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Summary of Status of EPA Office of Mobile Sources Characterization Projects as of March, 1982

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I. Overview and Background

The Pollutant Assessment Program of the EPA Office of Mobile Source Air Pollution Control (OMSAPC)* has focused on expanding the knowledge of pollutants as they are emitted from various mobile sources. This work has been done within OMSAPC, by in-house and extramural programs, as well as monitoring the characterization efforts performed by other organizations both within EPA and by industry and others. Some of the principal guiding objectives of the OMSAPC Pollutant Assessment program can be summarized by the following points.

1. The characterization of pollutants not normally tested and that may represent a human health concern.

   Currently, and in the past, a large amount of effort has been expended by industry and EPA characterizing the hydrocarbon, carbon monoxide and oxides of nitrogen emissions from a variety of engines and vehicles. However, there may be other compounds being emitted by vehicles that may be of concern. Especially of interest would be those compounds that may have a deleterious effect on human health. Some of these compounds would be emitted in varying amounts from uncontrolled as well as controlled engines. Other compounds (such as catalyst attrition products) could be emitted mostly from vehicles which have emission control systems designed to control HC, CO and NOx. Various systems to improve both emissions and fuel economy could have a large impact on unregulated emissions. Since motor vehicle technology is evolving in response to the need for improved emissions and fuel economy, it is critical that OMSAPC characterize new systems for unregulated pollutants. Consequently, the OMSAPC program has been focused on characterizing a broad range of compounds from present and future engine and vehicle technologies.

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* The Office of Mobile Source Air Pollution Control (OMSAPC) is now the Office of Mobile Sources (OMS) as a result of a recent organizational change in EPA.

2. Testing for a variety of pollutants under malfunction conditions.

Much, if not most, of the testing performed by EPA and other laboratories has been done with vehicles and engines tuned to manufacturers' recommended specifications. However, many vehicles that are in use today operate under conditions of tune that do not meet the manufacturers' recommended specifications. This could result in increased emissions of a variety of both regulated and unregulated pollutants, some of which could have negative human health effects. As a consequence, OMSAPC has tested a variety of engines/vehicles for pollutants of concern under malfunction conditions to estimate the impact that such vehicles/conditions would have on the environmental loading of pollutants.

3. Fuel parameters.

Fuel properties can affect emissions. The trends in Diesel fuel quality over the past decade are generally in the direction of poorer emission performance. Therefore, the relationship between fuel parameters and emissions has been, and continues to be, an area of importance.

The future fuel situation in the United States is somewhat unclear in that we are considering the development of a variety of alternate sources of fuel to supplement conventional petroleum sources. These alternate sources include lower grade petroleum crudes, alternative and synthetic fuels derived from coal and oil shale and fuels derived from biomass. These alternate source fuels may have a dramatic effect on emissions and, as such, OMSAPC has performed some characterization on these emissions as well as remained abreast of the field in general. Also, some testing has been done on emissions from Diesel vehicles, as these emissions may be impacted by fuel parameters. This effort will continue in an attempt to more fully characterize the future fuels. This work is of importance in that it helps assure that alternate fuels are environmentally acceptable. One can probably tailor fuel

composition and processes to obtain the maximum cost-effective environmental benefit from these fuels if one does this sort of characterization before these fuels are widely produced.

4. Characterization of pollutants from engines/vehicles that are involved in a transition environment.

   There are many engines/vehicles that are involved in a transition environment created by various market forces, regulatory initiatives, fuel economy incentives, etc. OMSAPC is very interested in characterizing the emissions from these vehicles/engines to be able to evaluate the impact that this transition may have. For example, the heavy-duty engine manufacturers have now currently changed most of their engines from the traditional, naturally aspirated type over to the turbocharged type. Also, there is currently a trend towards Dieselization of both the light-duty fleet as well as the mid-range heavy-duty fleet. Comparative application engines for both of these fleets have been tested so that an estimate can be made of how such a change will impact the environmental loading of pollutants. Also, a variety of other technologies have been evaluated so that their influence can also be estimated.

With these four broad objectives in mind, a variety of programs and projects have been performed. The more recent and more important of these projects are summarized in the following section. The purpose of this report is to provide a discussion of the characterization results obtained since the last summary report on this program (1)* was written in August, 1981. The data in this report are those available from May, 1981 to March, 1982.

* Number in parentheses represent references found in Section V titled "References".

II. Summary and Conclusions

EPA-OMSAPC is conducting a thorough assessment of regulated and unregulated emissions from a variety of current and prototype engines. Extensive work is also underway investigating the influence of various fuels on light-duty vehicle and heavy-duty engine emissions. This latter work includes projects on alternate fuels such as methanol as well as fuels derived from coal or oil shale. The following summarizes the status of the work in this pollutant assessment area as well as some of the more important findings.

1. Eight fuels from synthetic feedstocks were run in a light duty Diesel vehicle (Volkswagen) and the resultant emissions were compared to those from the vehicle operated on a Diesel fuel #2 (DF2) base fuel. The synthetic fuels tested were: 1) a Diesel # 2 Marine fuel processed from shale oil, 2) a Paraho JP-5, 3) a blend representing a combination of shale oil, coal-derived, and petroleum liquids designated "Coal Case 5A", 4) a 35% (volume) blend of SRC-II (Solvent Refined Coal) and DF2, 5) a blend representing the same liquids as number 3), designated "Broadcut Mid-Continent", 6) a 25% (volume) of EDS (Exxon Donor Solvent) with DF2, and 7) a 25% blend of EDS Naptha with DF2.

   The results of this work showed that HC, CO and NOx generally increased with the use of the synthetic fuels tested. The greatest increases came with the use of coal liquid blends. Particulate emissions were generally somewhat higher over the FTP with the alternate fuels, except for the "Broadcut" fuel which resulted in lower emissions. Smoke levels were generally higher also with the alternate fuels, with coal liquid blends giving the largest increases. Aldehydes were little changed or decreased with the alternate fuels and the same was true of phenols. The only exception was a large increase in phenol emissions with the use of the 25% EDS/DF2 blend. The Ames test bioassay data showed that for almost all strains, the revertants per microgram of extract and revertants per kilometer were always higher for the synthetic fuel emissions than from the base DF2. The only exception to this is the Paraho JP-5 fuel which occasionally resulted in lower values.

Comparison of the results of this work with previous fuels variables work shows few consistent trends. However, many of the alternate fuels tested had higher aromatics levels and lower cetane levels than the base fuel. Previous work has shown that this could result in higher emissions of some pollutants. The same trend occurred with the alternate fuels emissions.

2. A project studying the effects of alternate fuels on emissions from heavy duty Diesel engines has been planned and funded. The fuels studied will be selected from the following: DF2 (for comparison), SRC II/DF2 blend, EDS/DF2 blend, DF2 Marine (Shale), DF2/used lubricating oil blend and possibly a vegetable oil. The engine (Mack EM6-300) is at Southwest Research Institute (SwRI) and ready for testing. Testing has been delayed due to higher priority M.A.N. methanol engine work, but will proceed upon completion of the M.A.N. engine testing program.

3. The testing of light duty vehicles using gasoline (for a baseline comparison) and 100% methanol as the fuels is nearly complete and about 70% of the data are reported. Much of the program went well, but there were several problems. For example, the emission results from the Escort were not as repeatable from test to test as were the results from the VW. Also, the promoted base metal catalyst used for the Escort running on methanol was larger than the noble metal catalyst that was used when testing the vehicle in its stock condition. The Escort vehicle designed for methanol developed carburetor corrosion problems because it was not equipped with a methanol-protected carburetor. Also, W.R. Grace sent a promoted base metal catalyst using a foam substrate (usually used for prototype Diesel particulate traps) for use with the VW and this catalyst slowly disintegrated during the testing. Subsequent testing was done with the promoted base metal catalyst used for the Escort. Some of the data from these tests with the methanol-fueled VW may still be valid but some (e.g. the foam substrate promoted base metal catalyst data) will be difficult to analyze.

Tentative conclusions that can be reached at this time from the program are that vehicles can be set up such that they come close to meeting the levels of the emission standards at low mileage for HC, CO, and NOx with an attendant decrease in particulate emissions and individual hydrocarbons. However, we generally see an increase in methanol emissions as well as aldehydes and ketones. The use of a promoted base metal catalyst and methanol as a fuel resulted in low emissions. However, the most complete data are from the Escort, and the fact that the promoted base metal catalyst was twice the size of the noble metal catalyst makes a one-to-one comparison tricky. Also, W.R. Grace has not provided us with the composition or amount of active ingredients for the Davex 908 promoted base metal catalyst. There appears to be a slight increase in the level of cyanide and cyanogen with the use of the promoted base metal catalyst. This is something that will have to be investigated further.

4. The M.A.N. methanol heavy duty engine is now being tested after several delays due to shipping problems, dynamometer equipment failure and engine ignition failures. These problems have been corrected and data are being generated. A more complete report of the data will be available later.

5. A DDAD 6V-71N bus engine was tested in a baseline configuration followed by a malfunction condition. The malfunction condition was representative of a "smoky bus", yet was not so severe that the "bus" would have been withdrawn from service. Hot start transient tests showed increases in HC, CO, NOx, particulate and smoke. Composite transient and modal testing showed increases for CO, particulate and smoke, but some reduction in HC and NOx. Aldehydes were also increased from the engine operating in the malfunction condition. The Ames bioassay data showed no discernible difference between the two configurations on a revertant per brake horsepower-hour basis or revertant per microgram of extract basis.

6. Ten light duty gasoline vehicles that had been driven approximately 50,000 miles were tested for regulated and unregulated emissions (with special emphasis on aldehydes) and the results compared to low mileage vehicles. The results indicated that after 50,000 miles, the vehicles tested emitted substantially more HC, CO, and particulate (increases by factors of 3, 2.6, and 4 respectively). The increase in aldehydes at higher mileages was not as large (about 2 mg/km at low mileage to about 4 mg/km at high mileage) showing that aldehydes are well controlled at high mileages with catalyst-equipped vehicles compared to non-catalyst equipped vehicles (which emit about 40 mg/km aldehydes).

   There was no significant change in the level of emissions of organic sulfides, organic amines, ammonia, cyanide and cyanogen, hydrogen sulfide and nitrous oxide.

III. Characterization Results

A. Fuels Work

1. Alternative Fuels

a. Light-Duty Diesels

OMSAPC's first synthetic fuels emissions evaluation program (2) has recently been completed and the final report is in preparation. The major objective of this project was to study the effects of available alternate-source fuels on exhaust emissions from one Diesel vehicle, a 1980 Volkswagen Rabbit. The vehicle was operated on a chassis dynamometer following two transient driving cycles (FTP and HFET), and periodically, several steady-state conditions. Nine fuels were tested. Table 1 lists some of the properties of the fuels used. Some of the test fuels were blends of a base No. 2 Diesel fuel and alternate-source materials while others were fuels formulated in a study dealing with refinery modeling for alternative fuels. This latter study was conducted by the Department of Fuels and Lubricants Technology of Southwest Research Institute.

One of the major challenges in performing this work was acquisition of sufficient quantities of "state-of-the-art" alternate-source materials. In most cases, these materials were still in the laboratory in pilot plant phases of production. "First-generation" liquids can be described as those which have only been made liquid from the solid coal or shale. No further processing would have been done on such liquids. First-generation coal-derived liquids from two processes (Solvent Refined Coal, or SRC-II, and Exxon Donor Solvent, or EDS) were available in sufficient quantities for testing and these were therefore used in this program. "Second-generation" liquids can be described as those which have undergone some additional processing after their "first-generation" processing. Such processing may include hydrotreating, reforming, etc. The only second-generation liquids available in sufficient quantities for testing were shale liquids.

