RSTi

PB99-140378

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Remote Sensing Measurements of Real World High Exhaust Emitters

CRC Project No. E-23 - Interim Report

Prepared for:

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March 12, 1999

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PB99-140378

2. REPORT DATE
March 12, 1999

3. REPORT TYPE AND DATES COVERED
Final Report

4. TITLE AND SUBTITLE
"Remote Sensing Measurements of Real World High Exhaust Emitters"

5. FUNDING NUMBERS

6. AUTHOR(S) Peter McClintock, Ph.D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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Colordo Department of Public Health and Environment

8. PERFORMING ORGANIZATION REPORT NUMBER
CRC Project No. E-23

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Coordinating Research Council, Inc.
219 Perimeter Center Parkway, Suite 400
Atlanta, Georgia 30346-1301

10. SPONSORING/ MONITORING AGENCY REPORT NUMBER
CRC Project No. E-23

11. SUPPLEMENTARY NOTES
This is an interim report which is part of a five-year Coordinating Research Council study of Remote Sensing Measurements of Real World High Exhaust Emitters. Remote Sensing Technologies Inc. (RSTi) is one of several organizations supplying data on an annual basis.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Remote Sensing measurements were taken at five primary sites in the Denver Area between April 1997 and March 1998 using an RS2000 unit capable of measuring HC, CO, and NO. The RD unit also measures vehicle speed and acceleration to permit determination of the vehicle operating condition and captures an image of the vehicle plate for identification.

The dirtiest 10% of vehicles for each pollutant emitted 63% of total CO, 47% of total HC and 32% of total NO. Emission levels for these dirtiest 10% were six times higher for HC and CO than the fleet average at 3.5% CO and 446ppm HC. The 10% of vehicles with the highest NO levels had values three times higher than average.

RSD measurements were compared to results from subsequent IM240 tests for 10,000 vehicles. When average emissions measured by IM240 and RSD for each model year were plotted against each other, an excellent correlation was observed with an r^2 of 0.93 for HC and 0.99 for CO. Despite the older technology NO channel, an r^2 of 0.99 was obtained for NO. These results suggest that RSD measurements can be used to assess fleet emissions.

14. SUBJECT TERMS

Emissions Inventory
Remote Sensor
Carbon Monoxide (CO)
Vehicle Emissions
Remote Sensing Study
Hydrocarbons (HC)
Nitrogen Oxides (NO2)
On-Road Vehicle Emissions

15. NUMBER OF PAGES
45

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

List of Tables and Figures

Summary

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Remote Sensing measurements were taken at five primary sites in the Denver area between April 1997 and March 1998 using an RS2000 unit capable of measuring HC, CO and NO. The RSD unit also measures vehicle speed and acceleration to permit determination of the vehicle operating condition and captures an image of the vehicle plate for identification.

Vehicles operating on-road under loads in excess of those experienced in the Federal Test Procedure (FTP) or IM240 often emit increased pollutant concentrations as a result of commanded fuel enrichment. When vehicles are decelerating and engines are under no load, exhaust volume is dramatically reduced. This also results in high and rather variable concentrations even though the grams per mile emissions are low. In order to identify high emitters as determined by FTP or loaded I/M tests, it is necessary to screen out RSD measurements for vehicles whose engines were operating under low or high loads when measured. To this end, the RSD measurements have been screened to include those made when vehicles were operating within a moderate load range found within the IM240 and FTP tests and over which emission concentrations are more stable.

In order to reduce differences between results from different sites, RSD results have been adjusted to reflect emission levels at an on-road specific power of 15kW per metric ton (kW/t). This is an attempt to provide a common point of reference that can be used to compare results from different sites and different RSD studies. At this load, mean emission levels were determined to be 0.55% for CO and 79ppm for HC.

A fleet average NO level of 1617ppm was determined at 15kW/t. Average NO levels may be half this value over a complete driving cycle such as the IM240, which has an average positive specific power of 8.5kW/t. The NO channel on the RSD unit during the measurement period was older technology and less accurate than the newest model. NO measurements were achieved on only 45% of vehicles, and these results may be biased high. The unit has since been upgraded.

The dirtiest 10% of vehicles for each pollutant emitted 63% of total CO, 47% of total HC and 32% of total NO. Emission levels for these dirtiest 10% were six times higher for HC and CO than the fleet average at 3.5% CO and 446ppm HC. The 10% of vehicles with the highest NO levels had values three times higher than average.

RSD measurements were compared to results from subsequent IM240 tests for ten thousand vehicles. When average emissions measured by IM240 and RSD for each model year were plotted against each other, an excellent correlation was observed with an r^2 of 0.93 for HC and 0.99 for CO. Despite the older technology NO channel, an r^2 of 0.99 was obtained for NO. These results suggest that RSD measurements can be used to assess fleet emissions.

1. Introduction

This is an interim report which is part of a five-year Coordinating Research Council study of Remote Sensing Measurements of Real World High Exhaust Emitters. Remote Sensing Technologies Inc. (RSTi) is one of several organizations supplying data on an annual basis.

Remote Sensing measurements were taken at sites in the Denver area between April 1997 and March 1998. These are listed in section 2. The bulk of the measurements were made at five sites, and these were reasonably spread throughout the year.

A single RS2000 unit capable of measuring HC, CO and NO was used to collect data. The RSD unit also measures vehicle speed and acceleration to permit determination of the vehicle operating mode and captures an image of the vehicle plate for identification. The NO channel used was older technology and valid measurements were achieved on only 45% of vehicles. This has since been upgraded.

Statistics on the data collection effort are provided in section 3. Information is provided on the number of unreadable plates, out of state vehicles, valid measurement percentages and breakdowns of measurements per site.

Section 4 discusses unit accuracy, site differences and the effects of vehicle operating conditions on the concentration of emissions measured by RSD. The comparison of results from different sites has posed some difficulty with RSD. Since emission levels vary with specific power and the specific power of vehicles varies from site to site, RSD results from multiple sites are not directly comparable. This section provides a suggested solution to this problem. Equations are used to calculate the on-road specific power of vehicles in terms of speed, acceleration and site grade. These are confirmed through analysis of results from IM240 tests. A method is described for adjusting RSD measurements from any site to be representative of an on-road specific power of 15kW per metric ton (kW/t).

Section 5 provides a summary of the emission levels measured, percentile charts for HC, CO and NO, and charts showing emissions by model year. The results of the dirtiest 10% of vehicles are presented.

Section 6 discusses the comparison of RSD data to vehicle matched IM240 data. RSD results are plotted against IM240 results for each model year and demonstrate good correlation. The correspondence of vehicles with high RSD measurements to those failing the centralized IM240 test is examined in section 7.

2. Site Selection Criteria

2.1. *Site Selection Strategy*

Sites were selected based on geographic location, traffic volumes and site suitability for remote sensing measurements. In order to ensure that the maximum number of valid emission readings would be achieved, sites were selected which had a moderate upward slope and where vehicles would be accelerating slightly during the measurement process and where vehicles were likely to be fully warmed up.

Initial operational site selection criteria were:

- site offered a safe environment for operator, motorist and equipment.
- site location provided adequate vehicle acceleration and speed.
- site minimized cold start scenarios.
- traffic at the site could be directed to single lane.
- sufficient traffic volume existed to warrant testing.

No site was selected if it did not contain sufficient shoulder width and length to provide a safe operating environment for the operator and sufficient set up area to ensure motorists were not endangered nor traffic interrupted during the testing.

2.1.5. Site Descriptions

A set of sites that would capture traffic that would be reasonably representative of the Denver area was selected. The site locations are listed in Table 2-1.

Table 2-1 Selected Sites

Site Ref	Description	Slope (degrees)
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	1.0
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
D7	Denver: Pecos & I-70	-1.9
D8	Englewood: Hamden & Santa Fe	2.5
D9	Westminster: US36 & Federal	1.1
D10	Denver: Exit from N.B. I-25 to Speer Blvd.	2.3

The bulk of the data was collected from the five sites described in more detail below:

- Site D1 is a single lane on-ramp to southbound I-225 from eastbound 6th Avenue in Aurora. The ramp has a positive road slope of about 1.7 degrees. The ramp splits from 6th Avenue at the intersection of Potomac and 6th. It parallels 6th for about 400 feet then makes a tight curve south around an embankment. The embankment obscures the RSD from driver's view until they exit the curve. The RSD is set up about 250 feet down-the ramp from the curve. At the foot of the ramp—250 feet past the RSD—is a traffic-metering signal. The signal begins operation at 3:30 PM and it is not unusual for the ramp to fill with cars after this time. Prior to 3:30 PM traffic is moderate at about 250 cars/hour.

- Site D3 is a very long, straight two-into-one lane on-ramp to westbound C-470 from University Boulevard in Highland Hills. Traffic entering the ramp from southbound University is unregulated and does not stop. A turn lane and signal regulate traffic from northbound University. The ramp has a 1.6-degree positive slope. The SDM is setup 425 feet from University and vehicles continue on past the RSD another 7-800 feet before merging into C-470. Traffic flow is about 500 cars/hour.

- Site D4A is a short, steep, straight single lane on-ramp to southbound State Highway 157 from Pearl Street in Boulder. It has a 3.1-degree positive slope. Traffic entering the ramp from eastbound Pearl is not regulated. A turn lane and signal regulate traffic from westbound Pearl. The RSD is setup 250 feet from Pearl Street and traffic merges into State Highway 157 some 250 feet beyond the RSD. This site typically has a traffic flow of around 450 cars/hour. Since Boulder is a college town, traffic can increase significantly (800 cars/hour) at the beginning of fall semester and at the end of spring semester.

- Site D5A is a straight, single lane on-ramp to westbound I-76 from Sheridan Boulevard in Westminster. The ramp has a 1.9-degree positive slope. The SDM is setup about 350 feet from Sheridan. Traffic entering the ramp from southbound Sheridan is not regulated. A turn lane and signal regulate traffic from northbound Sheridan. Cars merge into I-76 another 500 feet down-ramp. Traffic flow is about 200-300 cars/hour.

- Site D6 is a straight, two-into-one lane on-ramp to westbound US36 from Sheridan Boulevard in Westminster. Traffic entering the ramp from southbound Sheridan is unregulated. A turn lane and signal regulate traffic from northbound Sheridan. Both lanes are relatively short. The two lanes are separated by a triangular median. The site has a 1.1-degree negative slope. The SDM is positioned about 350 feet from Sheridan—50 feet past where the lanes merge. The short length of the merge lanes coupled with the relatively high traffic count (about 400 cars/hour) sometimes chokes the flow of traffic right at the SDM location. Vehicles merge into US36 another 500 feet down-ramp.

3. Breakdown of Measurements Taken

3.1. Vehicle Coverage

One RSD unit was used to measure vehicle emissions from April 1997 through March 1998. The unit was active on the road for 112 days and collected a total of 172,633 measurements. The results of the data collection effort are summarized below:

Total Triggers	172,633	
False Trigger	93	
No plate visible in picture	5,430	
Unreadable		
Partial plate	9,323	
Hitch or other obstruction	3,370	
Picture dark or blurred	4,816	
Truck, Trailer, Bus, Motorcycle	9,528	
Subtotal Readable Plates	140,166	81%
Of which noted as:		
Out of State	5,815	
Federal & State	876	
Temporary or Dealer	4,038	
Other	351	
Subtotal Normal Colorado Plates	129,086	92%
Of which:		
Unmatched registration	19,543	
Subtotal Colorado Matched	109,543	85%
Of which:		
Valid CO	82,242	75%
Valid HC	74,977	68%
Valid NO	48,877	45%
Valid HC & CO	70,286	64%
Valid HC, CO & Speed	63,405	58%
Valid HC, CO & NO	44,474	41%
Valid HC, CO, NO & Speed	40,108	37%
By registration area (with at least valid CO):		
Enhanced I/M Area	76,652	93%
Basic I/M Area	2,907	4%
Other Counties	2,683	3%

In 19% of readings there was no plate, or the plate was unreadable, or the vehicle was a large truck, trailer, or motorcycle where the plate is usually not captured in the camera frame.

Of the vehicles with readable plates, 4% were noted to have out-of-state plates, 3% had dealer or temporary plates and 1% had federal, state or other plates. It should be noted that vehicles with temporary or dealer plates are unmatched and not included in the tables below. This is unfortunate because the I/M data indicates that vehicles with temporary plates have I/M readings that are typically 20% higher than vehicles with normal plates.

43% of the out-of-state plates were from Texas, California, Wyoming, Arizona and New Mexico. A further 26% were from Florida, Kansas, Illinois, Minnesota, Oregon, New York, Washington, Utah and Nevada.

A total of 70,286 records were collected with plates matched to vehicles registered in the State, with a valid HC measurement and a valid CO measurement.

The data collection effort is further summarized by site and by quarter in the following Table 3-1.

Table 3-1 Breakdown of Measurements Taken

Test Quarter	D1	D10	D2	D2A	D3	D4	D4A	D5A	D6	D7	D8	D9	Total
972	3,163		21	711	7,677	25	7,749	1,459	3,186				23,991
973	1,157			638	1,507		7,389	3,112	1,222				15,025
974	1,101			606	2,596		1,520	2,718	4,186				12,727
981	2,080	900			1,401		3,256	1,867	2,432	2,699	2,795	1,112	18,542
Total	7,501	900	21	1,955	13,181	25	19,914	9,156	11,026	2,699	2,795	1,112	70,285

Table 3-3 'Matched Plates by Registration County' further details the vehicles seen by the county of the registered owner. About 7% of the vehicles observed in the enhanced area were registered to other counties.

Table 3-2 Matched Plates by Registration County

Area	County	D1	D10	D2	D2A	D3	D4	D4A	D5A	D6	D7	D8	D9	Total
E	Adams	407	70	10	782	341	6	1,171	2,651	2,350	493	234	600	9,115
E	Arapahoe	4,445	93	5	82	3,164	-	601	277	381	347	870	73	10,338
E	Boulder	57	10	1	44	128	15	14,199	254	4,673	62	66	38	19,547
E	Denver	1,028	432	3	218	1,154	1	996	670	930	1,205	647	119	7,403
E	Douglas	704	32	-	25	3,598	1	160	93	112	71	147	12	4,955
E	Jefferson	405	206	2	661	3,763	1	1,565	4,609	1,890	325	626	192	14,245
Subtotal		7,046	843	21	1,812	12,148	24	18,692	8,554	10,336	2,503	2,590	1,034	65,603
		94%	94%	100%	93%	92%	96%	94%	93%	94%	93%	93%	93%	93%
B	El Paso	131	13	-	10	136	-	123	43	106	31	23	14	630
B	Larimer	21	3	-	9	82	-	342	36	180	14	32	3	722
B	Weld	34	8	-	29	369	1	300	78	146	49	27	29	1,070
Subtotal		186	24	-	48	587	1	765	157	432	94	82	46	2,422
Non-IM	Other	269	33	-	95	446	-	457	445	258	102	123	32	2,260
Total		7,501	900	21	1,955	13,181	25	19,914	9,156	11,026	2,699	2,795	1,112	70,285

3.3. *Unique Vehicles*

Previous tables have shown the number of readings without differentiating the number of unique vehicles observed. The number of unique plates and the number of plates seen once, twice and three times or more are shown in Table 3-5 'Unique Plates Seen'. As one would expect, a lower percentage of vehicles from outside the enhanced area have repeat readings.

