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The Colorado Enhanced I/M Program 0.5% Sample Annual Report

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The Colorado Department of Public Health and Environment

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I. Summary

A 0.5% remote sensing program has been operated in the Colorado Enhanced I/M Area since October 1995. In the period through July 1997, some 72,000 remote sensing measurements have been gathered on vehicles with recognizable plates. The RSD measurements have been used to characterize the on-road emissions and to compare the on-road vehicle emissions in the enhanced I/M area to vehicle emissions in the basic I/M area.

The RSD measurements of on-road vehicle emissions have been matched to the vehicle registration database and the enhanced IM240 test database. In over 12,000 instances a match was found between an RSD measurement and a subsequent IM240 test, of which almost 10,000 followed within 365 days of the RSD measurement. The matching RSD measurements and IM240 result pairs have been used to evaluate the effectiveness of RSD as a complement to the I/M programs by performing 'clean-screening' and 'high emitter identification'.

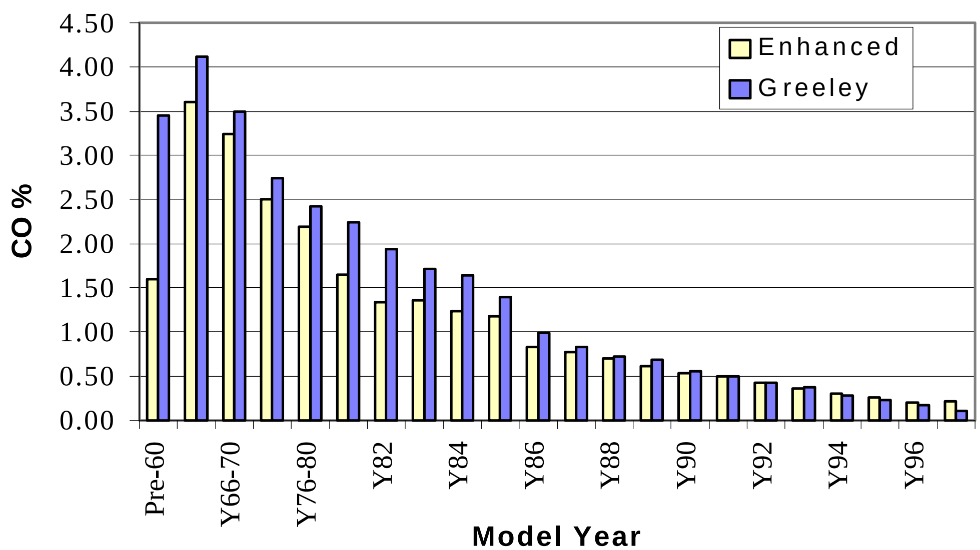
Clean-screening is the process of identifying vehicles that are operating cleanly and do not require I/M inspection. This can relieve owners of well maintained vehicles from the burden of unnecessary testing.

High emitter identification is used to identify vehicles that may have experienced an emission control system failure between I/M inspections. RSD can also be used to identify vehicles operating on the road that have not been inspected in the I/M program. These may be commuters or vehicles operating within the enhanced I/M area that are registered elsewhere.

Comparison of Vehicle Emissions in Enhanced and Basic I/M areas

RSD measurements were used to compare emissions levels between similar groups of vehicles registered to the enhanced I/M area and the Greeley basic I/M area.

Figure I-1 Comparison of On-Road Passenger Vehicle CO



Significantly lower levels of CO emissions were observed in passenger vehicles in the enhanced area than in the basic area as indicated in Figure I-1: Comparison of On-Road Passenger Vehicle CO.

The greatest differences in CO levels were observed in the older vehicles, starting with the mid 1980 model years that are some of the biggest contributors to total CO emissions. The lower levels of CO observed in the enhanced I/M area are probably the result of the centralized I/M 240 inspection program.

Clean Screen Results

The term 'clean screen' is used to describe the process of using RSD readings to determine whether a vehicle has sufficiently low emissions that it can be exempted from I/M inspection.

A comparison of RSD readings to IM240 inspection results for 1982 and newer vehicles shows that a clean-screen program is technically feasible. Vehicles with two RSD readings, drawn from all RSD sites, both having emission measurements of less than 0.5% CO, and less than 200 ppm HC, and less than 1500 ppm NOx, almost always meet the Federal EPA final high altitude IM240 standards when subsequently inspected. If vehicles meeting these screening criteria were to be exempted from the IM240 inspection, it is projected that 37% of the vehicles subject to inspection[1] would be exempted while 99% of excess CO emissions, 95% of the excess HC emissions, and 88% of the excess NOx emissions would be retained in the remaining vehicles.

With a single reading at RSD sites at which vehicle engines are operating under sufficient load, 40% of 1982 and newer vehicles could be clean screened while retaining almost 90% of the potential HC and CO emissions reductions that would be achieved using Federal EPA final high altitude IM240 standards.

Clean screening is almost 100% effective when used in conjunction with I/M program phase-in standards. The table below summarizes the results obtained using **two** RSD readings with screening standards of 0.5% CO, 200 ppm HC and 1500 ppm NOx. In each case 37% of vehicles pass the screen.

Figure I-2 Two-Hit Clean Screening Effectiveness

I/M Test Standard	HC	CO	NOx
Current Phase-In	100%	100%	n/a
EPA Phase-In	99%	100%	88%
EPA Final	95%	99%	88%

These findings are reasonably consistent with the results of the Greeley pilot, which found that vehicles seen more than once by RSD and having a maximum CO level of less than 0.5% CO

[1] In the Colorado enhanced program, new vehicles are exempt from inspection for four years but are subject to inspection upon resale to a new owner.

contained less than 5% of the CO emissions. The Greeley data indicate that 46% of vehicles would pass a 0.5% CO clean-screen criteria.

Results stratified by model year show that clean-screening is an effective tool for dealing with newer vehicles which contribute a significant fraction of excess NOx. It is estimated that 1990 and newer vehicles contribute 25% of the excess NOx emissions on-road. Clean-screening with even modest NOx cutpoints can relieve up to 60% of these newer vehicles from the need for inspection while retaining 80-90% of the emission reductions. Therefore, in areas where NOx is a concern, clean-screening is a better clean air strategy than extended new vehicle exemption periods.

It is recommended that the detailed design of a clean-screen program be developed with a view to the future implementation of a clean-screen program once EPA has approved the approach and issued the necessary guidance documents. Among the issues to focus on are motorist notification, economic feasibility and integration with the existing vehicle inspection program.

High Emitter Identification

RSD measurements have been compared to IM240 inspection results to examine the capability of RSD for identifying vehicles that exceed emissions standards. Vehicles with two RSD readings both exceeding 2% CO make up 9% of the vehicles measured by RSD. This group of vehicles contributed 51% of excess CO as measured by the subsequent IM240 inspections. The excess CO, however, comes from just 3% of the vehicles and the other two-thirds of the vehicles with high RSD readings went on to pass the IM240 inspection,i.e. there was an apparent false failure rate of about 70%. This high IM240 pass rate of vehicles identified by RSD as high emitters may be largely due to vehicle owners making repairs after the RSD measurement but prior to the IM240 inspection. Further research is needed to develop improved procedures and criteria to reduce the false failures.

Recommended Future Test and Analysis Activities

Future analysis should focus on refining High Emitter cutpoints including, taking into account vehicle age, weight and engine size. These analyses will require measurements on significant numbers of vehicles that fail the IM240 inspection.

If possible, the level of RSD activity should be increased. A 0.5% sample does not provide adequate sample sizes for detailed evaluation of emissions – especially with regard to high emitters. The increase in RSD measurements from May through July 1997 has been valuable in providing sufficient data from which to draw conclusions.

At present, RSD measurements are required to be made on a quarterly basis at locations distributed throughout the city. To monitor emission trends it would be useful to make measurements at some sites on a monthly basis or more frequent basis. This would allow better differentiation of the oxy-fuel program effect from a general improvement in fleet quality. Frequent measurements at the same site should also result in three or more RSD measurements on a significant number of vehicles. These can be used to determine improved strategies for high emitter identification. Sites yielding the highest number of hourly RSD measurements of vehicles subsequently failing IM240 inspection are recommended as the focus of this extra activity so as to produce the largest sample of failing vehicles. In order to capture a larger sample of commute vehicles, it may be useful to schedule some days for measurement of morning and evening commute hours. Measurement of vehicles on weekends would also help ‘round out’ a complete sample of the fleet.

One site in Commerce City was discontinued for technical reasons and replaced with a site in Westminster. Added back a site in the Commerce City area and/or in the Lakewood/Golden area would improve geographic coverage of the enhanced I/M area.

Continuing to monitor Greeley emissions would provide the data for ongoing comparison of emission levels in the Basic area.

To facilitate the comparison of RSD measurements to subsequent IM240 results, a mechanism should be established whereby the enhanced I/M program could turn off the fast-pass option for a pre-selected list of RSD measured vehicles identified by VIN.

In order to avoid potential timing differences between RSD plate identification and DMV records, it would be preferable to match plates to a registration database that contains a chronological history of vehicle registration information changes that is indexed by plate. A sample of the plates observed by RSD that could not be matched to registration records should be examined to determine the causes, which may include misinterpreted plates, out-of-state plates, dealer plates and expired plates.

Further research is needed on the conversion of IM240 mass emissions to equivalent RSD measurements. This would include more a accurate comparison of vehicle loads and adjustments for differences between HC measurements made using flame ionization detectors (FIDs) in the IM240 test vs. the non-dispersive infra-red (NDIR) measurements made by the RSD unit.

II. Description of the RSD Project

A. General

1. Project Requirements

The Colorado Department of Health (CDH) is required by the Clean Air Act Amendments of 1990, to supplement the Enhanced I/M program with an on-road/remote sensing element to the program. The Clean Air Act Amendments require that a minimum of 0.5% of the eligible motor vehicle population in the six county Denver/Boulder metro area be tested annually.

Section 51.371 of the Code of Federal Regulation (CFR) covering Enhanced I/M programs defines on-road testing as the measurement of HC, CO, NOx and/or CO2 emissions on any road or roadside in the non-attainment area or the I/M program area. On road testing is required in enhanced I/M areas and is an option for basic I/M areas.

The general requirements specified in CFR 51.371 are:

> (1) On-road testing is to be part of the emission testing system, but is to be a complement to testing otherwise required.
>
> (2) On-road testing is not required in every season or on every vehicle but shall evaluate the emission performance of 0.5% of the subject fleet, including any vehicles that may be subject to the follow-up inspection provisions of paragraph 4) below, each inspection cycle.
>
> (3) The on-road testing program shall provide information about the emission performance of in-use vehicles by measuring on-road emissions through the use of remote sensing devices or roadside pullovers including tailpipe emission testing. The program shall collect, analyze and report on-road sensing data.
>
> (4) Owners of vehicles that have previously been through the normal periodic inspection and passed final retest and found to be high emitters shall be notified that the vehicles are required to pass and out-of-cycle follow-up inspection; notification may be by mailing in the case of remote sensing on-road testing or through immediate notification if roadside pullovers are used.

These requirements are listed in greater detail in Appendix 7 of RFP for the Enhanced I/M Program RFP-RO-AIR940021 dated August 31, 1993.

2. Contractor

Remote Sensing Technologies inc. (RSTi) have carried out this work. Headquartered in Tucson, Arizona, RSTi has more program experience with remote sensing than any other company. RSTi uses technology derived from that originally developed at Denver University with whom RSTi has a royalty agreement.

3. Description of RSD

Theory of operation

The RSD is a system designed for a non-intrusive measurement of vehicle emissions. It generates and monitors a non dispersive infra-red and ultra-violet beam emitted and reflected approximately 10 to 18 inches above ground preferably across a single lane road. Gasoline, diesel, or other fossil fuel powered vehicles drive through this beam and the exhaust interferes with this transmission of the beam. Quantifying the interference enables the calculation of tailpipe concentrations of CO, HC, CO2, and NOX. A camera simultaneously captures a digitized video image of the rear of the vehicle and its license plate.

Equipment

The particular equipment deployed in Denver is an RSD-2000 mobile unit. This is based on a technical platform developed at the University of Denver by Dr. Donald Stedman. RSTi engineers have commercialized this equipment and continue its development.

The RSTi mobile unit includes the equipment required to provide measurement of emissions as well as speed and acceleration readings and license plate recognition. Five main components comprise the RST 2000 system:

- Infrared source detector module (SDM);
- Video system;
- Control console with computer system;
- Laser based speed and acceleration measurement system;
- Automated license plate reading system.

The primary combustion gases HC, CO and CO2 are measured simultaneously along the same optic path to ensure the proper application of the combustion gas equations. To avoid interference between vehicles, the RSTi unit is capable of completing the vehicle emission measurement within 0.6 second and of completing all measurements for a vehicle including emissions, speed, acceleration and plate image within one second.

The RSTi unit takes multiple rapid readings for each vehicle to characterize the exhaust plume profile and evaluate whether a valid measurement of a vehicle’s exhaust has been achieved. The criteria include how much vehicle exhaust plume is available for the duration of a 0.6 second sampling period, evaluation of whether plume measurements are consistent with normal plume dissipation, and correction for changes in background concentrations of emissions.

RSTi units are certified to meet accurate measurement of calibration gas trailed by a specially modified vehicle under controlled conditions using tri-blend (CO_2, HC, CO) and dual-blend (CO_2, NO) calibration gases. The RSD tolerance for each pollutant is:

- Carbon monoxide (CO): ±10% or 0.25% {whichever is greater} for all expected concentrations less than or equal to 3.0%, and ±15% for all CO expected concentrations above 3.0% CO.
- Hydrocarbon (HC): ±150 parts-per-million (ppm) or ±15% of the expected HC concentration {whichever is greater} throughout the range of HC concentrations. Hydrocarbon measurements are expressed in their **hexane** equivalent measurement.
- Oxides of nitrogen (NO_x): ±250 parts-per-million (ppm) or ±15% of the expected NO_x concentration {whichever is greater} throughout the range of NO_x concentrations.

The mobile unit is equipped with a speed and acceleration measurement system that uses extremely accurate low energy lasers to calculate the speed of the vehicle to within +/- 0.5 mile per hour and acceleration to within +/- 0.3 miles per hour per second at the moment exhaust is measured.

The system captures emissions readings and rear pictures of vehicles that pass through the RSD infrared beam. The video and emissions readings taken are stored directly on a removable media disk and can be used for future reference.

Data collected

For each vehicle the following information is collected:

- Plate number;
- HC, CO, CO2, and NOX emission concentrations;
- Max CO2;
- Speed and acceleration.

B. Overview of 0.5% Sample

1. Sample Design Criteria

The objective is to obtain the 0.5% sample from sites that will be generally representative of vehicles operating in the enhanced program area.

As shown in Figure II-1: ‘Site Locations’, six sites have been selected so as to be reasonably distributed within the Enhanced program area.

The intent is to collect tests on a random sample that is representative of all the on-road vehicle traffic. Measurements are distributed both geographically and temporally with no one area or period of the day receiving an undue amount of testing. Approximately, one quarter of the testing is performed in each quarter of the year.

2. Description of Sample Site Characteristics

Site selection is critical to obtaining RSD measurements that are representative of vehicle operation. Recommended site attributes include:

(1) Absence of cold start vehicle operating conditions

(2) Sites where vehicles will generally be accelerating or driving at a steady speed uphill to avoid the highly variable tailpipe emissions that can occur under deceleration

(3) Absence of enrichment due to high load conditions

(4) Single lane operation

(5) High volume traffic

(6) Unobtrusive citing of the remote sensing equipment

(7) Multi-year stability in the traffic mix

(8) Adequate median space for safe operation of the RSD equipment.

C. Sites selected for studies

Figure II-1 lists the site locations selected for the 0.5% sample. All the sites selected are on-ramps that provide the required physical characteristics of an appropriate RSD site. Sites were pre-qualified for:

- Single lane operation with space for the RSD equipment to be deployed without disrupting traffic flow
- Geographically dispersed throughout the enhanced I/M area;
- A satisfactory percentage of valid readings;
- An adequate traffic volume.

'Site Selection Summary' sheets for each site are contained in Appendix I.

Figure II-1 RSD Sites

SiteRef	Description	Slope
D1	Aurora: On-ramp to S.B. I-225 from W.B. East 6th Ave.	1.7
D2	Commerce City: On-ramp to W.B. I-270 from S.B. Vasquez Blvd.	0.7

D3	Highlands Ranch: On ramp to W.B. C-470 from University Blvd.	1.6
D4	Boulder: On ramp from W I-36 to N Rte 157	1
D5	Denver: On ramp from S.B. I-25 to S.B. Speer Blvd.	1.9
D6	Westminster:On ramp to N.B. US 36 from Sheridan	-1.1
D4A	Boulder: On ramp to S.B. Rte 157 from Pearl St.	3.1
D2A	Westminster: On-ramp to W.B. I-76 from Federal Blvd.	0.7
D5A	Westminster: On ramp to W.B. I-76 from Sheridan Blvd	1.9

Sites D2 and D4 were abandoned following an upgrade of the RSD unit. The nature of the RSD unit upgrade was to apply more discriminating criteria to the adequacy of the observed vehicle exhaust plume. In deceleration mode, vehicles have sharply reduced exhaust volumes that may not be typical of the vehicle in more normal cruise or acceleration modes. Following upgrade of the RSD unit, sites where a high percentage of vehicles were in decelerating became unproductive as the RSD unit rejected many measurements.

Site D5 had to be abandoned because a permit could not be obtained.

D6 was added in June 1997.

The original set of five sites provided widespread coverage of the enhanced area. The replacement for D2 in Commerce City by a second Westminster site diminishes the spread somewhat. A site in the Commerce City area and in the Lakewood / Golden area would improve geographic coverage of the enhanced area.

D. Sources of Data and Description of Elements

Data used in the analyses in this report come from three primary sources; the RSD unit measurements, the DMV database maintained on the AIR program contractor host computer, and the I/M test database also maintained on the contractor host computer system.

In the following description of data elements, key fields that are used to access other tables are shown in **bold**.

1. RSD Measurements

For each vehicle the following information is collected:

- **Vehicle Plate or tag;**
- Date and Time;
- **Site Reference;**

- HC, CO, CO_2, and NOX;
- Speed and acceleration.

2. RSD Sites

- **Site Reference;**
- Description of location;
- Slope of site in degrees;

3. Vehicle Registration Data

Data from the RSD is loaded into the Enhanced I/M database maintained by the centralized contractor. This database contains vehicle registration and inspection results. Using the vehicle plate identified by RSD, the registration file is accessed to determine the vehicle identification number (VIN) and additional vehicle information:

Vehicle Identification Number (VIN)
Vehicle Plate
Plate Type
Vehicle Make
Vehicle Year
Vehicle CWT (heavier vehicles only)
Body Style
Fuel
Mailing Address & Zip
Owner
Owner Registration County
Registration expiration Year and Month

4. I/M 240 / Air Program Data

The RSD data is matched to the I/M test data using the Vehicle Identification Number (VIN). For selected records the following IM240 information is selected:

I/M Test Date and Time
Station
I/M Program
VIN
Plate
Registration expiration Year and Month
Model Year
Make
Model
Type
Cylinders
GVW

Displacement
Fuel
V_Test (Test number)
V_Cust (Mandatory or Engineering test)
HC, CO, NOX standard
HC, CO, NOX grams per mile
CO2 grams
Test_End_Time,
HC, CO, Nox Calculation Indicators,
Fast-pass time,
HC, CO, NOX emission result,
Overall emission result,
Opacity result,
Ffr, cat, cap, o2, ais, eng results,
Sticker,
Overall test result,
Initial HC, CO, NOX results (only on retests),
Previous emissions result (only on retests),
Odometer reading,
Test indicator ?
Emission/Purge test requirement

E. Data Limitations

1. General RSD Limitations

Considerable improvements have been made in understanding the quality of remote sensing readings. In the past, inadequate quality control over remote sensing data has sometimes resulted in poor results when comparing remote sensing data to results from other emissions tests. These have been damaging to the acceptance of remote sensing as a reliable tool. Two conditions have to be satisfied in order to obtain a result that provides useful information about a vehicle:

1. The RSD unit has to obtain a reading based on an adequate exhaust plume;
2. The operating condition of the vehicle must be known (speed, acceleration and slope of the road at the measurement location).

RSTi continues to improve the algorithms used to determine whether a reading is valid. Criteria include the concentration of CO2 observed and the characteristics of the exhaust plume. With updated software, the RSTi instruments are better able to flag readings that may be prone to error than was previously the case.

The RSD unit used in Denver was most recently upgraded in April 1997. Following the upgrade, the RSD unit applied more discriminating criteria to the adequacy of the observed vehicle exhaust plume. Following the upgrade, the RSD unit rejected a much higher fraction of the readings for vehicles that were decelerating and had smaller or highly variable exhaust plumes.

2. I/M-240 fast pass algorithm limitations

Gram per mile results for vehicles that fast-pass the IM240 test in Colorado are projected from the grams emissions at the point the vehicle fast passes. Projected 240-second grams per mile results for fast-pass vehicles are useful for facilitating estimates of after repair benefits, etc. To assess the accuracy of the projection a sample of 140,000 vehicles was tested in Q1 1997 using the full 240-second test. These results were used to review whether the method used for projecting the 240-second results needed to be updated. The sample was also used to determine the impact of the fast-pass standards on program effectiveness.

Average emissions values for the projected results compared by vehicle type and model year were very close to the full test results. The difference in average emissions for the entire sample of vehicles fast-passing prior to second 170 was 0.03 gpm HC, 0.3 gpm CO and 0.05 gpm NOX. On an individual vehicle basis, however, the errors were much larger. The four figures below show the average per vehicle error and the vehicle final standard for HC and CO.

The average error is typically about 15% of the final standard, which could introduce some noise into the RSD clean screen comparisons for vehicles whose projected IM240 result is fairly close to the standard. This noise is likely to negatively impact the comparison, i.e. given that one is using the IM240 result as the standard against which the RSD result is being judged then to the extent the standard is unreliable we may never attain 100% agreement between the two.