TABLE 1 FUEL PROPERTIES AND COMPOSITION

Substance	Base DF-2	Shale Diesel Marine	Paraho JP-5	Coal Case 5A	35% SRC-II	Broadcut Mid-Continent	25% SRC-II	25% EDS	25% EDS Naphtha
Fuel Code (EM-	329-F	453-F	473-F	474-F	475-F	476-F	478-F	482-F	485-F
Cetane No. (D613)	50	49	45	42	31	35	38	44	45
Cetane Index (D976)	52	56	46	41	29	52	38	42	47
Gravity, °API @ 60°F	37.5	37.9	43.6	31.1	28.2	44.1	31.7	33.8	38.3
Density, g/ml @ 60°F	0.837	0.835	0.808	0.870	0.886	0.806	0.867	0.856	0.833
Carbon, wt. %	85.8	86.3	85.9	86.5	86.2	86.1	86.4	86.5	86.3
Hydrogen, wt. %	13.0	13.4	13.7	12.4	11.8	13.2	12.3	12.7	13.3
Nitrogen, ppm (oxid. pyrolysis)	48	5	<1	1600	3400	1000	2000	267	142
Sulfur (lamp), %	0.24	<0.005	0.005	0.100	0.31	0.17	0.23	0.16	0.28
Calculated H/C, numeric	1.81	1.85	1.90	1.71	1.52	1.83	1.70	1.75	1.84
Carbon No. range (G.C.)	8-24	9-20	10-15	9-24	8-20	3-24	8-20	8-20	7-20
Aromatics, vol. %	21.3	28.5	22.	34.9	47.0	16.2	39.9	36.4	25.5
Olefins, vol. % (D1319)	1.7	2.1	2.	1.4	0.6	0.0	1.2	0.0	0.5
Paraffins, vol. %	77.0	69.4	76.	63.7	52.4	83.8	58.9	63.6	74.0
Viscosity, cs @100 °F (D445)	2.36	2.61	1.38	3.08	2.53	1.53	2.45	2.37	1.76
Gum, mg/100 ml (D481)	14.3	0.3	1.4	38.8	89.7[b]	23.8	30.1	60.0	13.1
Total solids, mg/ℓ	7.4	0.3			13.1		7.2	3.1	1.2
Metals in fuel, x-ray	0[a]	0[a]	0	0	0	0	9ppm Fe	0	0
Boiling Range, °C (IBP-EP, D86)	191-340	207-317	179-248	192-366	171-328	21-354	178-327	179-353	108-334
10% point	219	236	189	234	207	53	209	207	157
20% point	231	246	192	244	215	121	220	218	182
30% point	242	252	196	253	225	151	231	227	203
40% point	251	259	198	259	234	178	240	239	223
50% point	260	266	202	267	243	216	250	251	238
60% point	269	272	206	276	252	239	259	263	254
70% point	278	278	211	277	263	255	270	276	267
80% point	290	286	218	292	274	270	281	293	281
90% point	307	295	228	330	292	303	303	316	302
95% point	323	302	237	353	309	327	319	336	319
Residue, wt. % (D86)	1.3	1.0	1.5	1.5	1.0	1.0	1.6	1.5	1.5

[a] <10 ppm of Cr, Fe, Ni, Cu, Zn, and Mg; <70 ppm Pb; <100 ppm Al and Si

[b] Sample not dry after 1 hr. in steam lit block

TABLE 1 (Cont'd). FUEL PROPERTIES AND COMPOSITION

Substance	Base DF-2	Shale Diesel Marine	Paraho JP-5	Coal Case 5A	35% SRC-II	Broadcut Mid-Continent	25% SRC-II	25% EDS	25% EDS Naphtha
Fuel Code (EM-)	329-F	453-F	473-F	474-F	475-F	476-F	478-F	482-F	485-F
Boiling Range, °C (IBP-EP, D2887)	104-387	118-341	157-286	140-416	103-346	24-399	129-508	128-419	72-455
10% point	197	216	175	217	158	68	193	192	139
20% point	220	237	187	238	178	123	214	210	174
30% point	239	254	195	254	196	155	232	228	197
40% point	256	265	201	264	207	196	248	243	225
50% point	268	274	210	271	219	233	259	257	249
60% point	280	285	216	284	229	251	271	273	264
70% point	292	297	224	299	240	262	285	289	279
80% point	307	307	234	315	255	280	302	305	298
90% point	330	319	244	344	278	314	321	332	314
95% point	347	325	254	367	295	342	345	356	336
Residue, wt. % (D2887)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Composition, Volume %									
Kerosene									
Petroleum	0.0	0.0	0.0	17.3	0.0	22.0	0.0	0.0	0.0
JP-5	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
JP-8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diesel									
Petroleum	100.0	0.0	0.0	66.7	65.0	23.0	75.0	75.0	75.0
Shale DFM	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coal SRC-II	0.0	0.0	0.0	16.0	35.0	6.2	25.0	25.0	25.0
Light Cycle Oil	0.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0
LSR Naptha	0.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	0.0
HSR Petroleum	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0
Shale	0.0	0.0	0.0	0.0	0.0	20.9	0.0	0.0	0.0
Coal (Simulated)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N-Butane	0.0	0.0	0.0	0.0	0.0	10.5	0.0	0.0	0.0

[a] <10 ppm of Cr, Fe, Ni, Cu, Zn, and Mg; <70 ppm Pb; <100 ppm Al and Si

The first-generation coal-derived liquids exhibited boiling ranges similar to petroleum-based Diesel fuels. They could not be used by themselves in a Diesel engine due in part to their low cetane number of 25 or less. Blends with petroleum-based Diesel fuel were used to raise the cetane level to above 35.

The second-generation shale oil liquids exhibited boiling ranges similar to petroleum-based Diesel fuels and had cetane numbers greater than 44. Vehicle operation with these fuels was good, based on a subjective evaluation.

The "3-bag" composite FTP values for HC, CO, and NOx are shown as bargraphs in Figure 1. The greatest HC and CO increases, as compared with the base fuel, were observed with the Broadcut and the 25% SRC-II blend. Hydrocarbon emissions with these two fuels more than doubled as compared to the base fuel and slight NOx increases were seen with all the test fuels. Coal Case 5A resulted in slightly more NOx emissions than the other blends. Of the two middle-distillate coal-derived fuel blends (25% SRC-II and 25% EDS), the SRC-II blend was associated with higher emissions. The 25% EDS middle-distillate and the 25% EDS naphtha gave almost identical HC, CO, and NOx emissions.

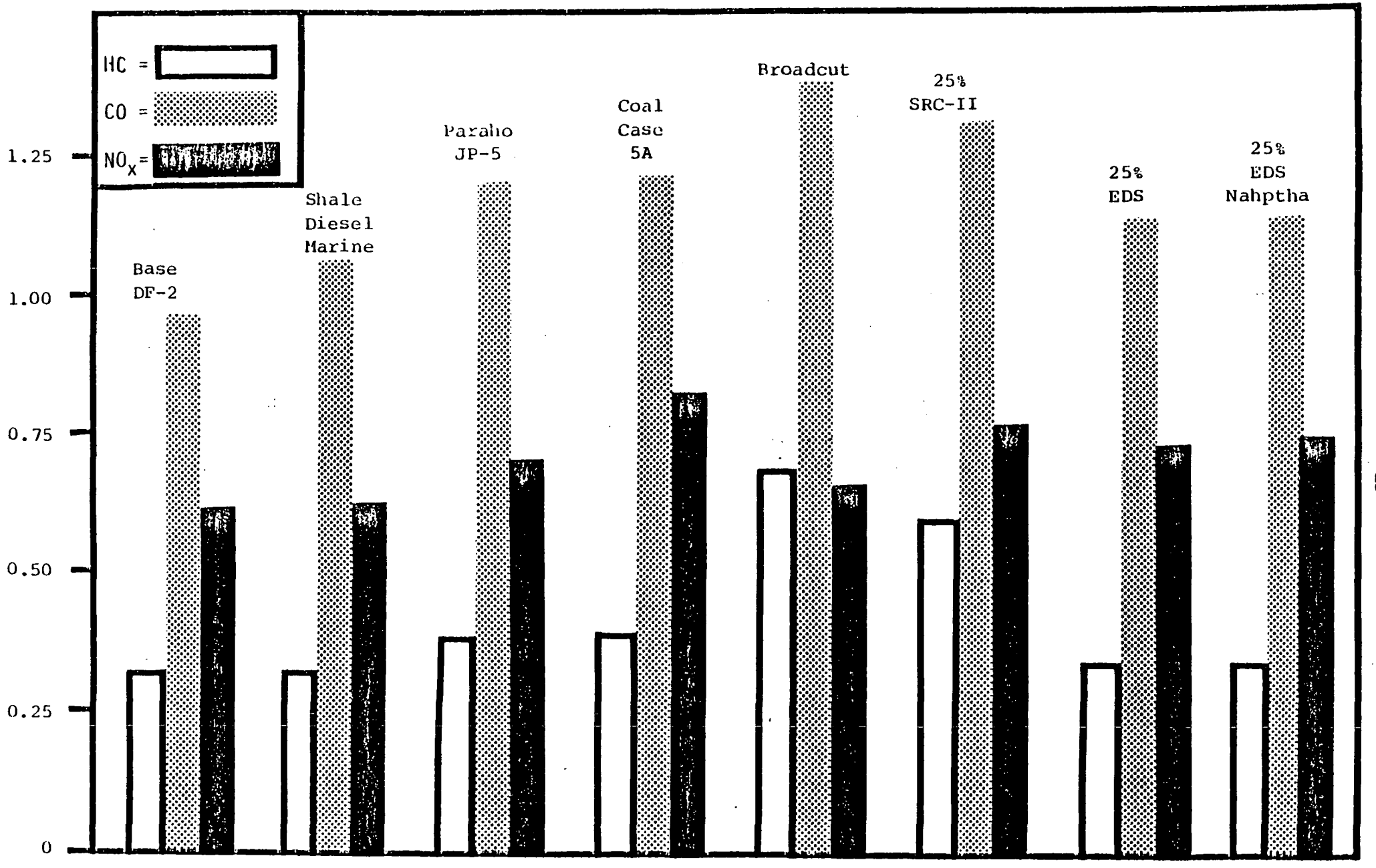

Figure 1. Regulated gaseous emissions during FTP (composite).

Fuel consumption results for the test fuels during both transient cycles are shown graphically in Figure 2. During both cycles, all the test blends showed slightly increased fuel consumption except Coal Case 5A and 25% EDS. The 25% EDS appears to result in the same or slightly lower fuel consumption as compared with the base fuel. Coal Case 5A showed increased fuel consumption compared with the base fuel during the HFET, but was about the same during the FTP.

Concentrations of a number of individual low-molecular weight aldehydes were determined in CVS-diluted exhaust. "Total" aldehydes refer to the sum of the individual aldehyde emissions. This "total" for each of the test fuels is shown graphically in Figure 3. The "total" phenols are also shown graphically in Figure 3.

"Total" aldehyde emission decreases, as compared with the base fuel, were observed with the 25% SRC-II and the 25% EDS blends. Both fuel blends gave similar aldehyde emissions (3 mg/km). No aldehyde increases over the base fuel were seen with the fuels tested during the FTP. Paraho JP-5 and Broadcut test fuel were associated with decreases in FTP phenol emissions as compared to base fuel. The 25% EDS blend roughly doubled the emission of phenols during the FTP compared to those from the base fuel. It is interesting to note that although the aldehyde emissions for the 25% SRC-II and 25% EDS blend were approximately the same, the 25% SRC-II blend did not increase phenols as did the 25% EDS blend.