Table 3-5 Unique Plates Seen

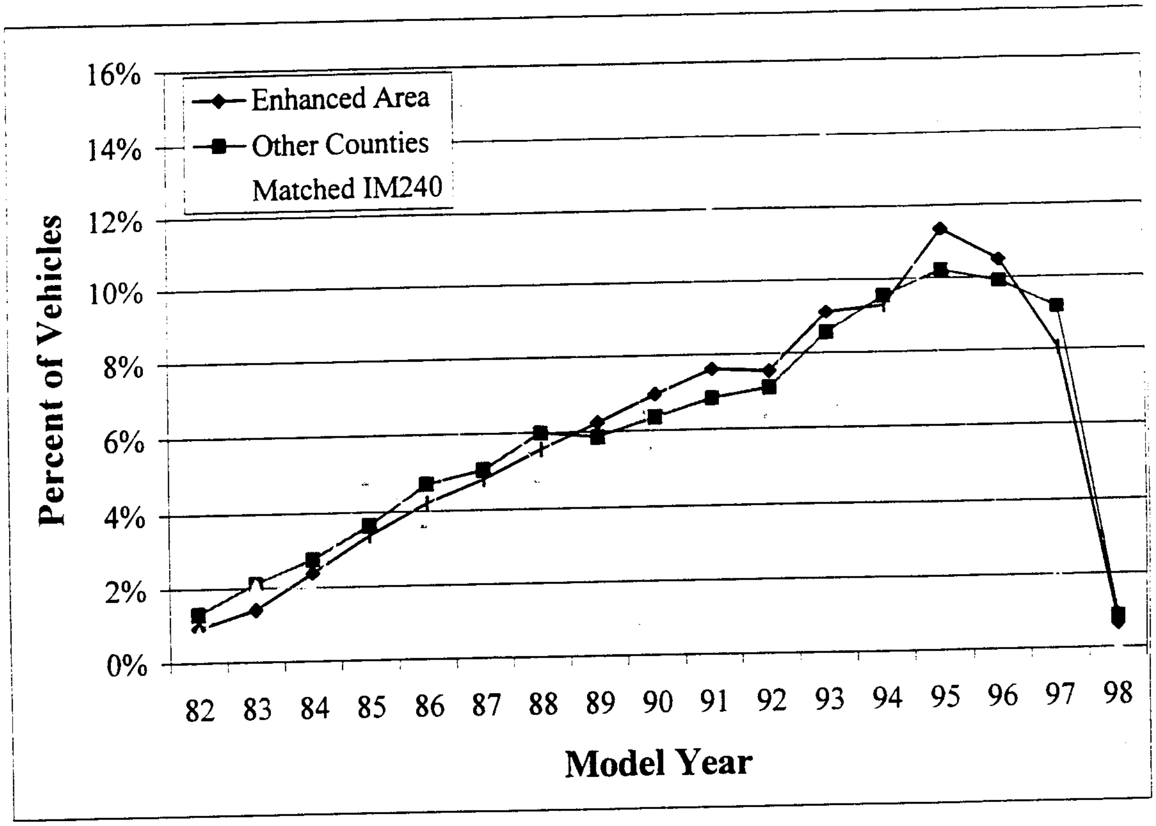
RSD Measurements	Enhanced Area Registrations	%	Other Counties	%
One	44,418	85%	3,730	90%
Two	5,613	11%	305	7%
3 or more	2,494	5%	90	2%
Total	52,525		4,125	

3.4. *Vehicle Model Year*

The distribution of vehicles by age is shown in Figure 3-1 'On-Road Unique Vehicles Model Year Breakdown'. Also shown is the model year distribution of matched IM240 tests conducted from April 1, 1997 through March 31, 1998. The time period selected and the biennial nature of the Enhanced I/M program resulted in a greater percentage of matches for odd model year vehicles. Because of the way the program started, most 1994 vehicles are inspected in odd years. Vehicles less than four years old are only subject to I/M inspection on a change of owner.

It is curious that a higher proportion of 1988 and older vehicles from other counties are seen in the enhanced area than newer vehicles. This may just be a feature of the age distribution of vehicles registered outside the enhanced area or it could indicate some older vehicles are deliberately registered outside the enhanced area while operating within. A comprehensive RSD program would facilitate follow-up on frequently observed high emitters that are registered to non-I/M counties.

Figure 3-1 On-Road Unique Vehicles Model Year Breakdown



4. Evaluation of Data Integrity and Data Screening.

Considerable improvements have been made in understanding the quality of remote sensing readings. 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 good quality reading;

2) The operating condition of the vehicle must be known.

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. The RSTi instrument used in the study was updated in mid April 1997 to be better able to flag readings that may be prone to error because the exhaust plume is not sufficiently well characterized by the sensor. This condition usually occurs on vehicles that are decelerating and which often show markedly increased concentration measurements although the mass emissions are relatively small.

The RSTi vans are equipped with speed and acceleration measurement devices that measure speed to 0.2mph and acceleration to +/- 0.5mph/s. Combined with knowledge of the slope of the site, this allows assessment of the operating condition of the vehicle at the time the emissions are measured.

4.1. *Preliminary Data Screening*

In addition to HC, CO, CO2 and NO values, RSTi units collect information about the quality of the reading having to do with the strength of the reference signal and the concentration and length of the exhaust plume detected.

A consistent series of readings for the exhaust plume is required to consider a reading reliable for analysis purposes. Indicators for the reading quality parameters are preset in the units, which report whether readings are valid, invalid, or suspect. For any vehicle on which the CO2 value is flagged as suspect, all other emission gas values are also considered suspect and are screened out.

A daily summary of RSD measurements is provided in Appendix A. Examination of the daily average emissions shows the data for 2/4/98 from site D7 has suspect HC values - the average HC for the day is several times that of other days at the same site. Inspection of the data reveals that quite a number of vehicles have HC readings of 5,000 ppm or more. Measurements from site D7, from which data was collected only during the first quarter of 1998, have been excluded from the analysis of fleet emission levels.

We found a seasonal pattern to the HC emission measurements that may indicate the interference of water vapor on the HC channel measurements in the RSD2000 unit. In newer units, the frequency band of the HC channel filter has been shifted slightly to reduce the amount of interference.

4.2. *Effect of Engine Load on Measured Vehicle Emissions*

Engine load is a function of vehicle speed and acceleration, the slope of the site, and characteristics of the vehicle including mass, aerodynamic drag, rolling resistance, transmission losses. Under moderate to heavy load conditions, vehicle engines will enter enrichment modes that can increase emissions many times. Under these conditions, vehicles that would run cleanly within the operating ranges found in the FTP, will have much higher emissions. If RSD results are to be used to identify excess emissions, it is desirable to screen out measurements of vehicles legitimately operating in enrichment mode. These readings may bias the average results and the vehicles may be incorrectly classified as high emitters. Therefore, it is useful to have a performance measure for determining whether a vehicle was operating within an acceptable power range when it was measured by RSD.

On-road Specific Power

A first principles approach to calculating the instantaneous power of an on-road vehicle has been proposed by Jose Jimenez[1], who has defined specific power using the following equation:

[1] Jose Jimenez-Palacios (1999). "Understanding and Quantifying Motor Vehicle Emissions with Vehicle Specific Power and TILDAS Remote Sensing", PhD Thesis, MIT

$$\text{Specific Power} = v.(a.(1+e_i) + g.grade + g.C_R) + \frac{1}{2} p_a \frac{C_D.A}{m} (v + v_w)^2.v$$

where:

- m : vehicle mass
- v : vehicle speed
- a: vehicle acceleration
- e_i: rotational mass factor which is gear dependent
- $grade$: vertical rise/slope length
- g : acceleration of gravity
- C_R : coefficient of rolling resistance
- C_D: drag coefficient
- A: frontal area of the vehicle
- p_a : ambient air density
- v_w : headwind into the vehicle

The 1986 Bosh Automotive Handbook gives typical values for rolling resistance C_R with radial tires of 0.015 and typical drag coefficient C_D values of 0.2 for a streamlined sedan to 0.6 for a van body. Jimenez uses a typical value of 0.0005 for $C_D.A/m$ and a value of 0.1 for the rotational mass factor, which is gear dependent. Using these values gives an expression of specific power in kilowatts per metric ton on a flat surface with no wind of:

$$SP_{\text{road kW/t}} = 1.1.v.a + 0.147\ .v + 0.000302.v^3$$

where speed is in m/s and acceleration is in m/s^2.

This is equivalent to:

$$SP_{\text{road kW/t}} = 0.22.v.a + 0.0657\ .v + 0.0000270.v^3$$

Where v is in mph and a is in mph/s. Although not the direct result of on-road measurements, this estimate has been designated as the 'on-road' specific power to differentiate it from the specific power estimate derived from IM240 test fuel combustion products.

Estimate of Specific Power in the IM240 Test

In an earlier study[1], a surrogate for vehicle load was derived by analyzing IM240 second-by-second combustion products from a set of 140,000 Colorado IM240 tests. Using this data, the coefficients of an equation of the same form as that above have been re-calculated to confirm the equation. The specific power of ten-second intervals in the IM240 test were plotted against the heat of formation of the combustion products represented by the CO

[1] Peter McClintock (1998). "The Colorado Enhanced I/M Program 0.5% Sample Annual Report" Prepared for the Colorado Department of Public Health and Environment

and CO2 grams measured during the same intervals. Each carbon atom was assumed to represent the combustion of 1.16 molecules of H_2. Coefficients were varied to obtain the best fit and resulted in the equation:

$$SP_{IM240} = 1.1.v.a + 0.627.v + 0.000133\ v^3$$

For separate groups of vehicles this yielded r^2 values of:

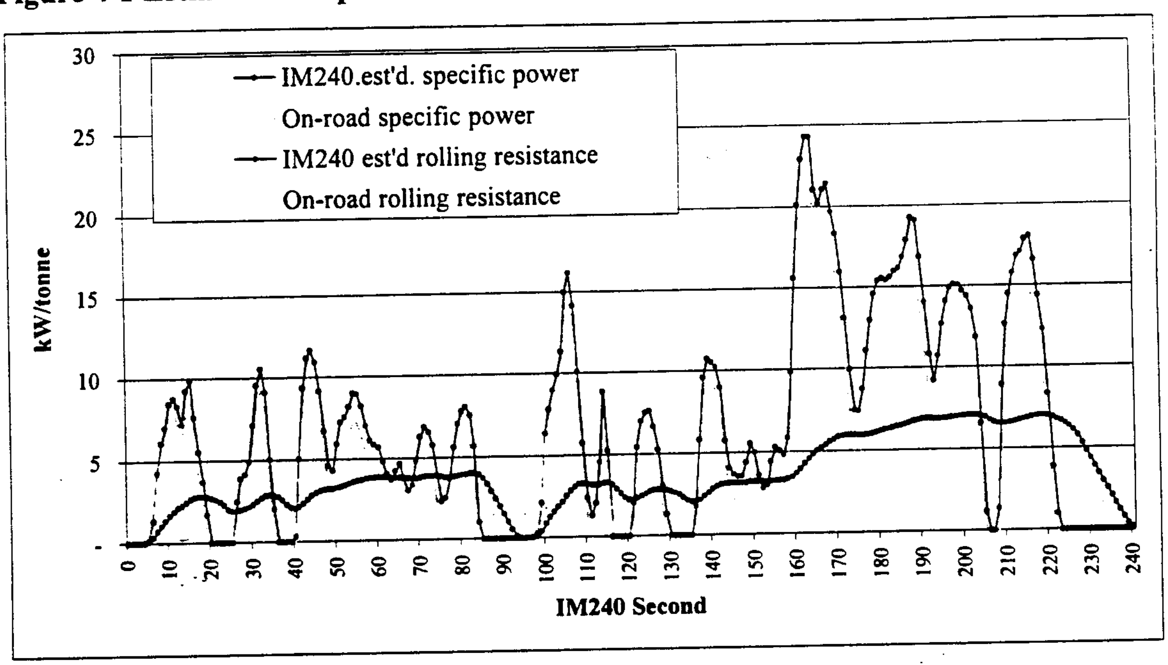
- 0.993 for 1982-1989 passing light duty passenger vehicles;
- 0.993 for 1982-1989 failing light duty passenger vehicles;
- 0.988 for passing 1982-1989 light duty gas trucks;
- 0.986 for failing 1982-1989 light duty gas trucks.

The units of specific power in this case are mph^2/s (v is mph and a is mph/s). Conveniently, to convert between these units and kW per metric ton the divisor is a factor of almost exactly five[1]. The equivalent equation is then:

$$SP_{IM240\ kW/t} = 0.22.v.a + 0.1254\ .v + 0.0000266\ v^3$$

The plots of positive specific power over the IM240 test cycle using the two approaches are shown in Figure 4.1. The positive specific power range of the IM240 test is from 0 to 25 kW/t with an average positive value of 8.5kW/t.

Figure 4-1 Estimates of Specific Power in the IM240 Test Cycle



The two estimates are close at low speed and further apart at higher speeds, with nearly all of the difference resulting from a difference in the estimated rolling resistance. If the estimated IM240 rolling resistance is multiplied by a factor of 52%, the two estimates of

[1] 1 kW/t is equivalent to 1.22 HP/ short ton.

specific power are almost identical. The greater IM240 rolling resistance is thought to result from driving on dynamometer rolls as opposed to a flat surface. On the twin IM240 rolls the tires have two points of contact vs. a single point of contact on a flat surface and may experience greater distortion on the convex surfaces of the rolls. It has yet to be confirmed whether the IM240 dynamometer loads were adjusted to account for this factor. Part of the difference may also come from engine and transmission frictional losses not fully accounted for in the on-road equation.

The correlation between the specific power calculated from first principles and the specific power derived from fuel consumption in the IM240 results provides confidence that the equations are approximately correct. The consistency of the result from the IM240 tests for different groups of vehicles using the same equation is also encouraging.

Effect of Road Grade and Other Factors

The load contributed by the slope of the site comes from acceleration against the Earth's gravitational force and in mph^2/s units is:

21.82 mph/sec x sin(slope)

where 21.82 is the mph/second equivalent of the better known gravitational acceleration constant of 32 feet per second per second.

A 5% grade, which is not that unusual for a freeway ramp, is equivalent to a horizontal acceleration of 1.9 mph/s. To put this in perspective, the IM240 test contains accelerations and decelerations that are in the range of -3.5 to +3.5 mph/s. Thus, the slope of the site can make a considerable contribution to specific power. Adding this term to the on-road equation for specific power and converting to kW gives:

$$SP_{road\ kW/t} = 4.364.\mathit{sin(slope^o)}.v + \mathit{0.22.v.a} + 0.0657.v + 0.0000270.v^3$$

Wind and variations in air density with temperature will also have some impact on the drag component of specific power. Currently these are not recorded with each RSD measurement.

Variation of Emission Levels with Specific Power

RSD emission values binned by specific power are plotted in Figures 4-2 through 4-4. With some exceptions, emission concentrations are relatively constant over the range of positive specific power found in the IM240 cycle. This is in contrast to mass emissions that increase more or less in proportion to specific power and vary widely.

At specific powers of less than 4 kW/t, HC emission concentrations are quite unstable and higher than normal. Above 4 kW/t, however, HC emission concentrations appear moderately flat.

CO emissions are relatively stable from 0 to 25kW/t and begin to increase more rapidly thereafter. NO emissions increase linearly up to 14kW/t and then flatten out.

