6.46		0.258	2.770	0.234		0.7110	0.02574
11 GM 350 2 LJPN 350 2G	0	0.05521	3	6.21	126.13	5.36		0.343	6.964	0.296		0.6157	0.03399
12 F300 1 300 1	0	0.05031	3	7.81	233.38	4.91		0.393	11.741	0.247		0.6940	0.03491
13 V345 719456 345 1	0	0.03620	3	6.41	94.02	5.59		0.232	3.403	0.202		0.6133	0.02220
14 GM366 ARBUCKLE 366 1	0	0.03865	3	8.59	187.92	5.32		0.332	7.263	0.206		0.7373	0.02850
15 F361 SHOE 361 1	0	0.03067	2	14.12	228.39	5.43		0.433	7.006	0.167		0.7795	0.02391
16 F360 EGG1 360 1	0	0.03742	3	7.96	132.19	6.63		0.298	4.947	0.248		0.6553	0.02452
17 GM292 RACKET 292 1	0	0.06380	2	8.54	172.86	5.14		0.545	11.029	0.328		0.7615	0.04859
18 D318 EGG2 318 1	0	0.03558	3	8.82	144.26	7.54		0.314	5.133	0.268		0.6603	0.02350
19 F361 BLE 19 361 1	0	0.03067	3	9.57	197.55	5.09		0.294	6.060	0.156		0.6893	0.02115
20 F360 EGG3 360 1	0	0.03742	2	5.92	75.32	6.88		0.221	2.819	0.258		0.6355	0.02378
21 GM350 TENNIS 350 2G	0	0.05521	3	8.64	150.36	4.58		0.477	8.302	0.253		0.6443	0.03558
22 D361-3 SLUG 361 1	0	0.02454	2	12.63	168.68	6.01		0.310	4.139	0.148		0.6850	0.01681
23 GM366 SWRI 366 1	0	0.03865	3	8.53	134.87	4.66		0.330	5.213	0.180		0.6653	0.02572
SALES-WEIGHTED GAS BAG TOTALS:								12.74	155.18	6.08	0.0		0.68821
90% REDUCTION FROM BASELINE:								1.27	15.52	0.61			

TABLE N 7: SALES-WEIGHTED TRANSIENT ENGINE EMISSIONS(G/BHP-HR) REFERENCE 6/

1979 GASELINE ENGINE(S)

OCT 31, 1979

ENGINE		WTG. FACTOR	SIZE	GRAMS / BHP-HR HC	GRAMS / BHP-HR CO	GRAMS / BHP-HR NOX	GRAMS / BHP-HR PART	WEIGHTED G/BHP-HR HC	WEIGHTED G/BHP-HR CO	WEIGHTED G/BHP-HR NOX	WEIGHTED G/BHP-HR PART	BSFC	<- WEIGHTED -> BSFC
09 IHC446 ELROY MV-8 5	0	0.08112	3	3.27	90.40	5.48		0.265	7.333	0.445		0.7160	0.05808
02 V345C 79BLE-2 V-345 3	0	0.02786	3	2.44	34.44	6.46		0.068	0.959	0.180		0.6500	0.01811
03 GM366 79BLE-3 114 1	0	0.08415	3	2.16	43.43	8.42		0.182	3.655	0.708		0.7190	0.06050
04 GM350 79BLE-4 113 3	0	0.04277	3	2.48	64.76	6.62		0.106	2.770	0.283		0.7167	0.03065
05 F400 79BLE-5 6.6L "E"9-73J	0	0.12448	3	4.89	112.43	4.29		0.608	13.995	0.534		0.7463	0.09290
06 F370 79BLE-6 6.1L "E"9-83H	0	0.10117	2	3.51	47.75	5.54		0.355	4.830	0.561		0.7795	0.07886
07 C360 79BLE-7 LA-1 CA1-4	0	0.11830	3	2.67	96.10	4.36		0.316	11.369	0.516		0.6890	0.08151
08 C440 79BLE-8 PBM CB3-2	0	0.09755	3	3.83	112.38	4.48		0.373	10.962	0.437		0.6813	0.06647
10 GM454 79BLE-10 115 1	0	0.06189	3	1.31	78.49	6.23		0.081	4.857	0.385		0.7653	0.04737
05 GM292 L25 CTE5 112 1	0	0.03205	1	2.12	54.98	9.74		0.068	1.762	0.312		0.6550	0.02099
02 GM454 CTE2 114 3	0	0.00338	3	2.36	55.36	6.55		0.008	0.187	0.022		0.6677	0.00226
6 GM350 CTE6 113 1	0	0.22529	1	2.66	114.02	6.58		0.599	25.689	1.482		0.7270	0.16379
SALES-WEIGHTED GAS BAG TOTALS:								3.03	88.37	5.87	0.0		0.72148

1979 model year (and to some extent for 1978) reflect the correction of these ambiguities to ensure that these manufacturers would perform the test properly. The important aspect of the data, however, is that the trend between 1974 and 1979 was one of continued improvements in LDV fuel economy.

The LDV fuel economy increased over these years in spite of the fact that more stringent emission standards were enacted over the years. Table N-8 compares the effect between pre-catalyst technology and catalyst technology on emissions and fuel economy. As Table N-8 indicates LDV HC and CO were reduced substantially between 1974 and 1975. During this emission reduction fuel economy improved approximately 17%. Comparing the HDG HC and CO reductions, and the allowable HDG NOx increase to the LDV historical data, it certainly seems reasonable to expect that HDG fuel economy will increase with the proposed standards.

Some may claim that the LDV fuel economy improvements are due to effects other than improved engine control technology. Such factors as vehicle streamlining, power train optimization, and changes in power to weight ratio do in fact account for a portion of the change in LDV mileage, especially the 1979 figures. However, there were very few of these changes between the 1974 and 1975 LDV model years. Therefore, it must be assumed that most of the almost 17% improvement in LDV fuel economy was directly attributable to improved engine control technology.

Others may claim that it isn't proper to compare just the standards (Table N-8) between pre-catalyst to catalyst technology, or pre-catalyst HD emission levels to catalyst standards without considering pre-controlled levels, and the potential effects of such issues as the proposed changes in useful life, a 10% AQL Selective Enforcement Audit (SEA) limit, etc. Table N-9 provides this comparison. The comparison between LDV and HDG is based on emission levels from various test programs. An attempt was made to compare emission levels based on similar service accumulation. For instance, the average service of the LDV test vehicles was 70,000 miles while for HDG it was 60,000 miles. The service accumulation for the comparison of the pre-catalyst and catalyst technology emission levels is based on the interval used for emission data vehicles or engines. In this manner, the impacts of durability and SEA can be evaluated as low mileage target (LMT) levels for emission data engines. The derivation of LMT levels for HC and CO is discussed in the Cost Effectiveness Chapter of the Regulatory Analysis document (Chapter VII). A similar procedure was used to derive the LMT for NOx.

Comparing the stringency of the HD proposal (Table N-10) to past LDV data, it is apparent that the estimated HD LMT levels represent an increase in the reduction of HC by approximately 11 percent and 23 percent for CO over that experienced by LDVs in the

Table N-8

Comparison of Fuel Economy and Emission Reduction versus Control Technology

		Pre-Catalyst	Catalyst Technology	Percent Change
HC	LDV	3.0 a/	1.5 b/	-50.0
	HDG	3.03 c/	1.3 d/	-57.1
CO	LDV	34 a/	15 b/	-55.9
	HDG	88 c/	15.5 d/	-82.4
NOx	LDV	3.1 a/	3.1 b/	0.0
	HDG	5.87 c/	10.7 d/	+82.2
F.E.	LDV	12.0 e/	14.0 e/	+16.7
	HDV	.721 f/	( )	( )

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a/ 1974 LDV Standard of 3.4/39/3.0 expressed as approximate 1975 FTP results, g/mi.
b/ 1975 LDV Standard, g/mi.
c/ 1979 Transient Baseline, g/BHP-hr.
d/ Proposed 1984 Standard, g/BHP-hr.
e/ Constant weight basis mpg, reference 1/.
f/ 1979 Transient Baseline, lb fuel/BHP-hr, reference 6/.