Figure II-2 Light Truck Final High Altitude HC Standards and Projected Fast Pass Result Average Error

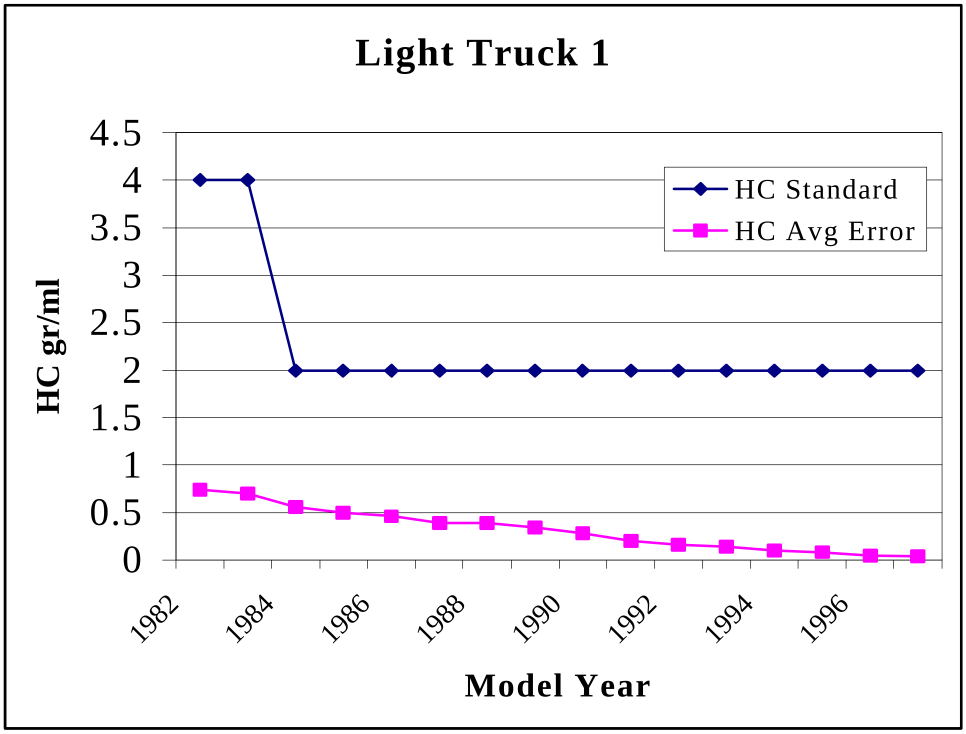


Figure II-3 Light Truck Final High Altitude CO Standards and Projected Fast Pass Result Average Error

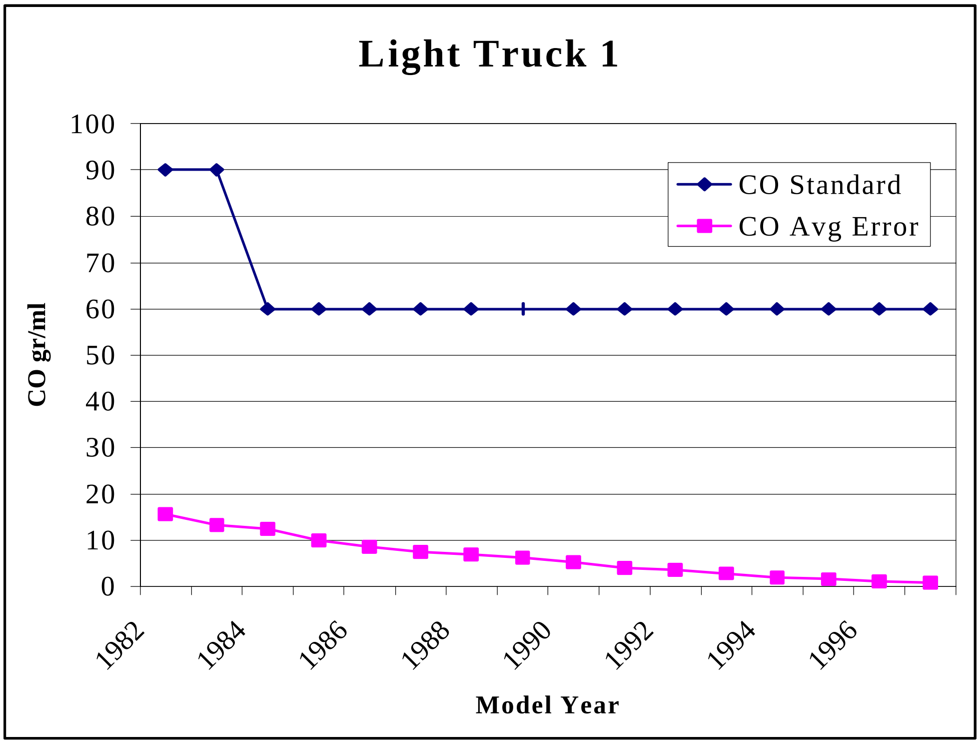


Figure II-4 Light Vehicle Final High Altitude HC Standards and Projected Fast Pass Result Average Error

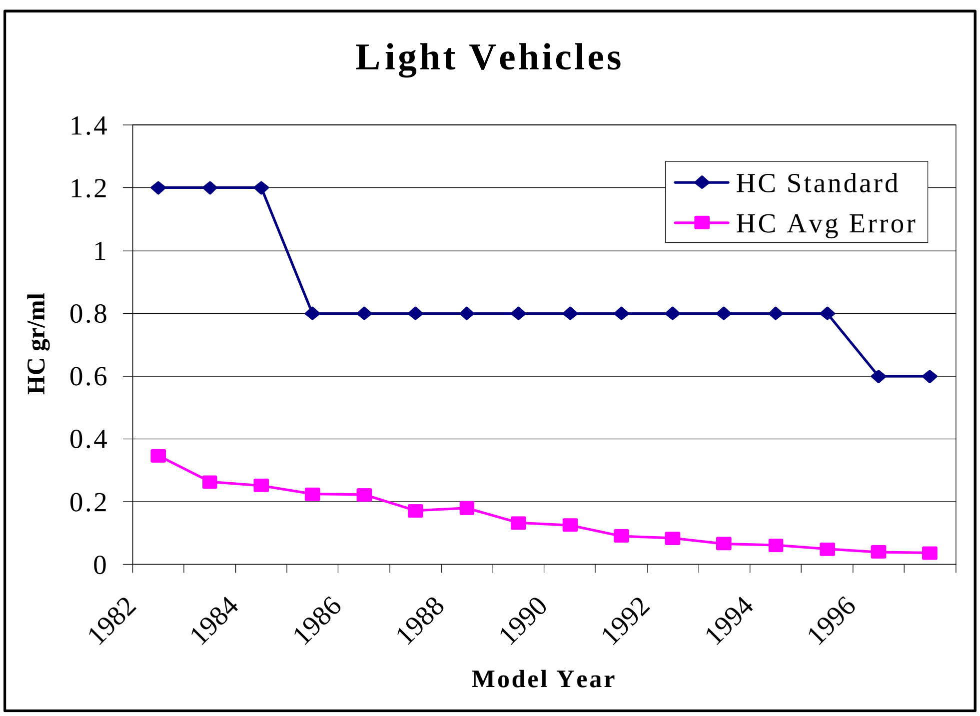
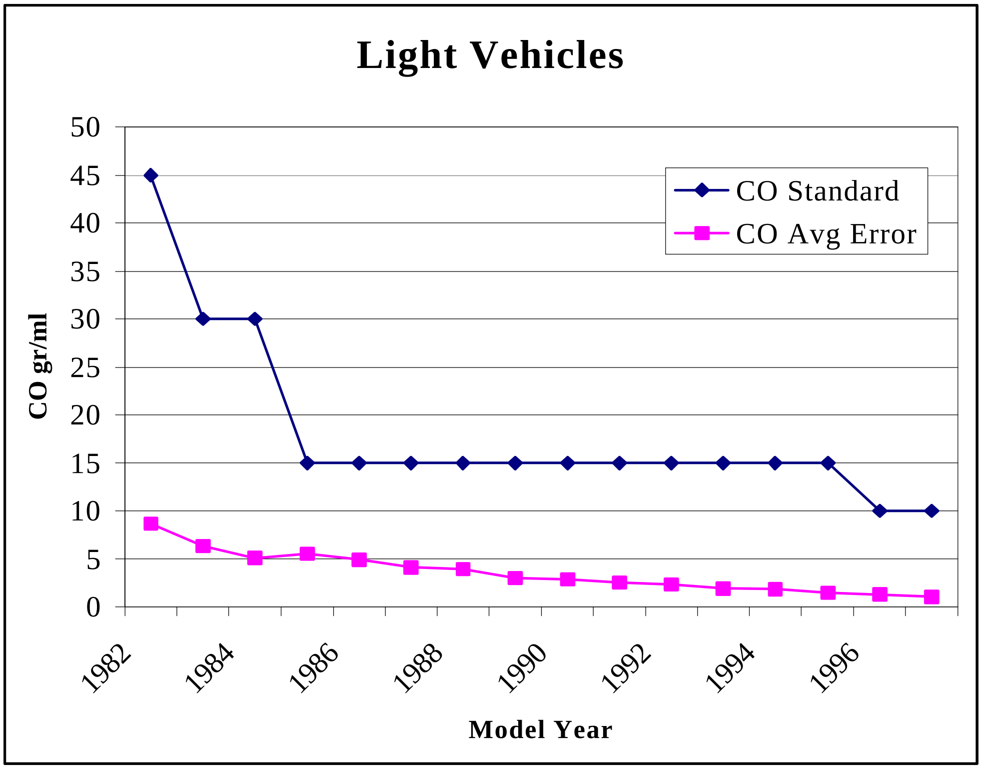


Figure II-5 Light Vehicle Final High Altitude CO Standards and Projected Fast Pass Result Average Error



To determine the suitability of using fast-pass results for assessing RSD effectiveness in conjunction with final IM240 standards, the 1997 Q1 sample of full IM240 tests has been used to quantify the impact of fast-pass projections on the calculation of emissions in excess of the final high altitude standard.

Figure II-6 summarizes the difference in excess emissions calculated from the actual full IM240 results vs. results projected from the cumulative emissions at the time the vehicle fast-passed the test. The projection algorithm is the same as that used in the enhanced I/M program. The attachment shows the sum of the excess emissions in each case and the failure rates. The variances in the projected excess emissions and the projected failure rates are small – perhaps within the range of repeatability of the IM240 test. The slight bias to the low side in the projections probably stems from the use of the algorithm that was calculated by model year at the end of 1995. Vehicle aging since then has had a greater effect than projected. Despite the loose phase-in NOx standards, the NOx projections appear to be as accurate as those for HC are and more accurate than those for CO.

It is believed that given good sample sizes of several hundred vehicles, excess emissions calculated using projected fast-pass IM240 values will correlate well with results calculated using full 240-second results.

As I/M programs move towards the final standards, we will be able to re-confirm these results. In general, one would expect noise in the fast-pass results to degrade rather than improve the RSD result to IM240 result comparison.

Figure II-6 Actual vs. Projected Excess Emissions and Fail Rates

Final High Altitude Standard Excess Emissions and Fail Rates- Actual vs. Projection from Fast-Pass Colorado Q1, 1997 - Full IM240 Initial Tests

Note: Excess emissions calculated as difference between vehicle emissions and the standard for the vehicle.

Type	Model Years	Initial Tests	Excess CO gpm Actual	Excess CO gpm Projection	Excess HC gpm Actual	Excess HC gpm Projection	Excess NOX gpm Actual	Excess NOX gpm Projection	Projection Variance CO	Projection Variance HC	Projection Variance NOX
LT1	1982-1985	5,724	36,556	34,415	5,811	5,609	1,136	1,112	-6%	-3%	-2%
LT1	1986-1989	10,950	18,372	17,135	3,375	3,113	2,258	2,115	-7%	-8%	-6%
LT1	1990+	23,073	4,424	4,326	710	652	1,777	1,656	-2%	-8%	-7%
Subtotal		39,747	59,353	55,876	9,896	9,374	5,171	4,882	-6%	-5%	-6%
LV	1982-1985	14,479	116,278	113,192	12,213	12,208	6,663	6,598	-3%	0%	-1%
LV	1986-1989	27,222	87,773	82,689	8,909	8,892	5,677	5,580	-6%	0%	-2%
LV	1990+	47,154	26,574	23,974	2,840	2,831	1,928	1,895	-10%	0%	-2%
Subtotal		88,855	230,625	219,855	23,963	23,930	14,269	14,073	-5%	0%	-1%
Total		128,602	289,978	275,731	33,859	33,304	19,440	18,955	-5%	-2%	-2%

Type	Model Years	CO Fail% Actual	CO Fail% Projection	HC fail % Actual	HC fail % Projection	NOX fail% Actual	NOX fail% Projection
LT1	1982-1985	17%	14%	46%	47%	13%	12%
LT1	1986-1989	10%	8%	30%	31%	9%	8%
LT1	1990+	5%	4%	16%	16%	4%	4%
Subtotal		8%	7%	24%	25%	7%	6%
LV	1982-1985	3%	3%	16%	15%	13%	11%
LV	1986-1989	1%	1%	6%	6%	8%	7%
LV	1990+	0%	0%	3%	2%	5%	5%
Subtotal		1%	1%	6%	5%	7%	6%
Total		3%	3%	12%	11%	7%	6%

3. Limitations due to timing between RSD and I/M data

This report uses IM240 inspection results to evaluate the ability of RSD to identify clean and dirty vehicles. When comparing IM240 and RSD data it is important to consider the likelihood of changes in vehicle emissions between the date of the RSD measurement and the date of the IM240 measurement. Changes in vehicle emissions are likely to arise from:

1. Natural vehicle deterioration over time;
2. Repairs made by vehicle owners in response to poor vehicle performance or breakdown;
3. Repairs to the vehicle made prior to a scheduled I/M inspection;
4. Repairs to the vehicle following failure of a scheduled I/M inspection.

The scenario described below illustrates that changes in vehicle condition are expected to have little impact when evaluating RSD as a tool for identifying clean vehicles but may have a significant impact when evaluating RSD as a tool for identifying high emitters. Specifically, we can expect a significant fraction of vehicles that were dirty on the date they were measured by RSD will be clean when they subsequently go for an IM240 inspection. These may be mis-interpreted as false failures on the part of RSD, when in fact the RSD made the correct determination but the vehicle was repaired prior to its IM240 inspection. Little data exists regarding the frequency of repairs made by vehicle owners prior to inspection, but an attempt at quantifying the effect of the actions of vehicle owners is described in the following scenario.

In a biennial program, assume that 15% of vehicles experience an emissions control system failure in two years. If they suspect a failure, the owners of these 15% of vehicles with ECS failures have a choice to make when their scheduled inspection date falls due. They can either have the vehicle repaired prior to inspection or risk the vehicle failing inspection. Since the first re-inspection is free, the only penalty for taking a gamble on the vehicle passing without repair is the potential inconvenience of having to return for a re-inspection. There may be other psychological factors at work, however, such as owners not wanting their car to fail. Absent survey results regarding motorist behavior, we have assumed that one-third the owners of vehicles with ECS failures will have them repaired sometime prior to a scheduled inspection. This leaves 10% of vehicles with ECS failures that fail inspection. Of these 10% of vehicles, the probability is that ¼ of them failed after being measured by the RSD and ¾ failed before measurement by the RSD.

Using this scenario, the probable emissions status of vehicles measured by RSD an average 180 days **prior** to their I/M inspection would be:

RSD	IM240	%	Explanation
Clean	Clean	85%	Vehicles clean the whole year
Dirty	Clean	5%	Failing vehicles repaired just prior to I/M inspection
Clean	Dirty	2.5%	Vehicles failing after RSD measurement and not repaired before I/M inspection
Dirty	Dirty	7.5%	Vehicles failing before RSD measurement and not repaired before I/M inspection

When viewed from the perspective of using the IM240 result to evaluate RSD performance, the above table can be summarized as:

IM240	Vehicle %	RSD Clean	RSD Dirty
Pass	90%	85%	5%
Fail	10%	2.5%	7.5%

These results suggest that even if the RSD and IM240 measurements are all correct, there will be some apparent disagreement between the results. When evaluating RSD for Clean Screen using RSD measurements made prior to IM240 inspections, one should expect an apparent false pass rate of about 3% (2.5/85). For High Emitter evaluation, one may see apparent errors of omission of 25% (2.5/7.5) and errors of commission of 40% (5/(5+7.5)).

Hence we must be careful about drawing conclusions as to RSD accuracy and effectiveness based on comparative subsequent IM240 results – especially for High Emitter evaluation. Correspondence between RSD and IM240 results should improve as the time gap between the RSD and IM240 reading is reduced.

The previous paragraphs examined the situation when the RSD measurement(s) preceded the IM240 inspection. For vehicles measured by RSD an average 180 days **after** a final IM240 test, and assuming all IM240 failures have been repaired, the vehicle status at the time of each measurement would be:

IM240	RSD	%	Explanation
Clean	Clean	96.5%	Vehicles remaining clean
Clean	Dirty	3.75%	Vehicles failing before subsequent RSD measurement

Data on RSD measurements following a final IM240 inspection are probably more useful for evaluating vehicle deterioration than for evaluating RSD.

4. Limitations due to county registration process and data processing delays

Using RSD, vehicles are first identified using the vehicle plate, which is then matched to vehicle registration data to determine the vehicle information. In a situation where upon purchase of a new vehicle, an owner may transfer the same plate from the old vehicle to the new vehicle, two data processing delays can result in incorrect identification of the vehicle measured by RSD. The first delay is the time between the RSD measurement and the matching of the measurement to the registration data. The second delay is the time between a vehicle being given new plates and the time plate change is noted in the DMV database and updated in the contractor registration table.

The chance of incorrect vehicle identification will be minimized if the two processing delays are about the same duration.

The chance of an incorrect identification can be avoided by maintaining a chronological history of DMV registration transactions and referring to it when subsequently matching the RSD measurements. This has not been done for the data in this report.

If typically 20% of owners change vehicles each year, then a one-month processing delay may affect up to 1.7% of vehicle identifications. This percentage is not considered to have a material impact on the results.

III. Summary of Data Collection

A. RSD Sample Quantity

The number of subject vehicles registered in the Enhanced I/M area is approximately 1.5M. The requirement of a 0.5% sample of subject vehicles therefore requires about 7,000 measurements per year. Figure III-1 shows a monthly count by site of measurements that have an identified plate. The activity started in the fourth quarter of 1995. In mid-1997, following the completion of the Greeley project, the number of measurements was increased to obtain larger sample sizes for IM240 comparison.

In total, 72,000 RSD measurements were made from December 1995 through July 1997, of which 14,000 readings have been matched to a subsequent initial IM240 inspection. Figure III-2 shows the percentage of RSD readings that have been matched by month and by site. These statistics may include duplicate instances of the same vehicle where the same vehicle has been measured by RSD more than once or has received more than one initial IM240 inspection. Figure III-3 illustrates the progression of the percentage matched vs. the months since the RSD measurement was taken. As one would expect, this shows a linear relationship. By estimation, it appears that 70% of the RSD measurements taken and matched to the registration file will be matched to an IM240 inspection in the two-year biennial inspection cycle. The other 30% include:

- 1981 and older vehicles subject to the idle test;
- diesels, trucks, buses, motorcycles, and other exempt vehicles that are not subject to IM240 inspection
- vehicles registered outside the enhanced I/M area.

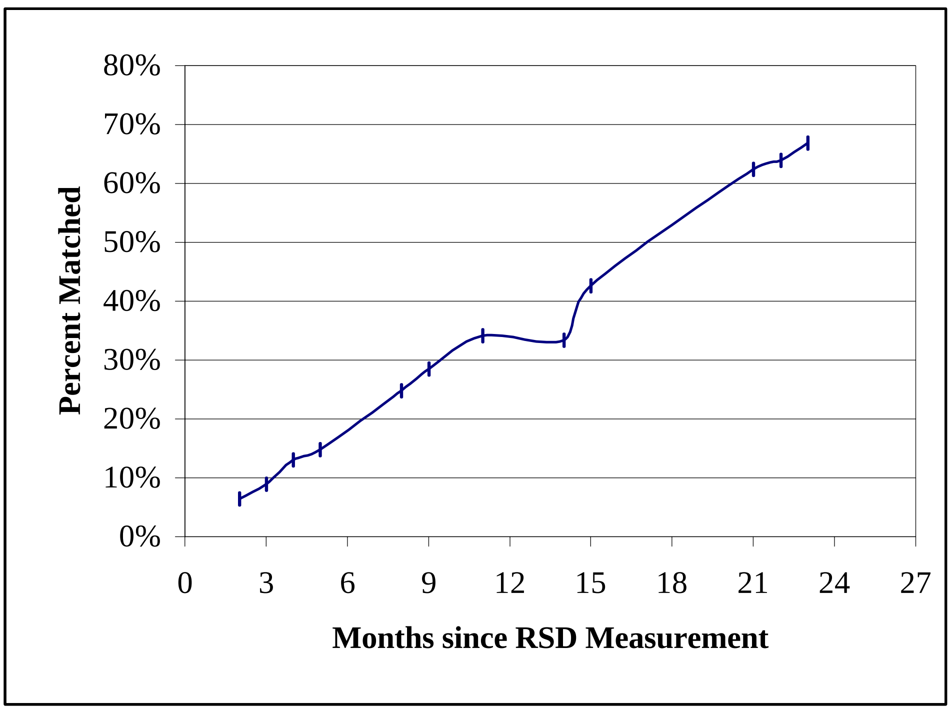
Figure III-1 Monthly RSD Measurements by Site

Month	*D1*	*D2*	*D2A*	*D3*	*D4*	*D4A*	*D5*	*D5A*	*D6*	***Total***
9510	909	789		2,411						4,109
9511					2,699					2,699
9512							327			327
9606	925	398		963	1,298					3,584
9607							135			135
9610		225		1,148	474					1,847
9612	1,002			3,766						4,768
9701	1,353									1,353
9704	1,627	101		5,388	459					7,575
9705	2,139		1,478	4,504		5,612		1,042	2,316	17,091
9706	877			2,124		5,215		1,051	3,271	12,538
9707	1,542		991	2,235		4,725		5,126	2,083	16,702
Total	10,374	1,513	2,469	22,539	4,930	15,552	462	7,219	7,670	72,728

Figure III-2 % of RSD Measurements Matched to a Subsequent Initial IM240 Test

Month	*D1*	*D2*	*D2A*	*D3*	*D4*	*D4A*	*D5*	*D5A*	*D6*	***Total***
9510	67%	63%		68%						67%
9511					64%					64%
9512							62%			62%
9606	43%	34%		43%	45%					43%
9607							33%			33%
9610		33%		37%	28%					34%
9612	28%			29%						28%
9701	25%									25%
9704	14%	25%		15%	13%					15%
9705	13%		13%	14%		13%		12%	12%	13%
9706	9%			9%		9%		9%	9%	9%
9707	7%		6%	6%		6%		7%	7%	6%
Total	22%	48%	10%	24%	51%	9%	54%	8%	10%	19%

Figure III-3 % of RSD Measurements Matched to a Subsequent Initial IM240 Test



B. RSD Sample Quality

1. Valid hits per site and daily average values

Figure III-4 'Daily RSD Statistics' shows the daily count of measurements, the percent of valid readings and average vehicle operation and emissions values. Some explanation of the changes that occurred during the period is necessary. Normally, only measurements taken by the RSD that included a minimum set of information are recorded on the host computer. The minimum set of information usually required are a license plate and an HC or CO emission reading. Throughout 1996, all readings were required to have a valid CO measurement. In 1997, the procedure was changed to record all measurements that had a recognizable plate.