Figure 4-2 Average HC vs. Specific Power

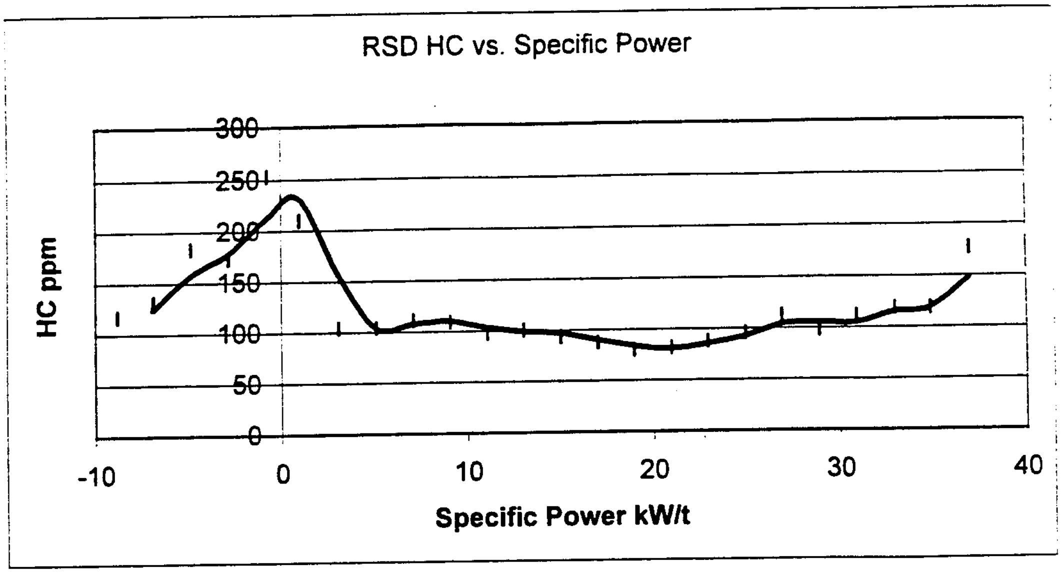


Figure 4-3 Average CO% vs. Specific Power

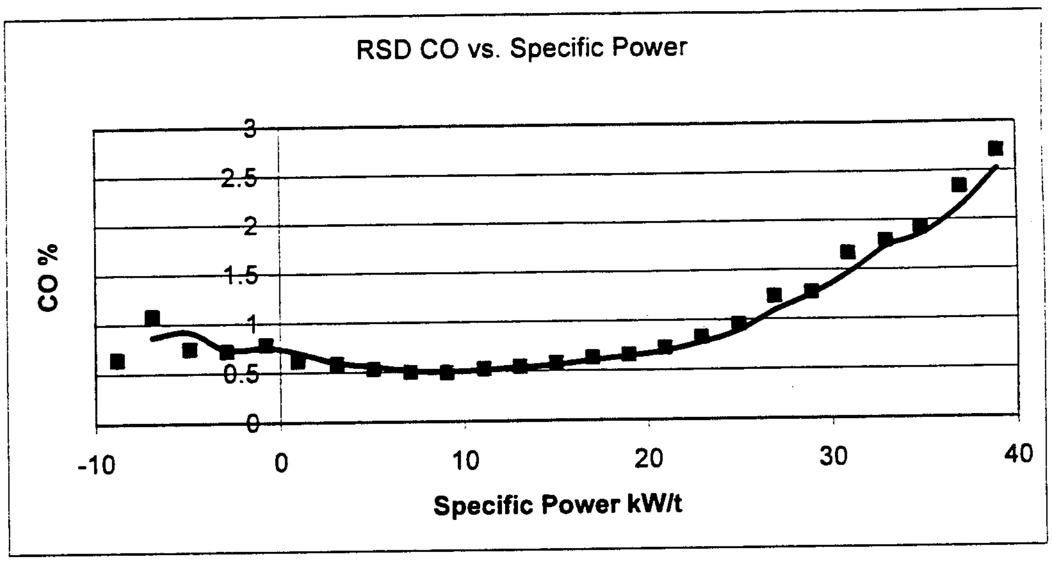
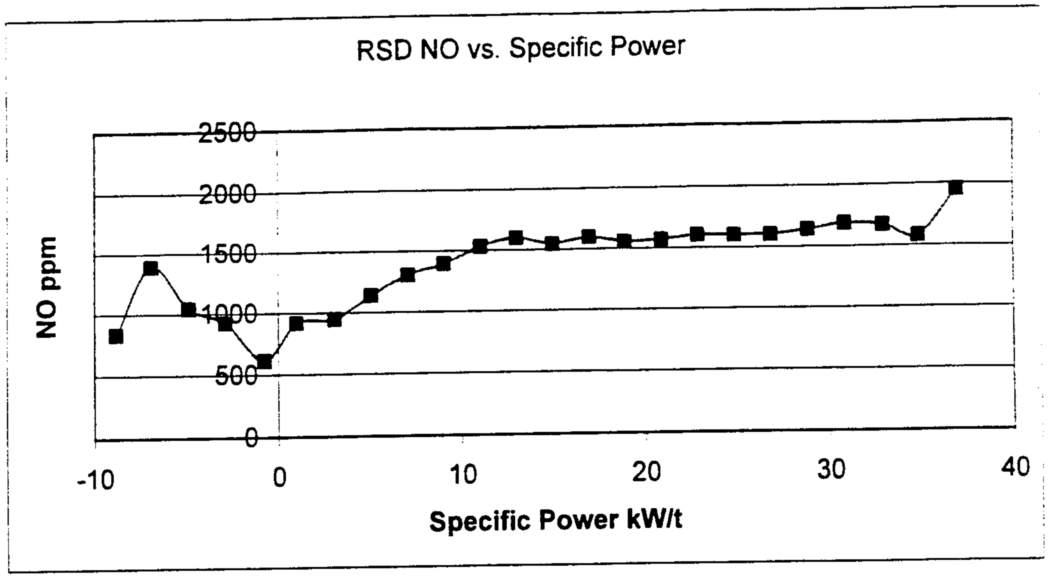


Figure 4-4 Average NO vs. Specific Power



Jimenez has observed that some recent modern cars go into enrichment at powers soon after the FTP maximum of 22kW/t. To avoid incorrectly classifying vehicles under heavy load or negative loads as high emitters, it is suggested that only RSD readings with specific power measurements in the range of 5 to 25 kW/t be used for high emitter identification and fleet characterization. Higher loads may be practical for identifying high emitters in combination with elevated cutpoints.

4.3. Cold Start Emissions

When vehicles are cold, the fuel air mixture is enriched to help combustion and the catalytic converter does not operate effectively. When a vehicle starts from a cold condition, we speculate that initially there will be heavy HC enrichment and no catalytic converter activity – thus the vehicle will emit high HC and CO. In some vehicles, the catalytic converter may begin to function before the enrichment cycle is complete and convert the excess HC to CO. In this case the vehicle may emit lower HC and higher CO.

To a remote sensing unit, these cold vehicles may appear as super emitters. When the remote sensing unit is being used to identify gross polluters or to determine fleet characteristics, it is desirable to avoid this mistaken identification. In most enhanced I/M programs, 'cold' vehicles are given a second chance to pass the test after conditioning.

Sites were selected to avoid cold starts.

4.4. RSD Unit Accuracy

The RSD accuracy specification 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 system automatically compensates for background emission.

The system measures the speed and acceleration (deceleration) of the vehicle approximately co-incident with emission generation to within:

a) ±0.5 MPH within the test range of 0 to 70 MPH;

b) ±0.3 miles per hour per second from 0 to 50 MPH and ±0.5 miles per hour per second from 51 to 70 MPH.

Early development of RSD focussed on high emitter identification. Consequently, RSD unit calibration was designed to assure reasonable accuracy over the entire range of emissions from low to high. With increasing focus on fleet characterization, it is now more important to have greatest measurement accuracy in the range where a majority of the vehicles fall; i.e., the lower end of the range.

An audit of the unit in November 1998 conducted by trailing HC and CO calibration gas blends behind an adapted truck, determined that the HC channel was negatively biased by about 50ppm at the zero point and the CO channel was reading slightly low. Figures 4-5 and 4-6 show the results of the audit runs for the unit using the lower range calibration gases. Unfortunately, the unit was not audited using NOx blends.

A linear correction has been applied to the HC and CO measured values to remove the biases determined by the unit audit.

Figure 4-5 HC Audit Test Results

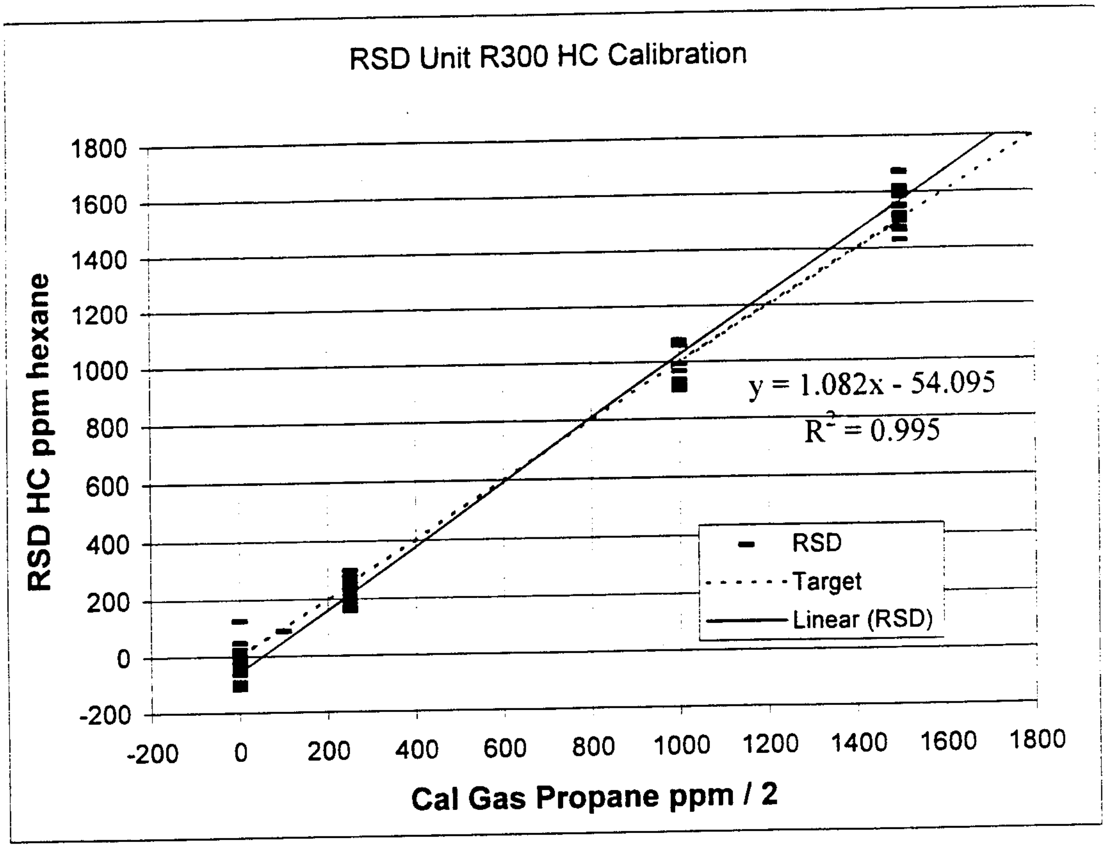
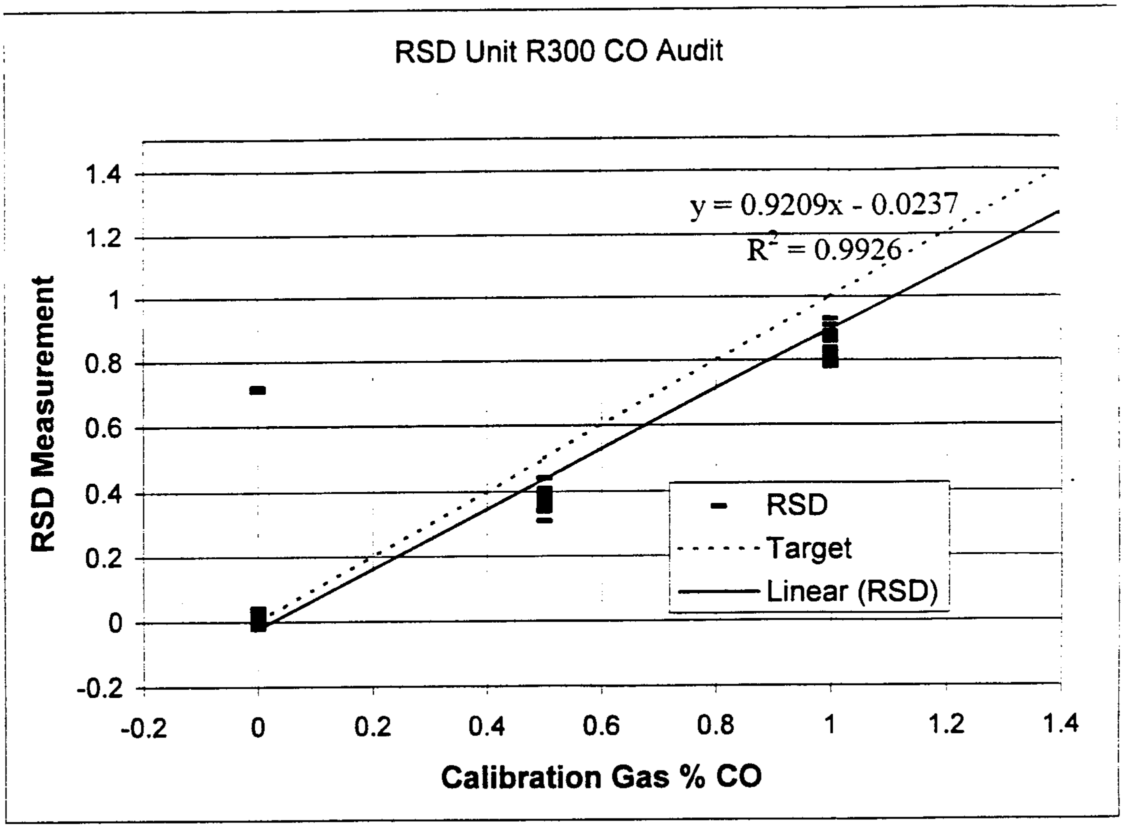


Figure 4-6 CO Acceptance Testing Results



4.5. Site Differences

The comparison of results from different sites has posed some difficulty with RSD. Since emission levels vary with specific power and the specific power of vehicles varies from site to site, RSD results from multiple sites are not directly comparable. This section provides a solution to this problem.

Figure 4-7 'Specific Power Distribution of Measurements by Site' shows the frequency of RSD measurements by specific power at each of the five primary sites. Measurements from these sites generally fall within the desired specific power range of 5 to 25 kW/t with a typical mean of about 15 kW/t. This compares to an average positive specific power of 8.5 kW/t in the IM240 test cycle.

Figure 4-8 Site Average CO %'s vs. Specific Power compares the average CO emissions of the different sites over the selected load range. The results from the different sites show similar patterns of variation of CO emission concentrations with specific power at each site. This suggests that site independent correction factors can be applied to RSD measurements to adjust them to be equivalent to a particular specific power and thus eliminate site bias.

The curve fit equation shown in Figure 4-8 was used to ratio the CO values to the 15kW/t equivalents shown in Figure 4-9. The adjusted values are reasonably independent of specific power over the selected range although small residual gradients are evident on some sites. This may indicate the on-road specific power equation still needs some fine tuning.

Figure 4-2 indicated that HC concentrations were relatively flat over the specific power range and no adjustment was made to HC values.

For NO, a linear adjustment was applied to RSD measurements made at a specific power of less than 12 kW/t. Above this value, the values are reasonably flat as shown in Figure 4-10. Site D3 appears unusual in that NO values did not decline at lower values of specific power. Therefore, NO values from site D3 were not adjusted.