Table N-9

Comparison of LDT and HDG
Emission and Fuel Economy Trends n/

		Pre-control	Pre-catalyst	Catalyst Technology: LDV Emission Factors/HD LMT	Catalyst Technology: Standards
HC	LDV	8.74 a/	3.08(-64.8) c/	1.32(-84.9) e/	1.5(-82.8) g/
	HDG	12.74 b/	3.03(-76.2) d/	.50(-96.1) f/	1.3(-89.8) h/
CO	LDV	86.5 a/	35.92(-58.5) c/	22.92(-73.5) e/	15(-82.7) g/
	HDG	155.18 b/	88.37(-43.1) d/	5.9(-96.2) f/	15.5(-90.0) h/
NOx	LDV	3.54 a/	2.90(-18.1) c/	2.44(-31.1) e/	3.1(-12.4) g/
	HDG	6.08 b/	5.87(-3.5) d/	7.0(+15.1) f/	10.7(+76.0) h/
F.E.	LDV	12.5 i/	12.0(-4.0) j/	14.0(+12.0) k/	-
	HDG	.688 l/	.721(-4.8) m/	(-)	-

a/ Surveillance Test Data, g/mi, 1965-67 LDV, avg mileage 70,000, Reference 8/.

b/ 1969 HD basline, g/BHP-hr, avg mileage 60,000, Reference 5/.

c/ Surveillance Test Data, 1974 LDV, avg mileage 6,000, Reference 8/.

d/ 1979 HD baseline, g/BHP-hr, emission-data engines, Reference 5/.

e/ Surveillance Test Data, g/mi, 1975 LDV, avg mileage 8,000, Reference 8/.

f/ Estimated low mileage target (LMT) emission levels for 1984 HD emission-data engines.

g/ 1975 LDV standards, g/mi.

h/ Proposed 1984 HD standards, g/BHP-hr.

i/ Constant weight basis LDV pre-control mpg, Reference 1/.

j/ Constant weight basis, 1974 LDV mpg, Reference 1/.

k/ Constant weight basis, 1975 LDV mpg, Reference 1/.

l/ 1969 baseline BSFC, lb/BHP-hr, Reference 5/.

m/ 1979 baseline BSFC, lb/BHP-hr, Reference 6/.

n/ Values in parenthesis represent change from pre-control value.

Table N-10

Fuel Economy Effects and Comparison of
Stringency of LDV and Proposed HD Standards a/

			Stringency of Emission Reductions b/	
		Precontrol	LDV Emission Factors/ HD LMT	Standards
HC	LDV	8.74	-84.9%	-82.8%
	HDG	12.74	-96.1%	-89.8%
			-11.2%	- 7.0%
CO	LDV	86.5	-73.5%	-82.7%
	HDG	155.18	-96.2%	-90.0%
			-22.7%	- 7.3%
NOx	LDV	3.54	-31.1%	-12.4%
	HDG	6.08	+15.1%	+76.0%
			46.2%	+88.4%
F.E.	LDV	12.5	+12.0%	-
	HDG	.688	(-)	-

a/ Values taken from Table N-6.

b/ Catalyst technology.

first year of catalyst control. The LMT HD NOx level actually represents a decrease in stringency of about 46 percent compared to LDV levels.

EPA test data shows that these LMT targets for HC and CO can easily be obtained. The Summary and Analysis of Comments on Technological Feasibility describes an experiment in which catalysts were added to a 1978 404-CID engine. HC and CO emissions could be incrementally eliminated by incrementally increasing the flow in the AIR injection system. Test data indicates that increasing the AIR injection rate cost about 2.5% to 4% loss in fuel economy for every 20CFM increase in flow rate.

The LDV data (Table N-10) shows that the LDV fuel economy increased by 12% on a constant weight basis between pre-control and the first year of catalyst technology. This fuel economy increase included the penalty incurred due to the addition of an air pump.

The HD experience indicates that the 11% and 23% HC and CO differentials in emission reductions between LDV and HD can be accomodated by increasing the AIR injection rate by 20 to 40 CFM over the LDV rate. Assuming a 4% fuel economy loss per 20 CFM increase, a 4-8% fuel economy penalty for HD engines would be incurred. However, since the data shows LDVs experienced a 12% increase in fuel economy with similar emission reductions, the 4-8% HD penalty would be subtracted from the 12% increase due to the addition of catalyst technology. The result would be a 4-8% increase in HDG fuel economy over the pre-controlled versions.

Table N-11 shows the emission results of the limited EPA experiments on the 404-CID engine. The amount of engineering time that went into the selection of hardware that resulted in these substantial reductions was very minimal. Possibly 4 to 8 person-hours were involved in the selection of initial hardware, and in the iterations from one modification to the other. Build up and testing time consumed maybe another 20-30 hours over a 2- to 3-week time span. Other than the catalysts and air pumps added to the engine, no other modifications were made. So even though this testing showed a small fuel economy loss, in as little as 2 weeks practically anybody would be able to modify this engine to show a fuel economy improvement, probably up to 10% over the standard configuration, and still meet the LMT levels.

Table N-12 presents data on another engine that EPA modified with the addition of oxidation catalysts (no other modifications). In this case, a comparison within the engine line could be made from data representing the 1969 pre-controlled condition, the 1979 certified condition, and a modified 1984 condition. The data (Table N-12) indicates that not only did the modified version reduce emissions to less than the proposed standards, the engine also produced more horsepower and obtained better fuel economy than the 1969 counterpart.

Table N-11

Fuel Economy and Emission Comparison a/
404-CID HD 8-Cylinder Engine
1978 California Calibration b/ (EGR/AIR)
172 BHP @ 3748

	HC	CO	NOx	BSFC
Standard Configuration (20 CFM Air)	3.98	54.56	5.01	.680 (+4.0) e/,f/
Modified Configuration w/Ox Catalyst, 40 CFM Air)	0.28 (-93.0)	8.98 (-83.5)	4.09	.708 d/
Modified Configuration w/Ox Catalyst, Simulated 80 CFM Air	0.32 (-92.0)	3.74 c/ (-93.1)	3.98	.765 e/ (-9.0)

a/ Transient test, g/BHP-hr; BSFC, lb/BHP-hr. Numbers in parenthesis represent change from standard configuration.

b/ 1978 California standards, steady-state test, 1.0 HC, 25 CO, 7.5 NOx, g/BHP-hr.

c/ Emission reduction exceeds LMT of 5.9.

d/ Measured transient BSFC.

e/ BSFC extrapolated from the same day comparison of WOT BSFC vs. varying air injection flow rates, see analysis in Summary and Analysis of Technological Feasiblity.

f/ Previous transient data (not same day comparison) in standard configuration indicates a BSFC of .672 (+5.1).

Table N-12

Fuel Economy and Emission Comparison *
292-CID HD 6-Cylinder Engine Line

	HP @ rpm	HC	CO	NOx	BSFC
Pre-Control	109 @ 3546	8.54	172.86	5.40	0.761
1979 Certified Configuration 20 CFM Air	114 @ 3760	2.12	54.98	9.74	0.655
1979 W/Catalyst, 20 CFM Air	114 @ 3760	0.58	12.25	7.30	0.638

* Transient test, g/BHP-hr; BSFC, lb/BHP-hr.

The previous analysis on both engines, did not include any potential fuel economy improvements available through system optimization due to the decrease in NOx stringency. Another aspect not to be overlooked is that a 4-8% HD fuel economy improvement over pre-controlled engines (1969) represents a 9-13% improvement over pre-catalyst engines (1979). (Table N-2 shows that the average pre-catalyst engine incurred a 4.8% penalty compared to pre-controlled engines.)

Based on the previous discussion and the incredible ease in which the emissions were reduced on the 404-CID engine (Table N-11), the promulgation of the 1984 HD emission standard will not cause a fuel economy penalty even at the HDG LMT levels, and will in fact probably allow an improvement in HDG fuel economy.

The final estimated amount of fuel economy increase can be evaluated in two ways. One, would be to assume the full 17% improvement between pre-catalyst and catalyst technology (1974 to 1975) LDVs could be obtained by HD engines. Then, the net HD fuel economy improvement could be calculated by substracting off the penalty incurred due to the additional AIR injection. However, not all pre-catalyst HD engines (1979) experienced the full HD fleet average fuel economy loss. These engines would tend to set a lower limit on fuel economy improvement. To calculate the lower limit, the estimated fuel economy improvement could be obtained by substituting the LDV pre-control to catalyst technology (pre-1968 to 1975) fuel economy improvement of 12% for the 17% figure, and once again subtract off the penalty incurred by the additional AIR injection.

Assuming many engines would require an additional 40 CFM AIR injection rate, the range of estimated fuel economy improvement resulting from the proposed 1984 HDG standards would be between 4% (12-8) and 9% (17-8).

From the data presented some may argue that even though the implementation of catalyst technology may cause a net improvement in HDG fuel economy, the higher AIR injection flow rates necessary for the catalyst technology rob power from the engine. In other words, the additional AIR flow creates a fuel economy foregone issue. While it cannot be denied that increasing AIR flow rates does increase engine fuel consumption relative to the useable power output, we suggest that this issue cannot be viewed from that perspective.

We suggest that the alternatives involved in this issue are: (1) propose a standard that forces catalyst technology and also allows an HDG fuel economy improvement 4-9 percent, versus, (2) staying with standards that do not force catalyst technology.

