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In-Use Testing Program for Heavy-Duty Diesel Engines and Vehicles

Technical Support Document

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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CHAPTER 1
Economic Assessment

This chapter contains our economic analysis of the costs associated with implementing a manufacturer-run, in-use NTE testing program for heavy-duty diesel engines and vehicles. The cost of the program is dependent on several key variables. One of these is the number of vehicles tested under the Phase 1 and 2 testing schemes. This, of course, depends on how many vehicles pass, or fail, the vehicle pass criteria at various points under the tiered testing procedures. Also important is just how each manufacturer will chose to design and conduct the test program, how many portable emission measurement systems (PEMS) will be purchased, and the availability of test vehicles. Obviously, it is difficult to project these variables for an all new program. However, based on our experience with in-use emissions testing, including the development and use of a portable emission measurement device for compliance testing, we have identified a set of reasonable testing scenarios that allow us to estimate the potential costs associated with the program.

As part of the comments on the proposed rule, one manufacturer provided comment on a number of the values and assumptions used in the analysis We have considered each of these and revised the analysis where appropriate. In most cases these changes increased costs, leading to what EPA believes to be a more conservative assumption. The most notable change is our decision to eliminate scenario 1, and to assume all engine family testing events involve longer trips and overnight travel as laid out in our original Scenario 2.

This chapter is divided into several parts. Section 1.1 contains a brief outline of the methodology used to estimate the associated costs is presented. Section 1.2 develops the fixed and variable cost components associated with the program. Section 1.3 summarizes the component costs into estimates of the overall cost of the program. All costs are estimated in Dec 2004 dollars. In most cases our estimates in 2003 were increased by 2.7 percent based on the CPI inflator.

1.1 Overview

All costs are divided into either fixed or variable cost components. Fixed costs are associated with the direct expense of purchasing the requisite portable emission measurement system (PEMS) units. Variable costs depend primarily on the number of families and vehicles tested. They include the direct costs for vehicle recruiting, labor for on-site testing, instrument calibration and maintenance, travel, data analysis, and reporting expenses. Variable costs also include indirect costs associated with overhead and general and administrative (G&A) expenses.

To explore the range of possible costs, we assessed a range of costs associated with different testing intensities under Phase 1 or Phase 2 of the program (i.e., the amount or number of vehicle tests that might occur under the two phases of testing). Finally, we combined this information to show a range of possible costs and a single point estimate by assuming a specific mix of the above testing variables. The results are presented for all heavy-duty engine manufacturers as annualized costs, total costs for the first five years of the program, and costs over 30 years.

1.2 Cost Components

1.2.1 Fixed Costs

Fixed costs for this program are primarily associated with buying PEMS units. Some of the fixed cost components have significant uncertainties associated with them. Portable measurement devices are already commercially available that can measure all the gaseous pollutants required by the program. These systems cost approximately $70,000 per unit. The commenter mentioned above indicated that costs were 40 percent greater, thus suggesting a cost of about $90,000 -$100,000 for the gaseous PEMS unit.

Based on our experience and investment in developing portable particulate matter (PM) measurement technology, we estimate that systems capable of measuring both gaseous and PM emissions will cost an additional $30,000 per unit over our estmate for a gaseous unit alone, for a total of about $100,000.[1] The commenter mentioned above indicated interactions with vendors indicating costs 3-4 times greater than EPA's estimate for the PM unit or an additional $90,000. EPA has elected to very conservatively estimate costs ranging from $100,000-$180,000. Taking the average, we estimate the capital cost for portable measurement devices that measure both gaseous and PM emissions is approximately $140,000 per unit.

As described in Chapter 2 of this document, we assume that engine manufacturers will initially purchase PEMS units with the capability to measure gaseous pollutants in time to coincide with the initiation of the pilot program during the 2005 calendar year. Add-on, modular devices that measure PM emissions will be purchased later in 2006 as this technology becomes available. Regardless of the purchasing strategy, we assume all equipment purchases occur at the beginning of 2005 in order to simplify the analysis.

We estimate that portable emission measurement devices have a product life cycle of five years for the purposes of the program. After that time they are assumed to be replaced with brand new equipment. Also, we assume there is no salvage value for units that may remain in service for other less rigorous or less important duties after five years, although this could occur in some instances. Alternatively, some manufacturers may chose to replace or rebuild component parts of a PEMS unit rather than replace the entire unit after five years. To the extent this may occur, we assume such a maintenance strategy will cost approximately the same as the replacement strategy. The annualized cost of a single PEMS unit can now be calculated by using the above values and assuming a typical capital recovery rate of seven percent per annum. The result is an annualized cost of $34,145 per unit.

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[1] Chapter 2 contains additional information on the status and development of portable emission measurement systems.

The total annualized fixed cost for the program depends on how many PEMS units each manufacturer will purchase, the fraction of time the equipment is used for the in-use testing program, and the number of manufacturers subject to the requirements. Each of these cost components is addressed separately below.

We assume that each manufacturer will purchase three units. We chose this number to illustrate the average equipment cost of the program recognizing that two units is adequate to perform more than the needed amount of tests for even the largest manufacturer if its program is designed so that testing can be conducted in an orderly, efficient manner. We recognize that manufacturers with a limited number of engine families may need only one unit with a backup unit. Manufacturers with a large number of families may prefer an additional unit for backup.

Our final assumption in estimating the total annual fixed cost of the program is that 13 engine manufacturers will participate in the program. This is the number of companies that certified heavy-duty diesel engines in the 2005 model year. The manufacturers are shown below.

Caterpillar, Inc.
Cummins Engine Company, Inc.
DaimlerChrysler AG
John Deere, Inc
Detroit Diesel Corporation
General Engine Products
General Motos Corporation
Hino Motors, Ltd.
International Truck and Engine Corporation
Isuzu Motors Limited
Mack
Mitsubishi Motors Corporation
Volvo Powertrain Corporation.

Using the above information, the total annualized fixed cost of the program $1,331,665, as shown in Table 1-1.

1.2.2 Variable Costs

Variable costs are grouped into two broad categories: cost per vehicle test and cost per family. This approach allows us to more easily account for tests that must be repeated on the same vehicle in order to obtain a valid test result. Repeat testing can occur in the laboratory due to equipment or vehicle malfunctions, and operator error. We expect that similar problems may occur in field testing, and assume that these issues can generally be remedied at the testing location. Further, a vehicle may be tested a second day under the terms of the program if less than three hours of non-idle operation are recorded during the first “shift day” of testing.

Obviously, multiple tests on the same vehicle do not directly affect other costs associated with testing an engine family, e.g., vehicle recruiting. Therefore, these costs are estimated separately in our analysis.

Also, as noted earlier, many of the costs of the program vary by the relative availability of test vehicles (i.e., how difficult it is to access, instrument, and test vehicles at a job site), and the type and amount of travel required to conduct the test campaign (e.g., overnight versus local travel). In order to reasonably bracket these cost elements, we constructed two testing scenarios that differ in the above characteristics. These scenarios are based on our direct experience in conducting in-use testing of heavy-duty trucks with portable emission measurement systems under the 1998 consent decrees, our continued development of portable measurement systems, and a recently awarded EPA contract to conduct a large scale, in-use testing pilot program in Kansas City, Missouri for passenger cars (USEPA 2003). The two testing scenarios are described in the following section by first identifying some of the key elements shared by both scenarios and then presenting the specifics of each scenario separately.

1.2.2.1 General Description of Testing Scenarios

Our testing scenarios share a number of key assumptions which we believe provide a reasonable representation of how manufacturers are likely to design and conduct testing under this program. Alternatively, if an engine manufacturer decides to contract for testing services, we expect the service provider to similarly design and conduct the testing campaign.

One of our most basic methodological assumptions is that field testing will usually consist of a multi-day campaign where a minimum of five vehicles are tested. This number was chosen for several reasons. First, it captures the type of back–to-back vehicle testing likely to be employed in order to facilitate efficient testing. Second, it represents the minimum number of test vehicles for Phase 1 testing under the program. Third, and finally, it simplifies the analysis when evaluating the potential costs of higher testing intensities associated with the maximum number of vehicles that may be tested under Phase 1 (10 total vehicles) and Phase 2 (20 total vehicles). These later testing levels are simple multiples the Phase 1 minimum testing scenario, i.e., two times or four times, respectively. Other key assumptions are described below.