Visible smoke was measured using an EPA-type smokemeter over the first 505 seconds (the "cold transient phase") of the FTP. The results are summarized in Table 2.

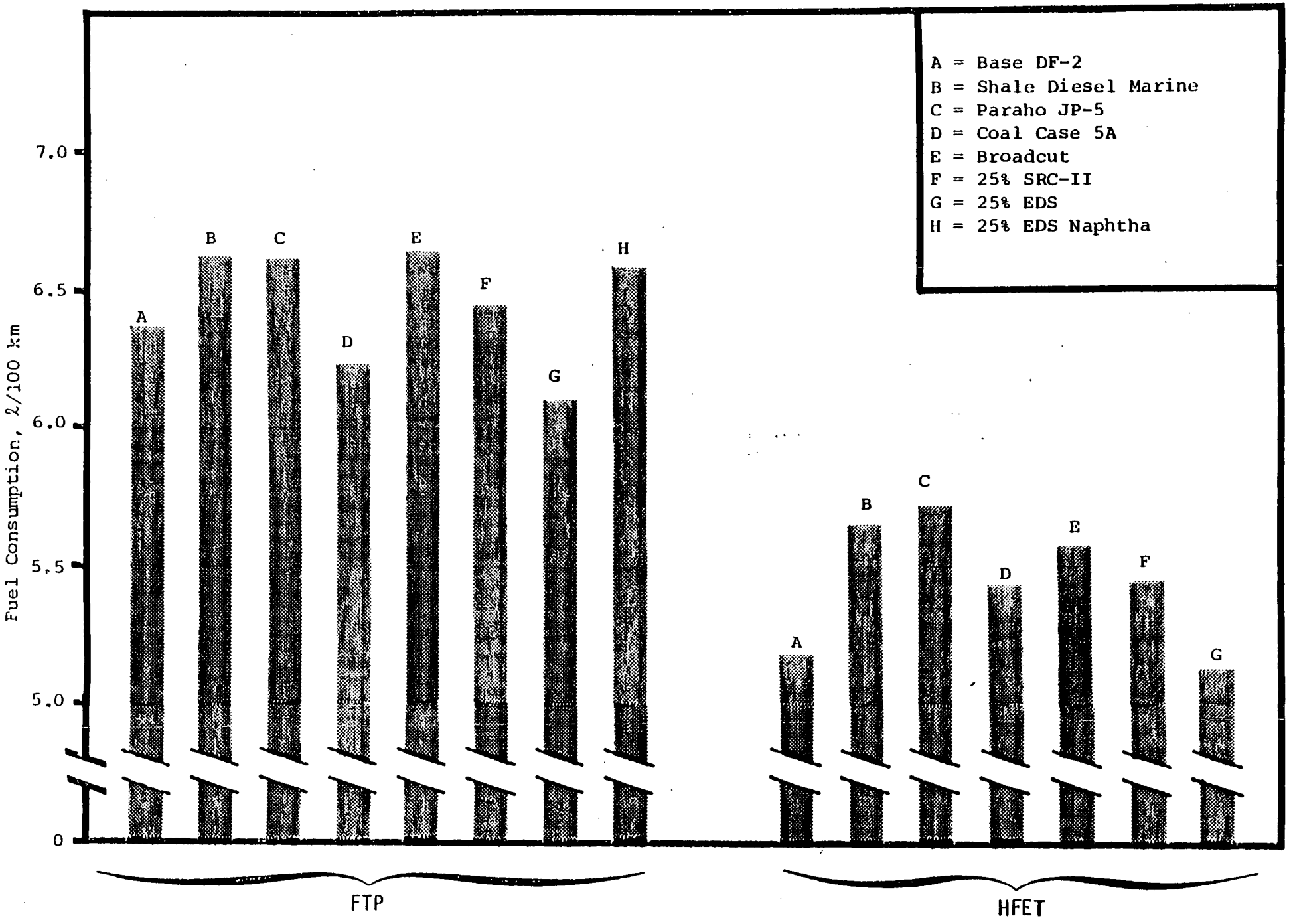

Figure 2. Fuel consumption during FTP and HFET.

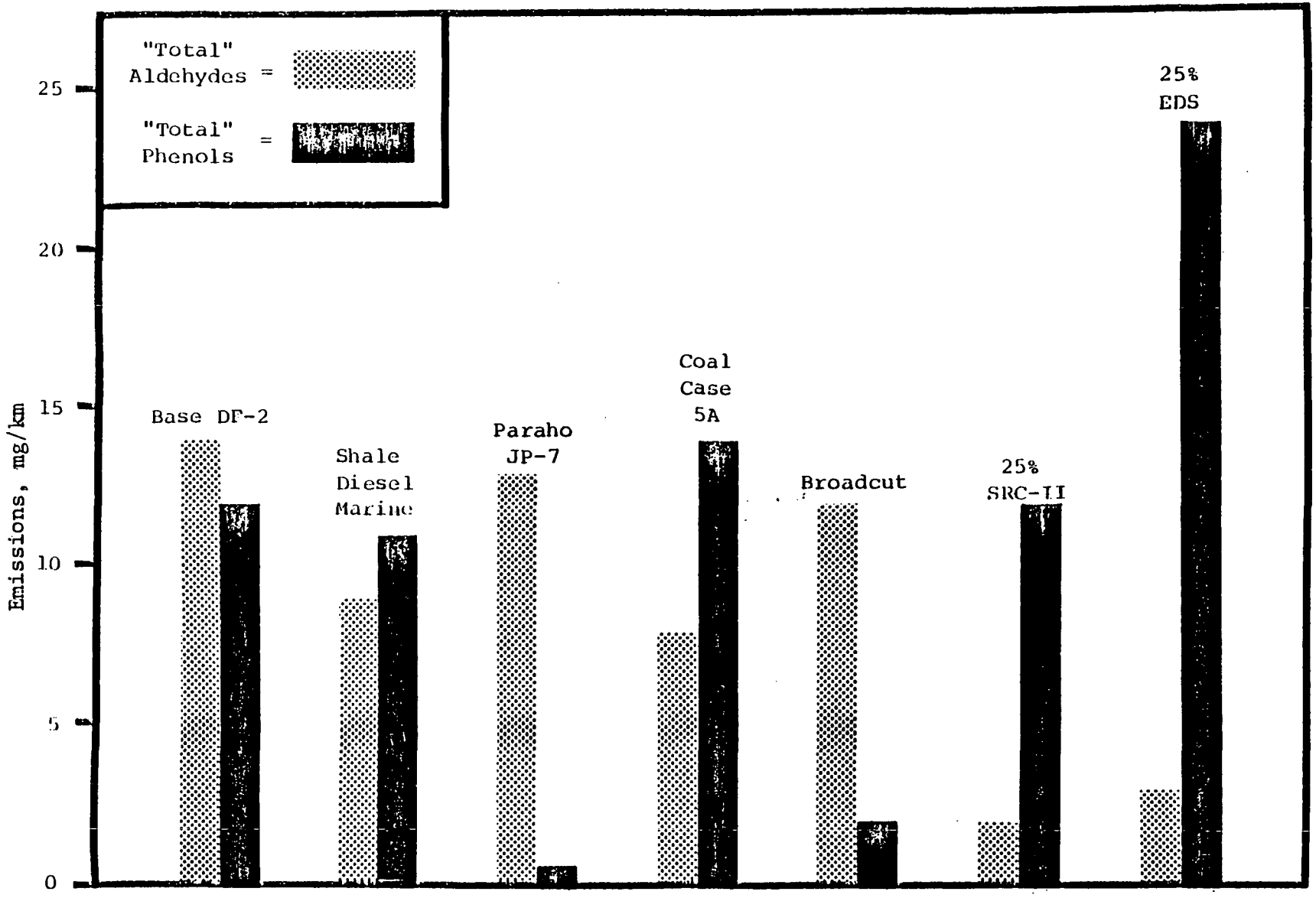

Figure 3. "Total" aldehyde and phenol emissions during FTP.

Table 2. Summary of Visible Smoke Data

Condition	Smoke Opacity, %, by fuel							
	Base DF2	Shale DFM	Paraho JP-5	Coal 5A	Broad-cut	35% SRC-II	25% SRC-II	25% EDS
Cold Start peak	21.2	46.8	36.0	66.0	33.0	66.0	58.8	58.2
Cold idle, avg. (after start)	0.2	1.0	1.4	0.4	3.0	60.0	3.5	4.0
1st accel. peak	28.2	44.2	61.5	40.5	44.2	92.0	63.5	67.8
Idle at 125 secs, avg.	0.7	0.5	0.8	0.6	0.5	21.0	1.0	1.7
Accel at 164 secs, peak	37.5	27.2	20.0	71.2	20.6	59.0	42.0	41.3

These data indicate rather dramatic smoke effects when running the 35% SRC-II blend. Its smoke levels were very high at the start and even at the 125 second idle, by which time the emissions from all the other fuels showed very little smoke. Because of such high smoke and particulate levels, the testing with 35% SRC-II was stopped. The fuel was then reblended with 25% SRC-II and a full set of runs performed.

At idle, the base fuel generally exhibited the lowest smoke levels. At the 164 second acceleration, however, several fuels did give lower smoke readings than the base fuel. Shale Diesel marine, Paraho JP-5, and the Broadcut all showed lower smoke at the 164 second acceleration than did the base fuel. With the exception of the 35% SRC-II, the greatest smoke level increases were generally associated with the other test fuels containing coal-derived liquids; Coal Case 5A, 25% SRC-II, and 25% EDS.

The FTP and HFET particulate mass emission results are presented graphically in Figure 4. The trends by fuel are similar for both operating cycles except for the 25% SRC-II. The 25% SRC-II particulate emissions were 56% above those from the base fuel during the FTP, but about the same during the HFET. One possibility is that the combustion of the SRC-II material improves as the vehicle warms up. Particulate mass emissions increases were observed with the Coal Case 5A, and to a lesser extent with the EDS blends.

The BaP results are presented graphically in Figure 5. The largest BaP emissions were associated with the Coal Case 5A fuel (about 3 times higher than for the base fuel). Values up to twice the base fuel level were seen with the Shale Diesel, Paraho JP-5, Broadcut, and 25% EDS. Slight reductions were observed with the 25% EDS Naptha and 25% SRC-II. Comparing the 25% EDS middle distillate with the 25% SRC-II shows that the 25% EDS produced twice the BaP associated with the 25% SRC-II. However, a lighter cut (i.e. lower boiling range) of the EDS material, 25% EDS naphtha, resulted in approximately the same BaP emissions as the 25% SRC-II.