In April 1997, the software on the RSD unit was modified to be more discriminating regarding the characteristics of an exhaust plume that would be deemed acceptable. This had the effect of substantially reducing the percentage of valid measurements at some sites where a high fraction of vehicles were decelerating to a point where the sites were no longer useful. Thus for example, sites D2 and D4 in early April returned a very low percentage of readings accepted by the modified RSD unit. Consequently, these sites were relocated to obtain better results. The replacement sites are designated D2A and D4A.

Vehicles that are decelerating have more widely variable emissions readings than readings taken for vehicles under load. In deceleration mode, the volume of exhaust gases may be substantially reduced as the air intake is closed off, but the ratio of the pollutant gases to CO2 is often higher. This is especially true for HC. Therefore, although the mass of emissions emitted per second under deceleration may be lower than when the vehicle is under load, the emissions concentrations as a percentage of the total exhaust gases is usually higher.

Figure III-4 Daily RSD Statistics

Date	Site	Tests	Pcnt Valid CO	Pcnt Valid HC	Pcnt Valid NO	Pcnt Valid Speed	Pcnt Valid Accel	Avg CO%	Avg HC ppm	Avg NO ppm	Avg Speed mph	Avg Accel mph/s
951009	D1	298	97%	94%	36%	0%	0%	0.96	423	484		
951011	D1	32	91%	88%	22%	0%	0%	0.55	272	766		
951018	D2	540	99%	99%	67%	0%	0%	0.45	218	277		
951024	D2	249	100%	99%	79%	0%	0%	0.40	151	214		
951025	D1	579	90%	85%	30%	63%	63%	0.90	496	422	31	(0.41)
951026	D3	1,187	98%	93%	42%	76%	76%	0.80	277	728	35	0.78
951027	D3	1,224	99%	98%	73%	0%	0%	0.75	196	526		-
951114	D4	1,408	100%	84%	17%	0%	0%	0.57	574	564		-
951115	D4	1,291	100%	83%	13%	0%	0%	0.44	736	642		-
951206	D5	327	100%	89%	87%	20%	20%	0.24	87	84	25	0.00
960605	D4	1,298	100%	75%	27%	86%	86%	0.83	538	554	46	(0.37)
960617	D2	398	100%	92%	51%	89%	89%	1.12	446	419	39	(0.14)
960618	D3	963	100%	76%	86%	89%	88%	0.96	272	457	35	1.17
960619	D1	925	100%	80%	70%	92%	92%	0.80	313	328	30	1.06
960715	D5	135	100%	25%	64%	94%	93%	1.06	184	525	23	0.30
961014	D3	1,148	100%	95%	12%	79%	78%	0.62	44	995	33	0.67

961016	D4	474	100%	88%	5%	82%	81%	0.55	74	1,283	35	(0.09)
961017	D2	225	100%	88%	0%	64%	63%	0.81	92		29	0.29
961209	D1	531	100%	86%	41%	99%	98%	0.86	131	355	46	0.50
961210	D1	471	100%	97%	51%	82%	73%	0.50	78	945	24	(0.56)
961211	D3	929	100%	93%	0%	75%	75%	0.70	58		32	0.63
961212	D3	756	100%	82%	2%	85%	84%	0.55	58	461	32	0.65
961230	D3	989	100%	98%	51%	100%	100%	0.57	88	265	31	0.60
961231	D3	1,092	100%	95%	49%	100%	100%	0.57	62	299	31	0.62
970120	D1	624	90%	87%	0%	98%	98%	0.58	83		23	0.56
970121	D1	729	93%	74%	0%	99%	98%	0.57	103		23	0.62
970408	D4	459	8%	5%	0%	80%	80%	0.32	181		39	(0.71)
970414	D2	101	22%	22%	11%	83%	83%	0.48	184	2,863	37	(0.10)
970415	D1	855	75%	73%	39%	93%	93%	0.78	89	2,218	36	0.87
970416	D3	1,140	77%	70%	28%	84%	84%	0.58	70	1,962	41	1.04
970417	D3	1,093	82%	81%	48%	81%	81%	0.51	66	1,914	37	0.88
970418	D3	1,193	71%	67%	37%	85%	85%	0.60	55	1,789	36	0.68
970421	D3	835	63%	50%	19%	83%	83%	0.59	132	2,020	22	0.65
970428	D1	772	78%	68%	19%	94%	94%	0.62	68	2,542	36	0.80
970430	D3	1,127	70%	62%	18%	92%	92%	0.55	74	1,956	36	0.83
970502	D3	1,212	68%	51%	18%	93%	93%	0.55	57	1,746	36	0.64
970506	D4A	2,059	75%	72%	48%	91%	91%	0.64	90	1,924	25	0.88
970507	D4A	2,012	76%	75%	44%	91%	91%	0.63	116	2,060	25	0.83
970509	D4A	1,541	74%	76%	42%	93%	93%	0.54	88	2,010	25	0.77
970512	D1	763	77%	69%	31%	84%	84%	0.77	110	2,277	34	1.35
970513	D1	671	80%	84%	57%	93%	93%	0.71	98	1,911	31	1.72
970514	D3	1,177	71%	71%	15%	92%	92%	0.50	56	2,492	36	0.92
970515	D1	705	86%	81%	39%	95%	95%	0.70	76	2,069	30	1.64
970516	D3	752	71%	72%	30%	62%	62%	0.60	34	1,847	36	1.34
970519	D2A	645	52%	52%	23%	90%	90%	0.59	94	2,385	36	0.86
970520	D2A	833	58%	51%	29%	91%	91%	0.54	71	1,552	36	0.89
970521	D5A	1,042	79%	74%	32%	90%	90%	0.67	59	1,963	36	1.01
970523	D6	1,268	70%	68%	32%	93%	93%	0.52	67	1,473	30	1.97
970527	D6	1,048	65%	57%	27%	93%	93%	0.42	68	1,415	30	1.74
970530	D3	1,363	75%	69%	46%	93%	93%	0.40	50	1,281	36	0.83
970609	D6	133	69%	62%	33%	92%	92%	0.42	64	1,177	30	1.85
970610	D4A	1,444	82%	84%	62%	92%	92%	0.61	119	1,243	26	0.90
970611	D6	1,071	64%	56%	31%	93%	94%	0.51	66	1,468	27	1.82
970612	D6	1,081	72%	61%	39%	92%	92%	0.40	70	1,038	30	1.83
970613	D5A	1,051	78%	75%	45%	92%	92%	0.61	59	1,606	36	1.00
970619	D1	167	78%	61%	54%	93%	93%	0.61	40	1,103	32	1.34
970620	D4A	1,329	84%	76%	75%	91%	91%	0.71	98	1,422	26	0.92
970623	D6	986	72%	54%	47%	94%	94%	0.64	78	1,244	27	1.84
970624	D4A	1,240	83%	82%	75%	90%	90%	0.62	96	1,456	26	0.97
970625	D3	900	78%	80%	55%	74%	74%	0.56	51	1,759	35	0.75
970626	D3	1,224	78%	75%	50%	93%	93%	0.50	49	1,466	34	0.85
970627	D4A	1,202	79%	80%	65%	91%	91%	0.69	85	1,684	26	1.03
970630	D1	710	81%	66%	53%	96%	96%	0.76	64	1,751	33	1.38
970701	D4A	1,253	71%	68%	51%	92%	92%	0.61	87	1,617	26	1.05
970702	D6	1,106	74%	56%	49%	82%	82%	0.42	67	1,199	27	2.76
970703	D1	839	85%	78%	62%	94%	94%	0.73	70	1,468	31	1.83
970707	D5A	966	78%	71%	59%	95%	95%	0.67	87	1,452	33	1.45
970708	D5A	647	77%	70%	56%	81%	81%	0.71	69	1,513	32	1.53
970709	D4A	1,259	84%	81%	73%	91%	91%	0.75	98	1,536	26	1.04

970710	D5A	1,141	81%	72%	53%	93%	93%	0.66	85	1,711	32	1.35
970711	D1	703	86%	83%	69%	95%	95%	0.63	72	1,703	31	1.70
970714	D6	977	76%	68%	44%	95%	95%	0.45	54	1,656	28	2.11
970715	D3	1,230	76%	71%	43%	93%	93%	0.46	44	1,573	34	1.28
970716	D4A	1,128	83%	83%	56%	92%	92%	0.67	91	1,849	26	1.07
970717	D5A	875	78%	57%	56%	89%	89%	0.58	62	1,368	32	1.32
970718	D2A	991	69%	46%	27%	93%	93%	0.82	90	2,461	41	1.02
970721	D3	1,005	82%	75%	51%	93%	93%	0.66	47	1,742	34	0.95
970722	D4A	1,085	83%	77%	66%	90%	90%	0.65	84	1,604	26	1.18
970723	D5A	659	82%	60%	63%	91%	91%	0.75	76	1,549	34	1.18
970724	D5A	838	82%	61%	60%	94%	94%	0.61	80	1,522	34	1.01
Total / Average		72,728	81%	74%	43%	83%	88%	0.63	132	1,395	31	0.97

2. *Measurements and Conditions by Time of Day*

Figure III-5 'Measurements by Time of Day indicates that most measurements have been made between 10:00 a.m. and 4:00 p.m. In order to capture a larger sample of commute vehicles, it may be useful to schedule some days for measurement of morning and evening commute hours. Measurement of vehicles on weekends would also help 'round out' a complete sample of the fleet.

Figure III-5 Measurements by Time of Day

Hour	D1	D2	D2A	D3	D4	D4A	D5	D5A	D6	Total	Hours	Avg/Hour
09	5			251				41		297	2.28	130.07
10	722	127	149	1,957	11	1,364		481	726	5,537	32.02	172.94
11	1,933	434	439	4,328	579	3,015		1,079	1,299	13,106	65.47	200.19
12	2,162	389	612	5,040	1,043	3,609		1,519	1,519	15,893	70.65	224.95
13	2,071	339	618	5,149	1,179	2,962		1,744	1,667	15,729	71.00	221.54
14	2,069	224	647	4,123	1,469	3,074	337	1,955	1,995	15,893	64.83	245.14
15	1,145		4	1,280	647	1,528	125	400	464	5,593	19.28	290.04
16	260			319	2					581	2.95	196.95
17	7			92						99	0.57	174.71

Figures III-6-8 show the average speed, acceleration and CO% for each site at different hours of the day. It is noted that sites D2, D4 and D5 have either low or negative average acceleration and generally higher CO values than other sites. The effect of vehicle load on CO emissions is discussed later in this report.

Figure III-6 Average Speed by Site and Time of Day

Hour	D1	D2	D2A	D3	D4	D4A	D5	D5A	D6
09				35.1				30.1	
10	31.1		39.5	34.5	39.2	25.9		34.2	29.0
11	32.3	36.3	38.7	34.3	43.5	25.9		33.9	28.7
12	32.0	35.0	37.6	34.1	42.9	25.7		33.9	28.3
13	32.2	36.7	38.0	34.3	41.7	25.9		33.5	28.3

14	30.7	38.5	37.8	34.9	42.8	26.0	23.0	33.6	28.1
15	28.8		39.0	33.6	39.2	25.6	25.6	33.5	28.0
16	27.3			28.3					
17				22.6					

Figure III-7 Average Acceleration by Site and Time of Day

Hour	D1	D2	D2A	D3	D4	D4A	D5	D5A	D6
09				0.58				1.30	
10	0.97		0.97	0.77	0.09	0.92		1.25	2.50
11	1.06	0.11	0.95	0.80	(0.55)	0.95		1.28	2.13
12	1.09	0.09	0.93	0.81	(0.22)	0.95		1.24	2.05
13	1.00	0.02	0.90	0.79	(0.46)	1.00		1.14	1.84
14	1.12	0.13	0.96	0.84	(0.73)	0.96	0.28	1.21	1.81
15	0.90		1.20	1.00	(0.41)	0.83	(0.31)	1.24	2.04
16	0.89			0.94					
17				2.31					

Figure III-8 Average CO% by Site and Time of Day

Hour	D1	D2	D2A	D3	D4	D4A	D5	D5A	D6
09				0.66				0.27	
10	0.56		0.72	0.62	0.09	0.61		0.75	0.45
11	0.58	0.93	0.62	0.53	0.69	0.64		0.55	0.48
12	0.68	0.94	0.56	0.56	0.72	0.61		0.70	0.47
13	0.72	1.00	0.69	0.56	0.71	0.60		0.56	0.50
14	0.75	0.94	0.68	0.57	0.82	0.67	0.84	0.65	0.43
15	0.74		0.08	0.61	0.36	0.62	0.21	0.61	0.52
16	0.56			0.87					
17				0.87					

3. Vehicle Composition

Figure III-9 Source of Vehicle Registrations shows that 3% of vehicles measured by RSD and plate matched to the registration database came from outside both the Basic and Enhanced I/M counties and 4% of matched vehicles came from the Basic I/M area.

In addition, about 10% of vehicles with plates were not matched to the registration database. This includes 4% of vehicles noted as having out of state plates in the April-July 1997 RSD measurements. Some portion of the remaining 6% may be due to incorrect interpretation of the plate.

Figure III-9 Source of Vehicle Registrations

	I/M Program		
Site	None	Basic	Enhanced
D1	3%	3%	94%
D2	5%	5%	90%
D2A	5%	2%	94%
D3	4%	5%	91%
D4	2%	4%	93%
D4A	2%	4%	94%
D5	4%	6%	89%
D5A	4%	2%	94%
D6	2%	4%	94%
Total	3%	4%	93%

Vehicle type was identified from the plate type in the DMV registration database. In Figure III-10 Vehicle Type by Area, 'Ltk' denotes vehicles with LTK in the plate type, 'Pas' denotes passenger vehicles with PAS in the plate type and 'Other' denotes vehicles that had neither TRK nor PAS in their plate type. The group of vehicles with 'Pas' plates includes sports utility vehicles and passenger vans that would normally be classified as light trucks. There were relatively few vehicles in the 'Other' category so the apparent higher percentages of these coming from non-I/M areas may not be significant. There are a slightly higher percentage of trucks and older passenger vehicles coming from the Basic and non-I/M area.

Figure III-10 Vehicle Type by Area

		I/M Program		
Type	Myr	None	Basic	Enhanced
Trk	82-86	5%	5%	90%
Trk	86-90	4%	4%	92%
Trk	91+	4%	4%	92%
Pas	82-86	4%	5%	91%
Pas	86-90	3%	4%	93%
Pas	91+	3%	4%	94%
Other	82-86	9%	6%	86%
Other	86-90	7%	4%	88%
Other	91+	6%	5%	89%
Total		3%	4%	93%

Table III-11 Vehicle Mix by Site show the percentage of each vehicle type and model year range seen at the sites. Site D2 especially has a higher fraction of older passenger vehicle and trucks than other sites.

Figure III-11 Vehicle Mix by Site

Type	Myr	D1	D2	D2A	D3	D4	D4A	D5	D5A	D6	Total
Ltk	82-86	3%	7%	6%	3%	3%	3%	1%	3%	2%	3%
Ltk	86-90	4%	6%	6%	4%	5%	5%	1%	4%	4%	4%
Ltk	91+	8%	12%	12%	10%	10%	9%	4%	12%	8%	10%
Other	82-86	0%	2%	0%	0%	1%	0%	0%	0%	0%	0%
Other	86-90	0%	1%	0%	0%	1%	0%	0%	0%	0%	0%
Other	91+	1%	1%	1%	1%	1%	0%	2%	1%	0%	1%
Pas	82-86	14%	18%	15%	9%	13%	13%	11%	13%	12%	12%
Pas	86-90	25%	23%	22%	23%	26%	25%	28%	23%	26%	24%
Pas	91+	45%	30%	37%	50%	41%	44%	53%	43%	47%	46%
Total		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

4. Emissions Distribution by Site

The significantly higher HC and CO emissions at site D4, the uppermost line in Figures III-12 'HC Emissions Distribution by Site' and III-13 'CO Emissions Distribution by Site', cannot be explained by the mix of vehicles observed at the site and is likely caused by the high number of vehicles measured as decelerating at this site, which was subsequently abandoned in favor of site D4A. Emission levels measured at site D2, the second highest line in the figures, are also affected to a lesser extent. Based on the average acceleration values, one would have expected higher emissions at site D5. There are two explanations as to why this is not the case: 1) relatively few readings were taken at site D5 so the results may not be fully representative, and 2) the vehicle mix at site D5 shows a significantly larger fraction of new vehicles than any other site and these are expected to have lower emissions.

The distribution for NO shows lower values for sites D2, D4 and D5, with D5 having the lowest value. This result is expected as NOX is mostly produced when vehicles are under load.

The effects of deceleration and vehicle load on tailpipe emission concentrations are documented in a technical note on '*Optimal Vehicle Operation Modes for RSD Measurements'* and included as Appendix B of this report.