- Vehicle recruiting and pre-screening of prospective test vehicles will be done by telephone or other means prior to the test site visit.
- All portable measurement systems will be inspected and pre-calibrated at the manufacturer's facility prior to deployment in the field.
- Field testing will be conducted by two people. One is an engineer and the other a qualified technician. Both are capable of installing and operating the portable measurement systems, screening vehicles for OBD trouble codes and MIL indications, performing maintenance on the portable systems, etc. The technician is also capable of performing all required inspections of the vehicle's mechanical,

electrical, and emission control systems; as well as performing allowable maintenance and the setting of adjustable engine parameters as required.

- The test engineer and technician will coordinate their activities to optimize their productivity. For example, the engineer may acquire and enter a vehicle's history and vital statistics into an electronic database concurrently while the technician performs vehicle inspection and allowable maintenance.
- Test vehicles for an engine family are obtained from two independent sources, as required by the regulation. It is assumed that the sources are located relatively close to each other to minimize travel distances between test sites.
- The test sites are not necessarily in relatively close proximity to a manufacturer's technical center, test center, maintenance facility, or other similar location thus increasing personnel travel and field logistics costs.
- In many cases test vehicles will depart and not return to the same location the same day, necessitating an overnight stay.
- Field personnel have access to the test vehicles and a service location before and after the shift day as needed to install and remove the portable measurement devices. Special arrangements with the vehicle owner/operator may be necessary.
- Two portable emission measurement systems will be deployed simultaneously during a test site visit when possible, i.e., two vehicles will be tested at the same time.
- All necessary tools, spare parts, testing supplies, office supplies, etc. will be taken to or otherwise supplied at the site of testing to avoid unnecessary delays.

It is also possible that test vehicles may be operated on multi-day driving routes, i.e., long-haul operation. We do not think this will be a standard practice for all vehicles/engines, but may happen for engines used in over the road trucks and buses. As alluded to above, we have incorporated this assumption into the analysis for all families.

There are also some common on-site work activities. These categories are described below in their approximate order of occurrence.

- Vehicle History/Documentation. Obtaining all relevant information not available prior to the field visit or verifying the accuracy of information previously obtained.
- Vehicle Set-to-Specification. Inspecting the vehicle, performing allowable maintenance, and setting all adjustable engine control parameters.
- PEMS Installation. Install the portable measurement system onboard the test vehicle. Warm the instrument to operating temperature, verify proper operation, perform final calibrations and span instruments, etc.
- PEMS Data Acquisition. Download the measurement data set; perform on-site data verification and initial quality assurance; and record and store all other relevant test information.
- PEMS Removal. Verify proper operation, perform post-test calibration, and remove system from the test vehicle.

- Miscellaneous Time. Non-routine labor for repairing or replacing parts of the portable emission measurement systems or test vehicles, obtaining supplies not at the test site, etc.

Now that the overall components of the testing scenarios have been identified, the specific scenario we have analyzed will be presented. We believe this is conservative since it assumes all families are used in overnight operation.

Limited Vehicle Access and Overnight Travel

Under this scenario, test vehicles are not readily available and the testing technician and engineer must sometimes work around a test vehicle's normal daily work shift. This means that the work day for the testing personnel includes the time the vehicle is being driven over its normal work route. In these instances, we made a worst case assumption that the testing personnel remain "idle" on the job site or that they are on the vehicle, with this time charged to the in-use testing program. Also, the test sites are located far enough away from the manufacturer's facility, or employees home base, that a single round trip to and from the job site and overnight travel is required. However, the sites are still close enough to one another that travel between the two locations is not restrictive or prohibitive.

1.2.2.2 Variable Cost Per Test

As described above, the cost to perform an individual vehicle test is based on a Phase 1 testing scheme where a minimum of five vehicles must be tested. Test costs consist of direct labor, labor overhead, other direct costs, and general and administrative overhead. Each of these cost components is described below.

1.2.2.2.1 Direct Labor

The cost of direct labor for each scenario is estimated by applying an hourly compensation rate by labor category to the various activities associated with the field testing campaign. Table 1-2 display the work flow for the scenario, broken down by activity, labor type, and number of hours spent preforming each activity. These depictions reflect the assumptions, work activities, and optimization of the work flow as described in Section 1.2.2.1. The time spent in the various work tasks are estimated based on EPA's direct experience in conducting in-use testing with portable emission measurement devices and on the recently awarded Kansas City, Missouri test program.

The test campaign is completed in five days. The lack of vehicle flexibility leads to long work days in this scenario. The total direct labor is 55 and 56 hours for the engineer and technician, respectively.

We developed an hourly estimate of employee compensation from information published by the Bureau of Labor Statistics, Office of Compensation and Working Conditions, Employer Costs for Employee Compensation (BLS 2003). When increased by the CPI, Table 1-3 shows our estimate of $32 and $29 per hour for an engineer and technician, respectively. These hourly compensation rates are "total compensation," and include wages and salaries, paid leave, supplemental pay, and insurance. By comparison, these labor rates compare well with the contract labor costs we incur in conducting our in-use testing under the consent decrees. Finally, we assume that labor exceeding 40 hours per week is paid as overtime, i.e., 1.5 times the normal hourly rate.

For convenience, Table 1-3 also shows an hourly compensation rate for a manager using the same literature source as described above. This labor category will be used in Section 1.2.2.3, where variable costs are discussed.

The resulting direct labor cost per test can now be calculated based on the above labor hours and hourly compensation rates. As shown in Table 1-4, the resulting per test cost is $773.

1.2.2.2.2 Labor Overhead

We assume that all direct labor is burdened at 100 percent of the total compensation rate. For simplicity, overtime pay is also burdened at this same overhead rate.

1.2.2.2.3 Other Direct Costs

A number of other costs not related to labor that are "consumed" during in-use testing include office supplies, DVDs, calibration gases, and fuel for the flame ionization detector (FID). Based on our experience with using portable measurement systems, we estimate that calibration gases will cost about $75 per test and all other supplies will cost about $25 per test. Therefore, we estimate that a total of $100 per test for other direct costs.

1.2.2.2.4 Repeat Tests

Some in-use tests will be voided due to operator error and test equipment malfunctions. Other tests will be repeated if less than three hours of non-idle vehicle operation are recorded during the first day of testing. At our National Vehicle Fuel and Emissions Laboratory in Ann Arbor, Michigan, we experienced a test void rate for laboratory-based, non-research testing of approximately four percent over the last two years. We expect a somewhat higher void rate for field testing. Also, as noted, some tests will be repeated do to the three hour non-idle requirement. Overall, we assume a combined repeat test rate of 10 percent for this analysis.

1.2.2.2.5 General and Administrative Overhead

Certain costs are incurred for common or joint objectives and therefore cannot be identified specifically with a particular project or activity. We assume these general and administrative costs to be 6.5 percent of all other costs.

1.2.2.2.6 Summary of Variable Cost per Test

Table 1-5 summarizes the various direct cost elements described above. As shown, the resulting total variable costs per test are $1,928.

1.2.2.3 Variable Cost Per Engine Family

As with the previous section, the cost per engine family is based on a Phase 1 testing scheme where a minimum of five vehicles must be tested. This overall cost is composed of a number of individual expenses such as paying the test vehicle's owner/operator an incentive, recruitment, travel, instrument pre-calibration, data analysis, and reporting. Each of the cost elements are described below.

1.2.2.3.1 Vehicle Incentives

We generally offer a vehicle's owner an incentive in the form of a government bond and free vehicle repairs as part of our in-use test programs. Sometimes the owner cooperates without such an incentive, as most often occurs in our in-use testing under the consent decrees. For the purposes of this analysis, we assume that a cash incentive of $150 per vehicle will be paid to the owner by the engine manufacturer. This is the average cost of the incentive, with some owners being offered more some less, and some cooperating without an incentive. Therefore, the total incentive for an engine family tested under the Phase 1 minimum requirements is $750.

1.2.2.3.2 Direct Labor

Each engine family will incur costs in three main labor categories: vehicle recruitment, instrument pre-calibration, and data analysis and reporting. We expect that manufacturers will rely heavily on their existing customer relationships to recruit appropriate test vehicles from fleets or individual owners. Alternatively, they will create new lines of communication with their customers. A significant amount of pre-screening and vehicle history will also be associated with vehicle recruitment. We assume that with a heavy emphasis on existing customer relationships and data bases, recruiting the requisite five test vehicles will average about $300 per engine family.