Alternative number 2 by necessity would rely on engine modifications (more refined, but similar to those encountered on 1974 LDV's and 1979 HDG's) to control emissions. In this case, as in Table 2, we could expect a decrease in fuel economy. So, we suggest that the choice is between a standard that allows a fuel economy improvement as well a providing significant ambient air quality benefits, versus a standard that does neither.

b. Diesel Engines

It is interesting to note that not one manufacturer claimed the proposed diesel emission standards would cause a fuel economy loss. Those that claimed a fuel economy loss, claimed others factors in the package such as crankcase emissions, and AQL limits would cause the fuel economy loss.

The one exception to these comments is the Caterpillar claim that in order to meet the proposed emission standards, Caterpillar would have to shift resources from fuel economy development to emission control development. This comment is a difficult one to discuss because it is so subjective for diesel engines. Caterpillar provided the fuel economy improvement trends on one engine line. Based on the Caterpillar data the yearly improvement in fuel economy for this engine is leveling out in the better portion of the normal range of diesel fuel consumption. For some unexplained reason Caterpillar claims the leveling out trend will suddenly take a sharp change in 1985. Further, Caterpillar qualified this claim by "Figure 8 illustrates the anticipated impact that the proposed emissions could have on the fuel economy trend." (Underlining added for emphasis.)

Caterpillar did not expand on the reasons for the drastic change in fuel economy improvement beginning in 1985. It is assumed that if such a change were to take place, it would be the result of new technology. Since none of the other diesel manufacturers directed comments to this area, we can only assume that the marketplace will force continued development of new technology resulting in improved diesel fuel economy.

Caterpillar also suggested that a 1-3% loss of fuel economy would occur on turbocharged engines due to the crankcase emission standards. Caterpillar apparently only evaluated one of several alternatives for controlling crankcase emissions, that of ducting the crankcase blowby into the turbocharger inlet. There are at least three other options discussed in the Summary and Analysis of Comments on Crankcase Emissions that Caterpillar apparently did not consider. At least one of the other options, and possibly more, need not cause a fuel economy penalty. However, considering the effect of ducting blowby into the turbocharger inlet is a realistic issue, the Summary and Analysis of Comments on Crankcase Emissions has recommended that crankcase emissions be controlled only from non-turbocharged engines. The analysis does recommend, however, that the issue of crankcase emission control on turbocharged engines remain in the proposal stage until more data is gathered. Therefore, the issue of potential fuel economy loss due to crankcase emission controls on turbocharged diesel engines is deferred.

Mack claimed less than 1% fuel economy loss between a 10% AQL and a 40% AQL. Mack based their analysis on a potential change in NOx that might be required to meet the 10% AQL. The analysis used data from the current steady-state 13-mode test.

A review of data from an ongoing diesel transient test program7/ suggests that the potential change in NOx levels that Mack claims will be required for the 10% AQL probably won't occur on a fleet-wide basis. Chapter 7 of the Regulatory Analysis discusses the impact of a 10% AQL as well as durability and other related issues in terms of low mileage targets (LMT). Using the derivation of LMTs from Chapter 7, an LMT for diesel engines with the proposed 10.7 g/BHP-hr NOx standard would be around 8 g/BHP-hr. A review of the data from engines tested to date7/ indicate that most engines are already well below the LMT NOx level. Therefore, most engines would not experience a fuel economy penalty at a 10% AQL.

Another important point to note about the Mack comment is that the only alternative apparently investigated by Mack was to lower the low mileage target (i.e., low initial emissions). The option of improving quality control of the product (engines) apparently was not considered. If Mack were to improve the product quality it is difficult to understand how a fuel economy penalty could be incurred.

GM and Cummins both commented on a fuel economy loss due to NOx control. But, they only discussed the loss in the context of the steady-state California standards of 6 g/BHP-hr HC + NOx. As stated previously most diesel engines appear to be well below the proposed transient 10.7 g/BHP-hr NOx standard as well as the estimated LMT NOx levels. Therefore, no fuel economy penalty is expected to occur with proposed 1984 standards.

4. Recommendations

We conclude from the foregoing analysis that heavy-duty gasoline-fueled and diesel engines will not incur a fuel economy penalty if the proposed HC, CO, and NOx standards are promulgated. Based on this analysis it is reasonable to expect that gasoline engines with catalyst technology will obtain a fuel economy improvement. In the long run (2 to 5 years) the fuel economy improvement from gasoline fueled engines could be as high as 13%. However, considering that initially the manufacturers will be on a learning curve and must consider such issues such as low mileage targets, audit quality limits AQL, etc., the potential fuel economy fuel economy improvement could be reduced to 4% to 9% for the first few model years after the proposed standards take effect.

For diesel engines a fuel economy improvement is also possible due to the relaxed NOx standard. Even though diesel engines are relatively closer to the proposed standards than current gasoline engines, they will also be on a learning curve the first couple of years after implementation. Therefore, it is expected that fuel economy from diesel s will remain stable.

Our recommendation is that the proposed standards be promulgated. For the purposes of determining the economic impact of the proposed regulations, we recommend the following fuel economy impacts.

HDG	4% Fuel Economy Gain
HDD	0% Fuel Economy Gain

References

1/ "Light-Duty Automotive Fuel Economy...Trends through 1979", SAE Paper Number 790225, J. D. Murrell, U.S. Environmental Protection Agency, February, 1979.

2/ "Intake Port Deposits Improved Fuel Economy," Automotive Engineering, October, 1979, pages 43-47, a magazine condensation of SAE 790938, L. B. Graiff, Shell Development Co., October, 1979.

3/ Data from EPA contracted test program on 1969 Light-Duty Trucks, Contractor, EG&G Automotive Research Inc., San Antonio, Texas, testing completed in the fall of 1979.

4/ Data from EPA contracted test program on 1972 and 1973 Light-Duty Trucks, Contractor, EG&G Automotive Research Inc., San Antonio, Texas, testing completed in the fall of 1979.

5/ "1969 Heavy-Duty Engine Baseline Program and 1983 Emission Standards Development", EPA/OMSAPC Technical Report, T. Cox, G. Passavant, L. Ragsdale, May, 1979.

6/ Data from In-house EPA HD Transient Test Program on twelve 1979 Model Year Certified-Configuration Engines, Ann Arbor, Michigan, testing completed in November, 1979.

7/ Data presented in Summary and Analysis of Technological Feasibility.

8/ "Automobile Exhaust Emission Surveillance - Analysis of the FY 1975 Program," EPA Report No. EPA-460/3-77-022, NTIS No. PB 279 355, December, 1977.

PART II

Analysis of Minor Issues

Issue - Test Procedure: Part II

1. Summary of the Issue

EPA has proposed a new transient test procedure. Aside from the major issues concerning the Test Procedure as a whole, numerous minor issues were raised pertaining to various technical points and details of the procedure.

In short, are these technical details properly specified to insure accurate test results, are they unduly restrictive, and can the test procedure be made more flexible?

Subissue - Exhaust Sampling and Analytical Systems

Summary of the Comments

Many commenters argued that other sampling systems be permitted besides those proposed in the NPRM. Cummins advocated usage of continuously integrated dilute sampling system, pointing out discrepancies between bagged and continuous NOx measurements. General Motors argued that use of computers for sample recording should be permitted. Numerous comments suggested changes in analyzer specifications, or clarifications in optimization procedures and equipment. Clarifications were requested on required equipment and components on the sampling system. In short, comments pertaining to the following areas were received:

- non-methane vs. a total hydrocarbon standard;
- use of CVS vs. alternate procedures;
- accuracy of CVS parameter measuring equipment;
- CVS calibration equipment: type and accuracy;
- CVS equipment;
- CVS backpressure;
- HFID optimization and calibration procedures;
- HFID calibration gases;
- HFID fuel impurities;
- HFID response time;
- Calibration gas accuracies;
- NOx measurement systems;
- Heated analyzers for bag analyzer;
- Computer-assisted sample recording

Analysis of the Comments

For the most part, all comments listed above were incorporated into Subpart N of the regulations.

One of the more significant issues raised pertaining to exhaust gas analysis involved Fords' assertion that only non-methane hydrocarbons should be regulated. Ford stated that by calculating the hydrocarbon standard based on a measurement of total hydrocarbons, including methane, EPA violated section 202(a) of the Act because methane does not endanger the public health and welfare. Ford made a similar challenge to the HC standard for light-duty vehicles which is also based on a measurement of total hydrocarbons. The U.S. Court of Appeals for the District of Columbia Circut unequivocably rejected Ford's assertion and concluded that the Clean Air Act authorized regulation of all hydrocarbon emissions. (See Ford Motor Company vs. EPA, No. 78-2041 D.C. Cir. 1979) (The Court of Appeals had not reached its decision when Ford submitted its comments on this matter). If Congress authorized the regulation of all hydrocarbon emissions from light-duty vehicles, it reasonably follows that regulation of all hydrocarbon emissions from heavy-duty vehicles is not prohibited by the Act.