Figure III-12 HC Emissions Distribution by Site

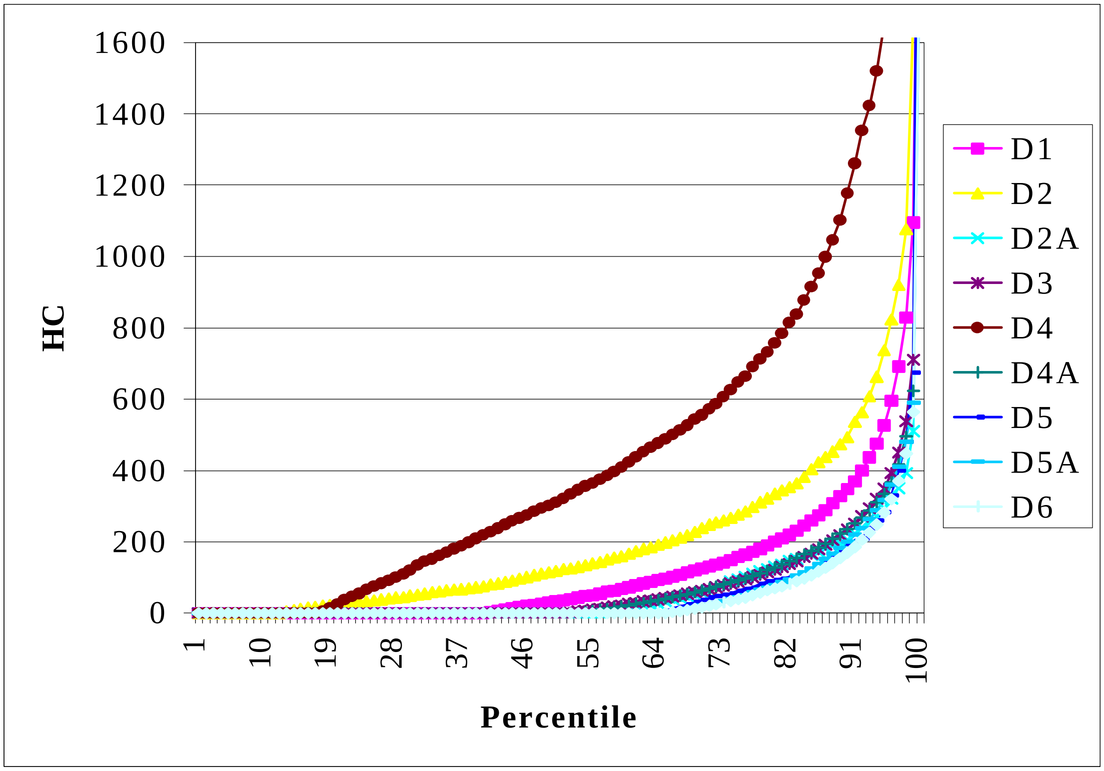


Figure III-13 CO Emissions Distribution by Site

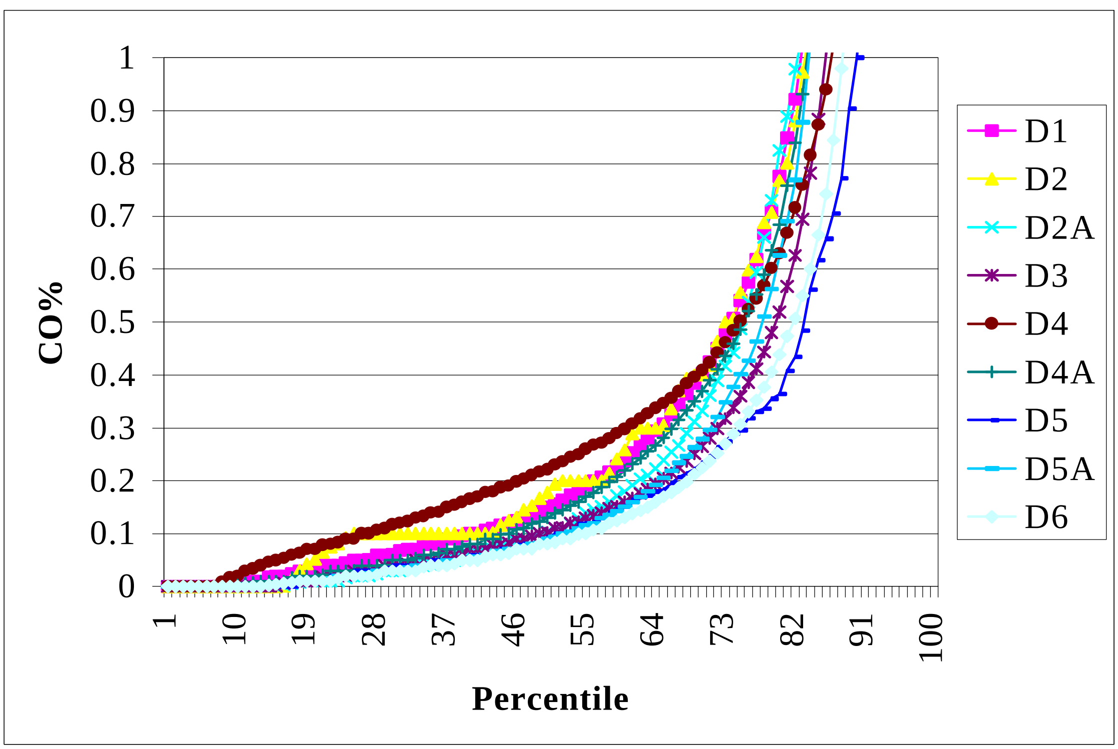
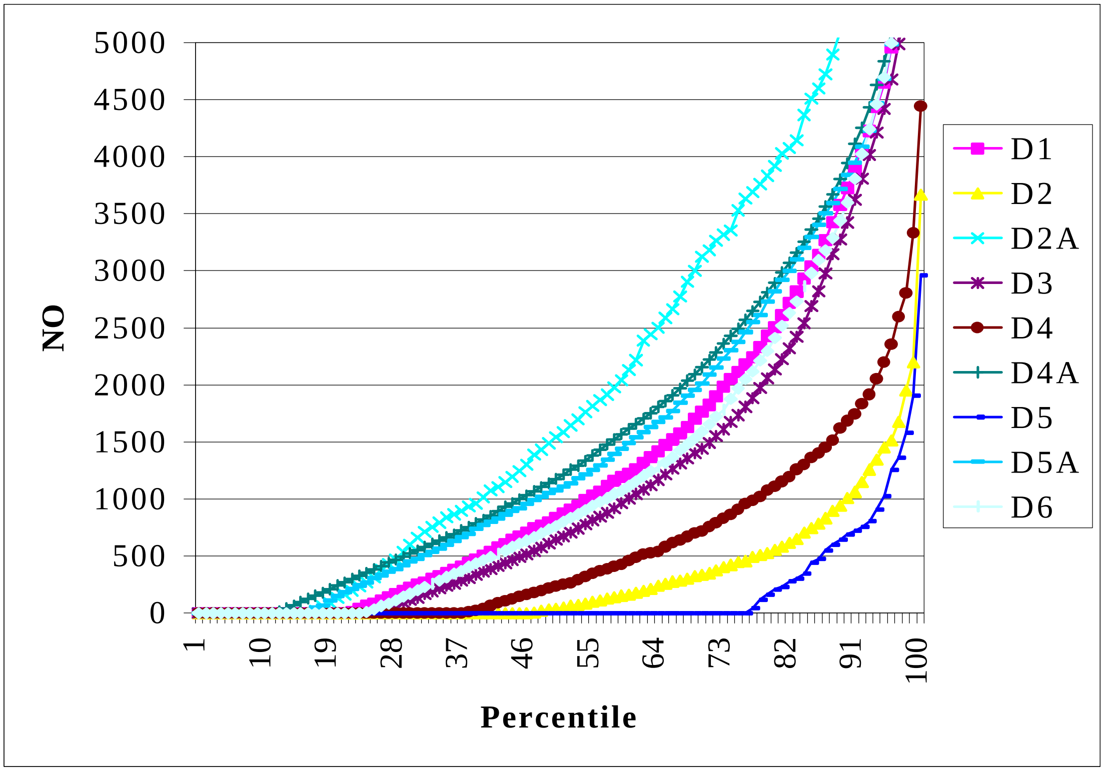


Figure III-14 NO Emissions Distribution by Site



IV. Use of RSD Measurements for Clean Screening

A. Summary

Clean Screening Effectiveness

A comparison of RSD readings to IM240 inspection results for 1982 and newer vehicles shows that a clean-screen program is technically feasible. Vehicles with two RSD readings, drawn from all RSD sites, both having emission measurements of less than 0.5% CO, and less than 200 ppm HC, and less than 1500 ppm NOx, almost always meet the Federal EPA final high altitude IM240 standards when subsequently inspected. If vehicles meeting these screening criteria were to be exempted from the IM240 inspection, it is projected that 37% of the vehicles subject to inspection[2] would be exempted while 99% of excess CO emissions, 95% of the excess HC emissions, and 88% of the excess NOx emissions would be retained in the remaining vehicles. Excess emissions have been calculated as the sum of the emissions in excess of the final high altitude IM240 test standards.

[2] In the Colorado enhanced program, new vehicles are exempt from inspection for four years but are subject to inspection upon resale to a new owner.

Without considering NOx, i.e. using just the HC and CO measurements from two RSD readings per vehicle, 48% of vehicles would pass the screen with the same screening standards of 0.5% CO and 200 ppm HC. In this case 94% of the excess CO emissions and 91% of the excess HC emissions would be retained in the vehicles failing the screen that would remain subject to IM240 inspection. With tighter screening standards of 0.3% CO and 200 ppm HC, the percentage of vehicles passing the screen drops to 40% while the excess emissions retained in the remaining vehicles increases slightly to 95% for both CO and HC. These findings are reasonably consistent with the results of the Greeley pilot, which found that vehicles seen more than once by RSD and having a maximum CO level of less than 0.5% CO contained less than 5% of the CO emissions. The Greeley data indicate that 46% of vehicles would pass a 0.5% CO clean-screen criteria.

With a **single** reading at RSD sites at which vehicle engines are operating under sufficient load, 40% of 1982 and newer vehicles could be clean screened while retaining almost 90% of the potential HC and CO emissions reductions that would be achieved using Federal EPA final high altitude IM240 standards.

Clean screening is almost 100% effective when used in conjunction with I/M program phase-in standards. The table below summarizes the results obtained using **two** RSD readings with screening standards of 0.5% CO, 200 ppm HC and 1500 ppm NOx. In each case 37% of vehicles pass the screen.

Figure IV-1 Two-Hit Clean Screening Effectiveness

I/M Test Standard	HC	CO	NOx
Current Phase-In	100%	100%	n/a
EPA Phase-In	99%	100%	88%
EPA Final	95%	99%	88%

Results stratified by model year show that clean-screening is an effective tool for dealing with newer vehicles which contribute a significant fraction of excess NOx. In the 140,000 sample of vehicles inspected using the full IM240 procedure in the first quarter of 1997, previously presented in Figure II-6, 19% of the excess NOx emissions were found to be from 1990 and newer vehicles on a per vehicle basis. Adjusting for the increased mileage traveled annually by newer vehicles compared to older vehicles, it is calculated the 1990 and newer vehicles contribute 25% of the excess NOx emissions on-road. Clean-screening with even modest NOx cutpoints can relieve up to 60% of these newer vehicles from the need for inspection while retaining 80-90% of the emission reductions. Therefore, in areas where NOx is a concern, clean-screening is a better clean air strategy than extended new vehicle exemption periods.

B. Methodology used to determine RSD Clean Screen effectiveness

The following procedure has been used to project the effectiveness of RSD measurements for Clean Screen.

1. All valid RSD vehicle measurements collected at sites in Denver were first matched by plate to the DMV registration file and subsequently by vehicle identification number (VIN) to the initial IM240 test results for vehicles tested at centralized inspection stations. The IM240 results cover only 1982 and newer vehicles.

2. The IM240 emission pass/fail results were compared to three sets of standards:

   a) The current phase-in standards being used in the Colorado enhanced I/M program;

   b) EPA phase-in high altitude IM240 standards;

   c) EPA final high-altitude IM240 standards;

   These standards are listed in Figures IV-2 and IV-3.

   For each vehicle whose initial IM240 emissions test result failed to meet a pollutant standard, excess emissions were calculated as the difference between the IM240 result and the standard for those pollutants that exceeded the standard. Three sets of excess emissions were calculated for each vehicle, one for each set of standards; the current I/M program standards, the EPA high altitude phase-in standard and the EPA final high altitude standard.

3. The RSD emission measurements taken prior to the initial IM240 test for the vehicle were paired with the IM240 test result and the gap in days between the RSD measurement and the IM240 test was calculated.

4. For each scenario, a selected set of 'clean-screen' criteria was then applied to the RSD measurement to determine whether the vehicle would be classified as 'clean'. Items defining a scenario include the IM240 program standards being compared to (current, EPA phase-in or EPA final), the 'clean-screen' RSD emissions cut-points, the sites included, and the maximum number of days accepted between the RSD measurement and the subsequent IM240 test. To examine scenarios using two RSD measurements per vehicle, the most recent two RSD measurements made prior to the IM240 test were selected.

5. The following results were calculated for each scenario:

   a) Tests - the number of RSD and IM240 result pairs or tests;

   b) Percentage of Vehicles Passing Screen - the number of vehicles passing the RSD Clean-screen divided by the number of tests;

   c) Percentage of False Passes - the number of vehicles incorrectly passing the Clean-screen divided by the number of tests;

d) Total Excess Emissions - the sum of excess emissions by pollutant for all vehicles failing the IM240 test– these are the total potential emission reductions;

e) Retained Excess Emissions - the sum of excess emissions by pollutant for vehicles failing the IM240 test and failing the 'Clean-Screen' criteria – these are the potential emissions reductions or excess emissions correctly retained with the clean-screen'.

f) Percentage of Excess Emissions Retained - the Retained Excess Emissions divided by the Total Excess Emissions;

In the current analysis, approximately 12,000 RSD results have been matched to subsequent initial enhanced IM240 inspections,

6. In scenarios that consider only HC and CO, the NOx results were ignored when determining the pass/fail status of the vehicle with respect to each set of standards.

7. In two-hit analyses where one of the two RSD measurements was missing a NOx value, the vehicle was assumed to have been measured as clean for NOx by the RSD on that measurement, i.e. in the two-hit analysis, some vehicles have only a single RSD NOx reading.

Figure IV-2 Colorado 1997 I/M Standards

Light Passenger Vehicle

From	To	HC gpm	CO gpm	NOx gpm
1982	1982	5	65	8
1983	1984	5	50	8
1985	1985	5	25	8
1986	1990	4	25	6
1991	1994	4	20	6
1995	1997	4	20	4

Light Truck

From	To	HC gpm	CO gpm	NOx gpm
1982	1983	8	107	12
1984	1985	8	80	12
1986	1990	6	67	9
1991	1997	6	53	9

Figure IV-3 IM240 Phase In and Final High Altitude Standards

Light Passenger - Phase In

From	To	HC gpm	CO gpm	NOx gpm
1973	1974	10	150	9
1975	1976	7.5	90	9
1977	1979	7.5	90	6
1980	1980	2	75	6
1981	1982	2	75	3
1983	1984	2	60	3
1985	1990	2	30	3
1991	1995	1.2	20	2.5
1996	1998	0.8	15	2

Light Passenger - Final

From	To	HC gpm	CO gpm	NOx gpm
1973	1974	7	120	6
1975	1976	3	65	6
1977	1979	3	65	4
1980	1980	0.8	30	4
1981	1981	0.8	30	2
1982	1982	1.2	45	2
1983	1984	1.2	30	2
1985	1995	0.8	15	2
1996	1998	0.6	10	1.5

Light Truck 1 - Phase In

From	To	HC gpm	CO gpm	NOx gpm
1968	1972	10	150	10
1973	1974	10	150	9
1975	1978	8	130	9
1979	1983	8	130	7
1984	1987	4	90	7
1988	1990	4	90	3.5
1991	1998	3	70	3

Light Truck 1 - Final

From	To	HC gpm	CO gpm	NOx gpm
1968	1972	7	120	7
1973	1974	7	120	6
1975	1978	4	80	6
1979	1981	3.4	70	4.5
1982	1983	4	90	4.5
1984	1987	2	60	4.5
1988	1998	2	60	2.5

Light Truck 2 - Phase In

From	To	HC gpm	CO gpm	NOx gpm
1968	1972	10	150	10
1973	1974	10	150	9
1975	1978	8	130	9
1979	1983	8	130	7
1984	1987	4	90	7
1988	1990	4	90	5
1991	1998	3	70	4.5

Light Truck 2 - Final

From	To	HC gpm	CO gpm	NOx gpm
1968	1972	7	120	7
1973	1974	7	120	6
1975	1978	4	80	6
1979	1981	3.4	70	4.5
1982	1983	4	90	4.5
1984	1987	2	60	4.5
1988	1998	2	60	3.5

C. Clean Screen Effectiveness for HC and CO

The matched RSD/IM240 results have been used to examine the effectiveness of RSD for Clean Screening using only HC and CO measurements: The results using two measurements including NOx are provided in section IV D.

The most recent and second most recent RSD tests prior to IM240 were found for 868 vehicles. All available matches were used without screening based on site or other factors. The average days between the RSD measurements and the subsequent IM240 inspection is shown in the table below. The maximum elapsed period from the first RSD measurement until the IM240 test was 695 days.

Figure IV-4 Average Days between RSD Measurements and IM240 Inspection

Model Years	**Vehicles**	**Average Days from 1st RSD until IM240**	**Average Days from 2nd RSD until IM240**
1982-1985	76	256	144
1986-1989	233	251	132
1990+	559	234	119
Total	868	241	125

With 0.5% CO and 200 ppm HC cut-points, 48% of vehicles are clean screened while retaining 94% of the potential excess CO emission reductions and 91% of the HC emissions reductions. With 0.3% CO and 200 ppm HC cut-points, the percentage of vehicles clean screened drops to 40% while the potential excess emissions reductions retained increases somewhat to 95%.

Figure IV-5 Two-Hit Clean HC & CO Screening Effectiveness – Various Cutpoints – Final Standards

Screening Standard	Tests	Vehicles Passing Screen	HC Excess Emissions Retained	CO Excess Emissions Retained
CO<0.5 and HC<300	868	52%	85%	85%
CO<0.5 and HC<200	868	48%	91%	94%
CO<0.3 and HC<200	868	40%	94%	95%

The table below shows the ‘two-hit’ results by the model year ranges. This is again based on results from all the sites and the high-altitude final IM240 standards.

Figure IV-6 Stratified Two-Hit HC & CO Clean Screening Effectiveness by Model Year – Final EPA Standards

IM240 Program Standards	Screening Standard	Model Year Range	Vehicles	Vehicles Passing Screen	False Passes (% of all vehicles)	HC Emission Reductions Retained	CO Emissions Reductions Retained
Final	CO<.5 and HC<200	1982-1985	76	22%	9%	94%	97%
Final	CO<.5 and HC<200	1986-1989	233	30%	6%	91%	95%
Final	CO<.5 and HC<200	1990+	559	59%	3%	69%	80%
Total			868	48%	4%	91%	94%

Figure IV-7 provides the same information using the current Colorado program phase-in standards with two RSD measurements per vehicle. Two RSD measurements are almost 100% effective for clean screening in conjunction with phase-in standards.

Figure IV-7 Two-Hit HC & CO Clean Screening Effectiveness by Model Year – Current Phase-In Standards

IM240 Program Standards	Screening Standard	Model Year Range	Vehicles	Vehicles Passing Screen	False Passes (% of all vehicles)	HC Emission Reductions Retained	CO Emissions Reductions Retained
Phase-in	CO<.5 and HC<200	1982-1985	76	22%	0.0%	100%	100%
Phase-in	CO<.5 and HC<200	1986-1989	233	30%	0.0%	100%	100%
Phase-in	CO<.5 and HC<200	1990+	559	59%	0.2%	100%	86%
Total			868	48%	0.1%	100%	97%

D. HC, CO and NOx Clean Screening

RSTi has recently made great improvements in the NOx channel and the new technology is now in the process of being fully tested. Preliminary testing using trailed calibration gas indicates the accuracy of the new unit will be close to that of the HC and CO channels. The unit used in Denver, however, was an older technology unit that 'missed' NOx readings on many vehicles. But even results with this older unit show a fairly high NOx identification rate when used in a clean screen mode.

In the tables below that show a 'two-hit' analysis, only vehicles with at least one NOx measurement are included. Missed NOx measurements are treated as though the vehicle tested clean for NOx on that RSD test. Because some vehicles had no RSD NOx measurements, the two-hit sample size is reduced from 868 pairs to 594 pairs.

The elapsed time between the RSD measurements and the subsequent IM240 inspection is shown in Figure IV-8.

Figure IV-8 Average Days between RSD Measurements and IM240 Inspection

Model Years	Vehicles	Average Days from 1st RSD until IM240	Average Days from 2nd RSD until IM240
1982-1985	51	268	140
1986-1989	156	242	127
1990+	387	226	111
Total	594	234	118

1. HC, CO and NOx Clean Screening in Combination with Final Standards

The addition of NOx as a criterion improved the percentage of excess HC and CO retained while diminishing slightly the number of vehicles that pass the clean screen. Figure IV-9 shows the results with varying NOx cutpoints. The best combination of excess emissions retention and clean-screen vehicle percentage occurs with RSD cutpoints of 0.5% CO, 200 ppm HC and 1500 ppm NOx. With these screening criteria, 37% of vehicles are clean screened while retaining 95% of the potential excess HC emission reductions and 99% of the CO and 88% of the NOx.

Figure IV-9 Two-Hit HC/CO/NOx Clean Screen Effectiveness vs. Final EPA Standards

Clean Screen Cutpoints	Vehicles	Clean Screen %	Excess Emissions Retained HC	CO	NOX
CO<.5 and HC<200 and NOx<99998	594	51%	91%	93%	72%
CO<.5 and HC<200 and NOx<2000	594	40%	94%	95%	85%
CO<.5 and HC<200 and NOx<1500	594	37%	95%	99%	88%
CO<.5 and HC<200 and NOx<1000	594	29%	96%	99%	93%

The breakout by model year range for the different NOx cut-points is shown below. With the inclusion of NOx, there is a significant improvement in the HC and CO retention rates for new vehicles.

Figure IV-10 Stratified Two-Hit HC/CO/NOx Clean Screen Effectiveness vs. Final EPA Standards

	Model		Clean	Excess Emissions Retained		
Clean Screen Cutpoints	Years	Vehicles	Screen %	HC	CO	NOX
CO<.5 and HC<200 and NOx<99998	1982-1985	51	24%	96%	100%	86%
CO<.5 and HC<200 and NOx<99998	1986-1989	156	32%	90%	91%	78%
CO<.5 and HC<200 and NOx<99998	1990+	387	63%	59%	73%	48%
Total		594	51%	91%	93%	72%

	Model		Clean	Excess Emissions Retained		
Clean Screen Cutpoints	Years	Vehicles	Screen %	HC	CO	NOX
CO<.5 and HC<200 and NOx<2000	1982-1985	51	12%	97%	100%	86%
CO<.5 and HC<200 and NOx<2000	1986-1989	156	24%	95%	100%	86%
CO<.5 and HC<200 and NOx<2000	1990+	387	50%	73%	73%	83%
Total		594	40%	94%	95%	85%

	Model		Clean	Excess Emissions Retained		
Clean Screen Cutpoints	Years	Vehicles	Screen %	HC	CO	NOX
CO<.5 and HC<200 and NOx<1500	1982-1985	51	12%	97%	100%	86%
CO<.5 and HC<200 and NOx<1500	1986-1989	156	22%	95%	100%	92%
CO<.5 and HC<200 and NOx<1500	1990+	387	46%	90%	94%	84%
Total		594	37%	95%	99%	88%

	Model		Clean	Excess Emissions Retained		
Clean Screen Cutpoints	Years	Vehicles	Screen %	HC	CO	NOX
CO<.5 and HC<200 and NOx<1000	1982-1985	51	10%	97%	100%	86%
CO<.5 and HC<200 and NOx<1000	1986-1989	156	18%	95%	100%	92%
CO<.5 and HC<200 and NOx<1000	1990+	387	36%	93%	95%	100%
Total		594	29%	96%	99%	93%

In Colorado, although vehicles were not failed for NOx until 1997, the fast-pass standards included NOx as criteria. Therefore high NOx emitters that were close to or above the phase-in NOx standard did not fast-pass and the NOx result for these is a full 240-second result. The ‘Phase-In’ standards for NOx, however, are quite loose.

2. HC, CO and NOx Clean Screening in Combination with Current Colorado I/M Standards

The emissions retained with respect to the current Colorado phase-in standards, shown in Figure IV-11, is virtually 100%. In the sample of 594 vehicles with two RSD measurements, there were none that exceeded the phase-in NOx standard.

Figure IV-11: Two-Hit HC/CO/NOx Clean Screen Effectiveness vs. Current I/M Program Standards

		Clean	Excess Emissions Retained		
Clean Screen Cutpoints	Vehicles	Screen %	HC	CO	NOX
CO<0.5 and HC<200 and NOx<2000	594	40%	100%	94%	n/a
CO<.5 and HC<200 and NOx<1500	594	37%	100%	100%	n/a
CO<.5 and HC<200 and NOx<1000	594	29%	100%	100%	n/a

3. HC, CO and NOx Clean Screening in Combination with EPA Phase In Standards

Figures IV-12 and IV-13 demonstrate the effectiveness of clean screen in comparison to high altitude EPA Phase-In standards. Using a NOx cutpoint of 1500 ppm, clean screening is almost 100% effective for HC and CO and is 89% for NOx. The effectiveness for NOx is actually higher with 1990 and newer vehicles.