Figure 4-7 Load Distribution of Measurements by Site

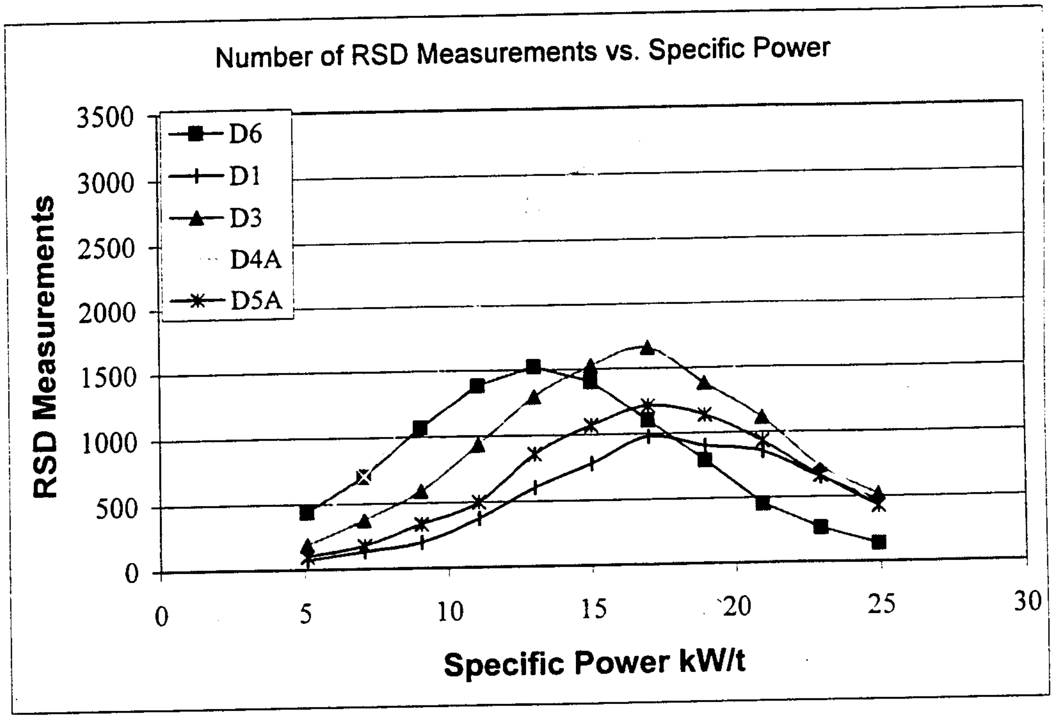


Figure 4-8 Site Average CO %'s vs. Specific Power

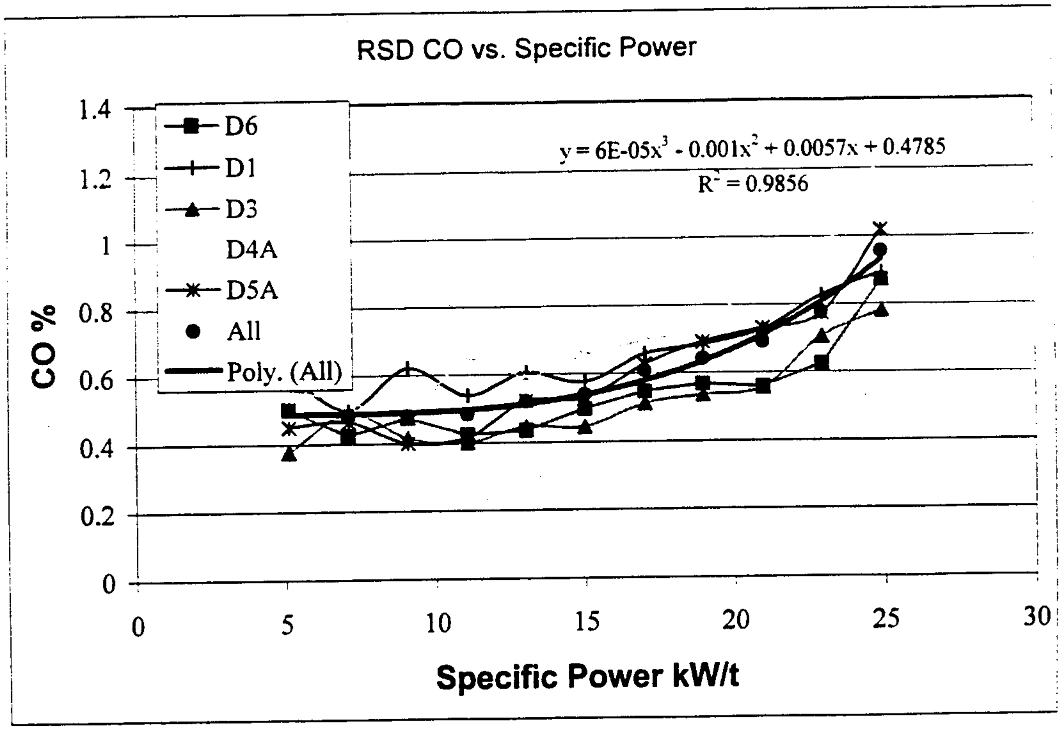


Figure 4-9 CO %'s After Adjustment for Specific Power

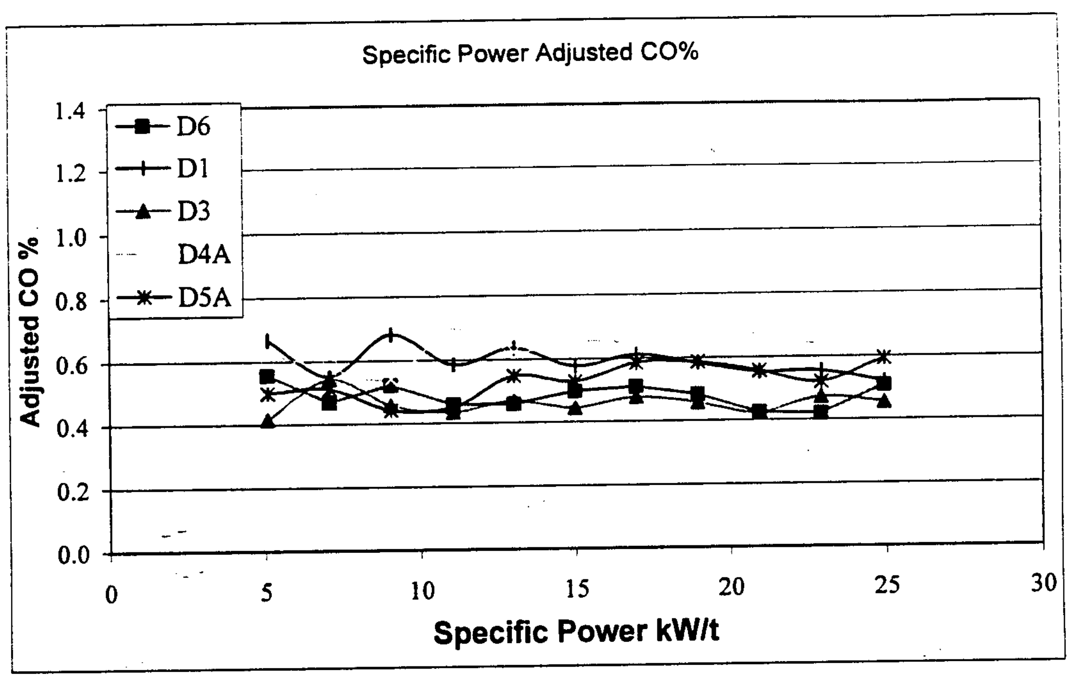
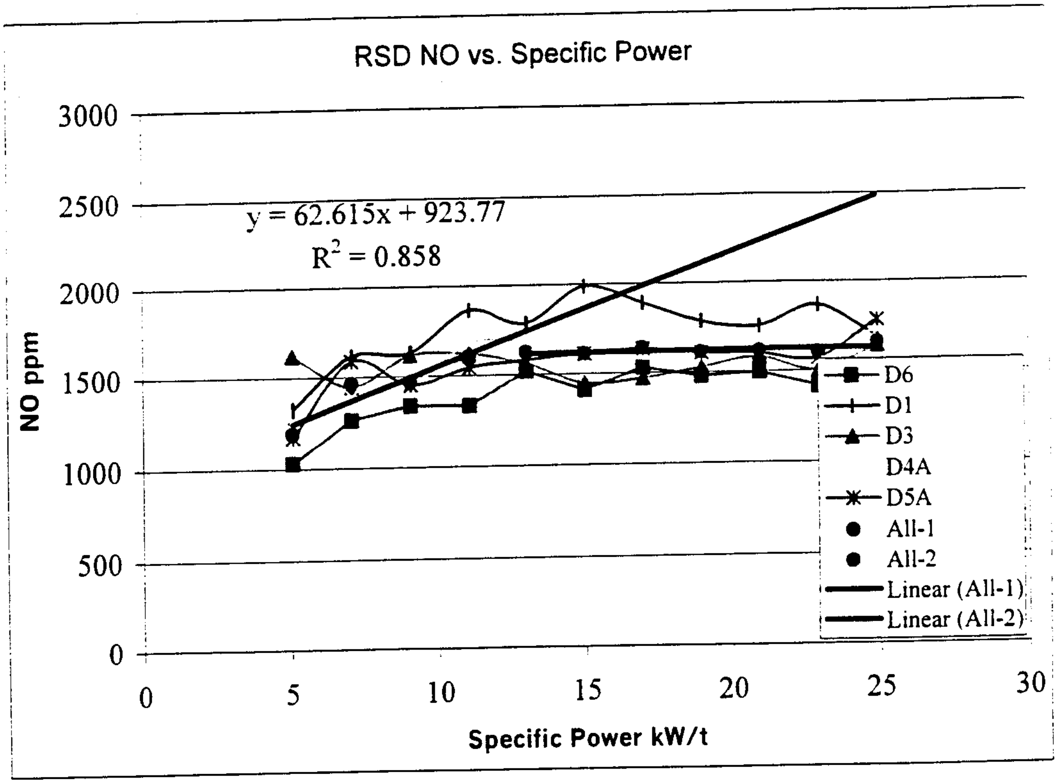


Figure 4-10 Site Average NO vs. Specific Power before Adjustment



4.6. *Ambient Conditions*

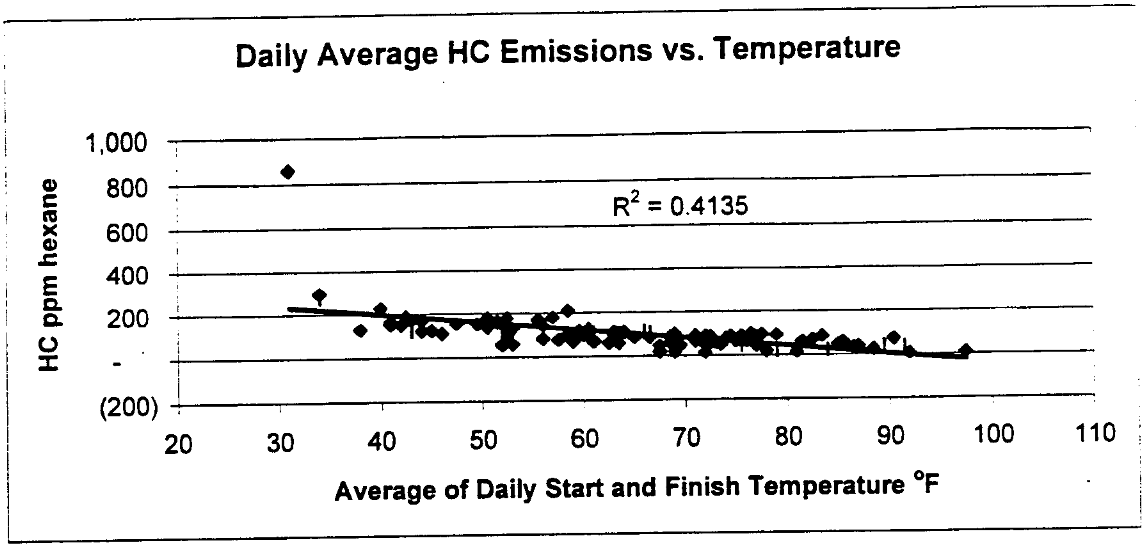
To offset the effects of changing conditions, RSD units are routinely calibrated every hour, and more frequently if the signal strength on the I/R reference channel changes by more than a preset amount.

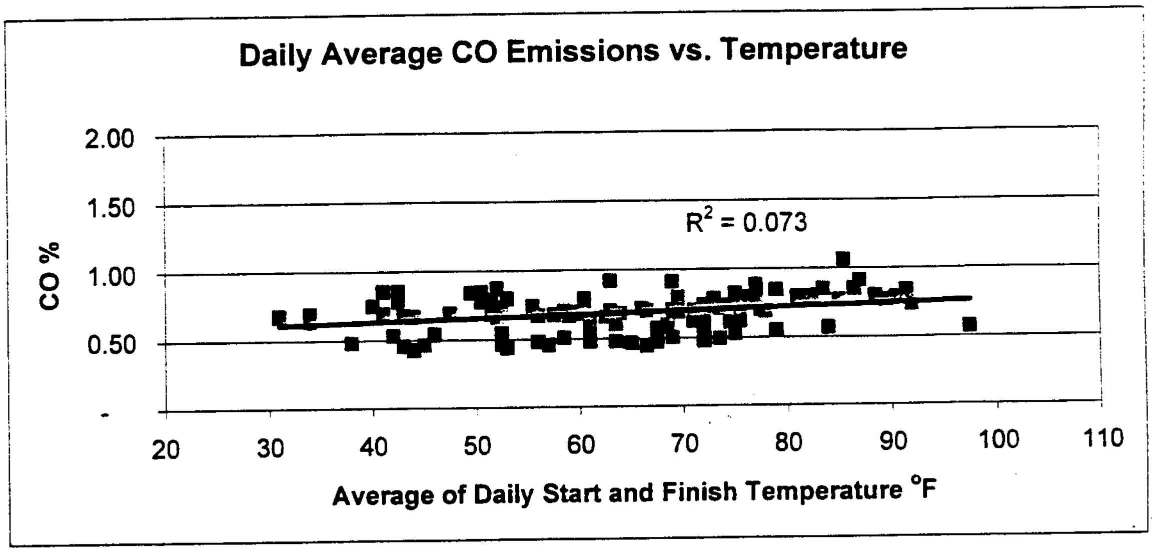
Vehicle performance and emissions may change with ambient conditions. Figure 4-11 charts the daily average emission values vs. the average of the temperatures recorded at the start and finish of each day of RSD operation. Weak correlations of emissions with temperature are observed for CO and NO, and a stronger correlation for HC. The high HC value is from site D7 on 2/4/98, which was previously mentioned.

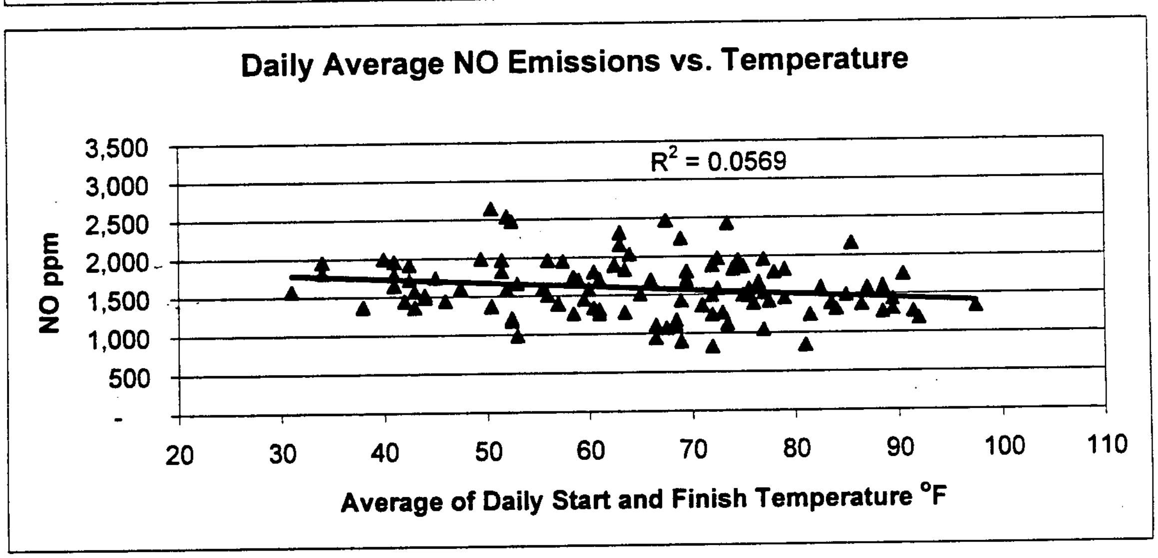
No adjustments for ambient conditions have been made to the RSD emission values reported here. In I/M programs, HC and CO measurements are not usually adjusted to account for ambient temperature and humidity but NO measurements are. For example, I/M 240 test raw measurements of NO are automatically adjusted to account for ambient temperature and humidity using EPA specified factors. Depending on the purpose of the RSD measurements it may be appropriate to make similar adjustments for ambient conditions.

At present, ambient conditions are not recorded with each RSD measurement. To facilitate future research, it is recommended that temperature, humidity and barometric pressure should be recorded at least hourly and interpolated values be stored with each RSD measurement.

Figure 4-11 Daily Emissions vs. Temperature







5. Vehicle Emissions

5.1. *Fleet Emission Percentiles*

The following three charts show the emission percentiles for HC, CO and NO from sites D1, D3, D4A, D5A and D6 for vehicles measured in the 5 to 25 kW/t range. In the case of CO and NO, values are shown adjusted and unadjusted for specific power. The curves for the adjusted and unadjusted values are sufficiently close that they mostly overlay each other. In the case of CO, the adjusted values are slightly lower. In the case of NO, the adjusted values are slightly higher. Average emission values were 79ppm hexane HC, 0.55% CO and 1617ppm NO. Unadjusted values for CO and NO were 0.60% and 1,587ppm respectively.

Average NO levels may be half these values over a complete driving cycle such as the IM240. The NO channel used was less accurate than the most recent technology and valid measurements were achieved on only 45% of vehicles. Negative values in Figures 5-1 to 5-3 result from noise in the RSD system. For HC and CO the range of negative values is consistent with the accuracy of the RSD device specified in section 4.4. For NO, it is clear that some measurements fall outside the expected range and indicate a problem with the accuracy of the NO channel on the RSD unit. The plot of RSD vs. IM240 results in section 6 suggests the RSD NO results overall are biased high.

The dirtiest 10% of vehicles for each pollutant emitted 63% of total CO, 47% of total HC and 32% of total NO. Emission levels for these dirtiest 10% were six times dirtier for HC and CO than the fleet average at 3.5% CO and 446ppm HC. The 10% of vehicles with the highest NO levels averaged 5,330ppm NO.