Even if the standard were recalculated to measure only non-methane hydrocarbons, the level of non-methane hydrocarbons control would remain the same because the stringency of the standard would be adjusted accordingly (Section 202(a)(3)(A) sets an HC standard of at least 90 percent reductions; Congress contemplated a more stringent standard if it was technologically feasible).

Recommendations

Retain the total hydrocarbon standard.

Allow the use of alternatives to the CVS concept if equivalent results are obtainable. Specify how equivalency is to be demonstrated.

Allow the use of metering venturis, large radius nozzles,and ASME flow nozzles for CVS calibration, if traceable to NBS standards.

Add specifications for either a mixing box or dilution tunnel for diesel sampling. (These specifications are consistent with requirements for particulate sampling procedures).

Add detailed specifications for the diesel HFID (e.g. probe location in tunnel, response time, "overflow" calibration procedure, etc.) for clarification and accuracy.

Add specifications for the continuous sampling of CO, CO_2, and NOx for diesel engines. Allow the option of continuous sampling for gasoline engines, provided results are equivalent.

Subissue - Engine Cool-down Procedures

As discussed in Section A of the Summary and Analysis of Comments, the industry argued for adoption of a forced cool-down procedure in lieu of the 12-hour cold soak. The industry also argued that the 36-hour cold soak limit was overly restrictive.

Analysis of the Comments

An EPA test program in conjunction with data submitted by Ford and Cummins has established the viability of such a procedure. The procedure as written in Subpart N of the regulations is flexible, constraining only the coolants, coolant temperatures, and methods of coolant application. A cold start emission test may begin when the oil temperature reaches a designated range. (For catalyst-equipped engines, a temperature range within which the catalyst must be prior to a cold start is also specified).

The oil temperature range specification is 68°F to 75°F, as opposed to an ambient range of 68°F to 85°F. This discrepancy arises from EPA's forced cool down test program in which statistically significant differences arose between engines tested after a natural 12-hour cool down and those tested after a forced cool down to oil temperatures exceeding 75°F. (A description of the EPA test program can be found in a separate EPA technical report).

Recommendations

Adopt the forced cool down procedure as detailed in §86.1335 of Subpart N.

Drop the 36-hour maximum time limit on natural cold soak; drop the 72 hour maximum time limit on the entire test sequence. There is no apparent need for these requirements.

Subissue - Engine Mapping Procedures

Summary of the Comments

Diesel manufacturers commented that the proposed mapping technique was inaccurate at lower speeds. Mack questioned the definition of "measured rated speed", in particular for engines which develop usable horsepower at speeds well above the speed at which maximum horsepower occurs.

Gasoline manufacturers questioned the safety of engine operation at low speeds and wide open throttle. Use of a cubic spline technique for maximum torque curve generation was also questioned; linear interpolation was suggested as an alternative.

Analysis of the Comments

Transient diesel testing at SwRI has substantiated the inaccuracy of the proposed diesel mapping technique. A transient mapping technique, a slow progression from minimum to maximum speeds at wide open throttle, has since been used with satisfactory results. (Both the proposed technique and the transient technique were originally recommended by an SAE subcommittee to insure safety at lower engine speeds).

Macks' comments pertaining to "measured rated speed" are well founded. The definition has been changed to allow emission testing at speeds up to a "rated" speed specified by the manufacturer. (See definition in Recommendations). This would assure emission testing across the true full range of engine speeds, but at the manufacturers option. As in the proposal, the speed of maximum horsepower remains the lower limit of 100 percent speed.

At no time during the transient baseline work at EPA or SwRI has trouble been experienced with steady-state mapping of gasoline engines. The manufacturer's concerns are unfounded. However, EPA recognizes that special cases may exist and an optional transient mapping procedure is allowed for gasoline engines.

Further recognizing the existence of special cases, both diesel and gasoline manufacturers are allowed to specify alternate mapping procedures if the techniques specified in the Final Rules are judged unsafe or unrepresentative. Advance approval of the Administrator is required before this option may be taken.

Finally, use of a linear interpolation between points is required to generate the maximum torque curve if transient mapping techniques are used. Requirements that data points be collected at least once a second during transient maps are no more stringent than those required to run the transient test itself.

Recommendations

Specify a transient mapping procedure for diesel engines, utilizing linear interpolation between the mapping points.

Allow an optional transient mapping procedure for gasoline engines, utilizing linear interpolation between the mapping points.

Redefine "measured rated speed" as the highest engine speed at which maximum horsepower occurs, or a speed specified by the manufacturer provided that the specified speed is at least 100 RPM greater than the highest speed at which maximum horsepower occurs, and provided that at least 50% of the maximum horsepower occurs at the specified speed.

Allow an "escape clause" for special case engines, i.e. those with which the Administrator agrees that a safe and/or representative map cannot be performed per the Final Rules procedures.

Drop the requirement that only 8 hours be allowed for practice cycle runs after mapping. Experience at the EPA Lab has shown this to be overly restrictive for certain control systems. No time limit shall be specified.

Details of these incorporated recommendations are found in §86.1332 of Subpart N.

Subissue - Engine Starting Procedures

Summary of the Comments

Several manufacturers argued that starter motors should not be required. The dynamometer can start the engine just as easily and the impact on emissions is negligible.

Cummins suggested that engine stalls during the hot start portion of the test cycle not be permitted to void the entire test; another hot soak and cycle should be allowed.

Caterpillar claimed that a limit of 15 seconds of cranking was less than that recommended to their customers and argued for longer permissible cranking times.

Analysis of the Comments

Starter motors have been used at EPA and SwRI from the first transient test until the present. No problems have been encountered and problems with additional equipment (batteries, battery chargers) were insignificant. Although emission impacts observed to date have been minimal, the Staff is concerned with the compromise in representativeness entailed in use of the dynamometer for starting, especially at lower emission levels and for harder-starting engines. Safety concerns of open electrical contacts in a fuel-filled environment are recognized; proper use of judgement and common sense in the location of batteries and switches, however, more than alleviate these concerns.

Engine restarts during stalls or other voiding incidents in the hot cycle portion of the test have been performed at EPA's lab for some time. Emissions can be affected, however, if the engine is shut down during the high power, high temperature LA Freeway portion of the cycle. The engine would then be restarted at a high temperature than normal. A single hot cycle restart should be permitted, however, if the engine is shut down before the LA Freeway begins (less than 580 seconds into the hot cycle).

Caterpillar's concern for greater cranking time is understood and incorporated into the procedure.

Recommendations

Retain the starter motor requirement.

Allow a hot cycle resoak and restart, provided that the engine is shut down before 580 seconds into the hot cycle.

Allow a greater cranking period, if a manufacturers' recommendation to the customer is consistant with a longer cranking time.

Subissue - Engine Testing Procedure

Summary of the Comments

Many commenters requested clarification of general test requirements, i.e. temperature, humidity, and barometric pressure.

The statisitical validation criteria were also questioned.

Questions were raised as to how the cycle was to be run with engines equipped with automatic chokes, or with engines designed for use with automatic transmissions.

Analysis of the Comments

Test ambient conditions were clarified. Humidity specifications were relaxed, forbidding testing (i.e. requiring humidity control) only when engine intake air humidity exceeds 90 grains per pound of dry air. No humidity restrictions are placed on test cell ambient air or CVS dilution air. Engine intake air and CVS dilution air are required to be temperature controlled (25°C $\pm$ 5°C), but test cell ambient air is not - provided that the emission control apparatus on the engine are not temperature-effected. (This is intended to preclude the need for high volume air conditioning systems in test cells). Barometric pressure requirements remained the same, but were clarified.

Inlet and exhaust restictions representing "normal" in-vehicle conditions for diesel engines were specified.

Allowances were made for testing of automatic choke gasoline engines, and for all engines used with automatic transmissions. These changes were included in the cycle themselves and/or in the validation criteria.

The statistical validation criteria were relaxed, per transient testing experience. An additional relaxation (over and above those outlined in the 1969 Baseline Report) was made: the standard error for Brake Horsepower was relaxed from 7 percent to 8 percent of maximum. This is based upon transient diesel testing experience acquired at SwRI. The statistical criteria was also changed to reflect operation of automatic choke and/or automatic transmissions.

Recommendations

Relax the general humidity, temperature, and pressure requirements, per §86.1330 of Subpart N.

Relax the statistical validation criteria per §86.1341 of Subpart N.

Allow for the use of automatic choke and automatic transmission, per §86.1333 and §86.1341 of Subpart N.

Subissue - Miscellaneous

Summary of the Comments

Various typographical errors and two mathematical errors were pointed out in the proposal.

Analysis of the Comments

The assertions of error were checked and changed if true.

Recommendations

Change the errors in the procedure for Final Rule.