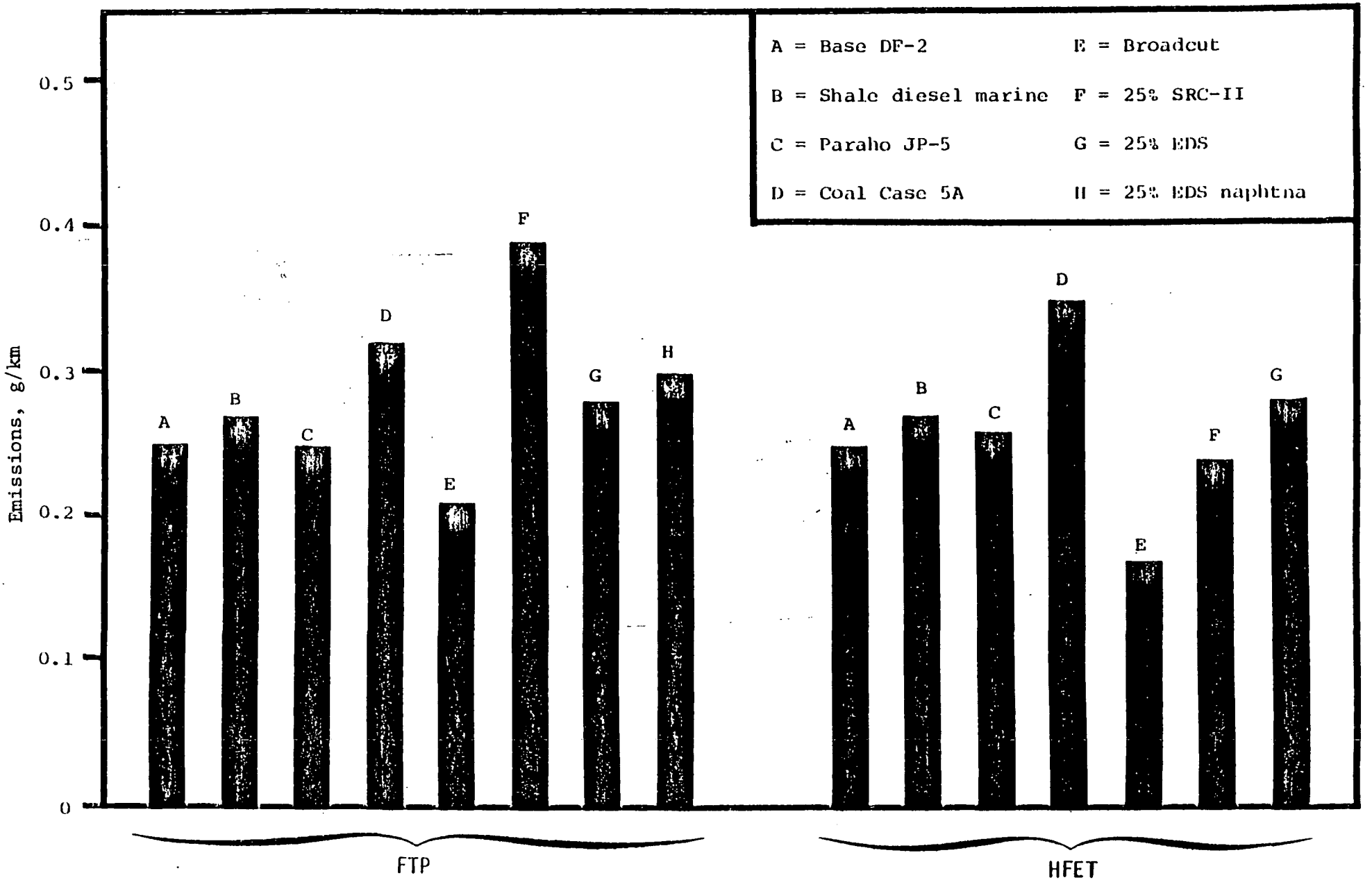

Figure 4. Particulate mass emissions during FTP and HFET cycles.

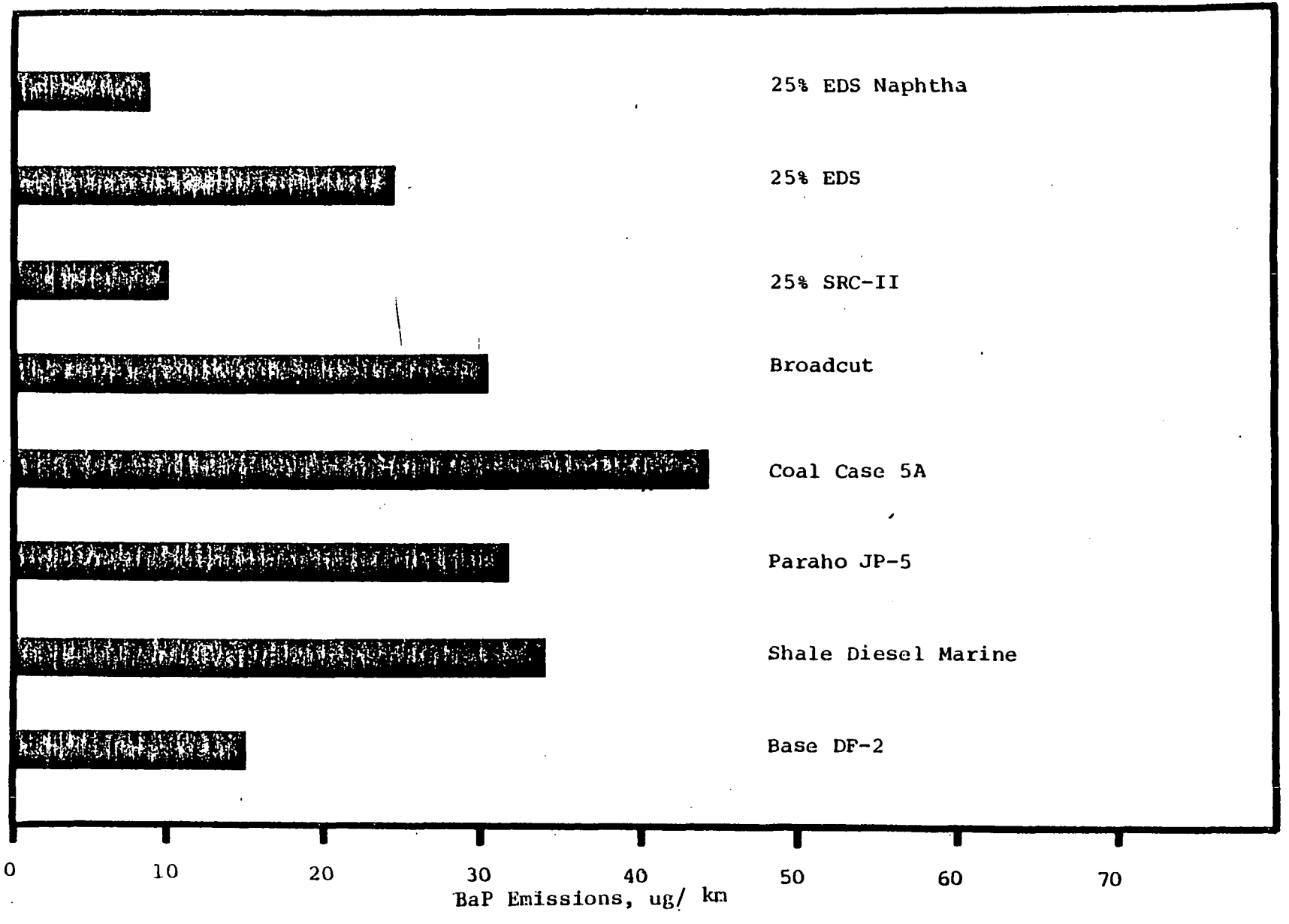

Figure 5. BaP emissions during FTP.

The Ames bioassay was performed on the extract from the samples taken as the vehicle was operated on the various fuels. The resultant data in terms of revertants per microgram of extract are presented in Table 3. The "distance specific" Ames activity is shown in Table 4. These data take into account the total particulate emissions and the percent extractables from each fuel blend. In reviewing these data for strains TA 1537, 1538, 98 and 100, and all of the fuels except the Paraho JP-5, it is seen that the revertants per microgram of extracts and revertants per kilometer are always higher for the synthetic fuels than for the base fuel. The Paraho JP-5 fuel occasionally has lower values. The importance of this has not yet been evaluated. The TA-1535 strain results were low or zero, which is normal for this strain.

Comparison of the results of this work with previous fuels variables work shows few consistent trends. However, many of the alternate fuels tested had higher aromatics levels and lower cetane levels than the base fuel. Previous work has shown that this could result in higher emissions of some pollutants. The same trend occurred with the alternate fuels emissions.

TABLE 3. SUMMARY OF AMES BIOASSAY ANALYSIS OF ORGANIC SOLUBLES FROM PARTICULATE MATTER COLLECTED DURING FTP

Fuel Code	Description	RLI-16 Activation	Model Predicted Mean Slope, revertants/µg extract				
			TA-1535	TA-1537	TA-1538	TA-98	TA-100
EM-329-F	base DF-2	No	0.5	1.9	3.7	6.0	17.1
		Yes	0.1	1.4	3.5	3.1	7.2
EM-453-F	shale diesel marine	No	0.5	4.3	6.6	12.0	30.5
		Yes	0.1	4.8	11.0	6.3	14.5
EM-473-F	Paraho JP-5	No	0	4.8	6.8	5.5	14.3
		Yes	0.2	1.9	10.3	4.0	5.7
EM-474-F	Coal Case 5A	No	0	5.8	8.3	13.2	23.8
		Yes	0.1	4.0	8.7	5.2	20.7
EM-476-F	Broadcut	No	0	5.5	9.6	13.4	23.8
		Yes	0.2	4.2	10.6	5.0	14.2
EM-476-F	25% SRC-II	No	0.6	6.3	10.0	10.4	61.3
		Yes	0.1	7.0	12.0	5.3	13.7
EM-482-F	25% EDS	No	0.1	12.5	11.4	24.3	19.7
		Yes	0.2	8.2	10.9	8.8	16.3
EM-485-F	25% EDS, naphtha	No	0	13.2	18.5	19.8	17.4
		Yes	0.1	12.2	16.2	9.0	8.6

TABLE 4. SUMMARY OF AMES BIOASSAY RESULTS IN REVERTANTS PER DISTANCE DURING FTP

Fuel Code	Description	RLI-16 Activation	Revertants per Kilometer [a]				
			TA-1535	TA-1537	TA-1538	TA-98	TA-100
EM-329-F	base DF-2	No	18	70	135	219	624
		Yes	4	51	128	113	263
EM-453-F	shale diesel marine	No	24	204	313	568	1444
		Yes	5	227	521	298	687
EM-473-F	Paraho JP-5	No	0	177	250	202	525
		Yes	7	70	378	147	447
EM-474-F	Coal Case 5A	No	0	296	423	673	1214
		Yes	5	204	444	265	1055
EM-476-F	Broadcut	No	0	316	552	771	2564
		Yes	12	242	610	288	817
EM-478-F	25% SRC-II	No	34	365	580	603	3553
		Yes	4	406	696	307	794
EM-482-F	25% EDS	No	5	620	566	1206	978
		Yes	10	407	541	437	809
EM-485-F	25% EDS naphtha	No	0	486	681	729	641
		Yes	4	449	597	331	316

[a]Calculation incorporates particulate mass rates based on 47mm Pallflex filters, percent organic solubles extracted from Pallflex "20 x 20" filters, and data in Table 3.

b. Heavy Duty Diesel

The heavy duty Diesel alternate fuels characterization work has been planned and funded through the current Task Order (Work Directive No. 14, Contract Number 68-03-2884). However, this work has not yet begun due to higher priority M.A.N. methanol engine work. The objective of the heavy duty Diesel alternate fuels effort will be to assess the pollutant emissions from a heavy duty Diesel engine that is operated with various alternative fuels. Final selection of the fuels to be tested has not yet been made. However, they may include a national average Diesel fuel No. 2 (against which the other fuels will be compared), an SRC-II/DF2 blend, an EDS/DF2 blend, a Diesel 2 Marine (Paraho shale stock), a blend of DF2 and used lubricating oil and the possibility of new or used vegetable oils blended with DF2 or neat. Another less likely possibility is to use a SASOL middle distillate fuel. One factor influencing the selection of fuels will be their availability.

The engine to be used for this work will be a Mack EM6-300, in-line six cylinder, 300 horsepower engine. This engine has been received by Southwest Research Institute and will be installed on the stand as soon as the M.A.N. methanol work has been completed. The testing will emphasize transient testing with some 13 mode backup and will focus on visible smoke, regulated gaseous emissions, individual HC, aldehydes, phenols, odor index, particulate characterization as well as a characterization of the organic solubles extracted from the particulate.