Figure 5-1 HC Percentiles

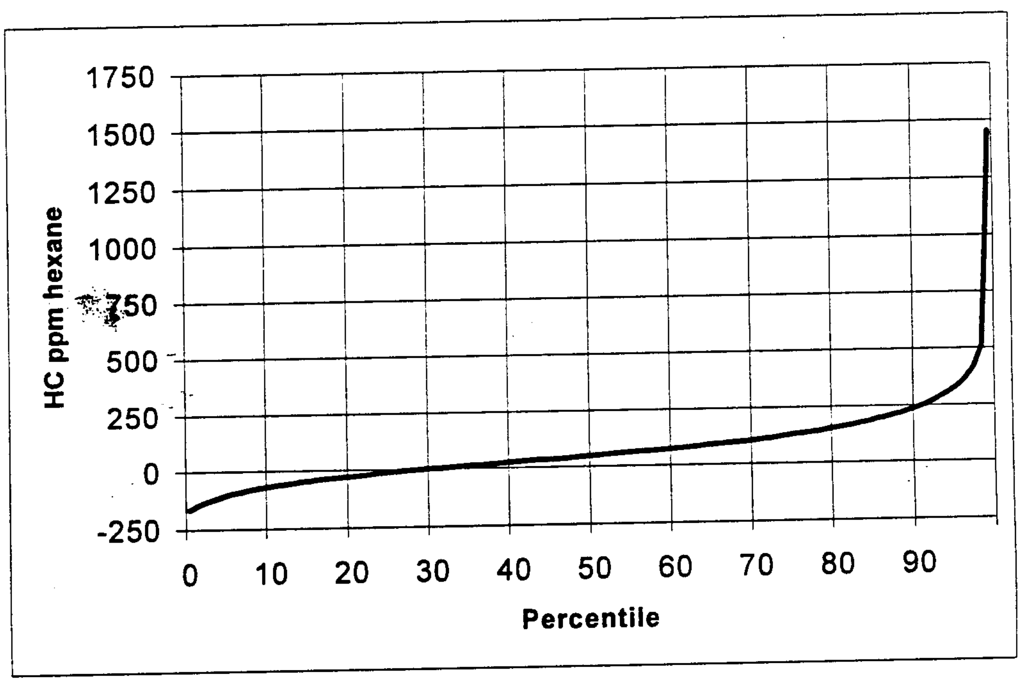


Figure 5-2 CO Percentiles

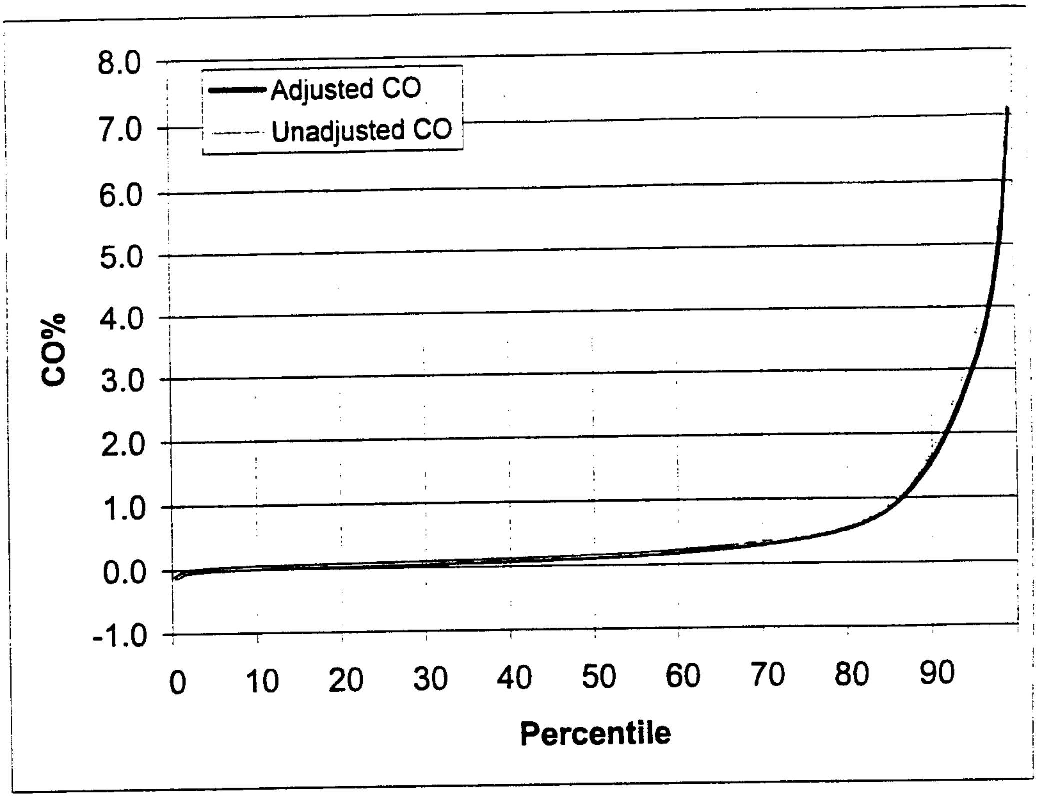
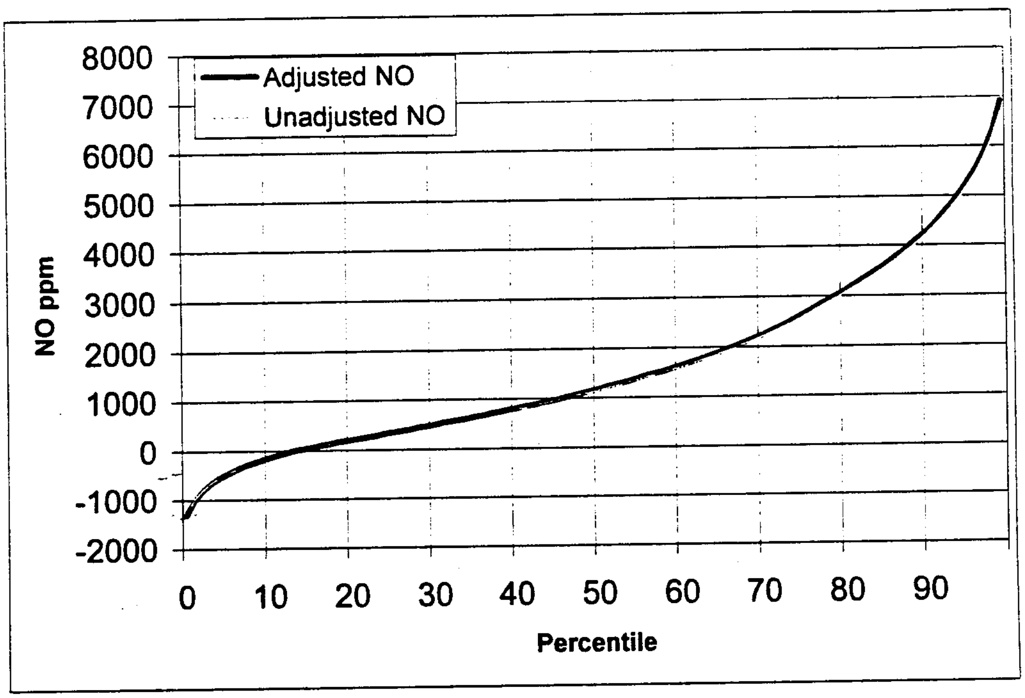


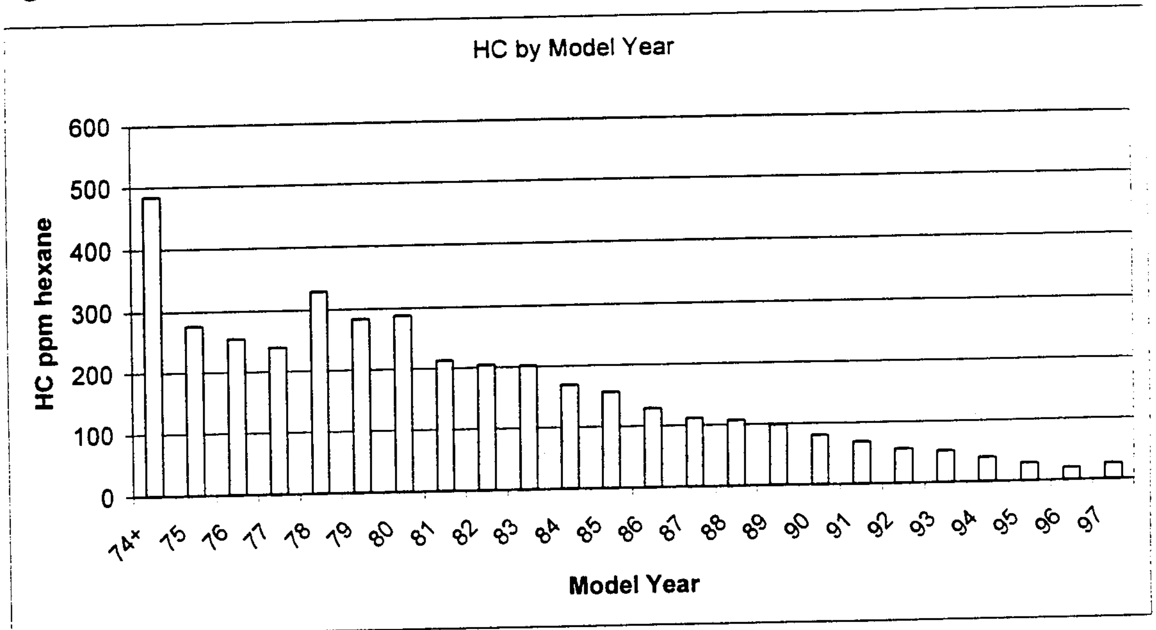
Figure 5-3 NO Percentiles



5.2. *Emissions by Model Year*

Emissions by model year follow the typical pattern for HC and CO. The average emissions of the worst 10% of vehicles in each model year have been included as these may provide a more sensitive indicator of the high emitters in the fleet.

Figure 5-4 RSD HC Emissions by Model Year



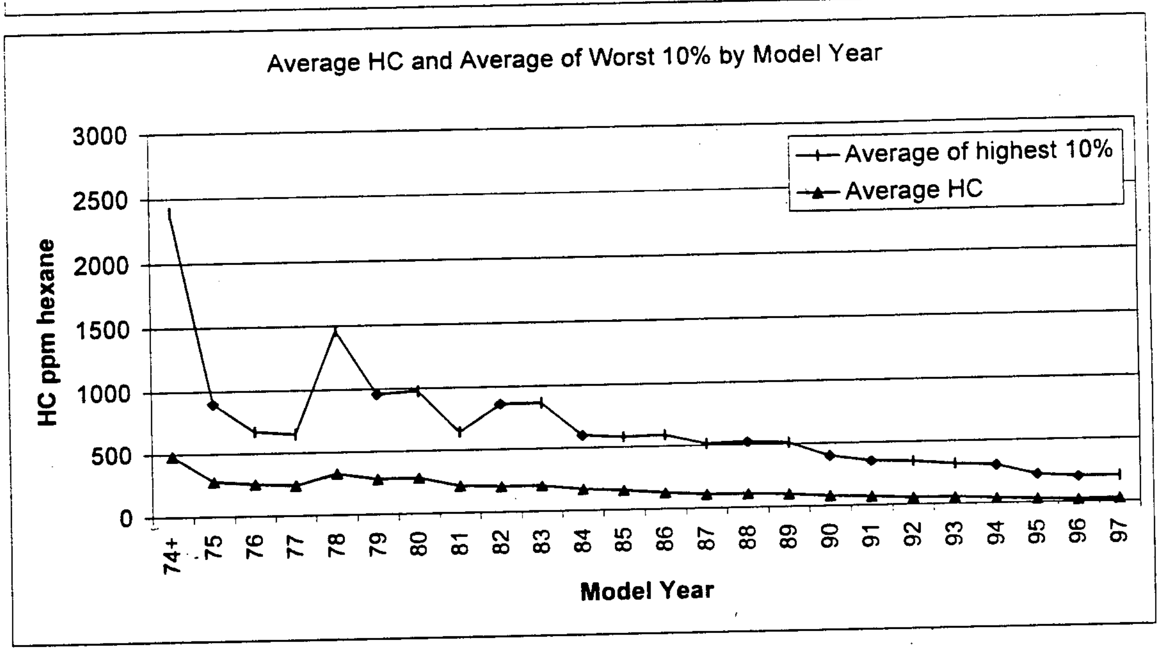
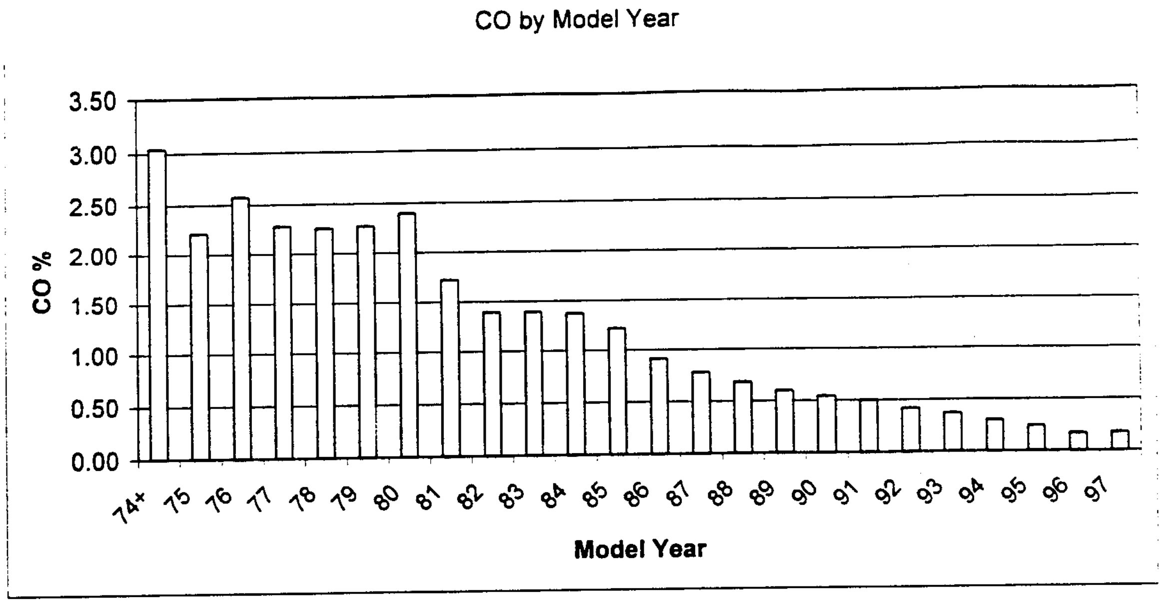


Figure 5-5 RSD CO Emissions by Model Year



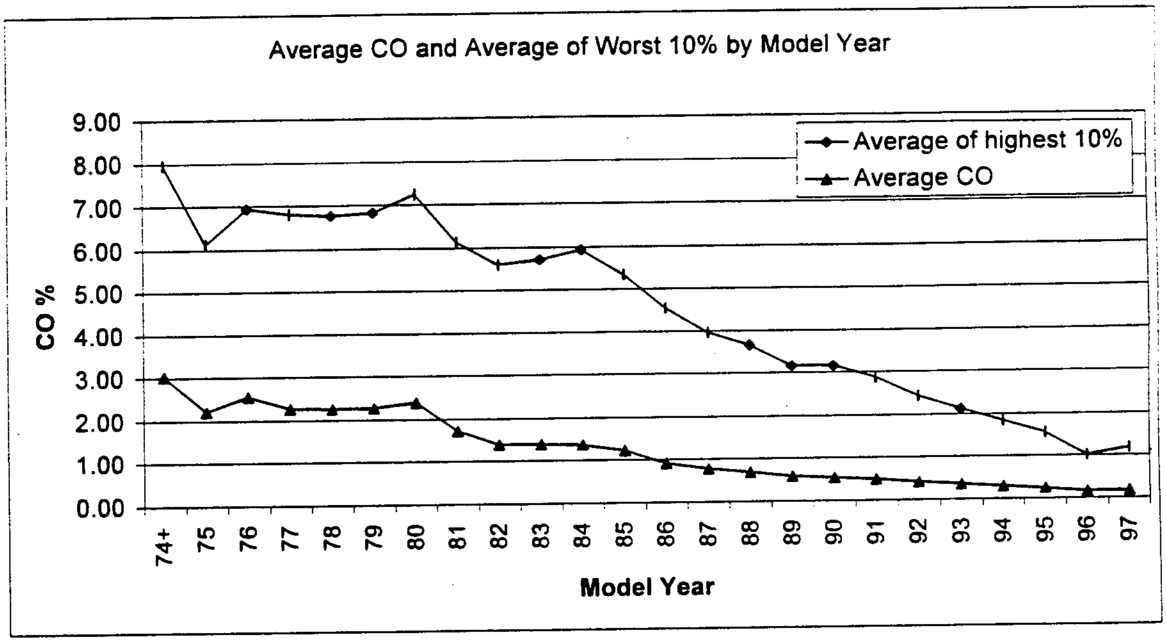
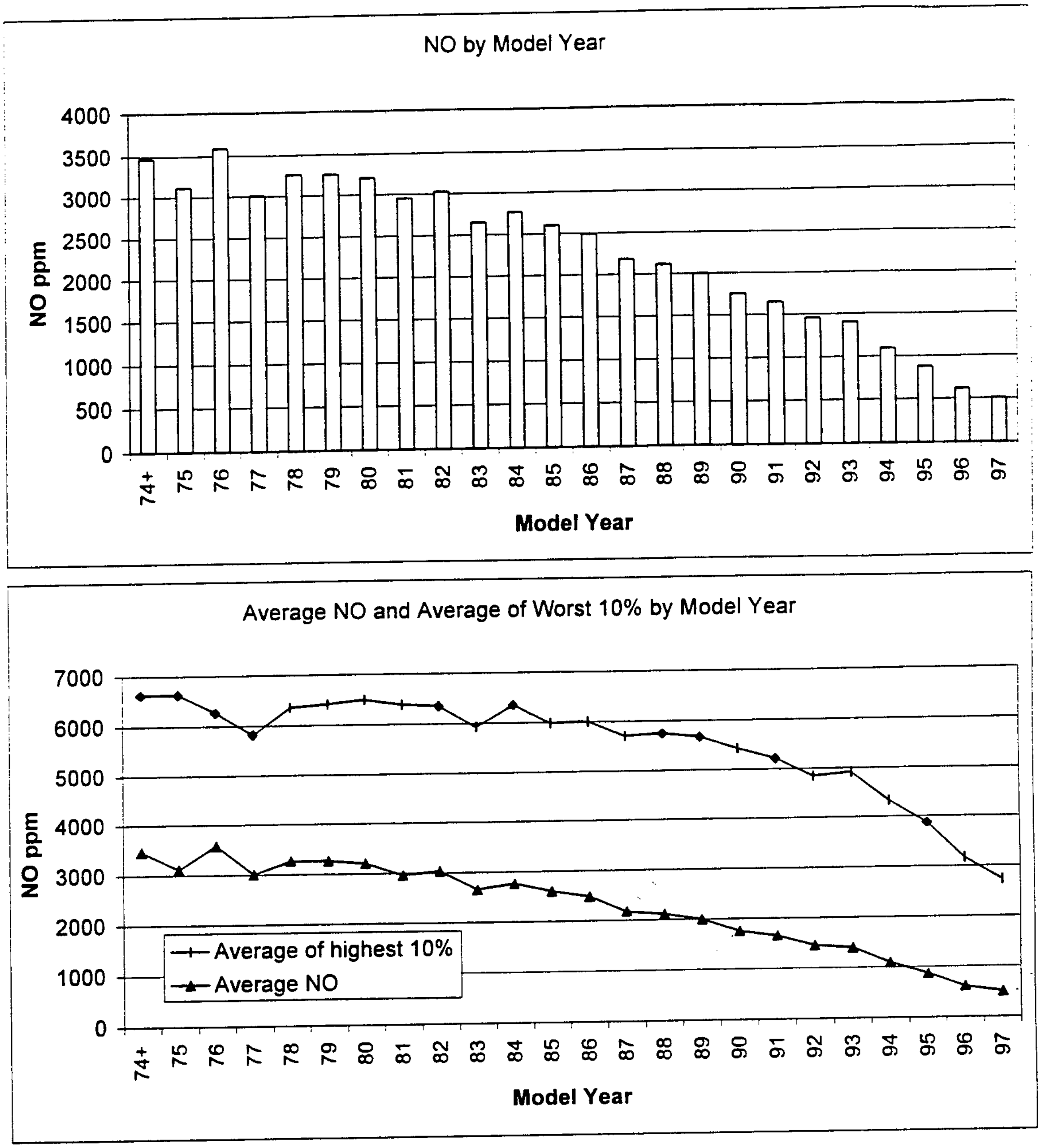