Figure IV-12: Two-Hit HC/CO/NOx Clean Screen Effectiveness vs. EPA Phase-In Standards

		Clean	Excess Emissions Retained		
Clean Screen Cutpoints	Vehicles	Screen %	HC	CO	NOX
CO<.5 and HC<200 and NOx<99998	594	51%	98%	93%	77%
CO<.5 and HC<200 and NOx<2000	594	40%	98%	93%	88%
CO<0.5 and HC<200 and NOx<1500	594	37%	99%	100%	89%
CO<.5 and HC<200 and NOx<1000	594	29%	99%	100%	93%

Figure IV-13: Stratified Two-Hit HC/CO/NOx Clean Screen Effectiveness vs. EPA Phase-In Standards

Clean Screen Cutpoints	Model Years	Vehicles	Clean Screen %	Excess Emissions Retained HC	CO	NOX
CO<.5 and HC<200 and NOx<99998	1982-1985	51	24%	98%	100%	85%
CO<.5 and HC<200 and NOx<99998	1986-1989	156	32%	100%	100%	83%
CO<.5 and HC<200 and NOx<99998	1990+	387	63%	82%	71%	69%
Total		594	51%	98%	93%	77%

Clean Screen Cutpoints	Model Years	Vehicles	Clean Screen %	Excess Emissions Retained HC	CO	NOX
CO<.5 and HC<200 and NOx<2000	1982-1985	51	12%	98%	100%	85%
CO<.5 and HC<200 and NOx<2000	1986-1989	156	24%	100%	100%	85%
CO<.5 and HC<200 and NOx<2000	1990+	387	50%	82%	71%	92%
Total		594	40%	98%	93%	88%

Clean Screen Cutpoints	Model Years	Vehicles	Clean Screen %	Excess Emissions Retained HC	CO	NOX
CO<.5 and HC<200 and NOx<1500	1982-1985	51	12%	98%	100%	85%
CO<.5 and HC<200 and NOx<1500	1986-1989	156	22%	100%	100%	88%
CO<.5 and HC<200 and NOx<1500	1990+	387	46%	100%	100%	92%
Total		594	37%	99%	100%	89%

Clean Screen Cutpoints	Model Years	Vehicles	Clean Screen %	Excess Emissions Retained HC	CO	NOX
CO<.5 and HC<200 and NOx<1000	1982-1985	51	10%	98%	100%	85%
CO<.5 and HC<200 and NOx<1000	1986-1989	156	18%	100%	100%	88%
CO<.5 and HC<200 and NOx<1000	1990+	387	36%	100%	100%	100%
Total		594	29%	99%	100%	93%

E. Effect of Shortening the Elapsed Time between RSD and IM240 Tests

Figure IV-14 looks at the effect of reducing the elapsed time between the RSD measurement and the subsequent IM240 inspection when using two RSD measurements per vehicle. Shortening the time period prior to the IM240 test in which the two RSD measurements are made does not result in a significant change in effectiveness.

Figure IV-14 Two-Hit HC & CO Effectiveness vs. Time to the compared IM240 inspection

Clean Screen Criteria	Tests	Max. days from RSD until IM240	Avg days from 1st RSD until IM240	Avg days from 2nd RSD until IM240	Vehicles Passing Screen	HC Excess Emissions Retained	CO Excess Emissions Retained
CO<.5 and HC<200 and NOx<1500	594	720	234	118	37%	95%	99%
CO<.5 and HC<200 and NOx<1500	436	365	121	72	39%	96%	98%
CO<.5 and HC<200 and NOx<1500	333	180	77	52	36%	97%	98%

F. Site Selection for Clean Screening

1. *Vehicle Operating Conditions for RSD Measurement*

Attached, as Appendix B is a technical note that reviews the expected best vehicle operating modes for RSD measurements. It examines how tailpipe concentrations vary in IM240 tests and RSD measurements across a range of vehicle loads. Understanding this helps explain RSD results that may otherwise be counter-intuitive, e.g. moderate load conditions have the lowest tailpipe concentrations as measured by RSD.

2. *Effects of Upgrading RSD Units and Changing Sites*

In April 1997, the RSD unit operating in Denver was upgraded with updated firmware. The primary change was to tighten the standards on exhaust plume characteristics required for acceptance of a valid RSD measurement. This change resulted in a high rejection rate of measurements at sites with a high proportion of vehicles in deceleration mode. Three of the Denver sites D2, D4 and D5 were subsequently relocated a short distance in order to obtain an acceptable percentage of valid readings. These sites were subsequently designated D2A, D4A and D5A.

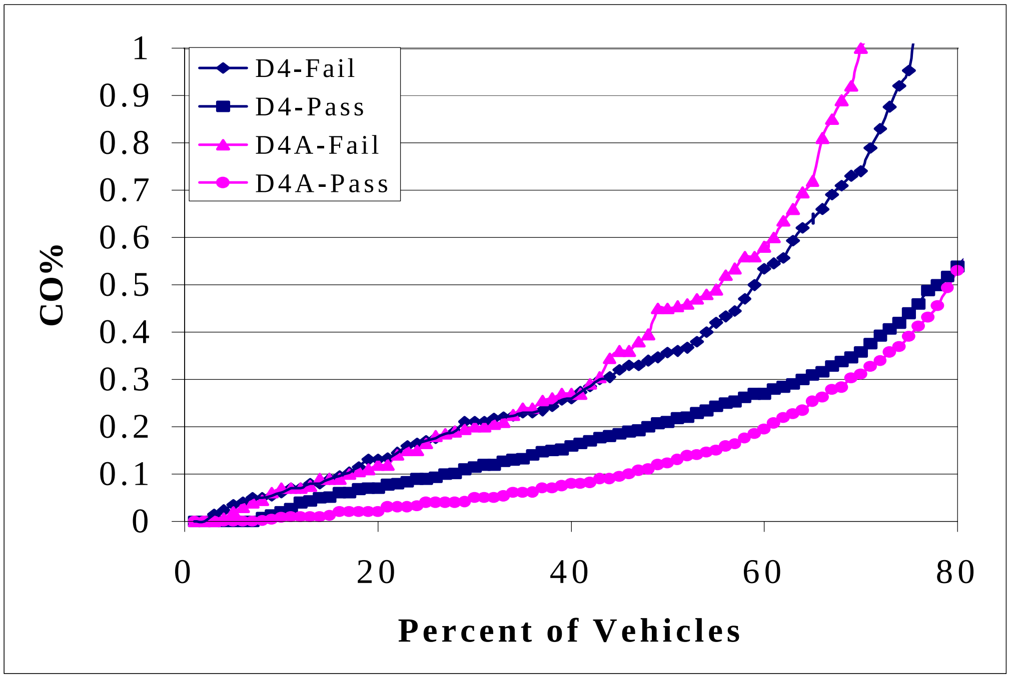
From Figure III-7 'Average Acceleration by Site and Time of Day' it is apparent that the difference in average acceleration between the old and new sites is quite marked. Figure IV-16 shows the cumulative RSD emissions frequency for vehicles passing and failing final IM240 HC/CO standards at site D4. The improved separation between the passing and failing vehicles is clearly visible at the new site D4A. As explained in the technical note in Appendix B, vehicles in deceleration often have high tailpipe concentrations of HC and CO relative to CO2 even though the mass of these emissions is small. If measurements for clean screening are made at sites with a large number of decelerating vehicles, many clean vehicles may be observed with misleadingly high readings. Sites with a majority of vehicles in acceleration mode allow for effective Clean Screening at lower cutpoints than sites with many vehicles in deceleration. With clean screen cutpoints of 0.075% CO and 200 ppm HC, the results measured against final standards for the before and after sites are:

Figure IV-15: Single-Hit HC/CO Clean Screen Effectiveness at Selected Sites

Site	Max. days from RSD until IM240	Tests	Vehicles Passing Screen	False Passes (% of all vehicles)	HC Emission Reductions Retained	CO Emissions Reductions Retained
2,4,5	365	1739	19%	2.2%	91%	88%
2A,4A,5A	365	1523	38%	3.3%	89%	89%

The sites with positive loads are able to double the number of vehicles passing the screen while retaining about the same level of excess emissions reductions.

Figure IV-16 RSD Measured CO Distribution of Vehicles Passing and Failing IM240 Before and After the RSD Unit Upgrade – site D4.



Based on the above data, it is recommended that sites used for obtaining RSD Clean-Screening data should have vehicle operating conditions such that the daily average vehicle load is greater than 1.5 times the standard deviation of the load, where vehicle load is calculated as:

Load = Slope Adjusted Acceleration * speed + 0.065 * speed + 0.014 * speed^2

And:

Adjusted Acceleration is 21.82 * sin(road grade in degrees) + vehicle acceleration;

Vehicle acceleration is measured in miles per hour per second;

Vehicle speed is measured in miles per hour.

With the upgraded RSD units, the effect of these criteria is to increase the percentage of vehicles that are clean screened at low cut-points rather than to change the quality of the result in terms of emission reductions. As shown previously, using a 'bad' site at the same cut-points as a 'good' site does not lead by itself to a difference in the lost emissions but rather in a lower percentage of vehicles being screened.

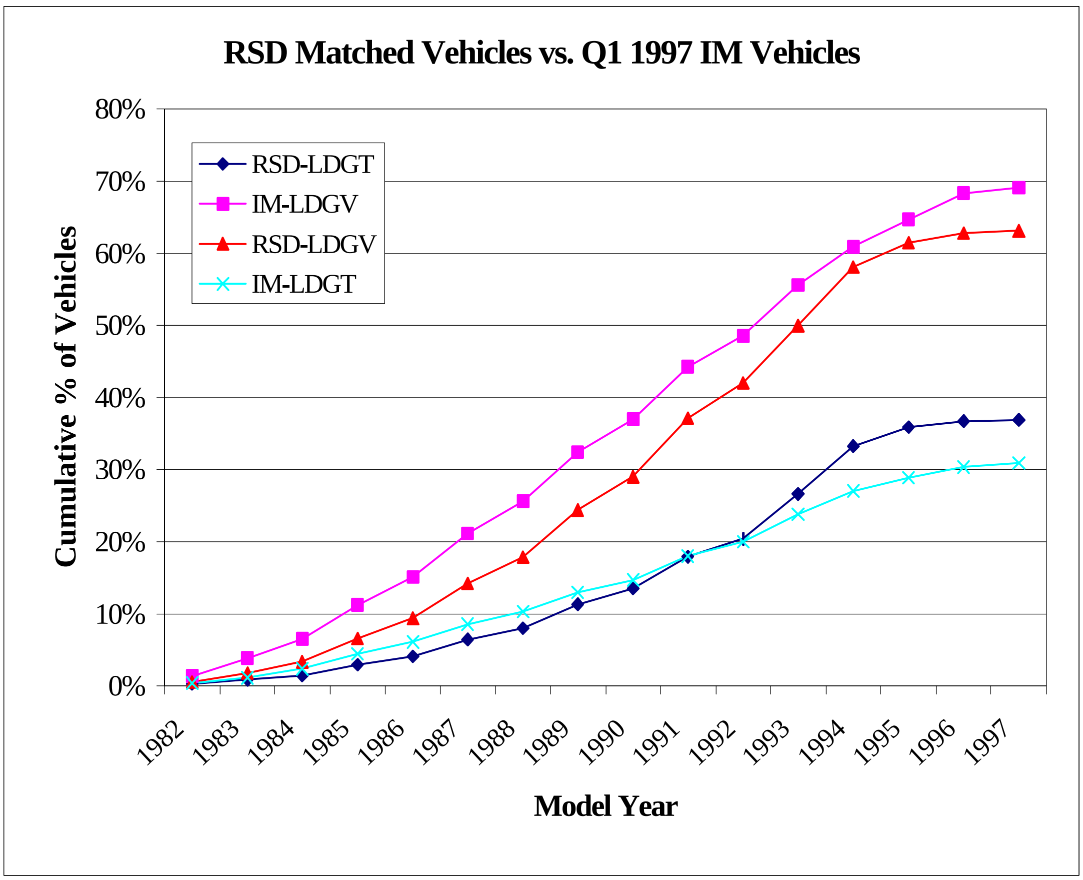
G. Comparison of the profile of the RSD sample to the general population of vehicles being tested.

Figure IV-17: Vehicle Distribution compares the cumulative percentage of passenger vehicles and light trucks by model year for:

- The RSD measured vehicles matched to IM240 test results, and
- Q1 1997 IM240 initial inspections

The RSD group contains a slightly greater proportion of newer vehicles – especially 1993 to 1995 trucks. This is believed to be a reflection of the higher than average miles traveled by newer vehicles that are consequently more likely to pass by an RSD unit.

Figure IV-17: Vehicle Distribution



V. Use of RSD Measurements for High Emitter Identification

A. Summary

When estimating high emitter identification effectiveness using a comparison of RSD measurements to subsequent enhanced I/M 240 test results, one must bear in mind that:

- The vehicles are all 1982 and newer model years;
- The fleet being sampled has generally already been subject to I/M 240 inspection, and perhaps most important
- It is likely that some vehicles will obtain a repair shortly before going for a scheduled enhanced inspection, which would have the effect of increasing the apparent false failure percentage for RSD.

Consequently, these results probably underestimate the effectiveness of RSD, are only applicable in the context of RSD being added to an enhanced program, and are not representative of the effectiveness of RSD in other situations such as decentralized programs, basic programs or areas with no other I/M inspection.

With two RSD readings both exceeding a 2% CO cutpoint, 9% of vehicles are failed and 51% of excess CO is identified. The excess CO, however, comes from just 3% of the vehicles and the other two-thirds of the RSD failures are false failures. This high false failure rate may in part be due to the nature of the data. Further research with a greater number of RSD readings per vehicle may reveal procedures and criteria to reduce the false failures.

B. Single RSD Reading

Figure V-1 Single Reading High Emitter Identification shows the percentage of excess emissions identified at different RSD cutpoints[3]. At a 1% CO cutpoint, 14% of vehicles are failed and 51% of excess CO is identified. Excess emissions are calculated in the same way as for 'Clean Screen' as described in section IV-B, that is the difference between the subsequent IM240 inspection emission level measurement and the high altitude final standard.

Of the 14% of vehicles failed by RSD, however, two-thirds went on to pass the IM240 test. Therefore only one-third of the vehicles failed by RSD had all the excess emissions identified. It is possible that some of the vehicles that failed RSD were repaired prior to the IM240 test. Therefore we cannot draw firm conclusions about either identification effectiveness or the false failure rate. In the absence of an I/M program, 50% emissions identification with a 14% failure rate might be considered somewhat reasonable.

[3] In Figures V-1 and V-2, a vehicle must have CO and HC values that both exceed the respective standard shown for the pollutant. A standard of negative 999 for HC means that HC is not considered since all vehicles have an HC values greater than –999. A standard of greater than 0 for HC is slightly different since a number of vehicles have a valid zero HC measurement.

Figure V-1 Single Reading High Emitter Identification

Standard	Vehicles	Fail Rate % of Vehicles	False Fail % of Vehicles	False Fail % of Fails	Excess HC Identified	Excess CO Identified
CO>1 and HC>-999	9890	13.9%	9.2%	66%	41%	51%
CO>1 and HC>200	9890	7.7%	4.6%	60%	32%	36%
CO>2.0 and HC>0	9890	8.0%	5.0%	63%	31%	43%
CO>2.0 and HC>50	9890	7.6%	4.7%	62%	30%	42%
CO>2 and HC>200	9890	5.3%	3.1%	59%	26%	33%
CO>2 and HC>300	9890	3.8%	2.1%	56%	20%	22%
CO>3 and HC>0	9890	5.2%	3.1%	59%	25%	35%
CO>3 and HC>50	9890	5.0%	3.0%	59%	24%	35%
CO>3 and HC>200	9890	3.7%	2.0%	54%	22%	30%
CO>4 and HC>-999	9890	3.2%	1.8%	57%	18%	25%
CO>4 and HC>50	9890	3.0%	1.7%	55%	17%	25%
CO>4 and HC>200	9890	2.3%	1.1%	49%	16%	23%
CO>5 and HC>-999	9890	1.7%	0.8%	48%	12%	18%
CO>5 and HC>100	9890	1.6%	0.7%	45%	11%	18%
CO>5 and HC>200	9890	1.4%	0.6%	44%	11%	17%

C. Two RSD Readings

With two RSD measurements, both required to exceed the standard, the performance improves as shown in Figure V-2. In this case 18% of vehicles have an average CO in excess of 1% and 70% of excess CO is identified.

With a CO cutpoint of 2%, the fail rate is cut in half to less than 9% while the excess CO identification is still over 50%.

Figure V-2 Two-Reading High Emitter Identification

Standard	Vehicles	Fail Rate % of Vehicles	False Fail % of Vehicles	False Fail % of Fails	Excess HC Identified	Excess CO Identified
CO>1 and HC>-999	870	17.9%	13.7%	76%	48%	70%
CO>1 and HC>200	870	11.3%	8.9%	79%	22%	52%
CO>2 and HC>-999	870	8.6%	6.2%	72%	25%	51%
CO>2 and HC>100	870	8.3%	6.0%	72%	24%	51%
CO>2 and HC>200	870	5.7%	4.3%	74%	15%	35%
CO>2 and HC>300	870	4.7%	3.4%	73%	15%	35%
CO>3 and HC>-999	870	2.6%	1.4%	52%	13%	33%
CO>4 and HC>-999	870	1.0%	0.3%	33%	8%	21%

VI. Regional Emissions Analysis

A. Comparison of Greeley fleet to Denver fleet using RSD results.

RSD measurements were collected in Greeley over roughly the same time period and using the same RSD units as were the measurements in the Enhanced I/M area. A comparison of the emissions levels measured by RSD in the two areas reveals lower emission levels among passenger vehicles in the Enhanced area as shown in Figure VI-1 'On-Road Passenger Vehicle CO'.

Light trucks in the enhanced area also show generally lower emission levels but the difference is much less marked. This may be because in the first two years of the enhanced program, the standards for trucks in the enhanced area were relatively quite a bit looser than for passenger vehicles.

The lower emissions levels observed in the enhanced area suggest the centralized enhanced program is having a greater effect on reducing pre-1990 vehicle CO emissions than the basic program. Another striking feature of the charts is the consistent deterioration in vehicle emissions with age.

Figure VI-1 On-Road Passenger Vehicle CO

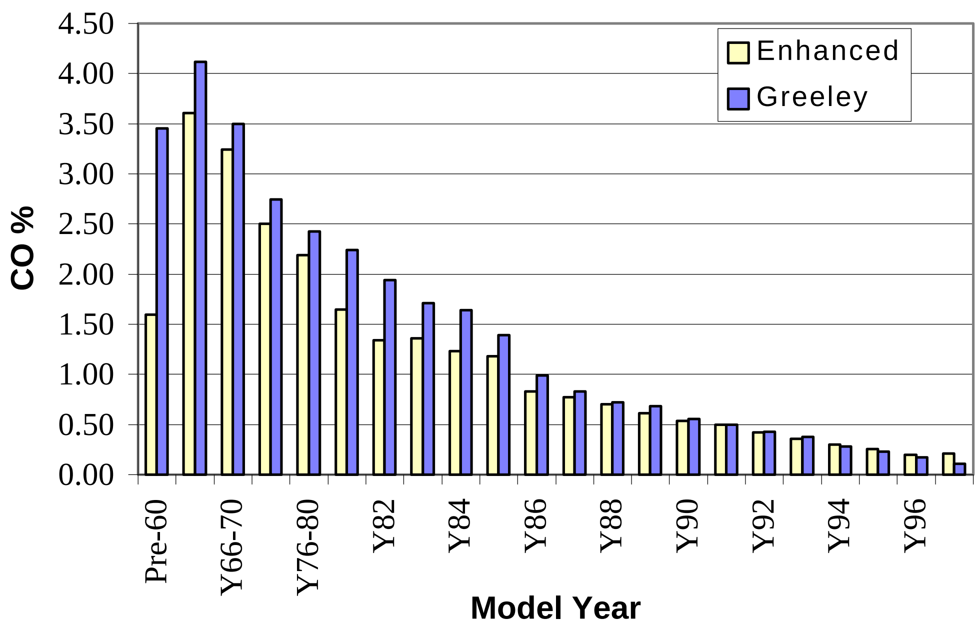
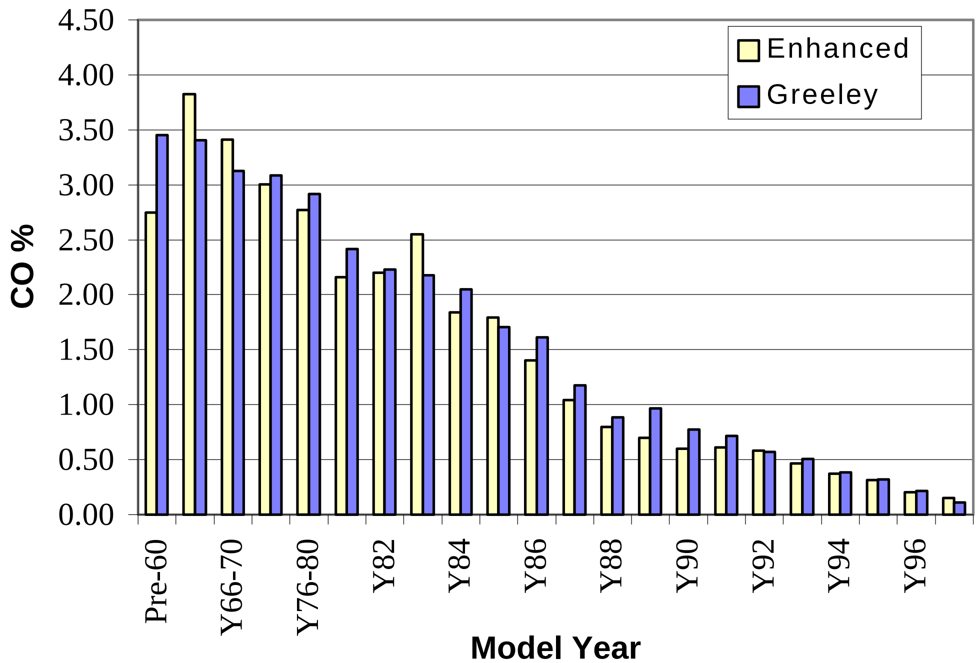


Figure VI-2 On-Road Light Truck CO

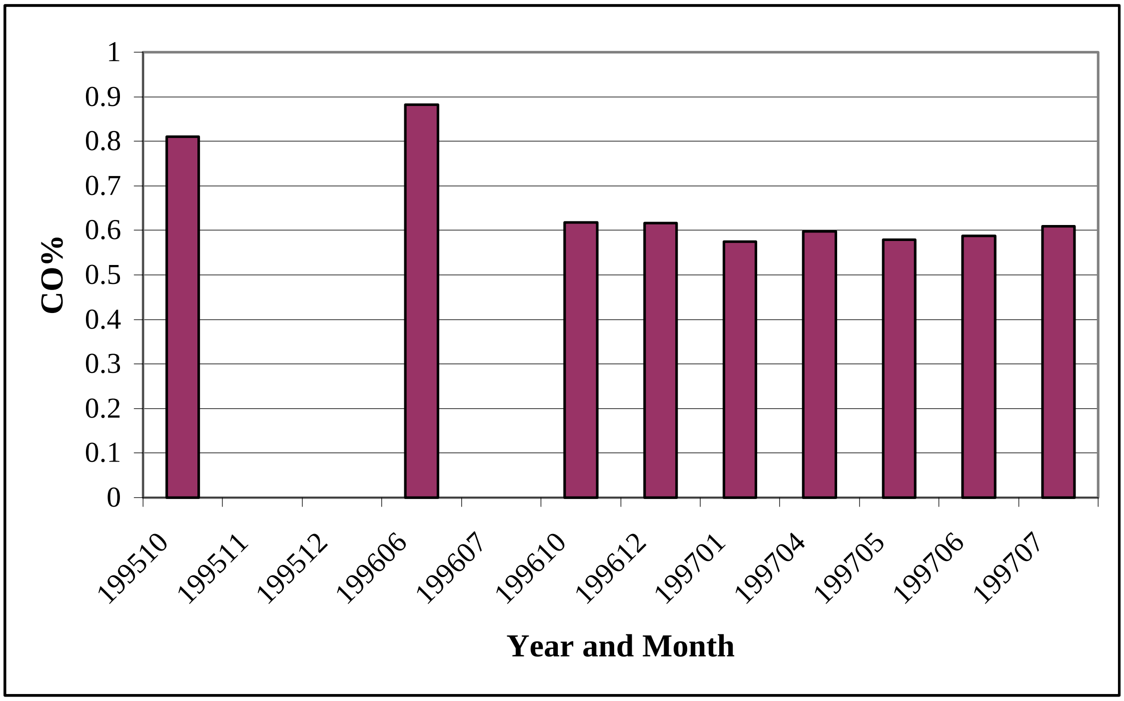


B. Seasonal effects on emissions

Sites D1 and D3 have been selected to look at the trend in average CO levels over time because these two sites have remained unchanged since the start of RSD testing. Figure VI-3 'Monthly CO at Sites D1 and D3' indicate a drop in CO levels over time.