Prior to being deployed in the field, each portable measurement system will be carefully examined at the manufacturer's facility to ensure proper operation. Based on our experience with portable emission measurement systems, we estimate that pre-calibrating each unit will require 0.5 and 1.5 hours of engineer and technician time, respectively. Using the total compensation rates previously described in Table1-4, this would cost $60 per unit. Since it is assumed that testing will be conducted using two portable systems, the total direct labor cost for pre-calibrating the instruments is $120 per engine family.

The last category of direct labor per engine family is primarily for final data analysis and quality assurance (beyond that which is conducted in the field), reporting results, and archiving information. We assume that engine manufacturers will develop a number of automated methods to perform many of these functions to minimize labor requirements. Our direct labor estimates are basically taken from another EPA report that was prepared to support a new pilot program aimed at developing new in-use data collection methods for nonroad diesel-powered equipment (USEPA 2004). That program will also collect, analyze, and report emissions data using portable emission measurement systems. For the purposes of this analysis, we doubled the time per test for managerial oversight, since the original estimate was developed to reflect an emission factor style program, while the in-use program potential compliance implications.

Table 1-6 presents the estimated labor hours for each data analysis and reporting activity, the cost per test, and the cost per engine family. The cost per test is based on a labor rate of $32 per hour for an engineer and $48 per hour for a manager. These labor classifications and compensation rates were previously discussed in Section 1.2.2.2 and presented in Table 1-3. The total cost of post-data analysis and reporting is estimated to be $751 per engine family.

The resulting total direct labor for the three categories described above is $1,171 per engine family.

1.2.2.3.3 Travel

As discussed above, we assume the test sites are located far enough away from the manufacturer's facility, or employees home base, that a single round trip to and from the job site and overnight travel is required. More specifically, we assume that commuting at the beginning and end of the work week is four hours one way for a total of eight hours. Again, using the total compensation rates previously presented in Table 1-4 of $32 and $29 per hour for an engineer and technician, respectively, the travel-related direct labor cost with 100% overhead is $976 per engine family.

The vehicle expenses consist of the round trip travel to the testing locations described above, and daily travel to and from the test sites as well as itinerant travel, e.g., lunch and dinner. The round trip travel expense associated with the eight hours of commuting time is estimated by using an assumed average speed of 50 miles per hour and a mileage fee of $0.40 per mile. The result is $160. The itinerant travel distances are assumed to be 30 miles for Day 1 and 45 miles each day for the next three days, or a total of 165 miles. Using the assumed vehicle reimbursement fee, this amounts to $226.

This scenario requires overnight travel. There will be approximately four days of full per diem expenses and a partial day of meals on the fifth day (Table 1-3). We assume it costs $100 per night for lodging and $40 per day for meals. This results in per diem expenses of $1200 for the full week. Combining this with the travel-related labor of $976 nd the vehicle cost of $226 from above, the total travel cost is $2,402 per engine family.

1.2.2.3.4 Labor Overhead

We assume that all direct labor is burdened at 100 percent of the total compensation rate.

1.2.2.3.5 General and Administrative Overhead

We assume general and administrative expenses to be 6.5 percent of all other costs.

1.2.2.3.6 Summary of Variable Cost per Engine Family

Table 1-7 summarizes the various cost elements discussed above. As shown, the resulting total variable costs per engine family are $5,851.

1.3 Costs of the Program

Now that the basic fixed and variable cost inputs have been developed, we will use that information to identify a range of total annual costs for the program. This range reflects the testing scenario, as described in Section 1.2.2.1, and three different levels of testing intensity that may occur under the Phase 1 and 2 requirements, which are described below. We will also develop a single point estimate of the program's annual cost. Finally, we will use this point estimate to present total costs for the first five years of the program, and costs over 30 years. These costs are presented for the entire industry.

The first level of testing intensity is the minimum number of vehicles that must be tested under Phase 1 of the program to demonstrate if a designated engine family passes the NTE criteria, i.e., five vehicle tests per family. This is the basis upon which the variable cost components were developed in Section 2.1, and is referred to as Phase 1 minimum. The second level of testing is the maximum number of vehicles that could be required under Phase 1, i.e., 10 vehicle tests per family. This is referred to as Phase 1 maximum. The third level of testing is a worst case where a manufacturer must complete Phase 2 testing for an engine family. At its maximum, Phase 2 requires up to 20 vehicle tests per family. This is referred to as Phase 2 maximum.

Overall, our methodology for estimating the costs associated with the three testing levels is simple. We assume that a manufacturer will complete each level of testing in discrete steps. For example, after completing Phase 1 minimum, the test results for the engine family will be thoroughly evaluated at the manufacturer's technical center. If one or more of the vehicles do not pass the testing criteria, the manufacturer is assumed to return to the field to continue testing five more vehicles, i.e., Phase 1 maximum. For the purposes of this analysis, this means that the variable cost of Phase 1 maximum testing is twice the cost of performing Phase 1 minimum testing. Similarly, the variable cost of Phase 2 maximum, i.e., 20 vehicles, is twice the cost of Phase 1 maximum, i.e., 10 vehicles. The fixed cost of testing is constant for each of the three testing intensities, since the cost of purchasing the portable measurement systems does not change with the number of tests performed.

1.3.1 Variable Costs by Level of Testing Intensity

As noted above, fixed costs do not change by the number of tests performed, although variable costs do vary by testing intensity. Therefore, the first step in estimating the range of annual costs is to determine variable cost per family for each of the testing levels. This is presented in Table 1-8.

The next step is to find the range of annual costs for all manufacturers, i.e., all engine families. Under the program, we may generally select up to 25 percent of an engine manufacturer' families for testing each year. In the 2005 model year, there were 71 heavy-duty diesel engine families certified. Hence, we may select up to 18 engine families per year. Using this value, the resulting range of annual costs for all manufacturers is shown in Table 1-9.

1.3.2 Total Annual Costs by Level of Testing Intensity

Table 1-10 summarizes the fixed and variable cost estimates and presents the total annual cost for each testing level. The low end of the range is about $1.6 million per year for Phase 1 minimum, and the high end of the range is $2.1 million for Phase 2 maximum.

1.3.3. Total Annual Cost Point Estimate

Our point estimate assumes the overall program will reflect the average of weighted at 80 percent of the Phase 1 minimum average cost, 10 percent of the Phase 1 maximum average cost, and 10 percent of the Phase 2 maximum average cost. This reflects our belief that most of the engine families will be designed and built in full conformance with the applicable NTE standards. But also that the program will identify some level of potential nonconformance. Table 1-11 summarizes the Phase 1 minimum and Phase 2 maximum costs from the previous table for convenience and presents our point estimate of the total annual cost for all manufacturers. The point estimate is $1.68 million per year.

1.3.4. Total Costs Over 5 and 30 Years

We developed an estimate of the total program costs over both 5 and 30 years using the annual point estimate costs from Table 1-12 and a discount rate of seven percent per annum. As shown, the 5 year cost is about $6.89 million and the 30 year cost is about $20.85 million.

Chapter 1 References

1. U.S. Environmental Protection Agency. 2003. *Characterizing Exhaust Emissions from Light-Duty Gasoline Vehicles in the Kansas City Metropolitan Area*. ERG. EPA Contract Number GS-10F-0036K. Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, Michigan. Awarded February 2004.

2. Bureau of Labor Statistics. 2003. *Employer Costs for Employee Compensation-June 2003.* USDL: 03-446. U.S. Department of Labor, Washington, D.C.

3. U.S. Environmental Protection Agency. 2004. *Mobile Source Emission Factors: Populations, Usage and Emissions of Diesel Nonroad Equipment in EPA Region 7*. Agency Form Number 0619.11, Supporting Statement, Part A. Office of Transportation and Air Quality. March 2004. EPA Edocket No. OAR-2003-0225-0003.

Table 1-1. Total Annualized Fixed Costs[1]

Cost per PEMS Unit ($)	Annualized cost of PEMS Unit ($)	Annual Cost per Manufacturer ($)	Number of Manufacturers (#)	Total Annual Cost ($)
140,000	34,145	102,435	13	1,331,655

[1] 2004 dollars.