Figure 5-6 RSD NO Emissions by Model Year



5.3. Emissions by I/M Area

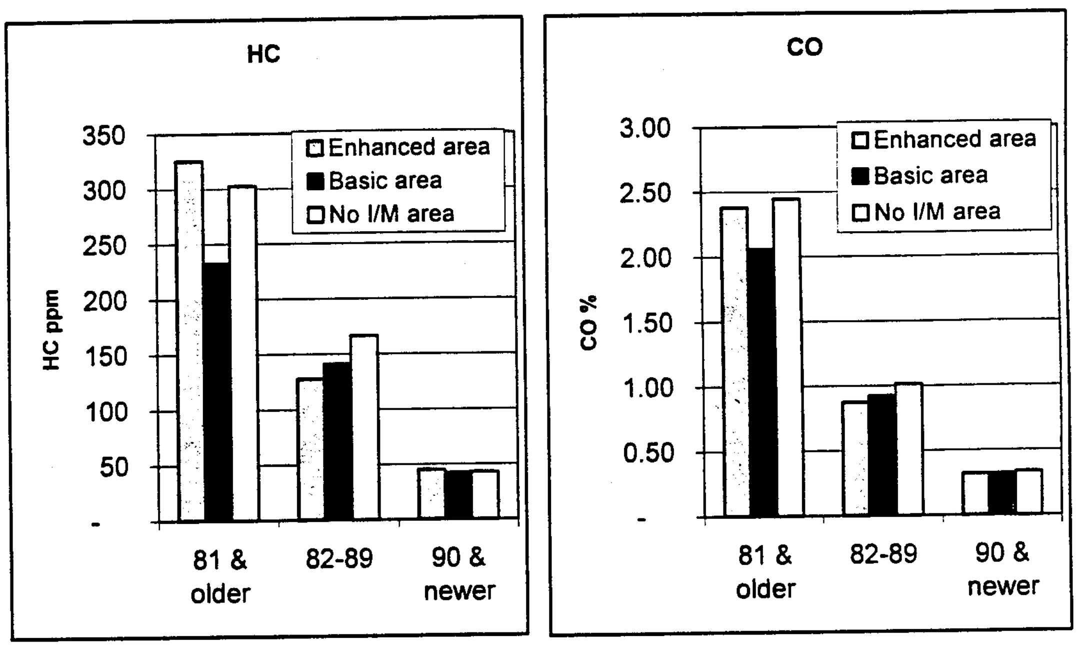
Valid RSD measurements for vehicles operating within the 5-25kW/t range at the five primary sites were sorted by I/M area using the county of registration in matching DMV records. A small number of vehicles were identified as being registered to the Basic I/M counties and No I/M counties as indicated in Table 5-1. The table also shows the average emission levels for the three pollutants.

Table 5-1 Average Fleet Emissions by I/M Area

I/M Area	HC & CO Tests	NO Tests	CO %	HC ppm	NO ppm
Enhanced	45,651	29,675	0.55	78	1,534
Basic	1,629	1,000	0.58	80	1,652
No I/M	1,471	945	0.68	97	1,637

Vehicles registered to the Enhanced I/M area had lower average emissions in all three pollutants followed fairly closely by vehicles registered to the Basic I/M area. When vehicles are separated into three model year ranges, shown in Figure 5-7, it becomes apparent that the lower overall emissions in the enhanced area are a result of lower emissions in the 1982 to 1989 model year vehicles. This group of vehicles also creates the majority of the excess emissions (see Table 7.2).

Figure 5-7 RSD HC & CO Emissions by I/M Area and Model Year Range



Emission levels by model year are shown in Figures 5-8 through 5-10. In the Basic I/M and No I/M counties, there are fewer than 15 RSD measurements per model year for 1981 and earlier vehicles.

The charts show reduced levels of HC and CO in the 1981 to 1985 model years in the I/M areas. There appears to be a biennial pattern in the average emissions of vehicles registered to No I/M counties. It is possible this results from some dirty vehicles that have changed their registration jurisdiction rather than pass the Enhanced I/M inspection. Additional follow-up and larger samples are required to more accurately compare the emissions of the Enhanced, Basic and No I/M areas.

Figure 5-8 RSD HC Emissions by I/M Area

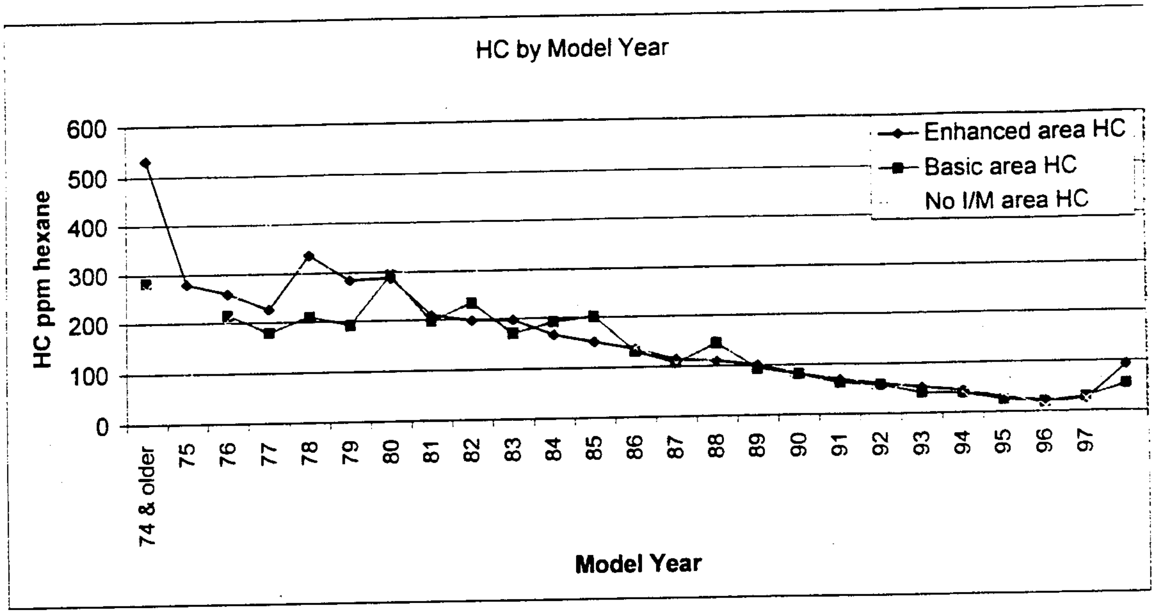


Figure 5-9 RSD CO Emissions by I/M Area

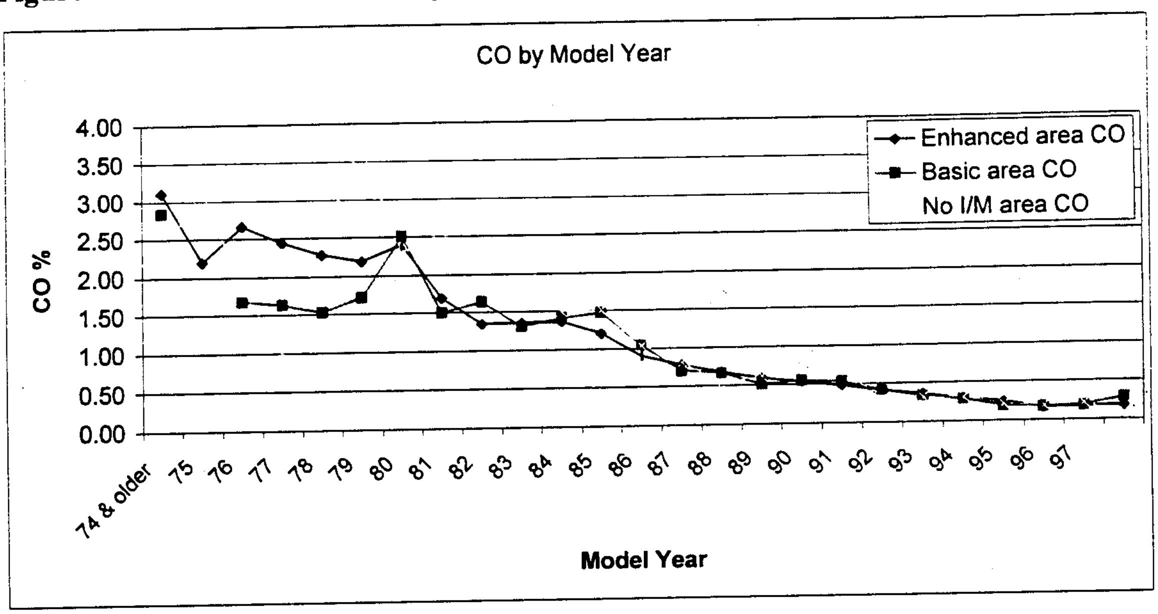
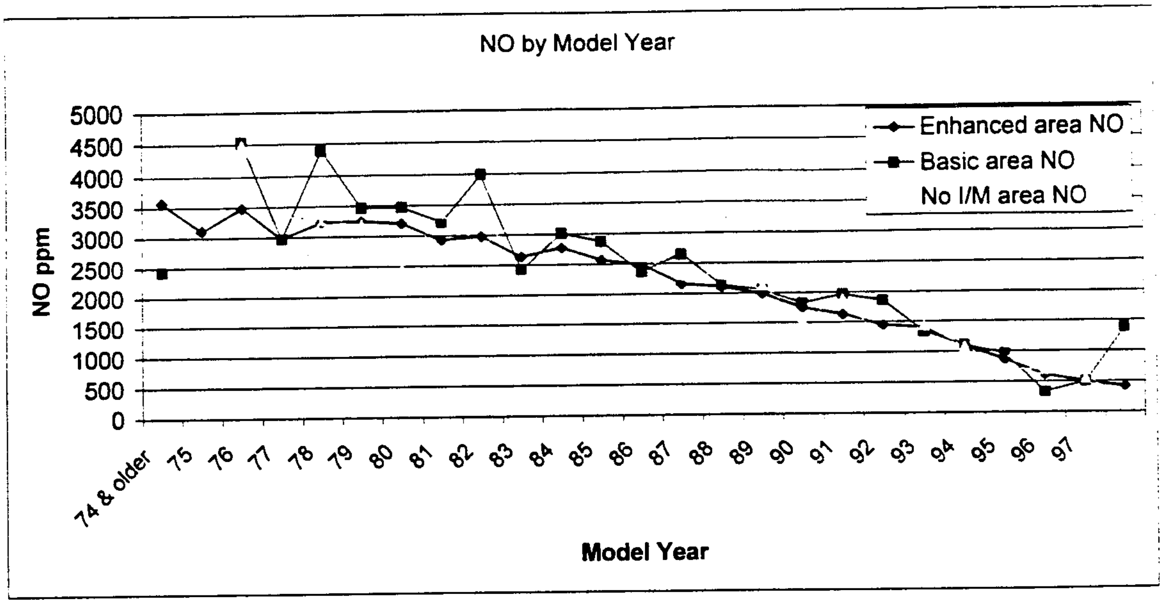


Figure 5-10 RSD NO Emissions by I/M Area



6. RSD vs. IM240 Comparisons by Model Year

The RSD measurements were matched to initial IM240 tests conducted in the Denver area centralized I/M program. To avoid the effects of changes in emission levels from vehicles repaired as part of the I/M program, RSD measurements were identified that occurred prior to an initial IM240 test and fell within the selected specific power range of 5 to 25 kW/t. Measurements from site D7 were also not included in the selection. This resulted in just over 10,000 vehicles with RSD HC and CO measurements prior to the IM240, and 7,000 vehicles with RSD NO measurements.

In Figures 6-1 through 6-3, each point represents a model year from 1982 through 1997. There is strong correlation between the average RSD measurements and the average IM240 measurements for all gases. RSD results for CO and NO are adjusted to a specific power of 15 kW/t although this adjustment made no difference to the R^2 values.

The largest variations in the HC results come from the three oldest model years for which there were a fewer number of vehicles in the sample. For example, the 1982 model year sample, which is the highest point on the IM240 axis, contained results from just 82 vehicles. It is also probable that vehicle HC emissions are the most variable of the three pollutants.

The excellent correlation for NO is surprising considering the limited accuracy of the RSD NO channel. A projection of the trend line does, however, suggest a positive bias of 250ppm in the RSD NO values.

The charts suggest that RSD can be used to assess average fleet emissions.