Although the sites remained the same, the RSD unit was upgraded in April 1997. The expected effect of this upgrade, if any, is to exclude more vehicles in deceleration mode that had a smaller exhaust plume and generally higher CO levels. Thus following the upgrade one might expect to see some reduction in the measured CO levels but this effect is not evident in the chart. It is possible the effect is being masked to some extent by lower CO levels in the winter months as a result of the oxy-fuel program. Because of the limited number of days of measurement at the sites and the upgrade in the RSD unit, it is hard to draw any firm conclusions.

Figure VI-3 Monthly CO at Sites D1 and D3



C. Impact of speed/accel on emission rates by model year, vehicle type

This effect of vehicle load on tailpipe emissions is addressed in detail in the technical note attached as Appendix B to this report. Charts created from the Denver data in the technical note are reproduced here as Figures VI-4 through VI-6.

In these charts, a surrogate for vehicle load is estimated using a combination of the vehicle speed, acceleration and the slope of the site. Each point on the chart shows the average of the RSD readings for vehicles within a 10-unit load range.

Estimated tailpipe concentrations vs. load from the Q1, 1997 sample of full IM240 are also plotted on each chart. For the IM240 results, each point represents the average emission values of all the vehicles and the average load over a 10-second interval in the IM240 test starting from second 30. Mass emissions are converted to tailpipe concentrations assuming stoichimetric combustion. Because of the considerable assumptions and manipulations required to estimate the IM240 tailpipe concentrations and loads, one should not be very surprised that the IM240 curves do not agree more exactly with the RSD curves.

In fact, the RSD results show generally similar characteristics to those derived from IM240 tests. HC is higher at negative and low loads, then stabilizes over a wide range of positive load. In the RSD case, the stabilization appears to occur at a slightly higher load.

In CO, there is a difference in the curves. The IM240 results indicate lower CO at low loads followed by a plateau followed by increasing CO at high loads. The RSD results seem to show higher CO at negative and low loads followed by a fairly flat range between 25 and 85 load units followed by significantly increasing CO levels at higher loads. RSD results at low loads may be biased towards the high side if vehicles with lower emissions are missed because of small exhaust volumes under deceleration.

RSD NOx follows a similar pattern to IM240 NOx, starting low, increasing with load until it levels off. In the RSD case, the leveling occurs at a higher load than with the IM240 case. On many vehicles, no RSD NOx result was obtained. If this occurred more frequently on vehicles with low NOx emissions, this may account for what appears to be a bias towards higher NOx values in the RSD results.

The differences in the curves suggest that the estimate of on-road load is not quite the same as for the IM240, i.e. the equation for the on-road load estimate may need to be slightly different than that used for the IM240. Some further research into on-road loads, as a function of speed and acceleration may help improve the correlation between IM240 and RSD measurements.

Figure VI-4: RSD HC vs. Load

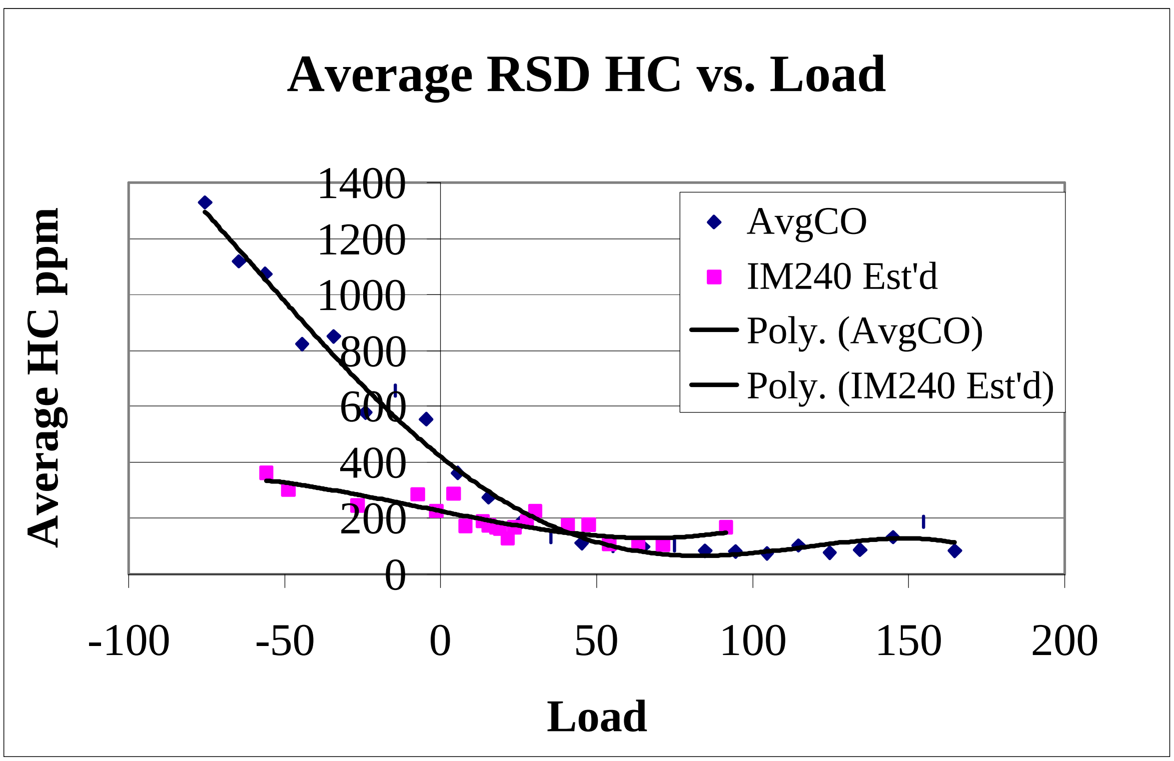


Figure VI-5: RSD CO vs. Load

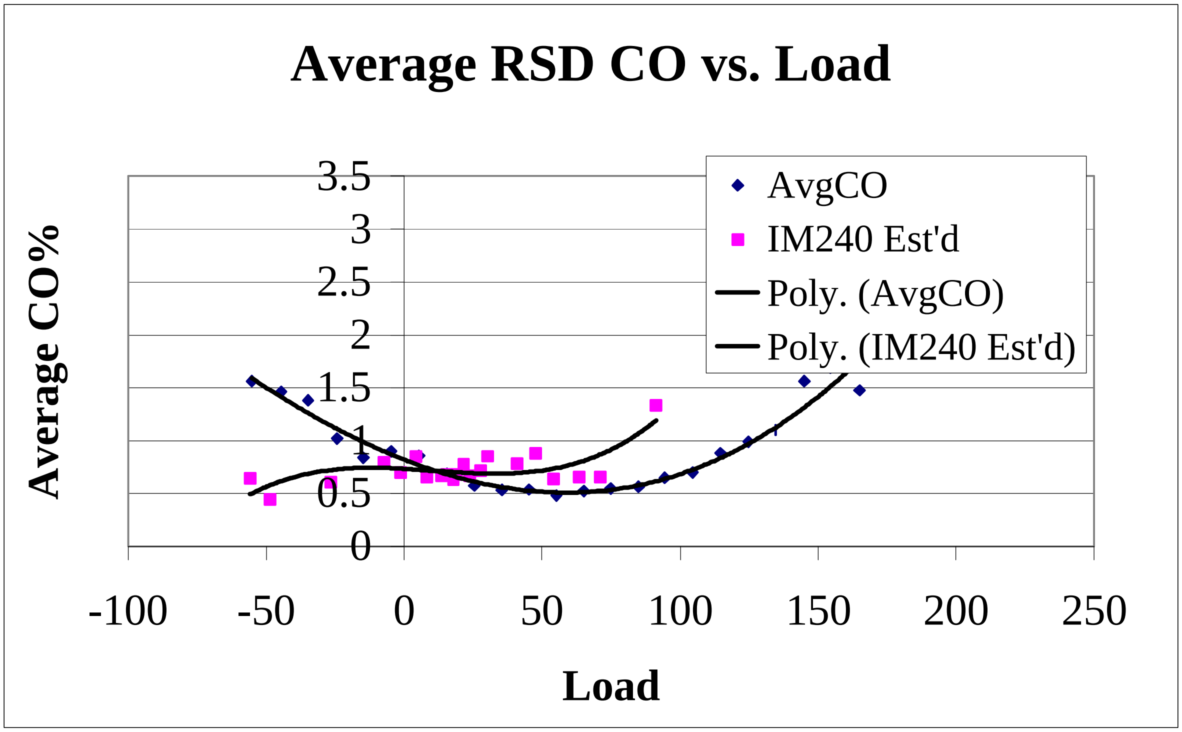
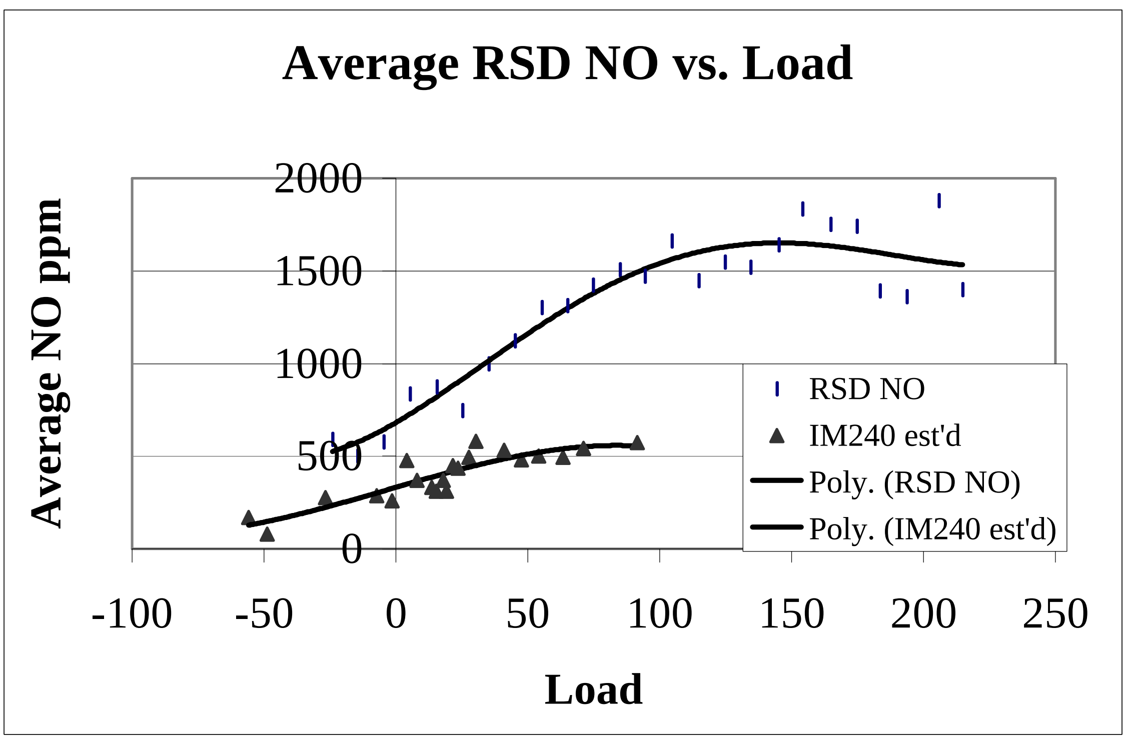


Figure VI-6: RSD NO vs. Load



D. Summary of I/M eligibility, registration and current emissions compliance

In early 1997, an exercise was undertaken to determine the level of compliance with the enhanced program. For this exercise, a sample of vehicles 'seen' by the Denver University remote sensing unit in December 1995 and January 1996 was used. These vehicles were subsequently plate matched to DMV registrations and then matched to the enhanced I/M test database for tests conducted in the two year period from 1/1/95 – 1/5/97. Figure VI-7 summarizes the results for vehicles that appear to be active and eligible vehicles currently registered in the I/M areas. About 2.5% of apparently eligible vehicles had not been tested.

Figure VI-7 Summary of Vehicle Compliance

Notes	Description	Vehicles	Percentage
	Unique Vehicles seen by RSD	26359	
	Vehicles with IM Tests	20993	79.6%
	Vehicles without tests	5366	19.4%
1.	Vehicles still in registration table	26090	99.0%
2.	Registered vehicles w/o tests	5163	19.8%
	Diesels	157	
	Gas '94 & newer	2821	
	Gas '67 & older	40	
3.	Unaccounted	2145	8.2%
4.	Registrations overdue	796	
	Registrations Current	1349	5.2%
5.	Current Registrations:		
	now outside area:	700	2.7%
6.	Basic area	69	0.3%
	Enhanced Area	580	2.2%

Notes:

1. The vehicle plates were originally matched to DMV registration data in early 1996 by Denver University (DU) and the set of information provided to CDPHE by DU included only vehicles registered at that time to the six county area. At the end of 1996, 99% of the matched VINs supplied by DU were found in the Envirotest host registration table.

2. Of the vehicles found, about 20% had not been tested.

3. After excluding diesels and vehicles '67 and older and '94 and newer that could have been exempt, 8.2% of vehicles remained.

4. Of the 8.2%, 5.2% have current registrations, i.e. they have registrations that expire in or after December 1996. A majority of the other 3% have registrations that expired in 1996 and may just be overdue - or they could be retired from service or have transferred out of state without notifying DMV.

5. Of the untested vehicles with current registrations about half are now registered outside of both the Basic and the Enhanced area. It may be instructive to take a closer look at a sample of these. A larger RSD program in the IM areas could confirm whether or not these vehicles have really moved.

6. About 2.5% of vehicles appear to be untested and active in the Basic and Enhanced IM areas.

Appendix A - Site Summaries

Appendix B - Optimal Vehicle Operation Modes for RSD Measurements

Technical Note

Peter M McClintock, Ph.D.
10/15/97

1. Summary

In order to make the best comparison between RSD measurements and IM240 test results it is useful to take into account the differences between the tests. In the RSD case, the load on the vehicle is somewhat uncontrolled and emissions are calculated based on the ratio of the pollutant gas concentration to the concentration of the combustion products, i.e. hydrocarbons, carbon monoxide and carbon dioxide. In the case of IM240, the vehicle is driven through a test with transient loads and emissions are measured in grams.

To understand these differences, we have converted IM240 10-second interval results into gas concentrations that are comparable to RSD measurements. Variations in IM240 emission concentrations through the test have then been examined to determine the vehicle operating modes in which gas concentrations can most consistently predict the IM240 test result and hence are most suitable for RSD measurements.

The estimated RSD equivalent gas concentrations for groups of vehicles passing and failing the IM240 test are compared to speed, acceleration and estimated relative engine load. The gas concentrations observed are far more constant throughout the IM240 test than the grams per mile[4]. Under moderate loads, vehicles burn more fuel and produce more emissions than under light loads but the concentration of the emissions is relatively stable. The results suggest there is a range of light to moderate vehicle loads over which tailpipe emissions concentrations are relatively stable. A majority of the emissions produced in an IM240 test are produced within this range of load.

Strong deceleration modes are characterized by high HC concentrations and large variations even though relatively little mass of emissions may be produced under deceleration. Heavy loads are characterized by increasing CO. The same general patterns of gas concentration vs. load are observed in on-road RSD readings.

The range of speeds and accelerations falling within the stable load range is charted to indicate the optimal spread of vehicle operating conditions for RSD measurement for fleet evaluation.

We predict the range of operating conditions that is best for identifying clean vehicles is moderate to heavy vehicle load. These conditions should give a good tailpipe plume for analysis and if the vehicle is clean under these conditions it should be clean during an ASM test or an IM240 test.

For identifying gross emitters, we again expect that a loaded condition will be best. In this case, however, if the load is too heavy the vehicle may enter an enrichment mode that is not reached in either an ASM or IM240 test. Therefore, we expect there is an upper limit to the load that should be used when identifying gross emitters or that the RSD standard used under heavy load should be different than that used under moderate or light loads.

[4] Concentrations of pollutants in this paper are in terms of the ratio of each pollutant to the total concentration of CO2, HC and CO rather than to the total volume of exhaust. This is convenient because it matches the method used by remote sensing devices.

2. Conversion of Mass Emissions to RSD Concentrations

To convert from IM240 mass emissions measured using CVS equipment to ‘tailpipe’ concentrations, an assumption is made regarding the air/fuel mixture. For vehicles with an optimal air / fuel mixture, the combustion product gases will be 13.4%, i.e. 13.4% = HC% (single Carbon) + CO% + CO2%. For incorrectly adjusted vehicles, this assumption will not quite hold true but variations should have only secondary effects on the calculated gas concentrations. Under vehicle deceleration, this may also not hold true because of severe fuel restriction. For comparison of IM240 results to RSD measurements, however, the conversion is still appropriate because the RSD units also use the ratio of HC, CO and CO2 to estimate concentrations of HC, CO and NOX.

The remainder of the conversion is then purely mathematics:

- Assume IM240 raw exhaust has volume of V cubic feet, then gas% = (gas grams/gas grams per cu ft at STP) / V
- At standard temperature & pressure: HC (single carbon) = 16.33 gr/cu ft, CO = 32.97 gr/cu ft, CO2 = 51.81 gr/cu ft, NOX = 54.16 gr/cu ft
- 13.4% = (HCgr / HCgpcf + COgr / CO gpcf + CO2gr / CO2 gpcf) / V
- 1 / V = 13.4% / [(HCgr / HCgpcf + COgr / CO gpcf + CO2gr / CO2 gpcf)]
- Est. CO% = (COgr/CO gpcf) *13.4% / [(HCgr / HCgpcf + COgr / CO gpcf + CO2gr / CO2 gpcf)]
- Est. CO% = 13.4 * CO gr * 0.03033 / (HC * .061237 + CO*0.03033+CO2 *.01930)
- Estd HC% Hexane = 13.4 * HC gr * .061237 / (HC * .061237 + CO*0.03033+CO2 *.01930) / 6
- Estd NOX% = 13.4 * NOX gr * 0.018464 / (HC * .061237 + CO*0.03033+CO2 *.01930)

The concentration for single carbon HC is divided by six to convert the result to the equivalent hexane value that is normally used for expressing HC concentrations.