Table 1-2. Limited Vehicle Access and Overnight Travel

Day 1			Day 2			Day 3			Day 4			Day 5		
Activity	Hrs	Labor Type	Activity	Hrs	Labor Type	Activity	Hrs	Labor Type	Activity	Hrs	Labor Type	Activity	Hrs	Labor Type
Travel	4	B[1]	V1, V2 Warm-Up	1	T	V4 Set-to-Spec	1	T	V5 Set-to-Spec	1	T	Travel	4	B
V1, V2[2] History	2	E	Shift Wait Time	8	B	V4 History	1	E	V 5 History	1	E			
V1, V2 Set-to-Spec	2	T	V3 Set-to-Spec	1	T	V4 Install V3 Warm	1.5	B	V5 Install	1.5	B			
V1, V2 Install	3	B	V3 History	1	E	Shift Wait Time	8	B	Shift Wait Time	8	B			
Misc. Time	1	B	V1, V2 Data Acquisition	1	B	V3, V4 Data Acquisition	1	B	V5 Remove	.75	B			
			V1, V2 Remove	1.5	B	V3, V4 Remove	1.5	B	V5 Data Acquisition	.5	B			
			V3 Install	1.5	B	Misc. Time	1	B	Misc. Time	1	B			
			Misc. Time	1	B									
Totals	10	T		15	T		14	T		13	T		4	T
	10	E		14	E		14	E		13	E		4	E

[1] T=Technician, E=Engineer, B=Both

[2] V = Vehicle (identifier).

Table 1-3. Labor Compensation Rates

BLS Category[1]	In-Use Testing Category	Total Compensation[2] ($/Hour)
Technical[3]	Engineer	32
Precision Production, Craft, and Repair[4]	Technician	29
Executive, administrative, and managerial[5]	Manager	48

[1] BLS 2003, inflated by 2.7%.
[2] Total compensation includes wages and salaries, paid leave, supplemental pay, and insurance. Rounded to the nearest whole dollar. June 2003 dollars.
[3] Table 11, Private industry, goods-producing and service-producing industries, by occupational group; All workers, goods-producing industries; White-collar occupations; Professional specialty and technical.
[4] Table 11, Private industry, goods-producing and service-producing industries, by occupational group; All workers, goods-producing industries; Blue-collar occupations; Precision production, craft, and repair.
[5] Table 11, Private industry, goods-producing and service-producing industries, by occupational group; All workers, goods-producing industries; White-collar occupations; Executive, administrative, and managerial.

Table 1-4. Direct Labor Costs Per Vehicle Test [1]
(Based on Phase 1 Minimum Five Vehicle Tests per Engine Family)[2]

	Labor Rate Type	Hours Per Family (5 tests)		Hourly Compensation ($ per hour)		Total Cost ($/5 tests)	Cost Per Test ($/test)
		Engineer	Technician	Engineer	Technician		
	Regular	40	40	32	29	2440	488
	Overtime[2]	15	16	48	44	1424	285
	Total	--	--	--	--	3864	**773**

[1] 2004 dollars.
[2] Based on Phase 1 testing five vehicles.
[3] Overtime paid for work exceeding 40 hours/week at 1.5 times the regular pay rate.

Table 1-5. Variable Costs Per Test Vehicle[1]
($/test)

Scenario	Direct Labor[2]	Labor Overhead[3]	Other Direct Costs[4]	Voided Tests[5]	General and Administrative[6]	Total
	773	773	100	165	118	1,928

[1] 2004 dollars.
[2] See Table 1-4.
[3] 100 percent of direct labor.
[4] General supplies, PEMS maintenance, calibration gases, FID fuel, etc.
[5] Assumes 10 percent of tests are void (i.e., 0.10 * (direct labor, labor overhead, and other direct costs)).
[6] 6.5 percent of all costs.

Table 1-6. Post-Test Data Analysis and Reporting Variable Cost Per Family[1]

Activity	Hours/Test (hrs)[2]		Cost/Test ($)		Cost Per Engine Family ($/5 Tests)		
	Manager	Engineer	Manager	Engineer	Manager	Engineer	Total
QA Measurements	0.056	3.0	2.69	96.00	13	480	493
Load Database	0.056	0.278	2.69	8.90	13	45	58
Analysis, Write Report, Archive	0.056	1.167	2.69	37.34	13	187	200
Total	0.168	4.445	8.07	142.24	40	711	**751**

[1] 2003 dollars.
[2] See USEPA 2004.

Table 1-7. Summary of Variable Costs Per Engine Family[1]
($/family)

	Direct Labor	Labor Overheard[2]	Incentive	Travel	General and Administrative[3]	Total
	1,171	1,171	750	2402	357	5,851

[1] 2004 dollars.
[2] 100% of direct labor.
[3] 6.5% of all costs.

Table 1-8. Summary of Variable Costs Per Engine Family by Level of Testing Intensity[1]
($)

	Phase 1 Minimum[2]			Phase 1 Maximum[3]			Phase 2 Maximum[4]		
Scenario	Vehicle Testing[5]	Engine Family	Total	Vehicle Testing[5]	Engine Family	Total	Vehicle Testing[5]	Engine Family	Total
	9,640	5,851	15,491	19,280	5,851	25,131	38,560	5,851	44,411

[1] 2004 dollars.
[2] Phase 1 minimum = 5 test vehicles.
[3] Phase 1 maximum = 10 test vehicles.
[4] Phase 2 maximum = 20 test vehicles.
[5] Cost per vehicle from Table 1-5 multiplied by the number of vehicles tested.

Table 1-9. Total Annual Variable Costs for All Manufacturers by Level of Testing Intensity[1]
($)

Scenario	Phase 1 Minimum[2]			Phase 1 Maximum[3]			Phase 2 Maximum4		
	Cost Per Engine Family	# Families Per Year[5]	Total	Cost Per Engine Family	# Families Per Year	Total	Cost Per Engine Family	# Families Per Year	Total
	15,491	18	278,838	25,131	18	452,358	44	18	799

[1] 2004 dollars.
[2] Phase 1 requires that a minimum of 5 test vehicles.
[3] The maximum number of vehicles tested in Phase 1 is 10.
[4] The maximum number of vehicles tested through Phase 2 is 20.
[5] 25% of a total of 71 engine families certified in the 2005 model year.

Table 1-10. Total Annual Costs for All Manufacturers by Level of Testing[1] Intensity
($ Thousands)

Scenario	Phase 1 Minimum[2]			Phase 1 Maximum[3]			Phase 2 Maximum[4]		
	Fixed Cost	Variable Cost	Total	Fixed Cost	Variable Cost	Total	Fixed Cost	Variable Cost	Total
	1,332	279	1,611	1,332	452	1,784	1,332	799	2,131

[1] 2004 dollars.
[2] Phase 1 minimum = 5 vehicle tests.
[3] Phase 1 maximum = 10 vehicle tests.
[4] Phase 2 maximum = 20 vehicle tests.

Table 1-11. Total Annual Cost Point Estimate for All Manufacturers[1]

($ Thousands)

	Phase 1 Minimum			Phase 2 Maximum			Phase 2 Maximum			Point Estimate[2]		
Scenario	Fixed Cost	Variable Cost	Total	Fixed Cost	Variable Cost	Total	Fixed Cost	Variable Cost	Total	Fixed Cost	Variable Cost	Total
	1,332	279	1,611	1,332	452	1,784	1,332	799	2,131	1,332	348	1,680

[1] 2004 dollars.

[2] Assumes a 80/10/10 split between Phase 1 minimum, Phase 1 maximum, and Phase 2 maximum, respectively.

Table 1-12. Total Program Cost Over 5 and 30 Years[1]
(Based on Point Cost Estimate)
(thousands of $)

Years	Annualized Fixed Costs	Annual Variable Costs	Total Annual Costs
2005-2034	1332	348	1,680
30 Year NPV in 2005	16,530	4319	**20,849**
1st 5 Year NPV in 2005	5461	1423	**6,888**

[1] 2004 dollars.

CHAPTER 2
On-Vehicle Portable Emissions Measurement Technology Review

2.1 Overview

With respect to measurement equipment, we already have equipment available to measure gaseous emissions on-vehicle using the test procedures proposed for this program, and we believe that PM emissions measurement equipment will be available as needed.

In the NTE standard we have already taken into account the variation in emissions due to varying engine operation and ambient conditions. In addition, in this proposal, we have taken into account the measurement tolerances of on-vehicle measurement systems.