2. Methanol Fuel

a. Light Duty Vehicles

The light duty vehicle methanol characterization work (3) has consisted of the testing of two light duty vehicles (a VW and Ford Escort) that can use 100% methanol fuel and separate vehicles that represent their gasoline counterparts. These vehicles have been tested in their "as received" condition which includes the use of a noble metal catalyst; the testing was then done with promoted base metal catalysts. Also, some limited baseline (no-catalyst) work was performed on the Escort. The emissions for which analyses have been made include HC, CO and NOx, particulate, unburned alcohols (methanol and ethanol), aldehydes and ketones, individual hydrocarbons, ammonia, nitrosamines, and cyanide and cyanogen. The individual hydrocarbons were methane, ethane, ethylene, acetylene, propane, propylene, benzene and toluene. Also, on selected vehicles organic nitrites have been analyzed and a gas chromatographic-mass spectroscopic (GC-MS) analysis will be done for the emissions from one of the vehicles designed for gasoline and one that uses methanol fuel.

The vehicles that have been tested have been on loan from the manufacturers or, in the case of the Escort designed for methanol, on loan from the California Energy Commission. The vehicles have, for the most part, been tested and the pollutant analyses are currently being completed and the data compiled. The vehicles that use methanol have been run on 100% methanol rather than a methanol/isopentane (94.5%/5.5%) blend on which they have apparently been manufactured to operate. To set up a car for this blend versus pure methanol involves fuel metering recalibrations. It has been our experience that to operate a vehicle (the Escort) on the isopentane blend rather than 100% methanol tends to increase the emissions of HC and CO. Table 5 presents some preliminary data on the Ford Escort which show that the hydrocarbon emissions are higher for the methanol/isopentane blend. CO was also higher but there was a slight NOx reduction. These data have to be considered carefully, since the emission results on the Escort are not very repeatable and it was not cost-effective to do a large number of tests to examine test repeatability with this potential blending agent. Other reasons for the use of the pure methanol as opposed to the isopentane

Table 5

Effect of Methanol-Isopentane Blend
1981 Methanol-Fueled Ford Escort

	Composite FTP g/mile			
	Pure Methanol			Methanol/Isopentane
	Low	High	Average	Blend
HC	0.40	0.53	0.43	0.74*
CO	5.21	7.26	6.03	6.92*
NOx	0.37	0.42	0.40	0.37
	Cold-Start[1] g/mile			
HC	6.01	1.51	1.21	2.00*
CO	6.53	7.48	6.97	10.60*
NOx	0.82	1.05	0.90	0.87
	Cold-Start[2] g/mile			
HC	0.16	0.23	0.18	0.35
CO	4.79	6.85	5.52	6.15
NOx	0.16	0.23	0.19	0.18
	Hot-Start [3] g/mile			
HC	0.34	0.40	0.35	0.50
CO	4.51	8.54	6.29	5.58
NOx	0.35	0.45	0.39	0.37

*Car was not operated for four days prior to the cold-start 505.

[1] bag 1 values
[2] bag 2 values
[3] bag 3 values

mixture is that better use is made of scarce characterization funds by developing a data baseline with pure methanol and then later perhaps looking at possible fuel variations such as the isopentane mixture. Also, the isopentane is generally put in for cold start operation at low temperatures and this is not needed at normal FTP temperatures at which these tests are being performed. Also, it is the opinion of the author that it has not been shown that isopentane is the best compound to mix with methanol for low temperature cold start driveability and it may not be used by refiners for a mass methanol market but rather some other compound (e.g. MBTE or light boiling gasoline) may work better and/or may be more commercially feasible. A VW representative (Dan Hardin) also feels this way and states that some oil companies said this at the recent Carnegie-Mellon alcohol symposium in Dearborn (November 1, 1981).

Pure methanol was used to develop baseline data in this project. Some of the data that have been generated are presented later (e.g. see Table 7). Most of the data taken on the Volkswagen appear to be good. The only major difficulty with the Volkswagen data was with those taken with the foam promoted base metal catalyst. The catalyst had relatively low surface area in its initial condition, and the substrate was broken and lost in subsequent testing. The VW was also tested with a promoted base metal catalyst (Davex 908) on a monolith substrate with a volume 11% less than the noble metal catalyst with which the VW came. In any event, the catalyst data for the two vehicles are presented in Table 6. From Table 6 it can be seen that the Escort's promoted base metal catalyst had much more surface area than the VW's foam promoted base metal catalyst. Also, the Escort was tested with 4 biscuits, at the recommendation of W. R. Grace. (In retrospect, this may have been twice as many biscuits as should have been used.) This resulted in a total catalyst surface area for the Escort being 62,048/2484 or 25 times more than the VW. The catalyst material is Davex 908, on which OMSAPC is trying to get more data (e.g. loading, composition, etc.). It is important to have this type of information so one can make a preliminary assessment as to whether the Davex 908 may be a less expensive catalyst than a noble metal catalyst for this particular application.

Table 6

Table of Catalyst Information for Escort and Volkswagen Methanol Vehicles

Catalyst Material	Noble Metal Pt-Pd	Promoted Base Metal Davex 908	Noble Metal Pt-Rh	Foam Promoted Base Metal Davex 908	Monolith Promoted Base Metal Davex 908
Vehicle	Escort	Escort	VW	VW	VW
Shape of Cross Section	Elliptical	Elliptical	Round	Round	Round
Dimensions per biscuit					
dia, cm			10.2	10.2	
axis, cm	7.6*	6.8			6.8
axis, cm	12.7*	14.4			14.4
length, cm	7.2*	7.2	15.2	15.2	7.2
Volume, cm^3	554	554	1242	1242	
Biscuits used	2	4	1	1	2
Total Volume of Catalyst used, cm^3	1108	2216	1242	1242	1108
Catalyst Surface to Volume Ratio, cm^2/cm^3		28	NA	2	28
Total Surface Area of Catalysts used, cm^2	NA	62,048	NA	2484	31,024

*Approximate
NA-not yet available

After the last VW promoted base metal catalyst run was completed with the foam base metal catalyst, the exhaust system and dilution tunnel were disassembled and catalyst fragments were noticed. At some point the catalyst had begun to fracture and about one half of the catalyst was lost from the container. Emissions had increased over each successive run which indicates that the catalyst efficiency had been going down during these runs. Southwest Research Institute personnel removed the remainder of the catalyst, replaced the can and ran an FTP without the catalyst. (The car had been started in the morning and soaked until afternoon and then run, but since it was not soaked overnight it was therefore not an official FTP but close to it because the engine was basically quite cold prior to its testing.) The data from this test are shown in Table 7. It must be concluded the foam promoted base metal catalyst data taken from the Volkswagen are going to be difficult to analyze in a meaningful way. The HC, CO, and NOx emissions were lower with the monolith promoted base metal catalyst compared to the foam promoted base metal catalyst. However, the emissions with the noble metal catalyst were lower than those with either promoted base metal catalyst. All of these results are low mileage ones.

The data from the methanol-fueled Escort may be more difficult to evaluate. The methanol-fueled Escort that was shipped to Southwest Research Institute (SwRI) for this project had, in the opinion of the SwRI personnel who conducted the program, run poorly. It had subjectively evaluated driveability problems and could not follow the FTP trace well. At the end of the emissions testing phase, the vehicle got to the point of not running at all. Subsequent checks with Ford (Dr. Roberta Nichols, who is in charge of the Ford methanol vehicle project) revealed that this vehicle was one of the first three shipped to California and as such was sent without the carburetor designed to prevent corrosion due to methanol.

Table 7

Table of Preliminary FTP Emissions
Data From Vehicles Run on Gasoline
and Methanol - Noble and Base Metal Catalysts

Pollutant	Escort Gasoline Noble Metal Cat.	Escort MeOH Noble Metal Cat.	Percent Change[a] MeOH Gas.	Escort MeOH Promoted Base Metal Cat.	Percent Change MeOH Promoted Base Cat.	Escort MeOH Non Catalyst Noble	VW Gasoline Noble Metal Cat.	VW MeOH Noble Metal Gas.	Percent Change MeOH Gas.	VW@ MeOH Foam Promoted Base Metal Cat.	VW MeOH Monolith Promoted Base Metal Cat.	VW** MeOH Non-Catalyst Baseline
HC D. Level,@* g/mi	0.41	0.41	-	-	-	-	0.41	0.41	-	-	-	-
HC Emissions, g/mi	0.37	0.43	16.2%	0.31	-27.9%	0.28	0.11	0.39	254.5%	0.87	0.48	2.08
CO D. Level,@* g/mi	3.4	7.0	-	-	-	-	7.0	7.0	-	-	-	-
CO Emissions, g/mi	4.49	6.03	34.3%	1.51	-74.9%	40.77	1.08	0.55	-18.5%	3.60	1.70	7.51
NOx D. Level,@* g/mi	1.0	0.4	-	-	-	-	0.4	0.4	-	-	-	-
NOx Emissions, g/mi	0.55	0.40	-27.3%	0.35	-12.5%	0.61	0.16	0.68	325.0%	1.75	1.51	1.87
Fuels Economy, mi/gal	24.53	12.56	-	12.74	-	12.32	23.76	13.84	-	13.66	13.89	14.09
Particulate, g/mi	0.0092	0.0062	-32.6%	0.0038	-39.7%	N.A.	0.0112	0.0047	-60.0%	N.A.	N.A.	N.A.
Methanol, mg/km	0.0	252.5	N.C.*	N.A.	N.A.	N.A.	0.0	272.5	N.C.	572.7	N.A.	N.A.
Aldehydes and Ketones, mg/km	0.1	20.8	20,700%	2.1	-89.9%	N.A.	0.0	6.4	N.C.	N.A.	N.A.	N.A.
Individual HC, mg/km	96.0	31.0	-67.7%	24.6	-20.6%	N.A.	25.2	3.2	-87.3%	10.0	N.A.	N.A.
Ammonia, mg/km	N.A.*	6.21	N.A.	3.34	-46.2%	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Cyanide and Cyanogen, mg/km	N.A.	0.00	N.A.	0.11	N.C.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

* N.A. = Data Not yet Available
N.C. = Not Computable
@ Data suspect due to catalyst problems
** FTP not official
a. Percent change identified by ratio given. For example, in column 3, it is MeOH/Gas., or $\frac{(\text{MeOH} - \text{Gas.})}{\text{Gas.}}$ (100)
@* D. Level= Design emission level

As soon as the new carburetors became available, Ford and/or California Energy Commission personnel were to replace the carburetors on these first three vehicles such that they would then have the modified carburetor. This replacement unfortunately did not occur for this vehicle and the vehicle was loaned to EPA without EPA knowing about the potential carburetor problem. The end result was that the vehicle was tested with a carburetor that was at an unknown stage of corrosion. As such, the data must tentatively be considered representative of a malfunctioning vehicle. After Ford replaced the carburetor on the vehicle with one designed for use with methanol fuel, two FTPs and HFETs were run and the data compared to those from the vehicle with the original carburetor as given in Table 8.

Table 8

Average Emissions and Fuel Consumption
Data from Methanol-Fueled Ford Escort

	FTP		HFET	
	Original Carburetor	New Carburetor	Original Carburetor	New Carburetor
Number of Tests	3	2	3	2
HC, g/mi*	0.43	0.47	0.08	0.11
CO, g/mi	6.03	2.28	0.53	0.42
NOx, g/mi	0.40	0.40	0.32	0.31
Fuel Economy, mi/gal	12.56	12.95	17.98	18.80

*Measured HC expressed as methanol. Assuming measured HC is largely methanol, HC response on FID is multiplied by ratio of molecular weights of methanol and HC (2.3).