B. Issue - Redefinition of "Useful Life"

1. Subissue - Transfer of "useful life" into market.

a. Summary of the Comments

Cummins said that "EPA, by allowing each manufacturer to provide its own yardstick to do its own measurement with no appropriate standard, will be effectively transferring the entire useful life mileage question into the marketing arenas."

b. Analysis of the Comments

The associating of actual rebuild criteria with the definition of useful life addresses Cummins' problem by placing most of the emphasis on technical rather than market criteria. While we obviously intended that the proposed manufacturer-determined useful life alone would be based on technical aspects of the engine, we agree that without the rebuild criteria some manufacturers may have emphasized marketing criteria.

c. Staff Recommendations

We recommend no further changes in response to this comment.

2. Subissue - Encouragement for short useful lives.

a. Summary of the Comments

Cummins believes that to keep costs down, some manufacturers will sell short-lived engines. Especially when these engines are used past their useful lives, air-quality will suffer.

b. Analysis of the Comments

Currently the only incentive which EPA provides for longevity is a useful life roughly one-half of the average lifetime of the engines. It is toward the goal of durable emission controls that the extension of the useful life (and the defining of minimum maintenance intervals) is introduced. The "ambiguity" of the useful life will be reduced by the establishment of rebuild criteria as an end to the useful life. We expect that this package will result in more, not less, incentive for manufacturers to build in long-lasting emission control into their engines. The visibility of the "useful life" on the label should also provide an advantage to the makers of durable engines.

c. Staff Recommendations

We recommend no further changes in the regulations.

3. Subissue - Congressional Authority

a. Summary of the Comments

Cummins points to three issues, as follows:

(1) Congress specifies that the Administrator must determine the useful life, not the manufacturer.

(2) Congress specifies that the useful life must be "a period" of use, whereas the proposal would result in widely varying useful lives.

(3) If the Administrator were to disapprove a manufacturers' useful life, the timing would be such as to wreak economic hardship by delaying certification.

b. Analysis of the Comments

(1) Our view is that EPA is indeed defining the useful life as specified by the Act. The manufacturers determine for their engines what the values of the useful lives are (or the values of the rebuild criteria), but "useful life" is defined by EPA in the regulations.

(2) Similarily, for any given engine family or individual engine, a "period of use" exists and is called the "useful life". Congress did not constrain EPA to one number for all heavy-duty engines. Currently, in fact, two periods of use exist, one for each fuel type.

(3) Section 86.083-22 (d)(2) of the proposal clearly says that the Administrator does not approve a manufacturer's useful life. The problems that concern Cummins cannot occur.

c. Staff Recommendations

We recommend that no further changes be made regarding the useful life issue in response to these comments.

C. Issue - In-Use Durability Testing

There are no subissues needing consideration in this Part All pertinent comments have been addressed in Part I.

D. Issue - Allowable Maintenance

1. Subissue - Certification at shorter intervals.

a. Summary of the Comments

IHC was concerned that the proposed maintenance provisions did not permit more frequent maintenance during certification than the EPA established minimum intervals. Owners would get a free replacement under warranty, though the cost of the engines would have to go up to cover the replacement parts.

b. Analysis of the Comments

The primary intent of the new maintenance requirements is to encourage low-maintenance emission control systems. To allow more frequent maintenance than what is technologically necessary would be contradictory to this purpose. In any event, it is usually more costly for the consumer to pay for the replacement of a component at the time of purchase than to pay for the designing-in of greater durabilitry.

c. Staff Recommendations

We recommend that no changes be made in response to this comment.

2. Subissue - EPA's language in certain passages of the proposed regulations is vague or overly restrictive.

a. Summary of the Comments

Ford commented that defining "emission-related maintenance" as that having a "substantial effect" on emissions was not adequately specific for regulatory purposes.

In addition, Ford believes the EPA definition of "new technology" is too restrictive as it is used in §86.083-25(c)(1)(iv) of the NPRM as a criterion for EPA to authorize more frequent maintenance than that which is technologically necessary. Similarly, Mack said that the proposed definition and application of "unscheduled maintenance" should be no more restrictive than their current recommendation, which calls for maintenance when the operator observes malfunction symptoms according to their troubleshooting guide.

b. Analysis of the Comments

We believe that the term "substantial effect on emissions", while open to subjective judgement in an individual case, clearly signals that a rather large effect must be present. If performance of a certain maintenance item resulted in a small change in emission, near in magnitude to the limit of accuracy of the analysis instruments, EPA could hardly claim that the effect was "substantial". In any case 13 examples of non-emission-related maintenance are given in the regulations (§86.083-25(c)(1)(vi)). If a manufacturer were honestly confused as to how EPA would categorize a certain maintenance item, it is not uncommon to seek informal advice early in the certification process as to what EPA's interpretation might be.

Ford's concern about restricting "new technology" to that "not found in production on any motor vehicle prior to the 1980 model year" seems unnecessary. Certainly, EPA desires to allow more frequent maintenance only in extreme cases, since we believe we have adequately analyzed the maintenance requirements of current technology components. However, for a new component, design, system which has different maintenance requirements is introduced it should not be difficult to show that this "new technology" deserves special consideration. The specific terminology is necessary to prevent, for example, a new arrangement of current components from being introduced simply for the sake of a reduction in maintenance requirements.

Finally. we believe that the proposed constraints on unscheduled maintenance are not overly restrictive and serve to assure that maintenance is not casually or repeatedly performed if it is not scheduled.

c. Staff Recommendations

Based on the consideration of the comments, we recommend that the language of the instant provisions remain unchanged.

3. Subissue - Suggested Maintenance Criteria.

a. Summary of the Comments

Ford suggested the following as the only restrictions on maintenance during certification:

(1) Maintenance (and the interval at which it is performed) must be necessary for the proper functioning of the emission control system and the vehicle.

(2) Maintenance procedures must be performable by mechanics in the field.

b. Analysis of the Comments

EPA's reasoning behind the specifying of minimum intervals is discussed in the major portion of this document. However, it may be useful to explain why we believe the maintenance requirements, while more restrictive, do fulfill Ford's criteria. First, changes which will appear in the final rule will clearly relate the maintenance done during certification to that required in use, inherently requiring that maintenance be easily performed by mechanics. Second, by requiring that maintenance be technologically necessary, we are in effect requiring no less maintenance than has been shown to be adequate for the proper functioning of current systems and vehicles.

c. Staff Recommendations

We recommend no further changes in the maintenance requirements in response to this comment.

4. Subissue - Combustion chamber opening during certification.

a. Summary of the Comment

GM commented that requiring that the combustion chamber not be opened during servicing is inconsistent with normal service practices.

b. Analysis of the Comment

We have not proposed to change the unscheduled maintenance provisions in the current regulations. They require that additional unscheduled maintenance (other than for misfire, choke maladjustment, or incorrect idle speed) may not, among other things, require direct access to the combustion chamber. We do not believe that removal of the cylinder heads should be a routine practice during certification and support the current provisions.

c. Staff Recommendations

We recommend that the provisions relating to the opening of the combustion chamber be retained.

E. Issue - Parameter Adjustment

1. Subissue - Validity of the EPA Restorative Maintenance Study.

a. Summary of the Comments

Some commenters challenged the use of the EPA Restorative Maintenance Study (an Evaluation of Restorative Maintenance on Exhaust Emissions of 1975-1976 Model Year In-Use Automobiles, EPA 460/3-77-021, December 1977) as an basis for these regulations. They claimed that the Restorative Maintenance Study does not establish any correlation between in-use maladjustment and failure to meet the emission standards.

b. Analysis of the Comments

The position advanced by these comments is in error. Similar comments were received when parameter adjustment was proposed for light-duty vehicles. The implications of the Restorative Maintenance study are discussed in the Summary and Analysis of Comments which accompanied the final light-duty vehicle rule-making, at pages 7-12. The Restorative Maintenance study clearly identified parameter maladjustment as a major cause of excess in-use emissions.

In issue E of Part I, a summary of the results of the Restorative Maintenance program is provided (Table E-1). That table indicates clearly the impact of parameter maladjustment on emissions.

Staff Recommendations

None.

2. Subissue - The language defining what parameters must be identified is vague and ambiguous.

Summary of the Comments

This comment pertains to Section 86.083-21(b)(1)(ii), which defines those parameters which must be identified as including those which "may affect emissions." This definition was felt to be too vague, and possibly subjecting manufacturers to undue hardship and unexpected delays.

b. Analysis of the Comments

The staff recognizes the validity of this comment. The wording of the section in question can be revised similar to that wording proposed by Ford in its comments.

Staff Recommendations

Revise the wording of Section 86.083-21 (b)(1)(ii) to clarify the parameter to be reported.