Given the very active interest in portable measurement equipment in the rest of the industry, and given lead time, we believe that measurement equipment will be widely available well ahead of time so that this program will be fully implemented for all regulated emissions–including PM–by 2007 and 2008. For the 2005-2006 gaseous emission pilot program, equipment is already available for total hydrocarbons, carbon monoxide, and NOx that measure emissions at the concentrations associated with 2007 and later model year NTE standards. In 2004, units were introduced that measure NMHC, although some extra work is being instituted to verify the accuracy and precision of these new systems. For the 2006-2007 PM pilot program, and we also believe that PM emissions measurement equipment will be available. This chapter discusses this measurement technology and summarizes research results. Chapter 3 discusses the new emissions measurement allowance and cooperative test program that will comprehensively evaluate both gaseous and PM portable emissions measurement systems prior to the initiation of the fully enforceable in-use testing program.

2.2 Measurement Technologies

We expect that several complete systems will be commercially available in the 2005-2007 timeframe that will be capable of performing the measurements needed to determine whether or not a vehicle passes an on-vehicle emissions test. At a minimum, any such measurement system must include individual analyzers and sensors that can quantify the following parameters:

1. Regulated emissions concentrations in exhaust:
   a. Oxides of nitrogen, NOx.
   b. Carbon monoxide, CO (and carbon dioxide CO_2).
   c. Non-methane hydrocarbons, NMHC.
   d. Particulate mass, PM.
2. Exhaust flow rate.
3. Engine operation:
   a. Speed.
   b. Torque.

c. Coolant temperature and intake manifold temperature and pressure.

4. Ambient conditions:

a. Temperature.

b. Dewpoint.

c. Altitude.

In this section we describe the measurement technologies that we expect to be used to quantify these parameters. If these technologies are properly applied, we believe that they are acceptable for measuring emissions on-vehicle. Note too that we also allow for the use of alternate technologies according to §1065.10.

1. Regulated emissions concentrations in exhaust. Emissions concentrations need to be measured to determine brake-specific emissions.

a. NOx measurement technology. We typically accept NOx measured as the sum of NO and NO2 since conventional engines and aftertreatment systems do not emit significant amounts of other NOx species. NO may be measured either by a chemiluminescence detector (CLD) or a non-dispersive ultra-violet (NDUV) detector. NO2 may be converted catalytically to NO and detected by a CLD, or it may be detected directly via NDUV. NDUV and CLD are already available as components of complete on-vehicle emissions measurement systems, and they already have been performing well in on-vehicle applications. For example, a recent study by the California Air Resources Board (CARB) indicated that for 27 heavy-duty diesel chassis dynamometer tests, an NDUV-based on-vehicle system reported NOx emissions within 4.6 % of the current NOx standard, as compared to laboratory measurements.(1) We are currently studying NDUV analyzer performance with a 2002 light-heavy duty diesel (LHDD) on a chassis dynamometer. Our results so far indicate that the NDUV-based system reported NOx within 3.1 % of our laboratory, prior to a 5000-mile cross-country road test that we conducted. After running the NDUV-based system for the entire road test–with no failures, the vehicle was returned to the laboratory, and the NDUV-based system reported NOx emissions within 3.9 % of our laboratory. The manufacturer of the NDUV-based system has also indicated that several engine manufacturers have evaluated their system, and their results from 11 HDDE FTP tests indicate Nox emissions were reported within 4.4 % of the current standard in engine manufacturer's laboratories. (1)

b. CO (and CO2) measurement technology. Since we first regulated CO, non-dispersive infra-red (NDIR) detector technology has been used for measuring CO and CO2 in laboratory applications. Many laboratory NDIR analyzers have a moving part called a chopper-wheel to pulse infra-red light through the exhaust gas sample. The pulsing light is used to alternately detect the CO and CO2 concentrations and then the dark-current of the NDIR detector. This is done to maintain accuracy, but the moving chopper-wheel is not durable under the high vibration environment of on-vehicle testing. However, new NDIR analyzers have been commercialized that electrically switch the infra-red light source on and off. These new NDIR analyzers are already commercially available in complete on-vehicle emissions measurement systems, and they have been performing well in on-vehicle applications. For example, a recent study by the California Air Resources Board (CARB) indicated that for 27 heavy-duty diesel chassis dynamometer tests, an NDIR-based on-vehicle system reported CO emissions within 0.7 % of the current CO standard (2.1 % for CO_2), as compared to laboratory measurements.(1) We are currently studying NDIR analyzer performance with a 2002 light-heavy duty diesel (LHDD) on a chassis dynamometer. Our results so far indicate that the NDIR-based system reported CO within 1.0 % of our laboratory (1.1 % for CO_2), prior to a 5000-mile cross-country road test that we conducted. After running the NDIR-based system for the entire road test–with no failures, the vehicle was returned to the laboratory, and the NDIR-based system reported CO emissions within 7.1 % of our laboratory (2.2 % of the current CO standard) and 4.7 % for CO_2. The manufacturer of the NDIR-based system has also indicated that several engine manufacturers have evaluated their system, and their results from 11 HDDE FTP tests indicate CO emissions were reported within 0.5 % of the current standard in engine manufacturer's laboratories (3.55 % for CO_2).(1)

c. NMHC measurement technology. The flame ionization detector (FID) has been the measurement technology of choice for hydrocarbon measurements since the late 1950s. The FID has been used as a detector in liquid and gas chromatography systems for individual hydrocarbon speciation and quantification. It is used because of its response to a broad range of hydrocarbons, its inherent stability and its remarkably linear response from very high levels to very low levels of hydrocarbons. Because the FID responds to a very broad range of hydrocarbons, we chose to set our initial hydrocarbon standard based on the FID response to the total hydrocarbons (THC) in engine exhaust. Later, by allowing for the subtraction of methane (CH_4) from THC, we set non-methane hydrocarbon (NMHC) standards based on the FID's response to all non-methane hydrocarbons in engine exhaust. Because the FID has a range of response factors for all of the hydrocarbons that it detects, and because the mixture of hydrocarbon species in engine exhaust changes as a function of engine operation, fuel, and aftertreatment systems, the FID's response to NMHC in engine exhaust is characteristic to hydrocarbon measurement via FID technology alone. This makes it almost impossible for other hydrocarbon detector technology to equivalently detect engine exhaust NMHC. Fortunately, FIDs have been adapted for on-vehicle use. These new FID analyzers are already commercially available in complete on-vehicle emissions measurement systems, and they have been performing well in on-vehicle applications. For example, a recent study by the California Air Resources Board (CARB) indicated that for 27 heavy-duty diesel chassis dynamometer tests, a FID-based on-vehicle system reported THC emissions within 2.8 % of the current NMHC standard, as compared to laboratory measurements.(1) We are currently studying FID analyzer performance with a 2002 light-heavy duty diesel (LHDD) on a chassis dynamometer. Our results so far indicate that the FID-based system reported THC within 7.8 % of our laboratory after running the FID-based system for a 5000 mile road test–with no failures, (2.4 % of the current NMHC standard). The manufacturer of the FID-based system has also indicated that several engine manufacturers have evaluated their system, and their results from 11 HDDE FTP tests indicate THC emissions were reported within 1.3 % of the current NMHC standard in engine manufacturer's laboratories.(1)

d. PM measurement technology. PM measurement has been traditionally conducted by depositing diluted exhaust PM on a sample filter and then weighing the filter in a PM measurement laboratory before and after testing to determine the net mass gain due to PM.

This technique has been applied to on-vehicle testing by one on-vehicle emissions measurement system manufacturer. This system was tested by the California Air Resources Board (CARB) versus a chassis dynamometer laboratory.(2) Thirty-three tests were run on two different heavy-duty trucks, and one of the trucks was equipped with a PM trap. The 33 emissions results were collected over five different test cycles for each truck. For the current-technology truck, on-average, the on-vehicle system reported PM results within 0.6 % of the standard when compared to laboratory results. For the trap-equipped truck, on-average, the on-vehicle system reported PM results where the difference between the on-vehicle and laboratory was 38 % of the 2007 standard. However, because the trap-equipped truck was emitting PM at only 44 % of the 2007 standard (according to laboratory results), the 38 % error of the on-vehicle system would not have caused any false indication of a failure (i.e. 44 % + 38 % = 82 %). Furthermore, neither the laboratory nor the on-vehicle system were equipped to sample PM according to our specifications for measuring PM from engines that meet the 2007 PM standards. These specifications were tailored to reduce variability in this type of PM measurement.