These data indicate that there was little or no effect of the carburetor corrosion on the HC and NOx emissions. There was a 3% (FTP) increase in fuel economy with the use of the new carburetor and a decrease of 62% (FTP) and 21% (HFET) in CO. Therefore, one might conclude that there was at least a partial negative effect due to the original carburetor on the emissions data.

In reviewing the data in Table 7, it is seen that in the case of the Escort the use of methanol as a fuel reduces NOx, particulate and individual hydrocarbons. However, there is a very dramatic increase in the aldehydes and ketones with most of this increase coming from the emission of more formaldehyde from the Escort using methanol. In looking at the Escort methanol-fueled vehicle with a low mileage promoted base metal catalyst, reductions in HC, CO, NOx, and particulate as well as aldehydes and ammonia are found. However, an increase occurs for cyanide and cyanogen emissions from zero with use of a noble metal catalyst to 0.11 mg/km with use of the promoted base metal catalyst. This is below the level of concern for cyanide as recently determined by EPA (4). The durability of the promoted base metal catalyst at higher mileages is not known and is an important factor in determining whether this catalyst would be acceptable for commercial use on such vehicles.

In looking at the Volkswagen data, it is seen that the gasoline version is generally a low emitter of pollutants. When the vehicle using methanol is tested, HC and NOx levels were higher. The levels exceed the level of the standard in the case of the NOx emissions but the HC does not exceed the standard. Lower levels were seen with CO, particulate, and individual HC when the vehicle using methanol was tested. However, a large increase in methanol emissions was noted. These emissions were about the same as those from the Escort. Also, the aldehydes were increased but not to the same level as seen with the Escort. Ammonia and cyanide data are not available at this time. The tests also showed that there were no nitrosamine emissions detected in the exhaust from any of the vehicles tested under any fuel or catalyst situation.

Overall conclusions that can be reached at this time from the program are that vehicles can be set up such that they come close to meeting the levels of the emission standards at low mileage for HC, CO, and NOx with an attendant decrease in particulate emissions and individual hydrocarbons relative to their gasoline fueled counterparts. However, methanol emissions as well as aldehydes and ketones are generally higher. The use of a promoted base metal catalyst and methanol as a fuel resulted in low emissions but again this is a low mileage result. However, the only nearly-complete promoted base metal catalyst data are from the Escort, and the fact that the promoted base metal catalyst was twice the size of the noble metal catalyst makes a one-to-one comparison difficult, especially since the composition and loading of active material is unknown. There appears to be an increase in the level of cyanide and cyanogen with the use of the promoted base metal catalyst. This is something that will have to be further checked even though the level for cyanide appears to be below the level of concern recently determined by EPA (4).

The preliminary methyl nitrite data are available; methyl nitrite could theoretically form from reaction of methanol and NOx in the exhaust. Methyl nitrite is of concern due to its potential toxicity. Methyl nitrite was not found in the exhaust of the gasoline fueled vehicle but was found at low levels (1 ppm) in some of the tests of the methanol fueled vehicles. It is not known whether these levels would present any environmental problem.

There are some data that have not yet been reported but are expected soon which should help complete a determination of the influence of methanol use on vehicle emissions. These missing emission data are those for: 1) selected pollutant results (see Table 7 for the data Not Yet Available), 2) gas chromatograph/ mass spectroscopic data on methanol fuel and gasoline fuel exhaust streams, and 3) Ames test data on the particulate extract.

b. M.A.N. Methanol Engine

The M.A.N. engine is currently being tested and this testing seems to be proceeding well even though there were problems with initial stages of this project. The first problem was due to shipping and customs problems that ended up delaying the arrival of the engine until the first part of December, 1981. While there was only a slight delay waiting for an available dynamometer, the dynamometer that became available developed problems in its control circuitry which took several weeks to correct. Finally, the engine was installed towards the end of December and testing began. However, soon after testing began, the ignition system failed. This has been corrected but it now appears that when the ignition failed it was during a high load, high speed condition that may have resulted in some catalyst destruction. The catalyst has since been replaced and the engine is back running again with testing being conducted. The end result of this is a delay in the original testing schedule.

A very small quantity of 13 mode emissions data is now available as given in Table 9. Table 9 also includes data taken previously on the Volvo dual fueled (Diesel fuel/methanol) engine (5). These data indicate that the M.A.N. engine equipped with a catalyst emits low quantities of HC, CO and particulate compared to the Volvo dual fueled (Diesel fuel/methanol) engine equipped with a catalyst. The NOx emissions, however, were higher than those from the Volvo. The remainder of the data are being processed and will become available shortly.

Table 9

Table of Emissions and Fuel Consumption From M.A.N. Methanol and Volvo Dual Fueled (Diesel and Methanol) Engine - Both With Catalyst

	Emissions, g/kW-hr				Cycle BSFC[a]
	HC[d]	CO	NOx[b]	Part.	kg/kW-hr
M.A.N.[c]					
Cold Start	0.19	0.80	8.91	0.06	0.796
Hot Start	0.05	0.40	9.30	0.05	0.711
Composite	0.07	0.46	9.24	0.05	0.723
Volvo					
Cold Start	0.36	5.54	7.44	0.26	0.538
Hot Start	0.13	3.29	7.38	0.34	0.515
Composite	0.16	3.61	7.39	0.33	0.518

a BSFC is in terms of dual fuel rather than Diesel fuel for the Volvo. Approximately 80%, by mass, of the fuel consumed during a transient cycle was alcohol. Heating values are: Diesel at 18,400 BTU/lb and methanol at 8,550 BTU/lb. The M.A.N. BSFC is in terms of methanol.

b NOx values presented here are based on continuous measurement by chemiluminescence. Intake humidity was controlled - NOx correction of 1.00 used in all cases for transient NOx.

c Preliminary data.

d HC values reported here are based on indication of HFID (Beckman 402). HFID response has been reported to be very low for unburned alcohols and some other species.

B. Diesel Engine Characterization

1. Malfunction - Heavy Duty Diesel

The purpose of this work (6) was to test a typical bus engine (DDAD 6V-71) in a malfunction configuration that would be representative of a field condition in which the bus would remain in operation due to adequate performance, but which might be viewed as a "smoky" bus. It was difficult to decide on what item would cause a realistic malfunction without representing a part failure. It was decided that the malfunction configuration would be made up of individual maladjustments to the engine, which collectively would simulate a malfunctioning or worn engine. It was decided that the maladjustments would be made in a stepwise manner; one item of maladjustment would be incorporated, then a hot-start transient test would be conducted without changing dynamometer control parameters from the baseline configuration. This would simulate a driver demanding the same performance from a maladjusted/malfunctioning engine as from the baseline/stock engine. The hot-start transient emission test would quantify the relative influence each maladjustment contributed to the final malfunction configuration. During the hot transient test, emissions of HC, CO, NOx, particulate and visible smoke (as determined by an in-line smoke meter) were measured.

The first increment of maladjustment was the substitution of 50,000 mile injectors obtained from an in-use bus. These injectors had accumulated soot deposits on the tips, but from outward appearance seemed to be in good condition with no obvious defects. Injector timing was maintained the same as for the baseline configuration. Emissions were measured over a single hot-start cycle. Results from this single transient test are presented in Table 10 along with the average hot-start emission results from the baseline configuration. The worn injectors caused the CO emissions to increase by 67% and the particulates to increase by 34%. NOx decreased 10% and fuel consumption increased by 6%.

For the second increment of maladjustment, the timing was retarded by 0.020 inch in order to simulate a worn cam drive train which occurs normally with high mileage (7). This 0.020 inch increase in setting of the injector

TABLE 10 HOT START TRANSIENT EMISSIONS FROM DDAD 6V71 IN VARIOUS STAGES OF MALADJUSTMENT FROM THE BASELINE CONFIGURATION

Test Configuration	Regulated Emissions, g/kw-hr, (g/hp-hr) HC[d]	CO	NO_x[b]	Part.	Cycle BSFC[a] kg/kw-hr, (lb/hp-hr)	Cycle Work kw-hr, (hp-hr)
Baseline	2.47	5.84	9.79[c,d]	0.70	0.313	8.24
Hot Aug.	(1.84)	(4.36)	(7.30)	(0.52)	(0.515)	(11.05)
+50,000 Mile	--[a]	9.73	8.78[b]	0.94	-.331	8.21
Injectors	--	(7.26)	(6.55)	(0.70)	(0.544)	(11.00)
+0.020 Inch	--[a]	12.76	6.81[b]	1.34	0.343	8.09
Retard	--	(9.52)	(5.08)	(1.00)	(0.565)	(10.84)
+No Throttle	--[a]	13.85	6.77[b]	1.45	0.339	8.24
Delay	--	(10.33)	(5.05)	(1.08)	(0.558)	(11.05)
+Increase	3.35	15.38	6.89[c,d]	1.45	0.342	8.22
Intake Rest.	(2.50)	(11.47)	(5.14)	(1.08)	(0.562)	(11.02)

[a] Continuous HC instrument failed--bag HC was used to process data.
[b] These NOx values based on measurement of sample bag concentration--
[c] Continuous NOx instrument undergoing unscheduled maintenance.
Baseline NOx emission by continuous on-line measurement was 9.97 g/kw-hr. Cumulative maladjustment NO_x emission by continuous on-line measurement was 7.63 g/kw-hr.
[d] Presented on the basis of bag measurement for comparison purposes.

plunger pushrod from the 1.500 $\pm$ .005 inch timing setting effectively retards the timing by approximately 2.8 degree of crank angle (8). As shown in Table 10, the NOx was reduced another 22% and the fuel consumption increased by 3.6% with the retard timing. Both CO and particulate emissions increased by about 30%.

Along with the old injectors and the retard of timing, the throttle delay mechanism was adjusted such that essentially no throttle delay existed. This allowed the engine rack to respond immediately to the throttle command. It appears from the results of the single hot-start test that the absence of throttle delay had comparatively little effect on hot-start transient emissions, although both CO and particulate were increased by about 8% and NOx and BSFC were slightly reduced.

An increase in engine air intake restriction was added to simulate a dirty air cleaner or blower intake screen. The data presented in Table 10 indicate that the effect of the increased air intake restriction was minimal with regards to NOx, particulate and fuel consumption, but it did appear to increase CO emissions somewhat. Results from the hot-start transient test with the additional intake air restriction were also representative of the cumulative effect of all of the maladjustments.

Comparing the emission results from the cumulative maladjustments to the average hot-start emissions from the baseline configuration indicated that substantial changes in emissions had taken place. The HC appeared to have increased by 32%, CO increased by a factor of 2.6, NOx decreased by 30%, particulate increased by a factor of 2.1, and fuel consumption increased by 9%.

Overall engine operation changed very little relative to the changes in emissions. Observed power under the baseline configuration and the malfunction configuration are given below with associated end-of-stack smoke opacities.

Baseline

Max. Power: 440 ft lb at 2100 rpm = 175.9 hp

Smoke: 2.4%

Max. Torque: 550 ft lb at 1260 rpm = 132.0 hp

Smoke: 8.0%

Combined Maladjustment

Max. Power: 420 ft lb at 2100 rpm = 167.9 hp

Smoke: 9.8%

Max. Torque: 515 ft lb at 1260 rpm = 123.6 hp

Smoke: 23.5%

Even though the smoke and particulate emissions significantly increased, maximum power and torque were reduced by only 5% and 6%, respectively. One could infer that the malfunctioning engine would probably not be taken out of service on the basis of this level of power loss. On this basis, this cumulative maladjusted engine was selected to be characterized as the "malfunction" configuration and detailed emission characterization was performed to obtain comparative data.