3. Subissue - Timely determinations by the Administrator

a. Summary of the Comments

Commenters believed that the regulations should contain provisions such that early submittals result in an early response from EPA. EPA stated in the preamble that to avoid disruption of certification, it intended to make early determinations of those parameters subject to adjustment, the adequacy of limits, stops, seals, etc. if the manufacturer submits the necessary information early. However, the regulations do not require such early determinations.

b. Analysis of the Comments

The staff recognizes the validity of this problem. Manufacturers should be given a definable timetable within which to work in developing complying engines. In order for this to happen, the manufacturer should have a specified maximum waiting period for EPA determination.

c. Staff Recommendations

The regulations should be modified to provide a maximum time interval of 90 days for EPA to review submitted information and make its determinations. This time would be exclusive of time involved in obtaining additional information needed to make the determinations.

4. Subissue - The definition of what constitutes a "new parameter".

a. Summary of the Comments

Commenters objected to defining a new parameter as one which "was not present on vehicles of the same engine family in the previous model year." The objectionable part of this definition was the " same engine family" criteria, which commenters felt did not accomplish the objective of the definition. This objective they felt to be the distinguishing of a new parameter (which should be introduced in a conforming condition) from existing parameters (which need adequate lead-time to develop tamper-resistant designs). A change in engine family, commenters felt, had no direct bearing on whether a parameter was in fact a new one.

F. Issue - Idle Test and Standards

There are no subissues needing consideration in this part All pertinent comments have been addressed in Part I.

b. Analysis of the Comments

The staff recognizes the validity of this objection. The wording of the regulations can be revised to accomodate this problem.

c. Staff Recommendation

The wording of Subsection 86,083-22(e)(1)(i) should be changed to eliminate the "same engine family" criteria for identification of a new parameter.

5. Subissue - Manufacturers risk relative to in-use maladjustments.

a. Summary of the Comments

Comments on this issue contended that a determination by EPA of the adequacy of limits, stops, seals, or other means to inhibit adjustment of parameters constitutes a finding by EPA that the manufacturer has adequately fulfilled his responsibility to restrict adjustability. Consequently, any actual maladjustment occurring in-use should be considered tampering instead of maladjustment, and the manufacturer should bear no responsibility for such occurrence (such as recall liability).

b. Analysis of Comments

It is the manufacturer's responsibility to do a thorough job in designing non-adjustable parameters. EPA determinations during certification are based upon information available prior to accumulation of actual in-use experience. Notwithstanding the fact that EPA has issued a certificate of conformity to produce an engine family, the manufacturer remains liable for the performance of his engines in-use. The final test of the adequacy of any means to inhibit adjustability is the performance of that means in-use. Thus, it may happen that although a vehicle is certified, it is later recalled, because EPA may inaccurately predict in-use maladjustments. EPA's position, dating from prior to even the light-duty parameter adjustment regulations, is that the fact that an in-use vehicle is adjusted to non-recommended settings does not necessarily prove that it has not been properly maintained and used. EPA has, therefore, asserted that maladjusted in-use vehicles may be subject to recall action.

c. Staff Recommendations

None.

G. Issue - Leadtime

1. Subissue - Statutory Timetables

a. Summary of the Comments

Many commenters indicated that the 1977 Clean Air Act Amendments required EPA to promulgate final 1983 standards by December 31, 1978 and allow a four year leadtime for implementation by the industry. Because EPA has failed to meet the December 31, 1978 deadline, commenters felt that the complete rulemaking could not be imposed for 1983. Several alternatives were suggested as to how EPA ought to deal with this situation. These included allowing more time to implement the regulations, deletion of the transient test in favor of the current steady-state procedure, or implementation of a modified transient test (the "Caterpillar" cycle).

b. Analysis of the Comments

EPA acknowledges that the timetable foreseen by Congress was as outlined above. What neither the Congress nor EPA anticipated at the time the 1977 Amendments were enacted was the amount of additional time necessary to develop a test procedure designed to insure that the significant reduction in HC and CO emissions that Congress sought would actually be achieved. The Agency is approximately one year behind the schedule for implementation that Congress had expected. The decision to delay the year of implementation one additional year until 1984 maintains the four year leadtime inherent in the Clean Air Act timetable. That decision, made from considerations of feasibility alone, satisfies the commenters demands for a four year leadtime.

c. Staff Recommendations

In light of the decision to delay implementation until 1984, no specific action is needed in response to this subissue.

2. Subissue - Interpretations of legal issues have been made by technical and administrative personnel rather than by the EPA Office of General Council.

a. Summary of the Comments

In its comments, General Motors indicated that in their review of EPA documents obtained under a Freedom of Information Act request, they found that no formal legal opinion had ever been requested from the Office of General Council on any of the key legal issues involved in the rulemaking. Rather, GM believed that legal interpretations were being made by technical and administrative personnel. General Motors indicated the possible operation of a "housekeeping perspective" leading to an unwarranted desire to prematurely promulgate the transient test.

b. Analysis of the Comments

The idea that development of this rulemaking proceeded without input from the Office of General Counsel is incorrect. Informal contacts with representatives of that office were made as needed when matters of legal interpretations arose. Representatives of the Office of General Counsel also participated fully in the internal review process involved in promulgating the initial proposal (as well as these final regulations). The Office of General Counsel is also one of the key offices which must formally concur with a rulemaking before it is proposed or finalized. Such concurrence is only made after a careful review of the action involved.

c. Staff Recommendations

None.

3. Subissue - EPA determination of Technological Feasibility

a. Summary of the Comments

In its comments, GM contended that EPA had made a determination of technological feasibility for the proposed action at a time when adequate transient testing had not yet been done and before promulgating the final test procedure. This was believed by GM to have been an arbitrary and capricious action denying manufacturers knowledge of the standard and final regulations, opportunity to request a revised standard, and four year leadtime.

b. Analysis of the Comments

EPA did not make any final determination of technological feasibility until after a complete review of all comments submitted during the comment period for this rulemakng. EPA stated in the preamble to its proposal (44 FR 9471, February 13, 1979) that "manufacturers comments on the feasibility of meeting the proposed standards will be considered in setting final standards. If revisions to the statutory standards are warranted, they will be made." Preliminary conclusions concerning feasibility had to be made before the proposal could be published for comment. That the engineering judgement behind those preliminary conclusions were sound is born out by the finding in this final rulemaking that the regulations are indeed feasible (see issue I - Technological Feasibility). At no time prior to this did EPA make a final determination of feasibility under Section 202(a)(3)(C).

c. Staff Recommendations

None.

4. Subissue - Committments of Resources by Manufacturers Prior to Final Rulemaking.

a. Summary of the Comments

Several commenters believed that EPA was predicating the feasibility of its proposed timetable for diesels upon the expectation that manufacturers could begin working toward compliance with the regulations once the NPRM was published. These commenters contended that manufacturers could not be required to make significant resource committments prior to final rulemaking action by EPA.

b. Analysis of the Comments

In the preamble to the NPRM, EPA did indicate its belief that the diesel engine manufacturers could begin facility acquisition before promulgation of final rules. At the time of publication some companies had already taken such steps. Testimony supplied to EPA during the comment period indicated that all domestic manufacturers had made advance committments to obtain some limited test capability. However, EPA's belief in the feasibility of its proposed 1983 compliance date was not predicated upon these committments as the commenters suggest. In the NPRM, EPA also stated that "even assuming that the manufacturers do nothing until promulgation of final rules (assumed promulgation date is December 1979), EPA concludes that the proposed emission levels are achievable with already available emission control technology within the leadtime existing." (44 FR 9471, February 13, 1979).

The leadtime analysis used in this final rulemaking makes use of the information supplied to EPA concerning advance committments of resources. These committments have been made voluntarily by manufacturers to develop their own in-house testing capability. Since such advance facilities are being procurred, it is appropriate to incorporate their availability into leadtime considerations. EPA is not requiring that these actions be taken, but simply recognizing that they have.

c. Staff Recommendations

None.

H. Issue - Economic Impact

1. Subissue - Warranty Claims Associated with the Useful Life Redefinition

a. Summary of the Comments

Based on the useful life redefinition which was proposed, "the average period of use up to engine retirement or rebuild, whichever comes first", most manufacturers stated that they would incur increased warranty claims on as much as 50 percent of their sales. The figures submitted by each manufacturer are given below:

Caterpillar	$ 89 per engine
Chrysler	$200 - $400
GM	$100
IHC	$150

Other manufacturers discussed increased warranty claims but did not quantify the impact.

b. Analysis of the Comments

The revised useful life definition which is discussed in issue B reads:

> The useful life of a heavy-duty engine is reached when one of two possibilities occurs:
> a) the mechanical rebuild criteria are surpassed
> b) the average period of use is reached.

However, in no case can this be less than 5 years or 50,000 miles whichever occurs first. With this definition, some of the manufacturer jeopardy is removed. This is true primarily because the useful life is much more specific than in the original proposal.