Figure 6-1 RSD vs. IM240 HC by Model Year

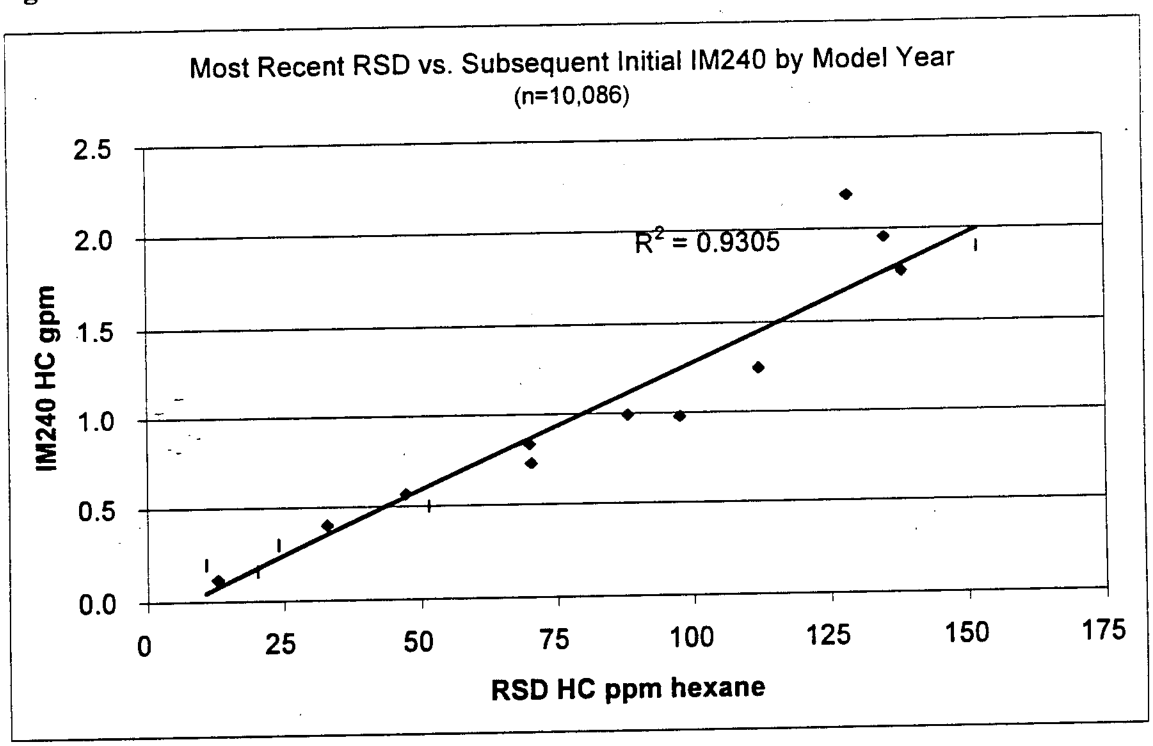


Figure 6-2 RSD vs. IM240 CO by Model Year

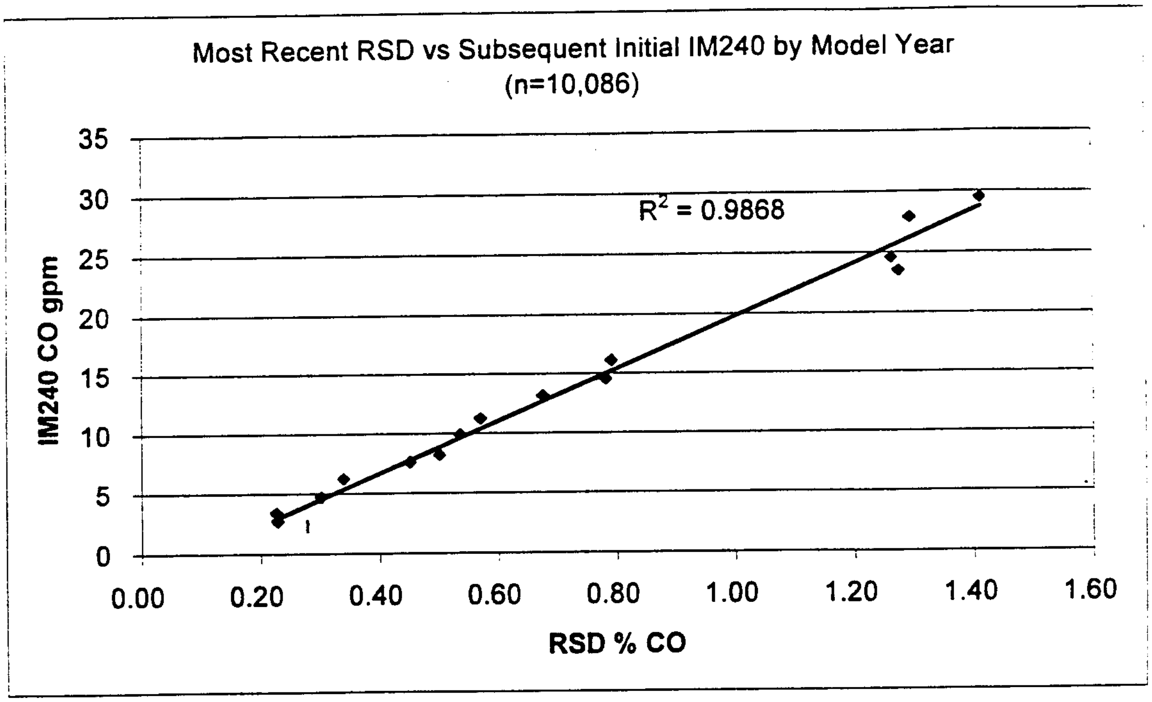
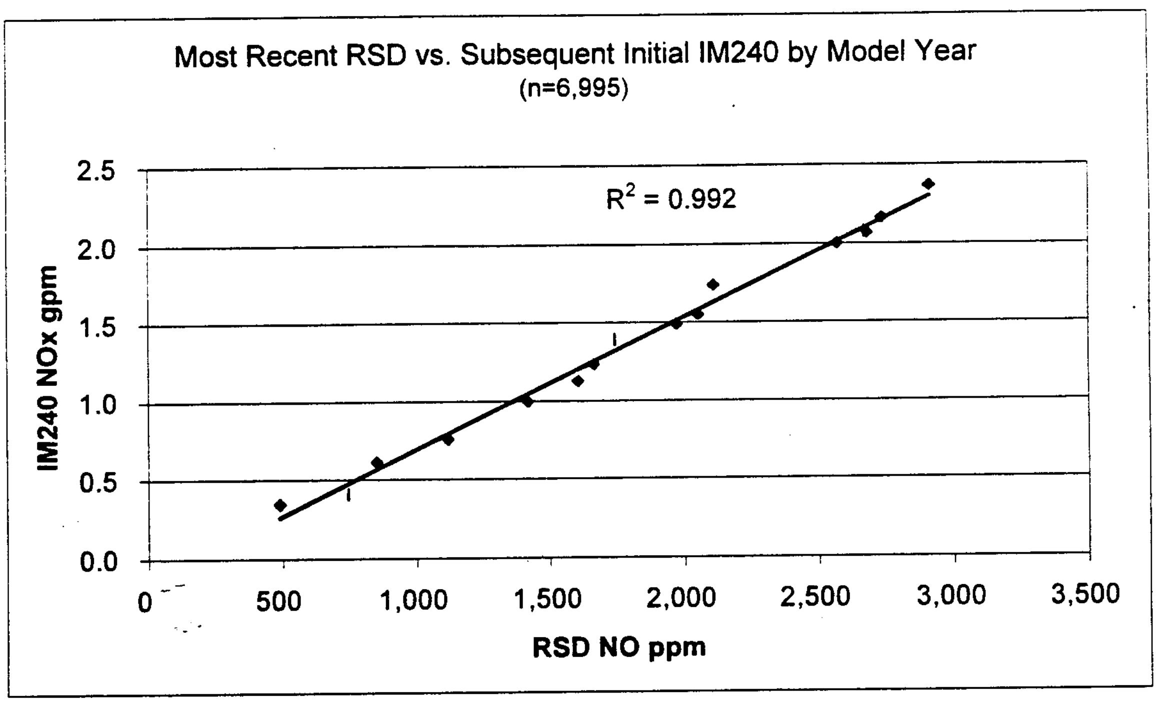


Figure 6-3 RSD vs. IM240 NO by Model Year



7. Identification of Vehicles Failing the IM240 Test

If RSD is used extensively for high emitter identification, it is likely that the high emitters identified will be subject to a follow-up I/M test. Comparison to subsequent IM240 results is therefore a useful exercise because the sources of differences between the test results will need to be understood and explained.

Data limitations and changes in vehicle performance create considerable differences between RSD measurements and the results of IM240 inspections conducted several months later – especially for high emitters. For example, pre-I/M tune-up and repairs alone will create many instances in which a vehicle is correctly identified as a high emitter by RSD and yet subsequently passes an IM240 test.

The results presented in this section demonstrate that using I/M tests conducted several months after an RSD measurement is not a good way of assessing the effectiveness of RSD in identifying high emitters. Rather they point to the need for a greater understanding of vehicle owner behaviour and variations in vehicle performance over time. At the same time, the comparison does offer qualitative information on the effectiveness of various RSD cutpoints and points to some areas for further study.

7.1. Inaccuracies in IM240 results and Vehicle Variability

A majority of vehicles passing the IM240 inspection are deemed to have passed the inspection before completing the full 240-second cycle. For these 'fast-pass' vehicles, projections are made of the gram per mile emissions they would have achieved over the full 240-second cycle. The average projection error is typically about 15% of the final standard. A majority of newer vehicles fast pass after 30 seconds.

Second, there is the question of the variability in vehicle performance. The 'Phase Two Study of Preconditioning Effects in IM240 Testing' presented by Sierra Research at the 13th Annual Mobile Sources/Clean Air Conference reported 47% of vehicles failing an initial IM240 test at final standards passed on a second test, and concluded that false failures due to preconditioning are more prevalent in vehicles failing the final IM240 standards than in vehicles failing the start-up standards. Therefore, even if the RSD unit was 100% accurate and the IM240 test followed very soon after the RSD measurement, one should not expect 100% agreement because of variability in vehicle performance during the IM240 test. This variability is most likely to occur during the early part of the test when many newer vehicles fast pass.

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

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:

- Natural vehicle deterioration over time;
- Repairs made by vehicle owners in response to poor vehicle performance or breakdown;

- Repairs to the vehicle made prior to a scheduled I/M inspection;
- Repairs to the vehicle following failure of a scheduled I/M inspection.

When evaluating RSD vs. IM240 tests by comparing results from RSD measurements made within a year prior to the IM240 test, one should expect to see an apparent false pass rate of about 3% on vehicles passing an RSD clean screen cutpoints. Using the same data for high emitter evaluation, one may see apparent errors of omission of 25% and errors of commission of 40% solely as a result of changes in vehicle condition between the RSD measurement and the IM240 test. Hence one 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 improves as the time gap between the RSD and IM240 reading is reduced.

7.3. 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.

Due to a year 2000 computer systems project at the Colorado Department of Revenue, which maintains the motor vehicle registration records, a temporary suspension of the communication of registration changes from Department of Revenue to Envirotest occurred at the beginning of 1998. Therefore, for RSD measurements made in the first quarter of 1998, there was an increased chance of incorrect plate to vehicle matching.

If typically 20% of owners change vehicles each year, then the three month delay could have affected 5% of vehicles measured during this period.

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 is not yet available but is expected to be available in 1999.

7.4. RSD vs. IM240 Comparisons

Table 7-1 shows IM240 total and excess emissions by model year range for the matched vehicles with one or more prior RSD measurements. Table 7-2 shows the same data for a smaller sample of vehicles that had two or more RSD measurements prior to IM240 testing. The sample with two RSD measurements is more biased towards new vehicles - a result of the higher mileage driven by this group. Excess emissions are calculated as the amount above the final high altitude IM240 test standards[1]. The final standards are generally more stringent than the in-use standards in the I/M program and the projected failure rates are higher than those actually experienced. One exception to this is the high altitude final CO standard for light trucks of 60 grams per mile.

The I/M data indicate excess HC is 22% of total HC but excess CO is only 11% of total CO. This may result from a combination of the enhanced I/M program's strong emphasis on CO reduction and the rather loose high altitude CO standard for 1984 and newer trucks. The 82-89 vehicles produce about 80% of both the excess HC and excess CO. We have focussed only on a comparison of HC and CO.

Table 7-1 IM240 Sample Matched to One or More RSD Measurement

MYR	Sample Vehicles	% of Sample	Sum of IM240 HC gpm	Sum of IM240 Excess HC gpm	%	Sum of IM240 CO gpm	Sum of IM240 Excess CO gpm	%	Projected IM240 Final HA Std Fail %
82-85	940	9.3%	1,763	642	36%	23,809	4,156	17%	49%
86-89	2620	26.0%	2,558	610	24%	35,047	4,282	12%	26%
90 & newer	6527	64.7%	2,675	272	10%	40,470	2,045	5%	6%
Total	10087		6,996	1,524	22%	99,326	10,484	11%	15%

Table 7-2 IM240 Sample Matched to Two or More RSD Measurement

MYR	Sample Vehicles	% of Sample	Sum of IM240 HC gpm	Sum of IM240 Excess HC gpm	%	Sum of IM240 CO gpm	Sum of IM240 Excess CO gpm	%	Projected IM240 Final HA Std Fail %
82-85	108	8%	181	63	35%	2,529	391	15%	44%
86-89	320	25%	339	94	28%	4,151	343	8%	34%
90 & newer	878	67%	357	28	8%	5,596	312	6%	7%
Total	1306		877	185	21%	12,277	1,046	9%	16%

Tables 7-3 and 7-4 show the results of using various RSD HC and CO cutpoints to select vehicles that may fail the IM240 test final standards. When two RSD measurements are used as in Table 7-4, the two RSD measurements are averaged. Excess emissions are defined using the IM240 test results as emissions in excess of the final high altitude I/M test standard not the vehicle certification standard. Note that the RSD standards are sometimes specified as 'CO>x **and** HC>y' and sometimes as 'CO>x **or** HC>y'. In the first case, both gas values must be exceeded for an RSD fail determination and in the second case only one of the gas values need be exceeded.

In most cases there were a significant number of vehicles identified as high emitters by RSD that passed the subsequent IM240 test. For the reasons discussed earlier, it is likely that many of these were higher emitters at the time of the RSD measurement.

[1] More rigorously, this should be the amount above the average repair level than can be achieved.

Using two RSD readings does not significantly reduce the differences. There is some reduction in the percentage of vehicles failing RSD and passing the subsequent IM240 at the expense of the percentage of excess emissions identified. Further analysis could determine if this is because the single reading is closer in time to the IM240 test. There appears to be a small group of very high HC emitters above 2000ppm HC that did not get repaired, failed the IM240 test and contributed almost 5% of the excess HC.

Table 7-3 Single RSD Measurement High Emitter Identification

RSD Standard	Vehicles Failing RSD and Failing IM240	Vehicles Failing RSD and Passing IM240	% Excess HC Identified	% Excess CO Indentified
CO>4.0	1.04%	1.57%	12.5%	25.2%
CO>3.5	1.30%	2.17%	15.8%	28.6%
CO>3.0	1.69%	2.98%	19.0%	33.2%
CO>2.5	2.09%	4.09%	22.4%	40.4%
CO>2.0	2.58%	5.24%	26.3%	43.8%
HC>2000	0.09%	0.01%	4.7%	0.2%
HC>1000	0.11%	0.04%	4.9%	0.2%
HC>750	0.18%	0.11%	5.5%	0.4%
HC>500	0.47%	0.48%	10.4%	5.9%
HC>400	0.96%	1.04%	15.9%	11.9%
HC>300	1.99%	2.44%	26.6%	27.2%
HC>250	2.98%	4.12%	37.2%	38.7%
HC>200	4.13%	6.75%	46.9%	44.9%
CO>3.0 AND HC>250	1.07%	1.42%	15.0%	24.4%
CO>2.0 AND HC>200	1.83%	2.59%	21.7%	31.4%
CO>3.0 OR HC>250	3.60%	5.69%	41.2%	47.6%

Table 7-4 Two RSD Measurement High Emitter Identification

RSD Standard	Vehicles Failing RSD and Failing IM240	Vehicles Failing RSD and Passing IM240	% Excess HC Identified	% Excess CO Indentified
CO>4.0	0.61%	0.84%	7.9%	14.9%
CO>2.4	1.68%	3.98%	16.0%	32.9%
HC>500	0.31%	0.15%	3.0%	0.0%
HC>300	1.91%	1.91%	21.2%	9.3%
HC>200	3.83%	5.59%	37.1%	20.3%
CO>3.0 or HC>250	3.45%	3.83%	37.8%	35.3%

Tables 7-5 and 7-6 provide a break down by model year range. This highlights that many of the differences between RSD and IM240 are coming from the newer vehicles, which are more numerous but produce relatively little of the excess emissions. This may be due to the larger number of IM240 results projected from 30-second fast-pass values for these newer vehicles.

Table 7-5 Single RSD Measurement High Emitter Identification by Model Year Group

RSD Standard	MYR	Vehicles Failing RSD and Failing IM240	Vehicles Failing RSD and Passing IM240	% Excess HC Identified	% Excess CO Indentified
CO>2.5	82-85	11.49%	7.55%	35.0%	55.6%
	86-89	3.05%	4.62%	21.3%	41.1%
	90 & newer	0.35%	3.39%	10.0%	24.2%
HC>250	82-85	14.04%	5.96%	43.3%	41.5%
	86-89	4.69%	5.38%	36.9%	46.5%
	90 & newer	0.70%	3.36%	23.6%	16.9%

Table 7-6 Two RSD Measurement High Emitter Identification by Model Year Group

RSD Standard	MYR	Vehicles Failing RSD and Failing IM240	Vehicles Failing RSD and Passing IM240	% Excess HC Identified	% Excess CO Indentified
CO>2.5	82-85	7.41%	12.04%	24.3%	39.4%
	86-89	3.13%	2.50%	14.2%	42.0%
	90 & newer	0.23%	2.16%	3.6%	13.3%
HC>250	82-85	11.11%	9.26%	26.1%	21.6%
	86-89	5.63%	4.06%	37.9%	28.7%
	90 & newer	0.80%	1.94%	30.8%	9.3%

Follow-up analysis should investigate:

- Differences between trucks and passenger vehicles.
- The incidence of vehicle repairs prior to I/M testing;
- The use of different RSD standards for different groups of vehicles;
- Identification effectiveness using various ranges of specific power;
- The role of NO in high emitter identification;

Ideally, the IM240 tests used in future studies should be full length IM240 tests run as soon as possible following the RSD measurements.