A summary of 13-mode composite emission results from both the baseline and malfunction configurations is given in Table 11. Thirteen mode composite HC was actually 23% lower for the malfunction configuration than for the baseline configuration. This was contrary to indications from the preliminary hot-start transient data. Examining the modal data, significant decreases in HC occurred in the malfunction configuration during maximum power and maximum torque conditions. A 27% reduction in NOx, primarily due to the retarded timing, was accompanied by an overall 6% increase in BSFC. Thirteen-mode CO emission increased by a factor of 1.8.

Table 11 SUMMARY OF 13-MODE GASEOUS EMISSIONS FROM THE DDAD 6V71 COACH ENGINE

Test Configuration	13-Mode FTP Emissions, g/kW-hr (g/hp-hr) HC	CO	NO_x	BSFC kg/kW-hr, (lb/hp-hr)
Baseline	2.374 (1.771)	9.922 (7.402)	9.595 (7.158)	0.297 (0.488)
Malfunction	1.822 (1.359)	17.832 (13.303)	6.977 (5.204)	0.316 (0.520)

Smoke was measured during the 13-mode testing as well as the FTP for smoke and selected steady-state points along the power curve. These smoke data are given in Table 12 and show significant increases in almost all power points tested. It is interesting that all of the relatively large changes in smoke occurred during the high power conditions, above 50% load. Relatively little change in smoke was noted for power points below the 50% load condition.

Several transient heavy duty engine dynamometer tests were run in both engine configurations. The average transient emission values from these tests are given in Table 13. In comparing the two configurations, the malfunction transient composite results showed a slight decrease in HC, similar to that indicated by the 13-mode results. Particulate and CO levels under the malfunction condition were substantially increased over the baseline levels. Composite NOx emissions under the malfunction condition were 26% lower than baseline levels. Composite fuel consumption was also increased, as expected, with the malfunction.

Table 14 summarizes the modal particulate results and also gives computed 7-mode composite results from both test engine configurations. In addition, these data are presented graphically in Figure 6. Preliminary maladjustment data had indicated substantial increases in smoke and particulate. From the steady-state data, it appears that the increases in particulate were primarily due to increased particulate emissions above the 50% load level as illustrated in Figure 6. Malfunction 7-mode composite particulate was 2.6 times that of baseline configuration due to the significant increase in particulate emissions at maximum power and torque.

Table 12 SMOKE OPACITY FROM THE DDAD 6V71 COACH ENGINE

Federal Transient Smoke Cycle Opacity

Configuration	Smoke Opacity, % "a"	"b"	"c"
Baseline	3.3	6.9	7.3
Malfunction	26.8	19.5	38.6

Steady-State Smoke Opacity

13-Mode FTP Mode	RPM	Power, %	Smoke Opacity, % Baseline	Malfunction
1	Idle	--	0.2	0.1
2	1260	2	0.2	0.1
3	1260	25	0.3	0.1
4	1260	50	0.4	0.3
5	1260	75	0.9	2.8
6	1260	100	8.6	23.5
7	Idle	--	0.3	0.4
8	2100	100	2.3	9.5
9	2100	75	0.5	3.9
10	2100	50	0.3	1.7
11	2100	25	0.3	1.3
12	2100	2	0.3	1.1
13	Idle	--	0.2	0.1

Power Curve Smoke

RPM	Smoke Opacity, % Baseline	Malfunction
2100	2.5	10.0
1900	2.2	11.3
1700	3.7	14.8
1500	4.1	16.3
1300	7.3	23.5
1260	7.5	--
1200	10.5	--

Table 13 SUMMARY OF AVERAGE TRANSIENT EMISSIONS FROM THE DDAD 6V71 COACH ENGINE

Cycle Type	Regulated Emissions, g/kw-hr, (g/hp-hr) HC	CO	NO_x[b]	Part.	Cycle BSFC[a] kg/kw-hr, (lb/hp-hr)	Cycle Work kw-hr, (hp-hr)
Baseline Configuration						
Cold Start	2.49 (1.86)	6.03 (4.50)	11.69 (8.72)	0.86 (0.64)	0.372 (0.612)	6.77 (9.07)
Hot Start	2.47 (1.84)	5.84 (4.36)	9.97 (7.44)	0.70 (0.52)	0.313 (0.515)	8.24 (11.05)
Transient Composite	2.47 (1.84)	5.87 (4.38)	10.21 (7.62)	0.72 (0.54)	0.322 (0.529)	8.03 (10.77)
Bus Cycle	2.72 (2.03)	4.65 (3.47)	10.27 (7.66)	0.83 (0.62)	0.339 (0.557)	3.31 (4.44)
Malfunction Configuration						
Cold Start	2.18 (1.63)	16.58 (15.17)	7.53 (5.57)	1.66 (1.46)	0.338 (0.579)	8.37 (11.44)
Hot Start	2.18 (1.63)	16.58 (12.37)	7.53 (5.62)	1.66 (1.24)	0.338 (0.556)	8.37 (11.22)
Transient Composite	2.18 (1.63)	17.12 (12.77)	7.52 (5.61)	1.70 (1.27)	0.340 (0.559)	8.39 (11.25)
Bus Cycle	2.48 (1.85)	20.72 (15.46)	7.98 (5.95)	1.97 (1.47)	0.345 (0.567)	3.80 (5.09)

Table 14 SUMMARY OF MODAL PARTICULATE EMISSION FROM THE DDAD 6V71

Test Condition rpm/load, %	Test Configuration	Particulate Rate mg/m^3 exh.	g/hr	g/kW-hr	g/kg fuel
1260/2	Baseline	12.45	7.54	4.21	2.00
	Malfunction	11.48	6.72	3.78	1.70
1260/50	Baseline	22.27	13.59	0.28	1.12
	Malfunction	25.67	15.08	0.33	1.26
1260/100	Baseline	161.46	98.93	1.01	3.96
	Malfunction	661.88	389.60	4.20	15.40
Idle	Baseline	8.64	1.53	--	1.82
	Malfunction	6.17	1.05	--	1.09
2100/100	Baseline	74.89	71.27	0.54	1.99
	Malfunction	224.56	205.40	1.63	5.63
2100/50	Baseline	42.37	39.97	0.61	1.91
	Malfunction	31.32	28.40	0.45	1.34
2100/2	Baseline	19.72	18.57	6.88	2.02
	Malfunction	18.70	16.94	7.09	1.81

	Composite of 7-modes	
	Brake Specific, g/kW-hr	Fuel Specific, g/kg fuel
Baseline	0.70	2.27
Malfunction	1.84	5.61

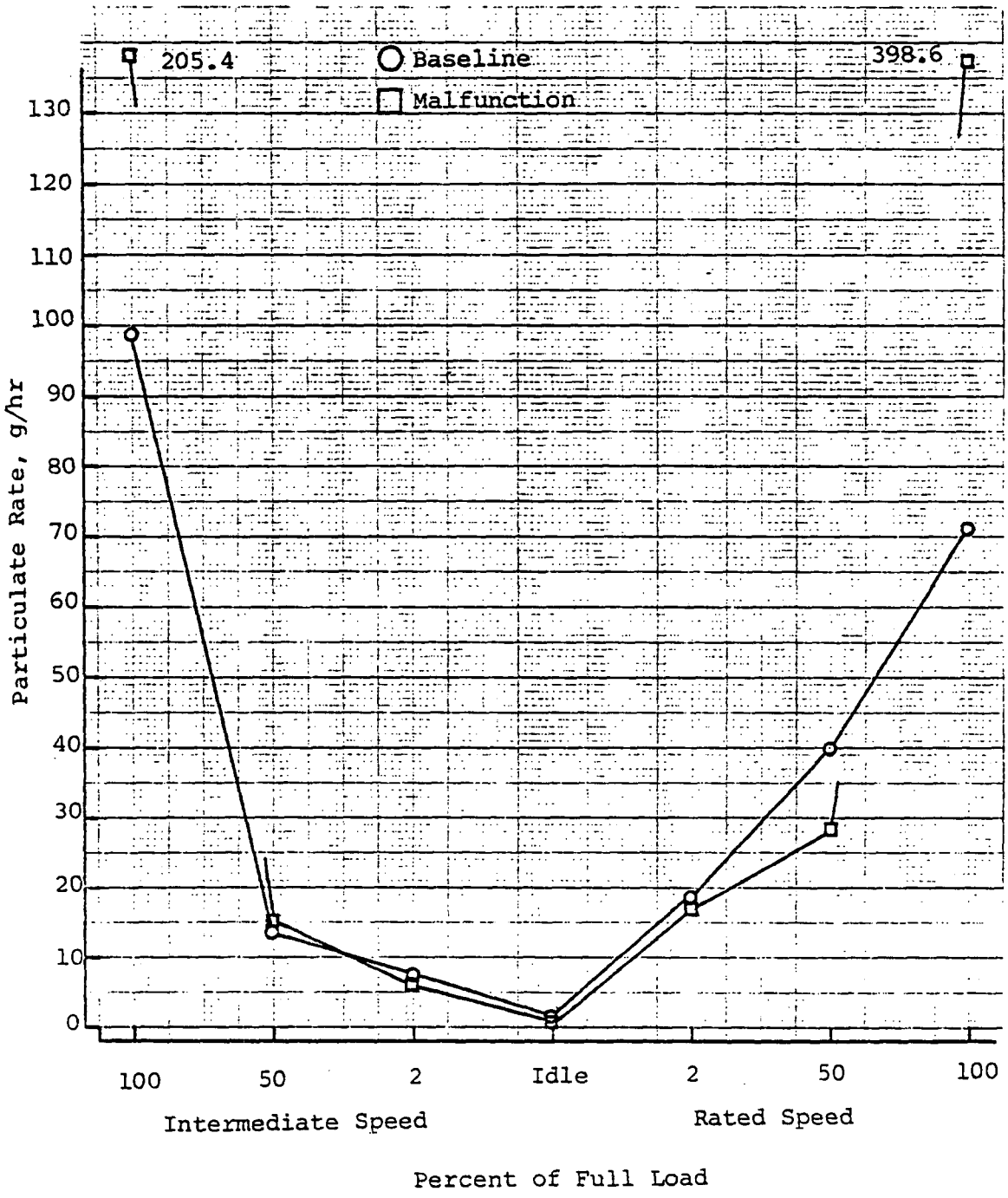

Figure 6 Modal Particulate Rates from the DDAD 6V71 Coach Engine

The soluble organic fraction (SOF) was determined from both transient and steady-state particulate samples from both configurations. Table 15 gives the percent of the total particulate soluble in methylene chloride along with the composite soluble fraction over the seven steady-state modes and the transient cycles. The percent of SOF was substantially lower for all of the malfunction conditions relative to the baseline configuration. The power specific SOF was also lower for the transient cycles but the same for the steady state composite. The 7-mode composite showed no difference between the malfunction and the baseline configuration on the basis of brake specific emission of SOF.

The Ames bioassay was performed on the SOF samples taken from the engine operating in the baseline and malfunction configurations. The results from this work showed no discernible difference in Ames response when the baseline sample data were compared to the malfunction sample data (9).

Aldehydes were measured using the DNPH procedure. A summary of aldehyde data from transient operation is given in Table 16. Formaldehyde, isobutyraldehyde and benzaldehyde were the only aldehydes detected over the transient cycle. Formaldehyde was detected from both cold and hot cycle exhaust samples, with slightly higher levels detected from the malfunction configuration. Essentially, no aldehydes were detected over the 13-mode test in either configuration, although some traces of isobutyraldehyde were found over the baseline bus cycle.