These filter-based results demonstrate that accurate on-vehicle PM measurement technology is already commercially available for the current level of PM emissions, and it demonstrates that proportional sampling of PM on-vehicle is commercially available today. However, we do not expect filter-based methods to be used for conducting NTE tests in the field. This is because for NTE testing, PM emissions must be quantified for several individual NTE events, which would require many filters and a means to switch these filters in an automated way. No such system is commercially available or in development to our knowledge, and we believe that such an automated system might be cumbersome on-vehicle.

We are currently evaluating more automated technologies for quantifying PM mass on-board. These automated technologies detect the inertia of particulate mass (PM) by accelerating it via vibration, rather than detecting its weight due to the acceleration of Earth's gravity. These inertial technologies include the Tapered Element Oscillating Microbalance (TEOM) and the Quartz Crystal Microbalance (QCM). Since these technologies are compact, they are suitable for on-vehicle applications. And since they impart greater acceleration upon PM versus Earth's gravity, they are more sensitive than a laboratory microbalance. They also eliminate the need to transport PM sample filters to a PM measurement laboratory for pre- and post-weighing. Researchers at West Virginia University have compared QCM and TEOM technologies versus laboratory PM measurements on a heavy-duty diesel engine, and they showed that for seven repeats of EPA's heavy-duty FTP, the TEOM and QCM can quantify PM within 5 % of a traditional microbalance at current emissions standards.(3)

These results demonstrate that this automated on-vehicle PM measurement technology is already commercially available today. However, conducting NTE tests in the field poses additional challenges. Namely, quantification of PM over sampling intervals as short as 30 seconds has yet to be demonstrated. Additionally, because PM equilibration is required before and after each NTE event, the time it takes to equilibrate PM mass after an NTE event might prevent sampling all or part of the next NTE event. Although these prototype systems are commercially available, more work is needed to demonstrate their accuracy in the lab and in the field.

Also, we are currently investigating the sources of error in the laboratory PM measurement of trap-equipped engines. When we initially compared the TEOM and QCM versus laboratory PM measurements from trap-equipped engines, we discovered that the laboratory results were very sensitive to sampling conditions. This is due to the fact that PM from a trap is mostly semi-volatile matter, such as high-molecular weight hydrocarbons and dilute sulfuric acid. These PM constituents can exist either as a gas or as PM, depending upon dilution conditions, pressures, temperatures, and PM collection media. It is important to note that the TEOM uses a different type of media than the lab, and the QCM uses a platinum substrate to collect PM. Within our current specifications for sampling post-trap PM, two different acceptable laboratory filter media give results where one is four times that of the other.(4) We believe that this difference is from a combination of gaseous hydrocarbons adsorbing onto one filter, while PM hydrocarbons are stripped off of the other filter. We are currently supporting a Coordinating Research Council study to resolve these laboratory PM measurement issues, and we expect that results from this study, which should be available before the end of 2004, will allow us to more accurately compare the TEOM and QCM to laboratory measurements of trap-equipped diesels. Based on the results of this study, we will select a single filter material specification for laboratory PM measurement. We expect that such a specification will resolve most of the current issues with post-trap PM measurement in the laboratory. Furthermore, based on this study, we will likely specify an on-vehicle PM sampling dilution rate and ratio, along with the on-vehicle equilibration pressure, temperature and humidity for PM samples. By specifying these sampling conditions, we can help assure that PM measurement on-vehicle will be sufficiently equivalent to laboratory PM measurements–even at our most stringent PM standard.

2. <u>Exhaust flow rate</u>. In a CVS laboratory the entire volume of engine exhaust is diluted and then measured. Since this is impractical for on-vehicle emissions measurement, the raw exhaust flow rate must be measured. We are aware of four commercially available technologies for on-vehicle exhaust flow measurement. One has been developed and patented by us, and it is based on an averaging Pitot tube (Patent No. 6,148,656). This technology is commercially available because we have licensed the technology to two on-vehicle emissions measurement system manufacturers. Another technology uses a hot-wire anemometer to measure the flow of ambient air induced by a sub-sonic venturi placed in the raw exhaust. A third technology uses a heated hot-wire anemometer directly in the exhaust. A fourth technology measures a known proportion of raw exhaust flow via the laboratory CVS technique. It's proportionality is maintained with the total raw exhaust flow by balancing certain partial flow pressures with the exhaust tailpipe and ambient pressures. All of these techniques have been demonstrated to be within 5 % of the true exhaust flow, and two of these

techniques were used to measure the flows required to achieve the gaseous and PM measurement results indicated in the previous section (1,3).

3. Engine operation. Certain engine parameters are required to calculate emissions or to determine whether or not an engine is operating in the NTE zone. Other parameters are used to determine if an EGR-equipped engine is sufficiently warmed-up for NTE testing. These parameters may be measured directly using the technologies described below. However, if the engine manufacturer determines that an engine's Electronic Control Module (ECM) accurately quantifies these parameters, the manufacturer may rely on ECM values for these parameters.

a. Speed. Engine crankshaft speed is required to determine whether or not an engine is operating within the NTE zone. Engine speed also may be used to determine engine power for emissions calculations. We have used magnetic flux detectors attached to the housing of an engine's belt-driven alternator to measure engine speed. Other on-vehicle emissions measurement system manufacturers detect alternator voltage ripple frequency. These signals are calibrated to actual engine speed during each engine installation with a portable reference tachometer.

b. Torque. Engine torque is required to determine whether or not an engine is operating within the NTE zone. Engine torque also may be used to determine engine power for emissions calculations. Engine torque may be measured directly by installing and calibrating a strain gage on the drive shaft. We also allow torque determination using fuel flow, as calculated via carbon-balance, in combination with engine speed and an estimated brake-specific fuel consumption. For details, refer to §1065.650, which is being revised in a companion final rule to this notice.

c. Coolant temperature, intake manifold temperature, and intake manifold pressure. These three parameters are used to determine whether or not an EGR-equipped engine is sufficiently warmed-up for NTE testing. These can be measured with standard thermocouples and automotive pressure transducers, which can be mounted into coolant and intake system caps or plugs.

4. Ambient conditions. Ambient conditions are used to calculate emissions or to determine if ambient conditions are within limits for NTE testing. These parameters may be measured directly using the technologies described below, or if the engine manufacturer determines that an engine's Electronic Control Module (ECM) accurately quantifies these parameters, the manufacturer may rely on ECM values for these parameters.

a. Temperature. We have used thermistor-based and thermocouple-based ambient temperature sensors for this purpose. Either technology is sufficient for this temperature measurement. These sensors are rugged because they are commonly used in remote weather station applications, however these sensors must be shielded from heat from the sun and heat from the engine to achieve accurate ambient temperature readings.

b. Dewpoint. We have used thin-film capacitor-based ambient dewpoint sensors for this purpose. This technology is sufficient for this dewpoint measurement. These sensors are rugged because they are commonly used in remote weather station applications.

c. Altitude. We have used Global Positioning System (GPS) technology to measure altitude. We have used this technology cross-country as part of a complete on-vehicle emissions measurement system, and it measured altitude accurately.

Chapter 2 References

1. "On the Road to Clear Skies: Semtech-D For On-highway Heavy-duty Diesel Applications." SAE Government/Industry Meeting May 13, 2003, Andrew Reading, Sensors Incorporated.

2. "Validation of the RAVEM Ride-along Vehicle Emissions Measurement System.", Final Report June 19, 2001, Christopher Weaver, Engine, Fuels, and Emissions Engineering.

3. "Evaluation of TEOM and QCM Technology for Particulate Mass Measurement", ETH Conference on Nanoparticle Measurement, Zurich, August 2001, David Booker, Mridul Gautam, West Virginia University.

4. "Particulate Mass Measurements of Heavy-duty Diesel Engine Exhaust Using 2007 CVS PM Sampling Parallel to QCM and TEOM.", Final Report No. 08.06129 September 30, 2003, Imad A. Khalek, Ph.D., Southwest Research Institute.