The manufacturers warranty liability should be limited inherently in that they would be expected to build durable engine/control systems. In no case does EPA anticipate the manufacturers paying for rebuilds on 50 percent of the engines it sells.

In conclusion, these regulations which are establishing a new useful life definition are not warranty implementation regulations. Increased warranty costs associated with a potentially longer useful life should be addressed when the warranty regulations are implemented.

c. Staff Recommendations

Increased warranty costs should be considered by the Office of Enforcement when the warranty regulations are implemented. These costs need not be included in this package.

2. Subissue - Inspection/Maintenance (I/M) Costs

a. Summary of the Comments

Several commenters stated that EPA had underestimated the costs of implementing I/M for heavy-duty gasoline-fueled vehicles in several areas: the I/M fee, vehicle downtime, and operator time.

b. Analysis of the Comments

The actual I/M costs are dependent upon the means by which the program is implemented. Two methods will be discussed, private garages and public inspection points.

A fee of $5 per test seems reasonable in light of the current range of fees being charged in light-duty I/M programs ($3-$12). Average vehicle lifetime I/M costs should not exceed $40 per vehicle. If the I/M program is run by private garages, this cost could be less because the new vehicle dealer could conduct the first I/M test as part of dealer preparation. This is often the case with mandatory safety inspection programs.

EPA believes that an annual vehicle I/M check would be conducted during a period of minimal vehicle usage, or concurrently with other routine maintenance, so no vehicle operating time would be lost. Therefore, the only additional cost might be associated with the operators time spent during the I/M test. If the annual I/M check is conducted by state owned facilities, then there would be a cost tied up with the time spent driving the vehicle to the inspection facility. In any case, this cost would cover only 60 percent of the heavy-duty gas fleet since only 60 percent are in commercial applications. If the I/M checks are done by private garages, then the checks could be done in association with routine maintenance, and no other costs would be incurred. In situations where a commercial vehicle would have to be driven to a state operated I/M facility, the inspection would probably take about one-half hour or $7 according to ATA estimates.

The regulatory analysis supporting the final rulemaking does not include I/M as an absolutely essential part of the comprehensive control strategy, so I/M costs need not be included as part of the cost effectiveness calculations.

c. Staff Recommendations

None required.

3. Subissue - Replacement Catalyst

a. Summary of the Comments

Several of the manufacturers of gasoline-fueled heavy-duty engines stated that they might require replacement catalysts to meet the new useful life definition. Base on the comments received from GM, the cost to replace a catalyst would be about twice the manufacturing cost.

b. Analysis of the Comments

The EPA technical staff is convinced that a full life catalyst is technologically feasible for use on gasoline-fueled heavy-duty engines. The basis for this decision is given in the allowable maintenance issue. Therefore, the regulatory analysis need not include the costs of a replacment catalyst.

c. Staff Recommendations

Do not include the cost of a replacement catalyst in the economic impact since it will probably not be necessary.

4. Subissue - Modified or Additional Pumping Facilities for Unleaded Fuel.

a. Summary of the Comments

The American Trucking Association (ATA) stated that an increased cost of this regulation would be the need for additional unleaded gasoline pumping facilities in the public and private sectors. Under their assumptions, they estimated a lifetime per vehicle cost of $52.

b. Analysis of the Comments

EPA concurs with the comments by ATA, and has included this cost in the economic impact analysis. This cost has been included by allowing an additional 0.5 cents in the leaded-unleaded price differential. In other words, the expected differential was increased from 2.5 cents to 3.0 cents per gallon to allow for the amortization of these facilities. Over the 114,000 mile average lifetime of each vehicle, this becomes about $57 per vehicle.

$$\frac{114{,}000 \text{ miles}}{\text{lifetime}} \times \frac{1 \text{ gallon}}{9.9 \text{ miles}} \times \frac{\$.005}{\text{gallon}} = \$57.57$$

c. Staff Recommendations

The cost of unleaded fuel pumping facilities should be included in the analysis.

5. Subissue - Incremental Cost/Benefit Analysis

a. Summary of the Comments

Several commenters, especially the Counsel on Wage and Price Stability, emphasized that EPA had not presented an adequate incremental cost benefit analysis covering all of the options considered in this rulemaking action.

b. Analysis of the Comments

The EPA technical staff recognizes the need for an in-depth incremental cost benefit analysis. The Analysis which was prepared for the final rulemaking action should be published in support of the final rule.

c. Staff Recommendations

Publish the alternative actions considered and the incremental cost/benefit analysis as part of the regulatory analysis supporting the final rulemaking action.

6. Subissue - Increased Cost Associated with a Fuel Economy Penalty

a. Summary of the Comments

Ford Motor Company stated that due to the cold start weighting requirements a 10 to 15 percent fuel economy penalty should be anticipated.

Cummins Engine Company estimated a 1-5 percent fuel economy foregone penalty due to the durability testing program. Cummins felt that durability testing would force them to delay the use of new technology in the marketplace.

b. Analysis of the Comments

The EPA technical staff is in absolute disagreement with the comments by Ford. Ford's "projected" fuel economy loss is based on an invalid extrapolation of steady-state data in an attempt to simulate the heavy-duty transient test.

Fords projected fuel economy loss of 10-15 percent is based on an increase in brake specific fuel consumption (BSFC) on their simulated transient test. They claim the fuel economy decreases from .620 to .721 lb/BHP-hr as the HC standard decreases.

The invalidity of Fords' approach is easily demonstrated by data generated during 1979 baseline testing at EPA. The same engine type which Ford used in their simulated transient test was tested on the transient test by EPA at the Ann Arbor Laboratory. Ford estimated a BSFC of .627 for their current technology 6.1 L engine on the transient test and a BSFC increase of 16 percent to .721 with the new emission standards. When EPA tested a similar current technology engine on the transient test, the BSFC was .7795, a full 25 percent greater than Fords' estimated value for engines designed to meet the same emission standard. Clearly, Fords' simulated transient test is not capable of accurately predicting fuel consumption on the EPA transient test.

EPA appreciates Fords' efforts to meaningfully comment on the NPRM, but obviously cannot consider Fords fuel economy decrease projections as valid.

Cummins Engine Company estimated a 1-5 percent fuel economy penalty in Appendix I of their comments, but no supporting statements or data were given. EPA expects that Cummins was trying to draw a parallel to their statements concerning the 1980 California emission standards for HC and HC + NOx. The EPA technical staff does not foresee Cummins using variable injection timing to meet the 1984 HC or NOx standards and does not believe Cummins has presented a firm basis for any fuel economy penalty for their engines.

c. Staff Recommendations

The final economic impact analysis should not include any costs associated with a fuel economy penalty.

7. Subissue - Dislocation in the Gasoline Engine Market

a. Summary of the Comments

International Harvester Company (IHC) raised fears that the proposed regulations would remove any marketing advantage currently held by gasoline-fueled engines and replace the gradual trend toward dieselization with a "stampede". Their major concerns are in the first price increase differental and operating cost increase differental.

b. Analysis of the Comments

The EPA technical staff is very concerned about the economic and employment impact of the proposed regulations. IHC's basic contention is that these regulations will rapidly decay the position of the gasoline-fueled engine in the heavy-duty market.

One must consider several different facets of this concept before drawing any conclusions.

The past history of the gasoline-fueled engine in the heavy-duty market is shown below for the last twelve years:1/

Year	Percent Gas	Percent Diesel
1967	81	19
1968	79	21
1969	76	24
1970	75	25
1971	75	25
1972	76	24
1973	74	26
1974	72	28
1975	79	21
1976	76	24
1977	69	31
1978	68	32

The data clearly shows that prior to the oil embargo of 1973 and 1974 and the 1974 economic downturn the market split between gasoline-fueled and diesel engines remained fairly constant at about 3:1.

However with the rising fuel prices in the late 1970's the market share for the gasoline-fueled engine began to decrease. This can be seen especially in weight classes VII and VIII which are the "heavy-heavies".2/ From this data it is clear that natural market pressures due to fuel economy concerns are forcing the shift to dieselization. Most studies expect classes VII and VIII to be almost 100 percent diesel by 1990.3/

What is the impact of these regulations on this sales mix shift? The average first price increase expected by EPA, $394 gasoline-fueled and $195, diesel, will decrease the selling price differential between the two engines by $200. In addition, unleaded fuel costs, less decreased exhaust system and spark plug maintenance, will increase operating costs by $83, for a total differential of about $300. However, EPA predicts a fuel economy increase of at least 4 percent in gasoline-fueled engines which should lead to decreased operating costs.4/

On this basis, the impact of these regulations on the selling prices of heavy-duty engines will be examined.