A RSD Readings

A.1 Daily Log by Site of Test Times and Readings with valid HC and CO

Date	Site	Tests	% with Valid NO	% With Valid Speed	Average HC ppm	Average CO ppm	Average NO ppm	Average Speed mph	Average Accel mph/s
970408	D4	25	0%	56%	170	0.47		33.1	0.60
970414	D2	21	48%	76%	198	0.55	2,932	38.1	0.25
970415	D1	591	53%	94%	100	0.91	2,231	36.4	1.07
970416	D3	759	39%	84%	62	0.66	1,894	40.7	1.21
970417	D3	845	59%	81%	67	0.58	1,891	36.7	1.03
970418	D3	758	54%	85%	52	0.69	1,699	36.4	0.99
970421	D3	384	39%	84%	112	0.69	2,035	21.7	0.78
970428	D1	493	28%	94%	60	0.72	2,429	36.0	1.03
970430	D3	651	30%	93%	80	0.68	1,949	36.2	1.06
970502	D3	601	33%	93%	56	0.66	1,598	36.4	0.94
970506	D4A	1369	66%	91%	78	0.74	1,836	25.5	1.04
970507	D4A	1384	58%	92%	90	0.73	1,973	25.5	1.00
970509	D4A	1072	57%	94%	91	0.62	1,954	25.6	0.93
970512	D1	486	44%	85%	111	0.92	2,163	33.7	1.41
970513	D1	510	68%	93%	68	0.82	1,873	30.9	1.76
970514	D3	779	21%	92%	47	0.57	2,468	35.8	1.12
970515	D1	543	48%	96%	74	0.80	1,962	30.3	1.76
970516	D3	494	42%	63%	19	0.69	1,788	35.6	1.55
970519	D2A	303	45%	89%	101	0.71	2,318	36.4	1.21
970520	D2A	408	52%	91%	69	0.62	1,374	36.2	1.24
970521	D5A	723	42%	91%	44	0.80	1,805	36.5	1.10
970523	D6	819	47%	94%	58	0.60	1,279	30.0	2.26
970527	D6	568	46%	94%	66	0.48	1,266	29.4	2.11
970530	D3	875	64%	93%	20	0.48	1,076	35.8	0.94
970609	D6	77	52%	95%	59	0.44	995	30.0	2.10
970610	D4	1124	74%	93%	110	0.70	1,113	26.6	1.02
970611	D6	583	55%	95%	51	0.62	1,253	27.4	2.14
970612	D6	626	64%	90%	14	0.48	832	29.4	2.06
970613	D5	736	60%	93%	46	0.70	1,433	35.9	1.14
970619	D1	98	83%	91%	13	0.80	850	31.7	1.52
970620	D4	947	92%	92%	62	0.79	1,244	25.8	0.99
970623	D6	513	80%	95%	48	0.87	1,050	26.7	2.11
970624	D4	972	90%	91%	91	0.70	1,370	26.1	1.10
970625	D3	673	66%	73%	45	0.62	1,574	35.2	0.82
970626	D3	858	66%	93%	24	0.57	1,313	34.5	0.97
970627	D4	882	80%	92%	71	0.80	1,586	25.9	1.13
970630	D1	442	74%	96%	40	0.91	1,579	33.0	1.45
970701	D4	772	74%	92%	68	0.73	1,491	26.5	1.16
970702	D6	589	82%	82%	19	0.51	904	26.9	3.08

970703	D1	609	77%	94%	61	0.79	1,273	31.4	1.93
970707	D5	627	79%	95%	26	0.80	1,273	32.8	1.53
970708	D5	419	75%	82%	34	0.85	1,382	31.7	1.70
970709	D4	949	87%	93%	88	0.85	1,397	26.1	1.14
970710	D5	772	68%	93%	47	0.77	1,492	32.3	1.42
970711	D1	548	82%	96%	58	0.74	1,588	30.5	1.70
970714	D6	633	63%	96%	22	0.55	1,463	27.4	2.34
970715	D3	791	60%	92%	8	0.57	1,341	34.0	1.42
970716	D4	881	68%	92%	73	0.79	1,758	26.4	1.15
970717	D5	463	81%	89%	6	0.74	1,193	32.1	1.40
970718	D2	437	53%	93%	60	1.06	2,158	40.6	1.24
970721	D3	716	66%	93%	25	0.80	1,608	33.9	1.06
970722	D4	770	82%	91%	38	0.77	1,444	26.2	1.31
970723	D5	363	88%	90%	37	0.84	1,280	33.8	1.33
970724	D5	468	84%	94%	37	0.77	1,316	34.1	1.12
970826	D2	201	31%	90%	102	1.60	3,002	42.6	0.67
970915	D4	800	78%	92%	92	0.85	1,829	26.2	1.12
970916	D4	671	86%	90%	67	0.79	1,396	26.2	1.24
970917	D4	804	76%	92%	89	0.74	1,524	26.1	1.23
970918	D4A	879	83%	92%	89	0.74	1,501	26.3	1.13
970926	D4A	863	70%	92%	101	0.76	1,661	26.1	1.14
971001	D6	635	63%	93%	69	0.53	1,503	26.5	2.06
971002	D1	534	65%	93%	85	0.89	1,522	31.2	1.77
971003	D4A	682	83%	92%	96	0.70	1,421	26.5	1.34
971006	D4A	838	82%	92%	115	0.72	1,702	26.6	1.34
971007	D6	632	81%	94%	52	0.50	1,130	26.9	2.26
971008	D5A	430	61%	91%	97	0.69	1,590	31.7	1.99
971009	D5A	447	65%	89%	108	0.63	1,715	38.7	0.71
971010	D3	856	73%	94%	58	0.59	1,179	33.9	1.44
971013	D3	626	60%	91%	92	0.54	1,184	33.1	1.47
971014	D6	663	62%	89%	85	0.48	1,517	26.2	1.95
971015	D3	751	65%	84%	76	0.54	1,321	33.7	1.33
971016	D5A	626	67%	90%	117	0.69	1,463	35.8	1.02
971020	D2A	338	35%	83%	144	0.84	2,643	38.3	1.05
971021	D2A	268	41%	91%	151	0.87	2,543	45.1	0.86
971022	D6	586	66%	96%	107	0.51	1,274	26.3	2.12
971023	D1	567	67%	95%	126	0.77	1,810	30.7	1.77
971030	D3	363	38%	82%	179	0.46	1,402	31.2	(2.28)
971124	D6	498	47%	93%	106	0.48	1,838	25.3	2.01
971125	D6	459	62%	93%	87	0.47	1,518	25.6	2.05
971126	D6	713	52%	94%	126	0.46	1,748	26.0	1.97
971205	D5A	621	46%	88%	299	0.64	1,957	35.3	1.12
971208	D5A	594	55%	91%	157	0.69	1,792	35.3	1.22
980119	D7	607	61%	84%	212	0.70	1,751	22.8	2.77
980120	D7	773	0%	80%	181	0.85		22.5	3.13
980123	D7	677	46%	80%	227	0.75	1,999	25.5	2.48
980126	D8	569	44%	88%	178	0.73	2,479	26.7	1.30
980127	D4A	851	68%	91%	160	0.69	1,975	26.8	1.14
980128	D8	508	62%	89%	166	0.79	1,825	28.8	0.95
980129	D8	527	73%	79%	153	0.84	1,990	29.1	1.51
980202	D1	516	48%	95%	166	0.68	1,964	30.8	1.76

980204	D7	642	66%	83%	860	0.68	1,583	24.4	2.90
980206	D3	750	64%	93%	112	0.54	1,454	33.8	1.34
980209	D3	651	52%	94%	152	0.54	1,453	33.1	1.41
980210	D6	610	57%	92%	124	0.46	1,369	25.9	2.12
980211	D6	596	67%	93%	131	0.48	1,383	26.0	1.98
980212	D8	630	75%	85%	189	0.85	1,729	29.2	1.33
980213	D1	598	72%	95%	156	0.69	1,612	31.0	1.89
980218	D6	606	60%	94%	122	0.43	1,532	26.5	2.03
980219	D5A	600	66%	91%	167	0.67	1,495	35.6	1.00
980220	D1	500	64%	95%	174	0.78	1,923	30.7	1.80
980223	D6	620	63%	93%	116	0.47	1,218	25.5	2.09
980224	D8	561	74%	86%	128	0.80	1,672	28.7	1.18
980226	D1	466	66%	94%	152	0.86	1,655	31.4	1.72
980302	D4A	872	77%	84%	172	0.68	1,572	25.9	1.45
980303	D4A	800	88%	91%	138	0.77	1,379	26.3	1.26
980306	D4A	733	68%	85%	280	0.69	1,812	26.2	1.27
980316	D9	665	50%	82%	171	0.74	1,596	30.2	0.06
980317	D9	447	42%	72%	143	0.67	1,968	33.9	1.78
980323	D5A	546	59%	90%	104	0.79	1,344	34.5	0.97
980324	D5A	721	57%	92%	67	0.67	1,710	35.4	1.04
980326	D10	337	67%	88%	87	0.59	1,118	21.8	0.19
980327	D10	563	83%	90%	88	0.45	955	22.3	0.17
Total / Average		70286	63%	90%	102	0.69	1,581	30.0	1.40

B Data File Formats

.B1 RSD Measurements

File: CRC_RSD

Name	Type	Bytes	Description
Accel_adj	Number (Single)	4	Acceleration adjusted for site slope
Load	Number (Single)	4	Surrogate load
V_VIN	Text	255	Plate matched VIN - link to VTR
R_PLATE	Text	255	
V_PLATE_TYPE	Text	255	
V_ST_MAKE	Text	255	
V_VEH_AYEAR	Number (Long)	4	Model Year
V_CWT	Text	255	
V_BODY	Text	255	
V_ST_FUEL	Text	255	
V_MCITY	Text	255	Registered City
V_MSTATE	Text	255	Registered State
V_MZIP	Text	255	Registered ZIP
V_OCOUNTY	Number (Long)	4	Registered County
V_REG_AYEAR	Number (Long)	4	Registration Expiration Year
V_REG_MONTH	Number (Long)	4	Registration Expiration Month
R_TEST_DATE_TIME	Date/Time	8	RSD Measurement Date Time
R_PERCENT_CO	Number (Double)	8	RSD CO %
R_PERCENT_CO2	Number (Double)	8	RSD CO2 %
R_HC_PPM	Number (Double)	8	RSD HC ppm
R_NO_PPM	Number (Double)	8	RSD NO ppm
R_SPEED	Number (Double)	8	RSD Speed mph
R_ACCEL	Number (Double)	8	RSD Acceleration mph/s
R_SITE_REF	Text	255	
R_RSD_UNIT	Text	50	

.B2 RSD Sites

File: DNVR_Sites

Name	Type	Bytes	Description
ID	Number (Long)	4	Ignore
SiteRef	Text	50	Site Key
Description	Text	100	
Slope	Number (Single)	4	Uphill(+) or downhill(-) degrees
Lo	Number (Long)	4	Ignore
Hi	Number (Long)	4	Ignore

.B3 IM240 Tests

File: CRC_VTR

Name	Type	Bytes	Description
EPA_Type	Text	50	EPA Vehicle Type (LV, LT1, LT2)
Final_Std_HC_CO_R	Text	1	Final HA Standard Projected P/F for HC & CO Only

slt			
Current_HC_CO_Rslt	Text	1	Standard at Test Time
PhaseIn_HC_CO_Rslt	Text	1	EPA Phase-In
Final_Std_HCN_Rslt	Text	1	Final HA Std. - Projected P/F for HC, CO & NO
Current_HCN_Rslt	Text	1	Standard at Test Time
PhaseIn_HCN_Rslt	Text	1	EPA Phase-In
EER_HC_C	Number (Single)	4	Emissions in excess of current standard
EER_CO_C	Number (Single)	4	
EER_NOX_C	Number (Single)	4	
EER_HC_P	Number (Single)	4	Emissions in excess of Phase-in Standard
EER_CO_P	Number (Single)	4	
EER_NOX_P	Number (Single)	4	
EER_HC_F	Number (Single)	4	Emissions in excess of Final HA Std.
EER_CO_F	Number (Single)	4	
EER_NOX_F	Number (Single)	4	
V_DATE_TIME	Date/Time	8	Test Date Time
V_STATION	Number (Long)	4	
V_PROGRAM	Text	1	E - Enhanced
V_VIN	Text	255	Vehicle VIN - Key link to RSD
V_PLATE	Text	255	
V_REG_MONTH	Number (Long)	4	
V_REG_YEAR	Number (Long)	4	
V_VEH_YEAR	Number (Long)	4	Model Year
V_MAKE	Text	255	
V_MODEL	Text	255	
V_TYPE	Text	255	Colorado vehicle type
V_VEH_TYPE	Text	255	P - Passenger, T-Truck
V_CYLINDERS	Number (Integer)	2	
V_GVW	Text	255	
V_DISP	Number (Single)	4	Engine size
V_FUEL	Text	1	
V_TEST	Number (Integer)	2	Test Number 1-Initial, 2+ - Re-test
V_CUST	Text	1	M-Mandatory test, E-Engineering testing
V_HC_STD	Number (Single)	4	
V_CO_STD	Number (Single)	4	
V_NOX_STD	Number (Single)	4	
V_HC	Number (Single)	4	HC grams per mile (projected if FSEC<240)
V_CO	Number (Single)	4	CO grams per mile (projected if FSEC<240)
V_NOX	Number (Single)	4	NOx grams per mile (projected if FSEC<240)
V_CO2	Number (Single)	4	CO2 grams per mile (projected if FSEC<240)
V_EM_END_TIME	Text	255	Not used
V_HC_IND	Number (Integer)	2	
V_CO_IND	Number (Integer)	2	
V_NOX_IND	Number (Integer)	2	
V_EM_FSEC	Number (Integer)	2	Fast Pass Second, Null if no fast pass
V_HC_RES	Text	1	HC emissions result
V_CO_RES	Text	1	CO emissions result
V_NOX_RES	Text	1	NOX emissions result

V_EM_RES	Text	1	Overall emissions result
V_OPAC_RES	Text	1	Opacity
V_FFR_RES	Text	1	Fuel Filler Restrictor result
V_CAT_RES	Text	1	Catalytic converter presence
V_CAP_RES	Text	1	Gas Cap
V_O2_RES	Text	1	
V_AIS_RES	Text	1	
V_ENG_RES	Text	1	Engine Check Light
V_STICKER	Text	255	Sticker number
V_RESULT	Text	1	Overall Inspection Result (P, F, W-waiver)
V_IHC	Number (Single)	4	Initial test HC grams per mile
V_ICO	Number (Single)	4	Initial test CO grams per mile
V_INOX	Number (Single)	4	Initial test NOx grams per mile
V_PEM_RES	Text	1	Previous emission test result
V_ODOMETER	Number (Long)	4	
V_TEST_IND	Text	1	
V_EM_PU_REQ	Text	1	B - indicates IM240 test

.B4 RSD Prior to IM240 Index

File: CRC_Prior3

Name	Type	Bytes	Description
V_VIN	Text	255	IM240 VIN
V_Date_Time	Date/Time	8	IM240 Date Time
Prior1	Date/Time	8	Most recent RSD prior to IM240
Prior2	Date/Time	8	2nd most recent RSD
Prior3	Date/Time	8	3rd most recent RSD
Gap1	Number (Long)	4	Days from Prior1 to IM240
Gap2	Number (Long)	4	Days from Prior2 to IM240
Gap3	Number (Long)	4	Days from Prior3 to IM240

.B5 IM240 Standards

File: Dnvr_FinStd_HighAlt
File: Dnvr_EPA_Phase_In

Name	Type	Bytes	Description
V_Type	Text	255	EPA Vehicle Type
Year	Number (Integer)	2	Model Year
HC	Number (Double)	8	Standard
CO	Number (Double)	8	
NOX	Number (Double)	8	

.B6 County Codes

File: Ocounty

Name	Type	Bytes	Description
V_OCOUNTY	Number (Long)	4	Owner County Code Key
Tests	Number (Long)	4	Ignore - old count of VTR's
Program	Text	1	E - Enhanced, B - Basic, Null - no I/M

Name	Text	50	County name
SumName	Text	50	Name used for summary reporting