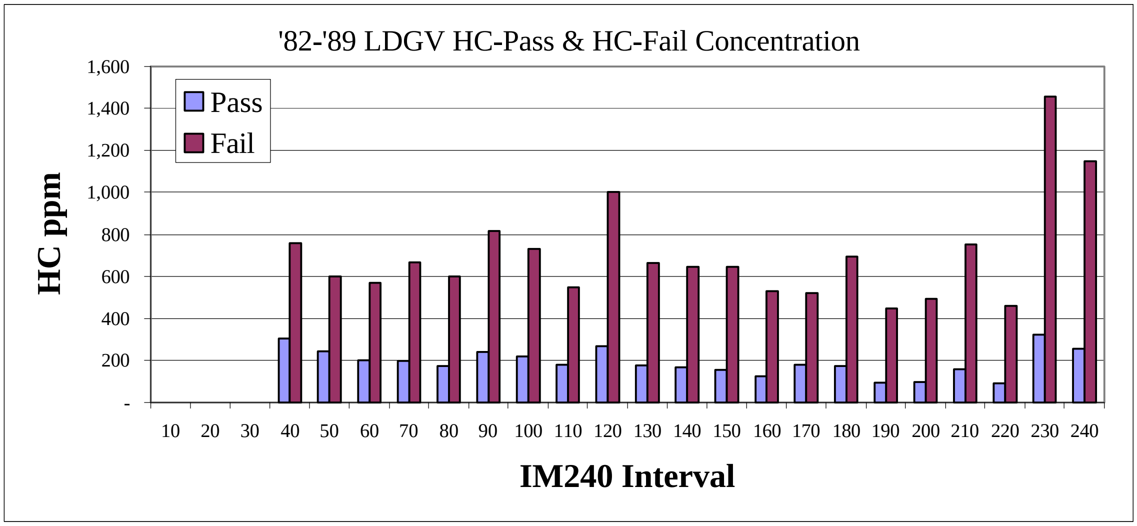
3. Average Tailpipe Concentrations through the IM240 Test

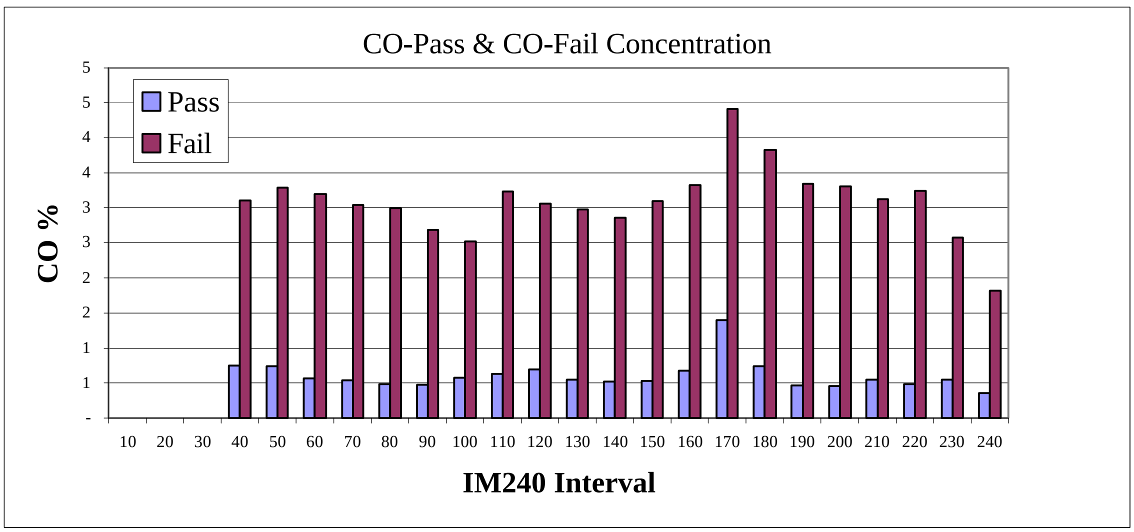
The following series of three Figures shows the estimated tailpipe concentrations for HC, CO and NOX for 1982-1989 light passenger vehicles passing and failing the IM240 test using high altitude phase-in standards. The sample size is 44,157 passing vehicles and 7,753 failing vehicles.

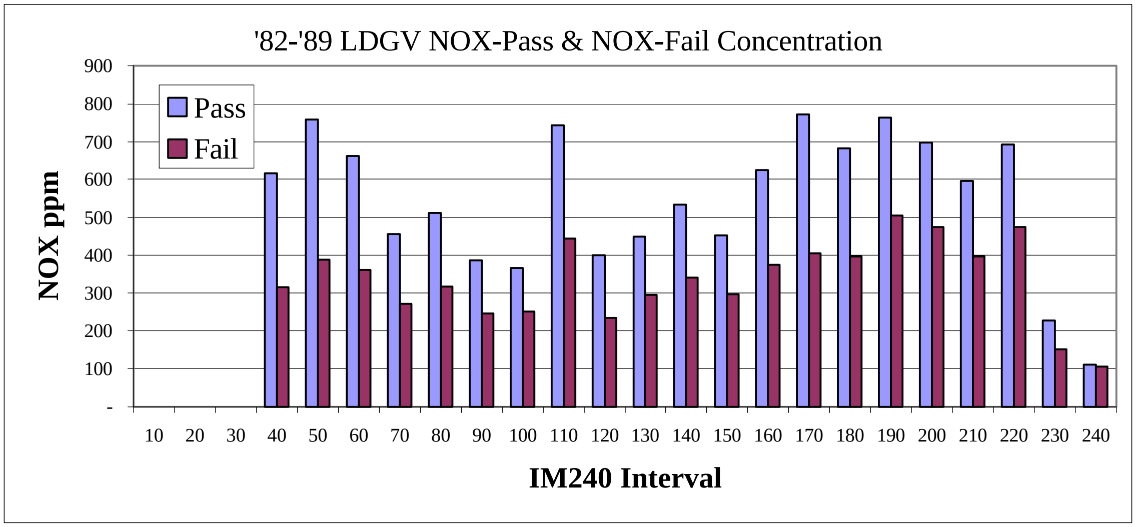
The tailpipe values are considerably more constant throughout the test than the mass emissions measured in grams. Peak concentrations of HC occur during deceleration rather than during normal load conditions. The separation between passing and failing vehicles is most evident with CO – although this may partially be attributable to the CO standards that are relatively more stringent than the HC standards.

It is notable that the NOX values are higher for vehicles passing the IM240 than for failing vehicles. The NOX standards are relatively loose with very few vehicles failing for NOX. Therefore, the IM240 failures are predominantly HC/CO failures and these vehicles with rich fuel/air mixture or lower compression are expected to burn cooler and produce less NOX.

Figure 3-1: '82-'89 LDGV Passing and Failing Tailpipe Concentrations







4. Engine Load

It is reasonable to suppose that tailpipe emission concentrations are related to engine load.

Engine load is a function of acceleration and running losses due to speed, e.g. wind resistance, internal friction, tire resistance, etc – and the mass of the vehicle. If we assume that engine power is geared to the mass of the vehicle so that, at least through the FTP cycle, the vehicle will not enter enrichment modes for a significant period, and other running losses are also loosely related to the size and mass of the vehicle, then an approximation for engine load relative to the non-enriched power output of the engine of the vehicle can be represented by the equation:

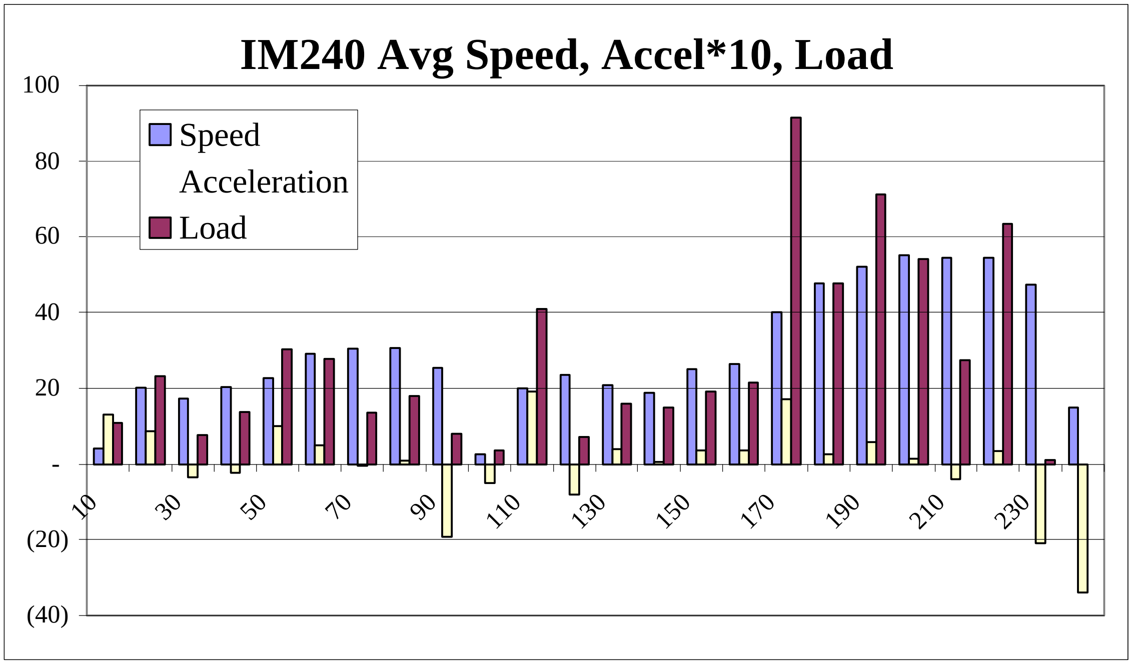
Relative Engine Load = max(accel * speed + c1 * speed + c2 * speed^2, 0)

Where c1 and c2 are constants. Obviously these constants may vary somewhat between different types of vehicle. The 'max' function is used to set the load to zero when the calculated load would otherwise be less than zero, i.e. during negative acceleration.

The constants, c1 and c2 were determined to be approximately 0.065 and 0.014 respectively by plotting fuel energy against the estimated load and adjusting the constants to obtain the best fit. Fuel energy was simplistically assumed to be twice the CO_2 grams plus CO grams – the CO_2 grams being by far the most dominant component.

Figure 4-1 shows the average speed, acceleration and estimated engine load for 10-second intervals through the IM240 test. The x-axis labels indicate the end of each 10-second interval. The highest load by a considerable margin occurs in the 160-170 second interval. The intervals containing the decelerations after the first and second hills have very low or no engine load.

Figure 4-1: Average Speed, Acceleration and Estimated Engine Load at 10-second intervals in the IM240 test



Figures 4-2 and 4-3 plot the estimated load for 10-second intervals against grams of combustion products (2 x CO2 grams + CO grams). Each point on the figures represents a 10-second interval from the IM240 test. The CO2 plus CO grams are used as an estimate of the energy productively released from fuel combustion. Although some of the combustion may be taking place in the catalytic converter, the figures indicate that the estimated 10-second loads are consistent with the fuel combustion energy throughout the IM240 test for two quite different groups of vehicles.

Figure 4-2: Combustion Energy vs. IM240 Load – Passing 1982-1989 LDGV

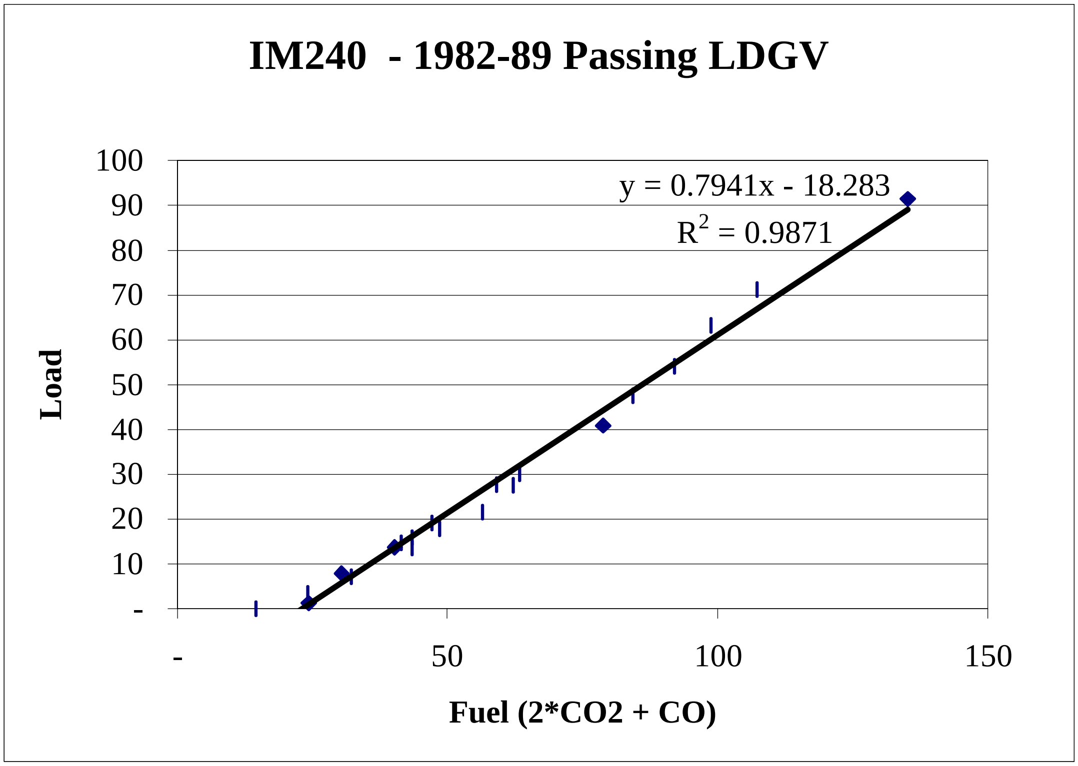
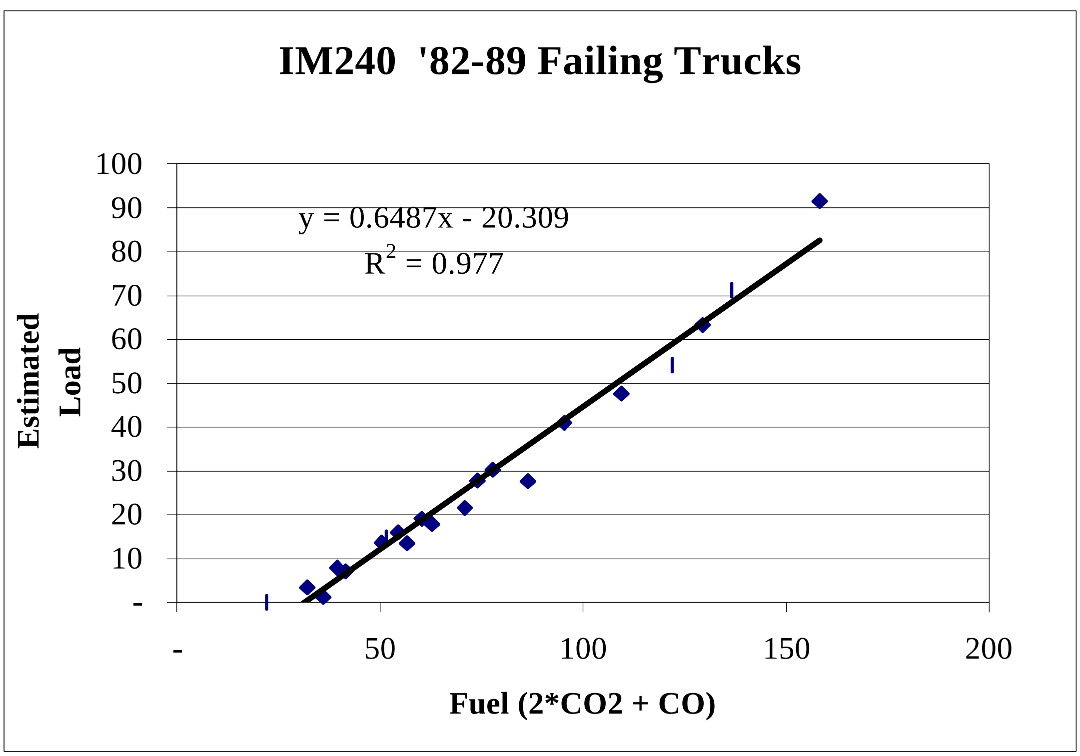


Figure 4-3 Combustion Energy vs. IM240 Load – Failing 1982-1989 LDGT



We therefore conclude that the equation for load:

$$\text{Load} = \text{accel} * \text{speed} + 0.065 * \text{speed} + 0.014 * \text{speed}^2$$

is a reasonable approximation for load at least with respect to the IM240 test cycle. We have yet to confirm the IM240 applied load is representative of on-road driving loads.

5. Tailpipe Concentration vs. Relative Engine Load

Using the estimate of relative engine load previously described, figures 5-1 and 5-2 illustrate tailpipe pollutant concentrations ordered by load for four groups of vehicles:

1982 – 1989 light passenger vehicles that pass IM240 (44, 157 tests);

1982 – 1989 light passenger vehicles that fail IM240 (7,753 tests);

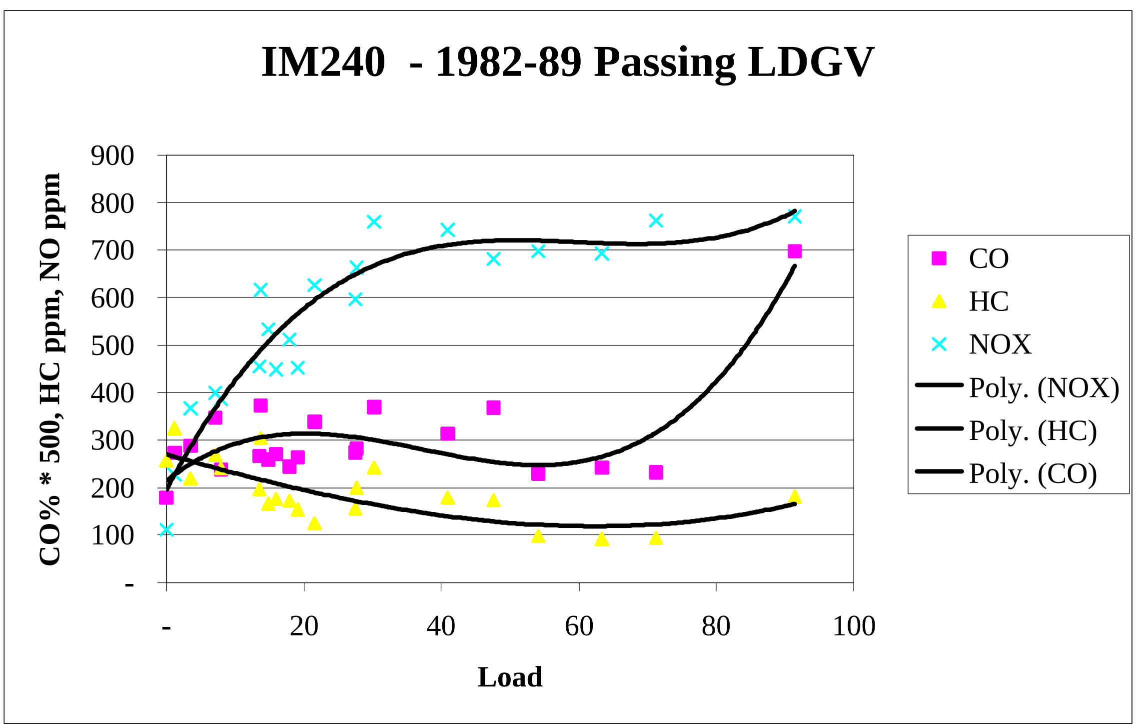
1982 – 1989 light trucks that pass IM240 (18,036 tests);

1982 – 1989 light trucks that fail IM240 high altitude phase-in standards (2,010 tests).

These figures clearly show a relationship between load and tailpipe emission concentrations. Tailpipe concentrations are seen to be relatively consistent from a load of 30 units through a load of 70 units. This represents a range of operation over which RSD results can be expected to be fairly consistent with one another.

In addition, since a majority of the emissions collected during IM240 inspection cycle