CHAPTER 3
New In-Use Testing Instrument Measurement Allowance

Before discussing the basis for the new measurement allowances for on-vehicle emissions measurements, it is instructive to review the restricted engine operation that the NTE zone covers, the list of other NTE allowances that we already have finalized, and other allowances that we propose elsewhere in this notice.

3.1 Review of NTE zone

On October 6, 2000 we published Not-To-Exceed (NTE) rules and regulations for heavy-duty diesel engines (65 Fed. Reg. 59895); effective for engines starting with model year 2007. NTE provisions were also incorporated into the regulations promulgated shortly thereafter requiring further reductions in emissions from heavy duty engines (66 Fed. Reg. 5001 January 18, 2001). Briefly, the NTE provisions specify brake-specific averaging periods as short as 30 seconds, and under these provisions testing is restricted to a limited region of engine operation. Namely, when all of the following conditions are simultaneously met for at least 30 seconds, an NTE event is generated. Note however, that if an aftertreatment system were to regenerate during this time, the minimum time under which all of these conditions must be met would increase to at least twice the regeneration interval:

1. Engine speed must be greater than 15% above idle speed.
2. Engine torque must be greater than or equal to 30% of maximum torque.
3. Engine power must be greater than or equal to 30% of maximum power.
4. Vehicle altitude must be less than or equal to 5500 feet.
5. Ambient temperature must be less than or equal to 100 degrees F at sea level to 86 degrees F at 5500 feet.
6. Brake-specific fuel consumption (BSFC) must be less than or equal to 105 % of the minimum BSFC if an engine is not coupled to a multi-speed manual or automatic transmission.
7. Engine operation must be outside of any manufacturer petitioned exclusion zone.
8. Engine operation must be outside of any NTE region in which a manufacturer states that less than 5% of in-use time will be spent.
9. For EGR-equipped engines, the intake manifold temperature must be greater than or equal to 86-100F, depending upon intake manifold pressure.
10. For EGR-equipped engines, the engine coolant temperature must be greater than or equal to 125-140 degrees F, depending on intake manifold pressure.
11. Engine aftertreatment systems’ temperature must be greater than or equal to 250 degrees C.

3.2 Review of existing NTE allowances

As part of these rules, we also finalized several compliance allowances with respect to meeting the Not-To-Exceed (NTE) standard. At that time we did not finalize any NTE allowances that were to specifically account for any differences between the quality of laboratory measurements and on-vehicle measurements. Note that we did finalize the following NTE allowances:

1. We allowed for the use of the family emissions limit (FEL) to which an engine was certified, rather than using actual emissions standard as the NTE standard. This allowance accounts for any differences in the engine's certified emissions and the actual emissions standard when comparing on-vehicle emissions to laboratory certified emissions.

2. We allowed for NTE multipliers of 1.25x and 1.5x times the engine's certified emissions, depending upon the level of the engine's certified emissions compared to the standard. This multiplier allowance accounts for any differences in engine operation and/or ambient conditions when comparing on-vehicle emissions to laboratory certified emissions.

3. We allowed for rounding of the compliance limit after multiplying the engine's certified emissions by 1.25x or 1.5x. Therefore, when an engine is certified at 0.01 g/hp-hr PM, this rounding effectively increases the 1.5x multiplier to 2.0x. This allowance creates an NTE compliance limit with the same number of significant figures as the emissions standard. This allows for a pass/fail determination with the same number significant figures when comparing on-vehicle emissions to laboratory certified emissions.

4. For NOx emissions, we allowed an additive allowance of 0.10, 0.15, or 0.20 g/hp-hr, based on an engine's model year, its certified emissions, and vehicle accumulated mileage. This additive allowance accounts for any differences in the performance of the first an in-use-aged NOx emissions control systems (including the engine and aftertreatment systems) when comparing their on-vehicle emissions to laboratory certified emissions.

5. For PM emissions, we allowed an additive allowance of 0.01 g/hp-hr, based on an engine's model year and its certified emissions. This additive allowance accounts for any differences in the performance of the first an in-use-aged PM emissions control systems (including the engine and aftertreatment systems) when comparing their on-vehicle emissions to laboratory certified emissions.

3.3 Review of other NTE allowances

As discussed elsewhere in this notice we also proposed additional NTE allowances for demonstrating compliance with this program. These allowances are based upon our settlement agreement with engine manufacturers. These include the following allowances:

1. We are allowing vehicles to meet the vehicle pass criteria for this program even though up to 10 % of the time-weighted NTE events exceed the applicable NTE threshold. For model years 2007 through 2009, however, none of these NTE exceedances can be greater than to 2x the NTE threshold. In the case of NOx emissions certified at or below 0.50 g/hp-hr–for model years 2007

through 2009, we are allowing these NTE exceedances to occur up to a threshold of 2.00 g/hp-hr. After model year 2009, there will be no upper limit to these individual NTE exceedances.

2. Elsewhere in this notice we are proposing that we would not require further testing of an engine family under this program even though a fraction of engines within that engine family failed to meet the vehicle pass criteria – even after applying all of the allowances discussed above.

3.4 Discussion of NTE measurement allowances

We have agreed to work co-operatively with engine manufacturers and the California Air Resources Board on a test plan to determine data-driven measurement allowances. The experimental methods and procedures specified in the test plan for determining, modeling, and comparing each of the various components of measurement error are designed to generate statistically robust data-driven measurement allowances for each of the gaseous emissions, namely NOx, NMHC, and CO. We have also agreed to develop a similar cooperative test plan for the determination of a PM measurement allowance.

As detailed in the gaseous emissions test plan, which is contained in the record for this rulemaking, we have an agreement with engine manufacturers and the California Air Resources Board on what components of measurement error are intended to be covered by the measurement allowances. Agreed upon sources of error include differences in emissions concentration measurements, differences in exhaust flow measurements, differences in PEMS environmental conditions, and differences in torque measurement versus inference of engine torque based on electronic control module (ECM) signals. We have agreed upon exploring the following environmental conditions effects on PEMS: ambient temperature and pressure, shock and vibration, electromagnetic radiation, and ambient hydrocarbons. We have also agreed that the test plan will comprehensively explore the sources of error that might arise because torque is not measured in-use, but rather it will be inferred from other signals from an engine's ECM. Specifically, lab measured torque versus ECM-derived torque will be compared over the following different conditions: different engine speeds and torques, different ambient pressures, temperatures, and humidities, different intake air and exhaust restrictions, and different charge air cooler temperatures. Furthermore, engine manufacturers are allowed to submit supplemental information regarding the effects of non-deficiency AECDs on the accuracy and precision of ECM-derived torque.

The test plan's measurement allowances will be calculated in a manner that subtracts lab error from PEMS error. Specifically, the lab error associated with measuring heavy-duty engine emissions at stabilized steady-state test points within the NTE zone, sampled over 30-second durations utilizing Part 1065 compliant laboratory emissions measurement systems and procedures will be subtracted from the PEMS error associated with measuring heavy-duty engine emissions utilizing PEMS over 30-second transient NTE sampling events under a broad range of ambient and environmental conditions. This subtraction will yield "PEMS minus laboratory" measurement allowances.

The error model developed in the test plan will not subtract any laboratory accuracy or precision determined from laboratory measurements of *transient* 30-second NTE events. However, such transient 30-second NTE data will be collected by laboratory measurement instruments during testing. Based on comments we received regarding the ability to conduct NTE testing in a laboratory, this data will be analyzed to determine whether or not we are correct in our belief that Part 1065-compliant engine dynamometer laboratories can accurately and precisely measure transient NTE events as short as 30 seconds. If not, we have agreed with engine manufacturers and the California Air Resources Board on a separate process to address this situation, should it arise. If results show that the lab 95th percentile transient 30-second NTE error is greater than the lab 99th percentile steady-state 30-second NTE error, then EPA, CARB, and EMA would agree to the following:

a. EMA will work with EPA and CARB to optimize laboratory NTE measurement specifications and procedures. This work will primarily be in the form of participating in and supporting joint laboratory NTE test procedure development efforts and meetings.

b. EPA would intend to issue a guidance document and/or propose changes to Part 1065 to reflect any optimized specifications and procedures for laboratory NTE testing as a result of those efforts and meetings no later than the end of calendar year 2008.

We are confident that based on the results of the test plan, we will be able to determine emissions-specific, brake-specific, additive, data-driven measurement allowances for NO_x, NMHC, and CO with sufficient lead-time for engine manufacturers to prepare for the 2007 fully enforceable program for gaseous emissions.