	Gasoline-Fueled Engine	Diesel
Selling Price:	$3000	$6000
First Price Increase:	394	195
Operating Costs:	83	0
Fuel Economy Benefit:	-788	0
Selling Price	$3394	$6195
Operating Cost Change	-705	0

As can be seen in the example above, the average price differential of $3000-$4000 5/ dollars is decreased only $199, about 5.7 percent. This first price increase should have only a minimal impact on sales of heavy-duty gasoline powered vehicles (.91 percent to 1.8 percent decrease).4/

The anticipated net decrease in operating costs may actually make the gasoline-powered vehicle more attractive than it presently is in some applications.

In conclusion, EPA does not believe that these regulations will have any substantial impact on sales of heavy-duty gasoline-fueled engines. Any orderly displacement in this market which is being caused by fuel economy pressures will remain relatively unaffected by these regulations. In addition, the full impact of the mandated diesel particulate and heavy-duty NOx regulations may ultimately have an influence on this market split which easily outweighs the minor impact expected here.

c. Staff Recommendations

None required.

8. Subissue - Manufacturer and Dealer Profit

a. Summary of the Comments

The commenters did not concur with EPA's exclusion of manufacturer and dealer profit from the first price increase for gasoline-fueled and diesel heavy-duty engines.

b. Analysis of the Comments

The EPA technical staff recognizes that prudent business practice will force the manufacturers and dealers to seek at least an average profit on the funds which they invest in emission control technology.

Unfortunately, these additional profits substantially increase the price for cleaner air. Some would argue that profits on emission controls are really a transfer payment from one segment of society to another and are not really a "cost" which should be considered in the cost effectiveness calculations for the emission control strategy under consideration. At the present time, EPA will be conservative in their cost effectiveness calculations and include profit at all levels in these figures.

Having determined that manufacturer and dealer profit should be included in the economic impact analysis, the amount of this profit must be determined. Based upon the vastly different nature of the gasoline and diesel heavy-duty markets the EPA technical staff believes that profit levels should be evaluated for each segment of the market.

To determine these profits and, in addition, overhead figures, EPA studied financial data for the major domestic manufacturers in both segments of the heavy-duty market. For gasoine-fueled engines EPA studied data for 1976, 1977, and 1978 from General Motors (GM), Ford, Chrysler, and International Harvester (IH). For diesel engine EPA studied data from GM, Cummins, Caterpillar (CAT), Mack Trucks, and IH.

(i) Gasoline Engine Manufacturers

The data below represents the overhead and profit levels which EPA estimated using financial data found in Moody's Industrial Manual.6/ The values below are the fraction of the costs of sales which overhead and profit comprised for each of the manufacturers in 1976, 1977, and 1978. For example an overhead fraction of .11 implies that overhead is equal to 11 percent of the cost of selling the product. The same example can apply to the profit figure.

	1976		1977		1978	
	Ovhd	Profit	Ovhd	Profit	Ovhd	Profit
GM	.117	.145	.109	.141	.117	.129
Ford	.113	.080	.099	.100	.103	.081
Chrysler	.102	.049	.067	.023	.104	-0
IH	.172	.075	.169	.074	.193	.056

In terms of overhead the values range from .067 to .193 with an average of .122. Profit values varied from less than zero to .145 with an average of .079. The range on these values is too large to be explained simply. All four of these manufacturers produce heavy-duty trucks and light-duty trucks, but only three produce light-duty vehicles. Two produce diesel engines, and one produces other farm type equipment. The EPA technical staff does not believe that the average profit figure cited above represents the profits which the industry would seek on their investment. The EPA technical staff believes that using the GM average figures for the period (.114 overhead and .138 profit) would conservatively estimate the highest expected overhead and profit figures. GM's profit figures are the highest and their overhead figures the second highest of the four corporations studied. A figure of .252 for manufacturer overhead and profit should be used.

(ii) Gasoline Vehicle Dealers

Dealers could be expected to seek a profit on their increased investment when purchasing a new truck or bus for sale to the ultimate vehicle owner. Dun's Review, 7/ a well known business magazine, contained an article on dealer profit after taxes and other expenses. This was estimated at 1.5 percent. To account for taxes etc., EPA shall use a figure of 3 percent for dealer profit.

The use of emission control technology on gasoline-fueled engines does not inherently cause an increase in dealer overhead. No additional personnel or engine servicing is required. There should not be any increase in dealer overhead.

(iii) Diesel Engine Manufacturers

The data below represents the overhead and profit levels EPA estimated using financial data found in Moody's Industrial Manual. The values below are the fraction of the cost of sales which overhead and profit comprised for each of the manufacturers in 1976, 1977, and 1978.

	1976		1977		1978	
	Ovhd	Profit	Ovhd	Profit	Ovhd	Profit
GM	.117	.145	.109	.141	.117	.129
IH	.172	.075	.169	.074	.193	.056
Cat	.121	.165	.113	.172	.109	.172
Cummins	.308	.169	.335	.150	.336	.115
Mack	.123	.055	.096	.067	.085	.099

The overhead values ranged from .085 to .336 with an average of .167. Profit values ranged from .055 to .172 with an average of .119. Although these numbers also have a large range, these is more reason available to explain the range in the figures.

Of the five compaines listed, three make heavy-duty engines and vehicles and two make only engines. GM produces light-duty vehicles, light-duty trucks, and buses as well as a wide variety of other motor vehicle related products. IH makes heavy-ducy engines (diesel and gasoline) as well as vehicles and other farm equipment. Caterpillar (Cat) produces not only diesel heavy-duty engines for over the road use, but produces a wide variety of off-road construction equipment. Cummins produces only engines, and engine related components for sale to other manufacturers. Mack is a pure producer of diesel heavy-duty trucks, producing both diesel engines and vehicles.

The EPA technical staff believes that the average figures cited above adequately represent the heavy-duty diesel industry and suggests their use in the economic analysis.

(iv) Diesel Vehicle Dealers

The EPA technical staff realizes that diesel vehicle dealers (retail franchises or manufacturer representatives) will try to seek a profit on their slightly increased investment in a new heavy-duty diesel engine. Although some new diesels are sold as single units, as to independent owner-operators, a large percentage of the sales are multiple units sales to large truck fleets or bus companies. It is reasonable that any minor profit sought by the vehicle dealer on the sale of a diesel engine with emission controls would be lost in the final price negotiations on the purchase of the vehicle. Heavy-duty vehicles with diesel engines often sell for more than $50,000 a piece.

Best judgement dictates that due to the higher selling price and the tendency toward multiple unit sales in heavy-duty diesel vehicles, the minor profit on emission control technology would be ulimately lost in the final price negotiations. In any case, the first price increase estimates developed in the economic impact analysis may have a larger estimate error than the profit sought.

c. Staff Recommendations

Based on the discussion above several recommendations are presented.

For gasoline-fueled engines an overhead figure of .114 and a profit figure of .138 should be used. A dealer profit of 3 percent is also recommended. In total this becomes:

RPE = (Manufacturing Cost) (1 + .114 + .138) (1.03)

RPE = (MC) (1.29).

For diesel engines the manufacturer overhead and profit figures recommended are .167 and .119 respectively. Best judgement dictates no further increase in dealer overhead or profit. So in total, RPE = (MC) (1 + .167 + .119) = MC (1.29).

In conclusion, it should be noted that the manufacturing costs cited above and used in the regulatory analysis contain 20 percent overhead and 20 percent profit at that level in the production of the hardware. This is taken from the Rath and Strong report as a gross estimate.8/ These 20 percent figures are realistic in the cases where the parts are supplied to the engine manufacturers by independent vendors, but are conservatively high for the parts produced within the engine corporation.

References

1/ Based on MVMA data.

2/ See Regulatory Analysis, Chapter III.

3/ See for example "Will Diesels Dominate", Neil M. Szigethy, Fleet Specialist Magazine, May-June 1979.

4/ See Regulatory Analysis, Chapter V.

5/ Based on IHC written comment, June 14, 1979. Appendix A, page 9.

6/ "Moody's Industrial Manual", 1979, Volume I.

7/ "Dun's Review", November 1978, Vol. 112, No.5 pp 119-121.

8/ "Cost Estimates for Emission Control Related Components/ Systems and Cost Methodology Description, Leroy H. Lindgren, Rath & Strong, Inc. March 1978, EPA -460/3-78-002.

I. Issue - Technological Feasibility

There are no subissues needing consideration in this part All pertinent comments have been addressed in Part I.

J. Issue - Selective Enforcement Auditing

Subissues on this topic are addressed in a separate submission to the docket prepared by the Office of Enforcement.

K. Issue - Nonconformance Penalty

There are no subissues needing consideration in this part. All pertinent comments have been addressed in Part I.

L. Issue - Diesel Crankcase Emissions Control

There are no subissues needing consideration in this part All pertinent comments have been addressed in Part I.

M. Issue - Numerical Standards/Standards Derivation

There are no subissues needing consideration in this part. All pertinent comments have been addressed in Part I.

N. Issue - Fuel Economy

There are no subissues needing consideration in this part All pertinent comments have been addressed in Part I.