Figure 5-1: Tailpipe Concentrations vs. Estimated Engine Load - LDGV



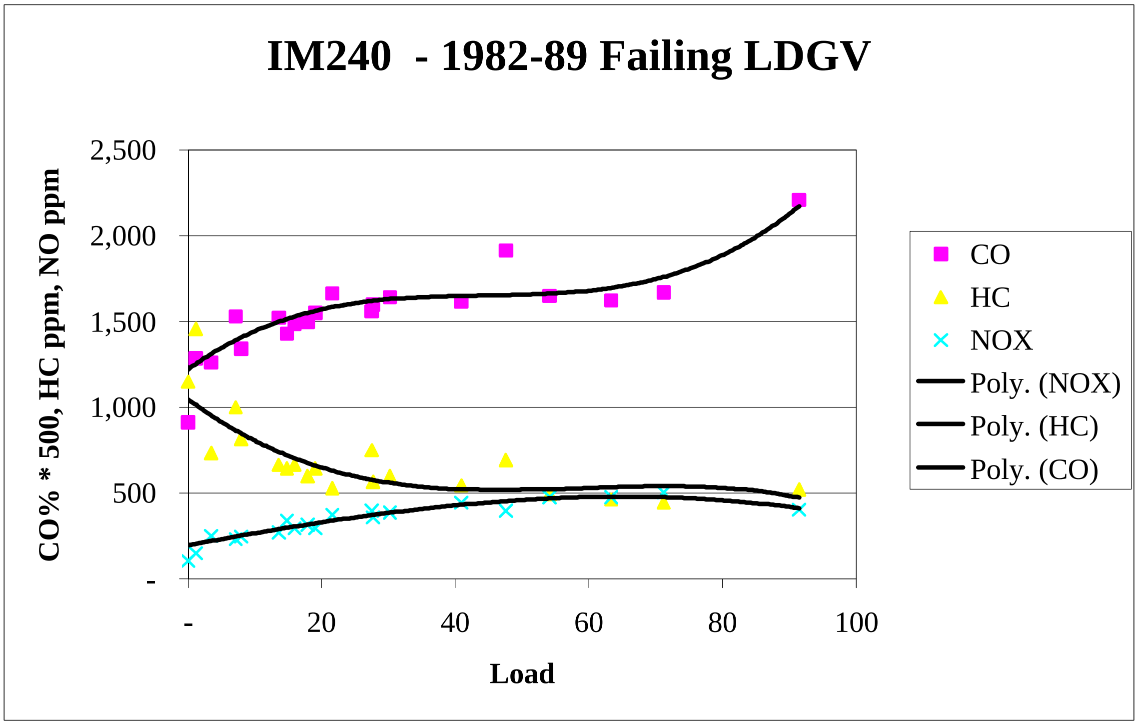
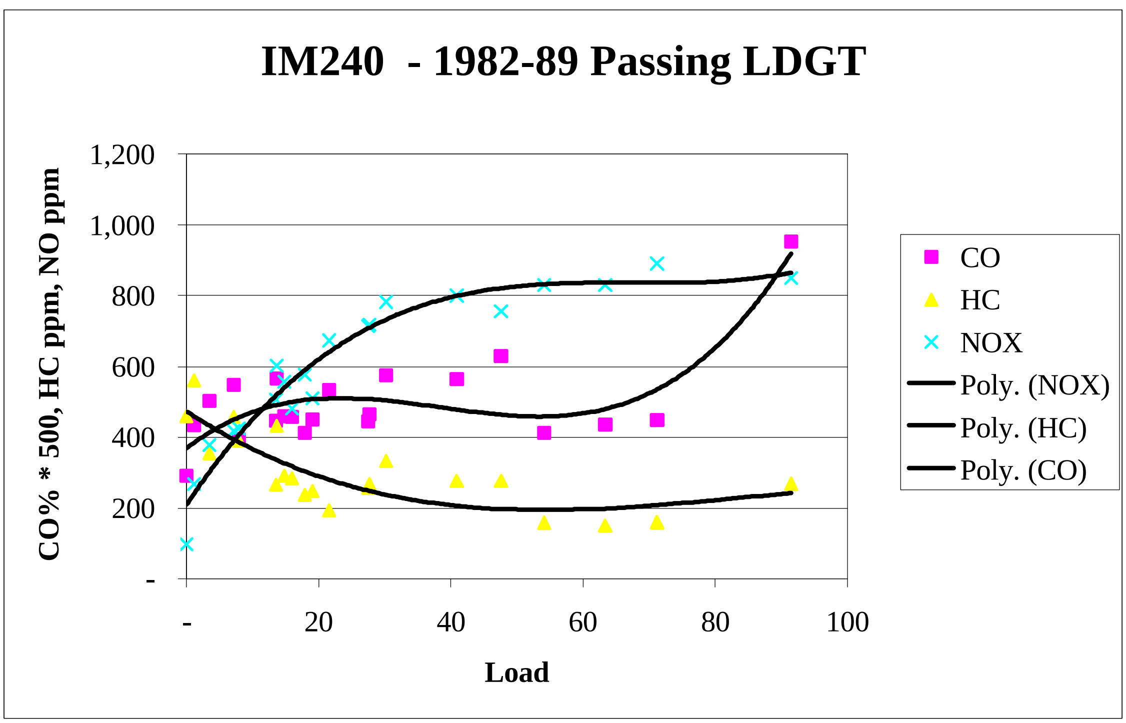
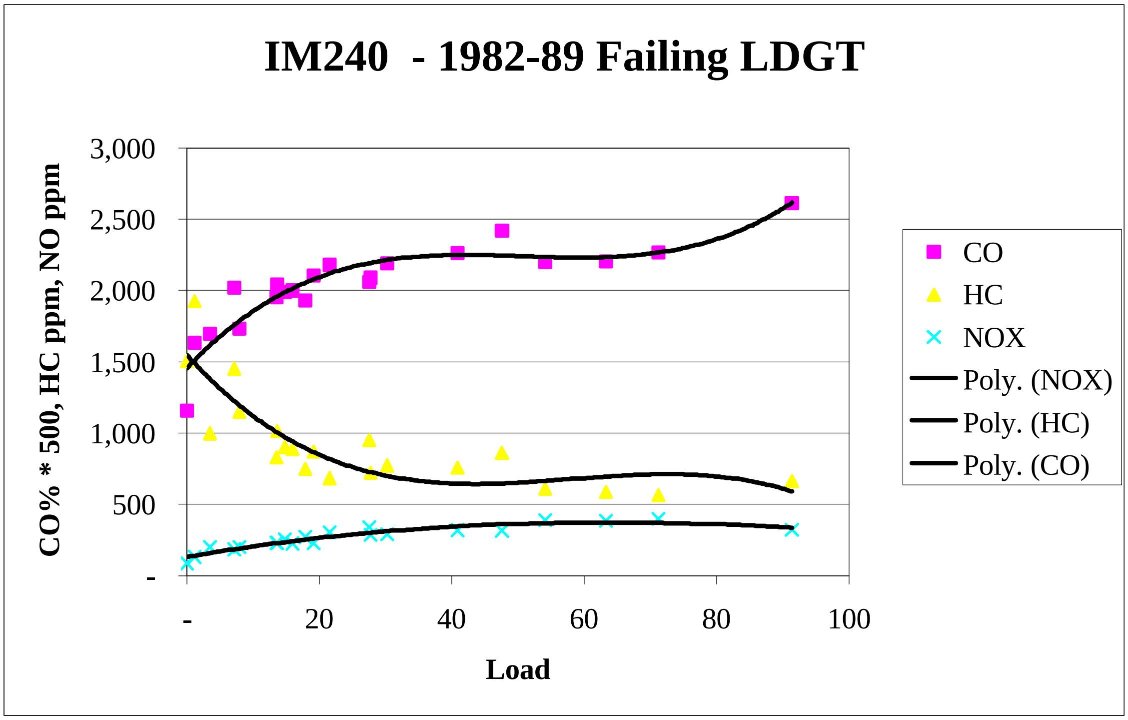


Figure 5-2: Tailpipe Concentrations vs. Estimated Engine Load - LDGT




IM240 - 1982-89 Failing LDGT
CO% * 500, HC ppm, NO ppm
3,000
2,500
2,000
1,500
1,000
500
-
-
20
40
60
80
100
Load
CO
HC
NOX
Poly. (NOX)
Poly. (HC)
Poly. (CO)

6. Average RSD Tailpipe Concentrations vs. Estimated Load

Figures 6-1 through 6-3 show the average RSD tailpipe measurements vs. load from a set of approximately 25,000 Denver RSD readings. In these charts, load has been calculated using the same formula except that negative loads have not been set to zero. Each point on the chart shows the average of the RSD readings for vehicles within a 10-unit load range.

The graphs show generally similar characteristics to the charts derived from the IM240 tests. HC is higher at negative and low loads, then stabilizes over a wide range of positive load. In the RSD case, the stabilization appears to occur at a slightly higher load.

In CO, there is a difference in the curves. The IM240 results indicate lower CO at low loads followed by a plateau followed by increasing CO at high loads. The RSD results seem to show higher CO at negative and low loads followed by a fairly flat range between 25 and 85 load units followed by significantly increasing CO levels at higher loads.

RSD NOx follows a similar pattern to IM240 NOx, starting low, increasing with load until it levels off. In the RSD case, the leveling occurs at a higher load than with the IM240 case.

The differences in the curves suggest that the on-road load is not quite the same as the IM240 load, i.e. the equation for the on-road load estimate may need to be slightly different than that used for the IM240 load.

Figure 6-1: RSD HC vs. Load

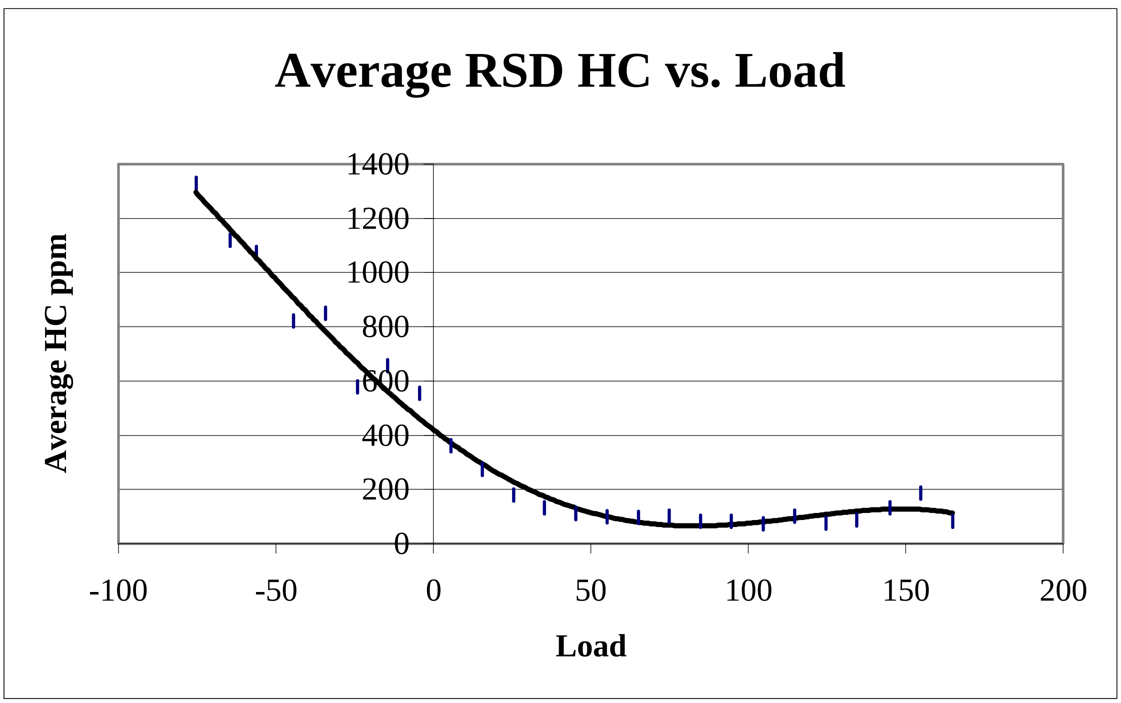
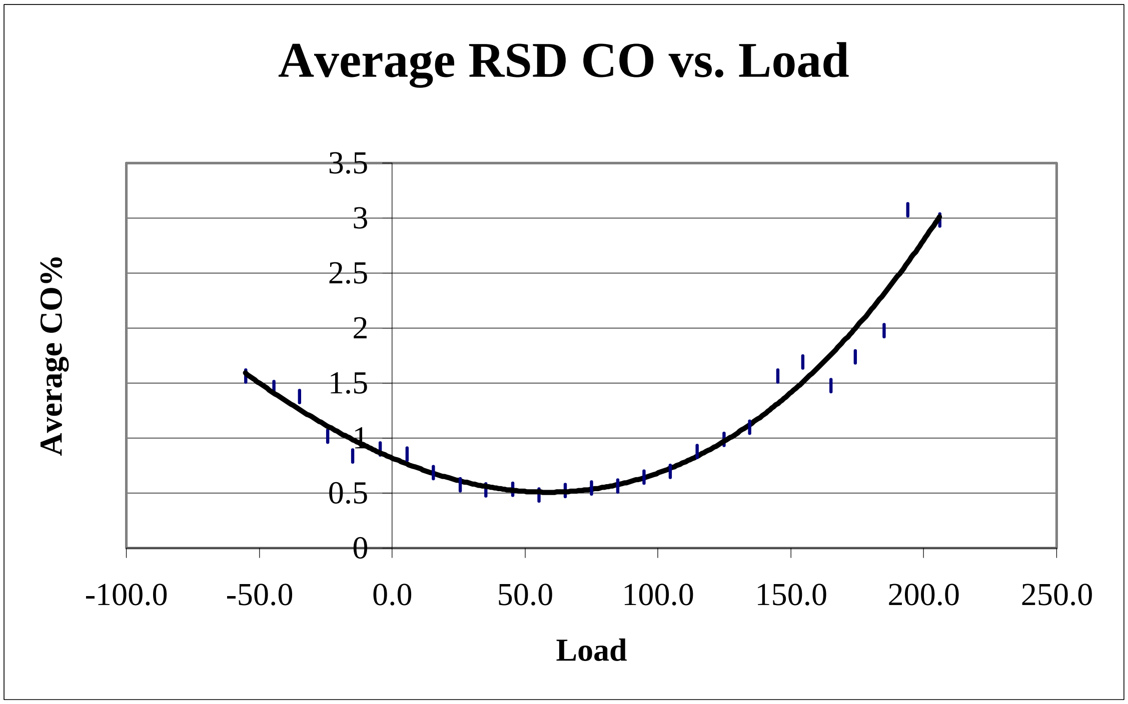
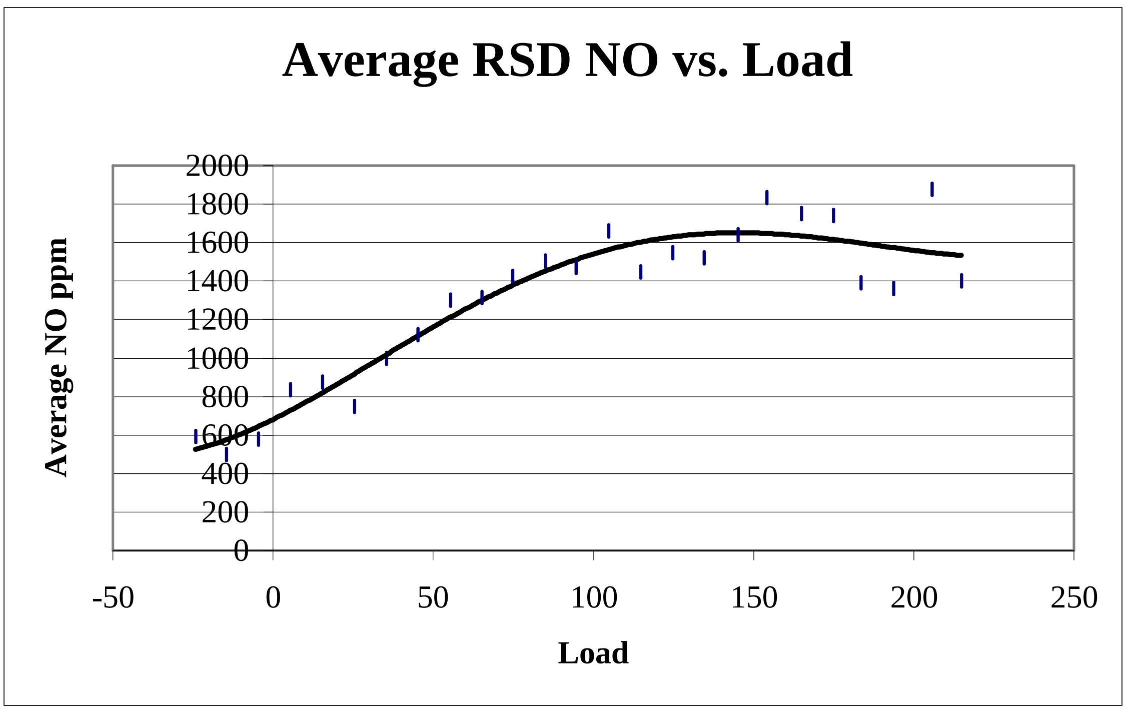


Figure 6-2 & 6-3: RSD CO & NOx vs. Load





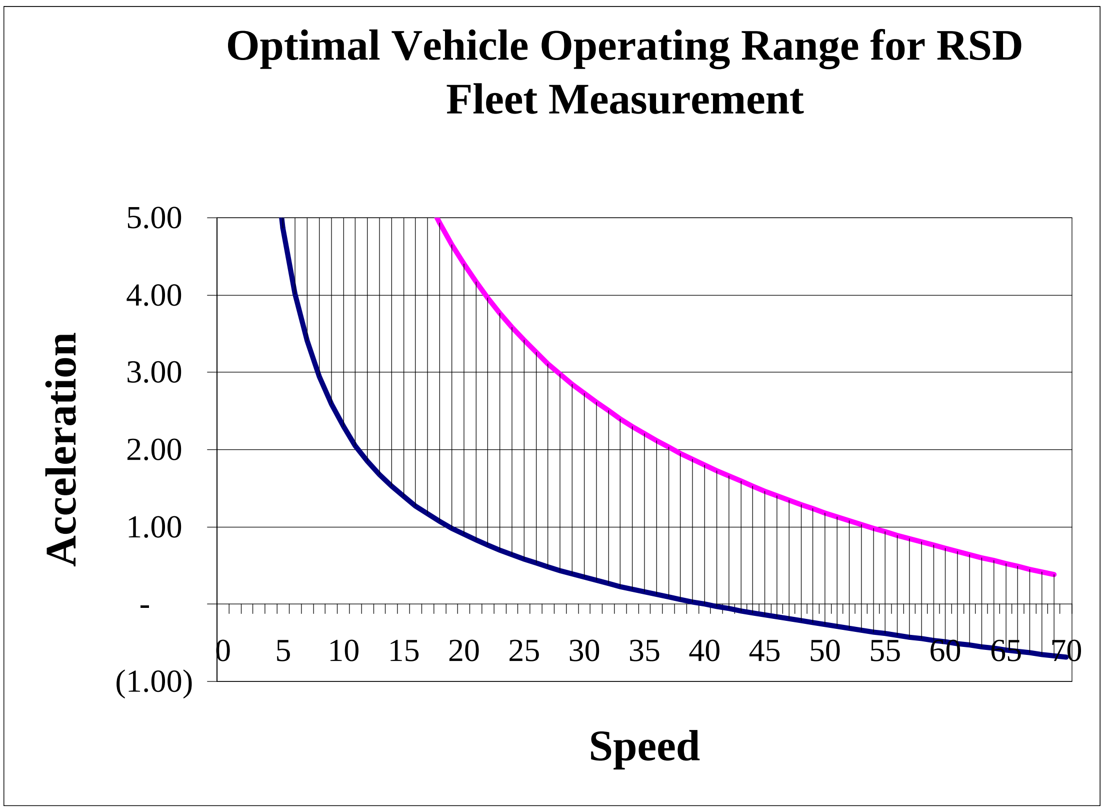
7. Vehicle Operating Mode and Characteristics of a 'Good' RSD Site for Fleet Characterization

For fleet characterization, vehicles should ideally be operating in the range of loads that gives relatively stable emissions concentrations.

7.1. Operating Range on a Flat Surface

Figure 7-1: Optimal Operating Range for RSD shows the speed and acceleration range within the range of load from 25 units to 100 units that should be in the stable range for a majority of vehicles.

Figure 7-1: Optimal Operating Range for RSD Fleet Measurement



7.2. Operating Range on Uphill and Downhill Sites

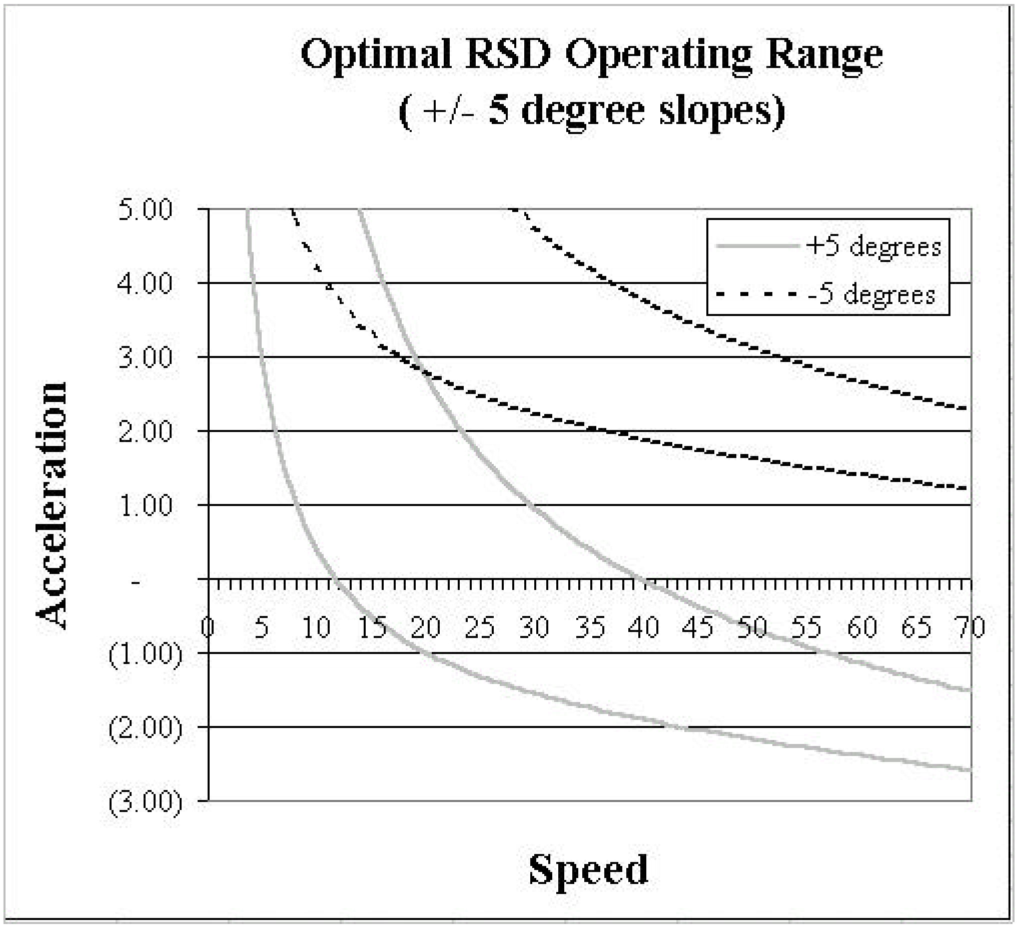
A vehicle traveling uphill is accelerating against gravity. The acceleration is given by:

Acceleration = 21.82 * sin(slope)

Where slope is the slope in degrees and 21.82 is gravitational acceleration in mph/sec/sec.

Figure 7-2: Optimal RSD Operating Range +/- 5 Degree Slopes shows how the operating range is affected by the slope of the site. A positive slope depresses the acceleration range and a positive slope increases the acceleration range.

Figure 7-2: Optimal RSD Operating Range +/- 5-Degree Slopes



8. Vehicle Operating Mode and Characteristics of a 'Good' RSD Site for Clean Screening

For a Clean Screening application, it seems likely that we are primarily concerned with having a sufficient load on the vehicle to properly test its emission control system and avoid the uncharacteristicly high pollutant concentrations associated with deceleration. Therefore, for productivity reasons, the goal is to select a load that is above the lower limit lines in Figures 7-1 and 7-2. A site with excessive acceleration, however, may also produce uncharacteristicly high pollutant concentrations in some vehicles and reduce the number of vehicles meeting the clean-screen criteria. Consequently, a site in which most vehicles are under moderate load will be the most productive.

9. Vehicle Operating Mode and Characteristics of a 'Good' RSD Site for High Emitter Identification

For High Emitter Identification, it seems likely that we are still primarily concerned with having a sufficient load on the vehicle to properly test its emission control system. In this case, however, we may have to be careful not to have an excessive load that may cause the vehicle to enter an enrichment mode that it would not enter during the course of an ASM or IM240 test. On the other hand, it is possible we will find that vehicles that exceed certain levels of emissions when under heavy loads will also consistently fail an ASM or IM240 test. Therefore it could be that the combination of high load and higher cutpoints provides the best high emitter detection scenario.