As noted above, we intend to develop a similar test plan for determining a PM measurement allowance, and we are confident that we will be able to determine data-driven measurement allowances for PM with sufficient lead-time for engine manufacturers to prepare for the 2008 fully enforceable program for PM emissions.

For measurement allowances in the interim before the test plans are completed, we have finalized generous emissions-specific, brake-specific, additive measurement margins. Based on the correlation studies detailed in the previous section of this document, we believe that these interim measurement allowances provide considerable margin for error based on the existing information on the accuracy of existing PEMS units.

APPENDIX A: Examples of Determining the Number of Engine Families to be Tested

This appendix contains a few examples showing how many engine families EPA may designate for testing each year under the in-use, manufacturer-run program. More specifically, they illustrate how we would calculate the maximum annual number of engine families for more complex cases where the four-year average annual cap and 25 percent per year limit might apply to a manufacturer with four or more engine families, all of which have annual production volumes more than 1,500 units.

The multi-step methodology is identical regardless of number of engine families a manufacturer has in these cases. The steps are discussed below and illustrated in Tables A-1 through A-3.

Step 1. For the calendar year in which we are testing (*the evaluation year)*, identify the number of engine families produced in the model year corresponding to that calendar year and each of the three preceding model years.

Step 2. Divide by 4 the number of engine families produced in the model year corresponding to *the evaluation year* and round the result to the nearest whole number using the rounding convention specified by the National Institute of Standards and Technology (NIST 1995).[2] The result is the *25 percent annual limit* on the number of engine families that potentially may be designated for testing in the evaluation year.

Step 3. Sum the engine families identified in Step 1 to determine the total four-year engine family production.

Step 4. Divide by 4 the total four-year engine family production from Step 3 and round the result to the nearest whole number using the rounding convention specified by the National Institute of Standards and Technology (NIST 1995). The result is the *four-year average cap* on the number of engine families that may be designated for testing in the evaluation year.

Step 5. Subtract the number of engine families we have required to be tested under this program over the past three years from the *four-year average cap.* The result is the *four-year average annual cap*.

[2] Under the rounding convention contained in this reference, when the first digit discarded is exactly five, the last digit retained should be rounded upward if it is an odd number, but no adjustment made if it is an even number.

Step 6. Select the lower of the rounded *four-year average annual cap* from Step 5 and the rounded *25 percent annual limit* from Step 2. The result is the maximum number of engine families that may be designated for testing in the evaluation year.

As noted, Tables A-1 through A-4 illustrate the procedure described above. They also show that the actual number of engines which may be designated in any year never exceeds the four-year average annual cap, and may be less for some years, especially for the initial model year of testing, i.e., 2007.

Table A-1. Example of Engine Family Selection for One or Two Families Per Year

Inputs

Model Year	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**
# Certified Families	1	1	1	1	1	1	2	2	2	2	2	2
4-Year Total Families (3 preceding years + current year)				4	4	4	5	6	7	8	8	8
4-Year Ave. Cap (simple)				1.00	1.00	1.00	1.25	1.5	1.75	2.00	2.00	2.00
4-Year Ave. Cap (NIST 811 rounded)				1	1	1	1	2	2	2	2	2
25% Annual Family Limit (simple)				0.25	0.25	0.25	0.25	0.50	0.50	0.50	0.50	0.50
25% Annual Family Limit (NIST 811 rounded)				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Calculations

4 -Year Ave. Cap (from above)				1	1	1	1	2	2	2	2	2
25% Annual Family Limit (from above)				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
# Tests Allowed/Year (4 Year Cap Applied?)				1 (no)	0 (yes)	0 (yes)	0 (yes)	2* (no)	0* (yes)	0* (yes)	0* (yes)	2 (no)
#Tested/4 -Year Ave. Annual Cap (% Tested)				1/1 (100)	1/1 (100)	1/1 (100)	1/1 (100)	2/2 (100)	2/2 (100)	2/2 (100)	2/2 (100)	2/2 (100)

* Alternatively, one family could have been tested in any two of the four years shown.

Table A-2. Example of Engine Family Selection for Six or Seven Families Per Year

Inputs

Model Year	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**
# Certified Families	6	6	6	6	6	7	7	7	7	7	7	6
4-Year Total Families (3 preceding years + current year)				24	24	25	26	27	28	28	28	27
4-Year Ave. Cap (simple)				6.00	6.00	6.25	6.5	6.75	7.00	7.00	7.00	6.75
4-Year Ave. Cap (NIST 811 rounded)				6	6	6	6	7	7	7	7	7
25% Annual Family Limit (simple)				1.50	1.50	1.75	1.75	1.75	1.75	1.75	1.75	1.50
25% Annual Family Limit (NIST 811 rounded)				2	2	2	2	2	2	2	2	2

Calculations

4 -Year Ave. Cap (from above)				6	6	6	6	7	7	7	7	7
25% Annual Family Limit (from above)				2	2	2	2	2	2	2	2	2
# Tests Allowed/Year (4 Year Cap Applied?)				2 (no)	2 (no)	2 (no)	0 (yes)	2 (no)	2 (no)	2 (no)	1 (yes)	2 (no)
#Tested/4 -Year Ave. Annual Cap (% Tested)				2/6 (33)	4/6 (67)	6/6 (100)	6/6 (100)	6/7 (86)	6/7 (86)	6/7 (86)	7/7 (100)	7/7 (100)

Table A-3. Example of Engine Family Selection for 10 Families Per Year

Inputs

Model Year	04	05	06	07	08	09	10	11	12	13	14	15
# Certified Families	10	10	10	10	10	10	10	10	10	10	10	10
4-Year Total Families (3 preceding years + current year)				40	40	40	40	40	40	40	40	40
4-Year Ave. Cap (simple)				10	10	10	10	10	10	10	10	10
4-Year Ave. Cap (NIST 811 rounded)				10	10	10	10	10	10	10	10	10
25% Annual Family Limit (simple)				2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
25% Annual Family Limit (NIST 811 rounded)				2	2	2	2	2	2	2	2	2

Calculations

	04	05	06	07	08	09	10	11	12	13	14	15
4-Year Ave. Cap (from above)				10	10	10	10	10	10	10	10	10
25% Annual Family Limit (from above)				2	2	2	2	2	2	2	2	2
# Tests Allowed/Year (4-Year Cap Applied?)				2 (no)	2 (no)	2 (no)	2 (no)	2 (no)	2 (no)	2 (no)	2 (no)	2 (no)
# Tested/4-Year Ave. Annual Cap (% Tested)				2/10 (20)	4/10 (40)	6/10 (60)	8/10 (80)	8/10 (80)	8/10 (80)	810 (80)	8/10 (80)	8/10 (80)

Table A-4. Example of Engine Family Selection for 9, 10, or 14 Families Per Year

Inputs

Model Year	04	05	06	07	08	09	10	11	12	13	14	15
# Certified Families/Year	9	9	9	9	9	10	10	10	10	14	14	14
4-Year Total Families (3 preceding years + current year)				36	36	37	38	39	40	44	48	52
4-Year Ave. Cap (simple)				9.00	9.00	9.25	9.50	9.75	10.00	11.00	12.00	13.00
4-Year Ave. Cap (NIST 811 rounded)				9	9	9	10	10	10	11	12	13
25% Annual Family Limit (simple)				2.25	2.25	2.50	2.50	2.50	2.50	3.50	3.50	3.50
25% Annual Family Limit (NIST 811 rounded)				2	2	2	2	2	2	4	4	4

Calculations

4-Year Ave. Cap (from above)				9	9	9	10	10	10	11	12	13
25% Annual Family Limit (from above)				2	2	2	2	2	2	4	4	4
# Tests Allowed/Year (4-Year Cap Applied?)				2 (no)	2 (no)	2 (no)	2 (no)	2 (no)	2 (no)	4 (no)	4 (no)	3 (yes)
# Tested/4-Year Ave. Annual Cap (% Tested)				2/9 (22)	4/9 (44)	6/9 (67)	8/10 (80)	8/10 (80)	8/10 (80)	10/11 (91)	12/12 (100)	13/13 (100)

Appendix References

1. National Institute of Standards and Technology. 1995. Guide for the Use of the International System of Units (SI), NIST Special Publication 811, 1995 Edition. U. S. Department of Commerce.