The levels of formaldehyde were higher in the malfunction configuration than the baseline. They were higher by 26% for the cold start and 76% for the hot start [(Malfunction - Baseline)/Baseline) x 100].

Table 15 SUMMARY OF CYCLE AND COMPOSITE SOLUBLE ORGANIC FRACTION FROM THE DDAD 6V71 COACH ENGINE

Test Cycle Composite	Cycle Composite Soluble Organic Fraction			
	Baseline		Malfunction	
	% SOF	g SOF/kW-hr	% SOF	g SOF/kW-hr
7-mode Composite	28.9	0.20	10.7	0.20
Cold Start Cycle	56.8	0.49	13.0	0.26
Hot Start Cycle	56.1	0.39	18.0	0.30
Transient Composite	56.2	0.40	17.1	0.29
Bus Cycle	64.6	0.54	17.9	0.35

Table 16 SUMMARY OF ALDEHYDES FROM TRANSIENT OPERATION OF DDAD 6V-71 COACH ENGINE

Configuration	Transient Cycle	Units	Formaldehyde	Isobutyr-aldehyde	Benzaldehyde
Baseline	Cold Start	mg/test	190	180	33
		mg/kw-hr	27	25	4.7
		mg/kg	76	70	13
	Hot Start	mg/test	170	44	--
		mg/kw-hr	21	5.4	
		mg/kg	67	17	
	Bus	mg/test	--	40	--
		mg/kw-hr		12	
		mg/kg		36	
Malfunction	Cold Start	mg/test	240	43	
		mg/kw-hr	28	5.0	
		mg/kg	79	14	
	Hot Start	mg/test	300	79	--
		mg/kw-hr	36	9.5	
		mg/kg	110	28	
	Bus	mg/test	--	--	--
		mg/kw-hr			
		mg/kg			

Note: No acetaldehyde

2. Normal Operating Conditions

Since the last ECTD characterization report, no work has been done in this area. Some funds are available for the work on heavy duty Diesels under normal operating conditions through EPA Contract No. 68-03-2706 with Southwest Research Institute. However, work in this area has not been possible because of a lack of availability of dynamometer capacity due to SwRI commercial work and due to dynamometer capacity being preempted by the Volvo dual-fueled engine and M.A.N. methanol engine work of EPA. However, work in this area will begin as soon as the M.A.N. engine and the alternate fuels heavy duty Diesel engine work has been completed and the dynamometer becomes available. One possibility for work under this area will be testing of particulate traps for bus engines. CTAB has obtained the loan of a DDAD 6V-71 bus engine, which is currently at SwRI. This engine could be used for any trap work done under this contract. Another possibility would be the testing of the new Chevrolet 6.2 liter Diesel engine or possibly some other power plant.

C. Aldehydes at High Mileage

1. Summary of Data

The major objective of this project (10) was to evaluate regulated and unregulated exhaust emissions, particulate and aldehydes from 1978 and 1979 catalyst equipped automobiles that had been driven approximately 50,000 miles. The automobiles were tested as received and after a tune-up to the manufacturers specifications. The resultant data were then compared to data that had been acquired on similar vehicles that had been tested under previous EPA contracts.

This high-mileage aldehyde study involved ten automobiles, seven 1978 model year automobiles equipped with oxidation catalysts, one 1978 model year automobile equipped with a three-way catalyst and two 1979 model year automobiles equipped with three-way catalysts. Engine sizes ranged from a

98 CID four-cylinder engine to a 400 CID eight-cylinder engine. The unregulated emissions measured included: particulates, metals and other elements, aldehydes, organic sulfide, organic amines, ammonia, cyanides, hydrogen sulfide and nitrous oxides.

A large data base for the cars evaluated and tested was generated under this project. This large data base was condensed and summarized in Table 17, which presents an average of the emissions of the pollutants for all of the vehicles. For example, an average of the hydrocarbon emissions of all 10 vehicles tested in this program in the "as received" condition is presented. This is compared to the average of the HC emissions for the vehicles after a tune-up. These data are then compared to the average HC emissions of eight low mileage catalyst vehicles tested in another project. Additional comparison data are provided on the average HC emissions for four 1970 non-catalyst vehicles, also tested in another project. These data are then provided for the remainder of the pollutants for which analyses were made.

From Table 17, trends in emissions changes can be observed. For example, with the 10 vehicles tested in this program the average "as received" HC emissions were 780 mg/km and the average "after tune-up" HC emissions were 600 mg/km, which would appear as though the fleet experienced a 23% [((600-780)/780)(100) = 23] decrease in HC emissions. However, average data can occasionally be misleading. Therefore, all of the data were analyzed as to whether the individual data trends supported the trends of the averaged data. The results of this analysis are presented in Tables 18 and 19. Again using the HC example to clarify this, the changes in HC between "as received" and tuned-up were analyzed for all of the vehicles (in this case only eight vehicles needed tune ups). This showed that of the eight data cases, only three vehicles had lower HC emissions after tune up. Three vehicles had increased HC and two had no change. This, then, seems to make the 23% decrease shown in Table 17 seem less definite and it was judged on a subjective basis that the probable trend (right hand column) was "little change" rather than a "decrease" that Table 17 would have suggested. This process was repeated for the remainder of the data.

Table 17

Emission	Average FTP Emission Rate, mg/km: Ten High Mileage Cars-This Project, As-Rec'd	Ten High Mileage Cars-This Project, After Tune-Up	Four 1970 Model Non-Catalyst Cars Previous Tasks[a]	Eight Low Mileage Catalyst-Equipped C Previous Projects[b]
Hydrocarbons	780	600	1,900	200
Carbon Monoxide	9,200	6,610	17,100	2,525
Oxides of Nitrogen	1,340	1,020	2,600	670
Total Particulates	49	32	99	8
Aldehydes & Ketones	6	4	37	2
Organic Sulfides	0.2	0.1	0.1	0.4
Organic Amines	0.1	0.1	0.1	0.1
Ammonia	7	9	4	12
Cyanide & Cyanogen	1	1	3	1
Hydrogen Sulfide	0.1	0.1	0.1	0.1
Nitrous Oxide	46	36	—	22

[a]Data for four 1979 model cars from Tasks 4 and 5 of this contract, EPA Report EPA-460/3-81-020

[b]Data for eight 1978 and 1979 model catalyst-equipped cars from previous contracts, 68-03-2499, 68-03-2588, and 68-03-2697. EPA reports EPA-460/3-80-003, -004, and -005.

Table 18

Comparison of "As-Received"
Data to "After Tune-Up" Data
To Note Effect of Tune-Up
on Emissions - Ten High Mileage Cars

Pollutant	Trend in Table 17	Number of Individual Data Points with Same Trend*	Probable Trend
HC	decrease	3/8	little change
CO	decrease	7/8	decrease
NOx	decrease	4/8	little change
Total Particulates	decrease	5/8	decrease
Aldehydes and Ketones	decrease	6/8	decrease
Organic Sulfides	decrease	3/8	little change
Organic Amines	same	8/8	same
Ammonia	increase	4/8	some change
Cyanide & Cyanogen	no change	1/8	little change
Hydrogen Sulfide	no change	8/8	no change
Nitrous Oxide	decrease	5/8	decrease

*The first number represents the number of individual data points that exhibit the same trend as in Table 17. The second number represents the total possible. In this case, 8 of the 10 vehicles required a tune up.

Table 19

Comparison of Low-Mileage
Catalyst Equipped Cars Data To
Ten High Mileage Cars (After Tune-Up
Data) To Note Effect of High Mileage on Emissions

Pollutant	Trend in Table 17	Number of Individual Data Points with Same Trend*	Probable Trend
HC	increase	10/10	increase
CO	increase	9/10	increase
NOx	increase	7/10	increase
Total Particulates	increase	9/10	increase
Aldehydes and Ketones	increase	6/10	some increase
Organic Sulfides	decrease	9/10	decrease
Organic Amines	no change	10/10	no change
Ammonia	decrease	3/10	little change
Cyanide & Cyanogen	same increase	5/10	little change
Hydrogen Sulfide	no change	8/10	no change
Nitrous Oxide	increase	4/10	little change

*The first number represents the number of individual data points that exhibit the same trend as Table 17. The second number represents the total possible. In this case, 10 vehicles were tested at the two mileage points.

In reviewing the influence on emissions of the tune up (Table 18), it would appear that there would be little change in a fleet sense in HC, a decrease in CO, some decrease in NOx, a decrease in total particulates and aldehydes and little or no change in the remainder of the pollutants for which analyses were made. Table 19 presents the probable trend in emissions as a function of accumulated vehicle miles. This analysis showed a probable increase in regulated emissions (HC, CO and NOx), and total particulates, some increase in aldehydes and ketones (Table 17 indicates an increase from 2 to mg/km, low mileage to higher mileage-tuned-up vehicle), a decrease in organic amines and little or no change in the remaining emissions. The most significant result of this work is that aldehyde emissions do not g reatly increase at high mileage. Thus, even at high mileage, it appears that the catalyst results in good control of aldehydes.

V. References

1. Baines, Thomas M., "Summary of Current Status of EPA Office of Mobile Source Air Pollution Control Characterization Projects", Report EPA/AA/CTAB/81-18, August, 1981.

2. Bykowski, Bruce B., "Characterization of Diesel Emissions from Operation of a Light-Duty Vehicle on Alternate Source Diesel Fuels", Draft Final Report for EPA Contract No. 68-03-2884, Task Specification 3, November, 1981.

3. Data taken from ECTD/CTAB memo from Karl H. Hellman to Charles L. Gray, "Update on CTAB Methanol Projects", January 15, 1982.

4. DeMeyer, Colleen L. and Garbe, Robert J., "The Determination of a Range of Concern for Mobile Source Emissions of Hydrogen Cyanide", Report EPA/AA/CTAB/PA/81-13, August, 1981.

5. Ullman, Terry L. and Hare, Charles T., "Emission Characterization of an Alcohol/Diesel-Pilot Fueled Compression-ignition Engine and Its Heavy-Duty Diesel Counterpart", Report EPA-460/3-81-023, August, 1981.

6. Monthly Progress Report No. 33 for Contract No. 68-03-2706, July 20, 1981.

7. Springer, Karl, "Field Demonstration of General Motors Environmental Improvement Proposal (EIP)- A Retrofit Kit for GMC City Buses", Final Report, Contract No. PH22-68-23, December, 1972.

8. Letter from Dave Merrion (GM Detroit Diesel Allison Division) to Karl Springer (SwRI) discussing timing changes, March 15, 1972.

9. Memo, Craig A. Harvey to Charles L. Gray, titled "Recent Ames Test Results", January 6, 1982.

10. Smith, Lawrence R., "Characterization of Exhaust Emissions from High Mileage Catalyst-Equipped Automobiles", EPA Report No. EPA-460/3-81-024, September, 1981.

VI. List of Recent CTAB Characterization Reports

The following reference list contains all of the recent in-house characterization reports written by various CTAB personnel. The list also contains most of the recent CTAB contract reports in the characterization area. The NTIS numbers, where available, are given for these reports. In cases where an access number has been requested from NTIS and is not yet available, the notation "NTIS-PB" followed by several blank spaces is given.

Recent CTAB Technical Reports

1. "Summary of Current Status of EPA Office of MSAPC Characterization Projects", EPA/AA/CTAB/PA/81-18, NTIS PB 82105909, August 1981.

2. "Gasoline Equivalent Fuel Economy Determination for Alternate Automotive Fuels", EPA/AA/CTAB/PA/81-16, NTIS PB 82120072, August 1981.

3. "Summary of EPA & Other Programs on the Potential Carcinogenicity of Diesel Exhaust", EPA/AA/CTAB/PA/81-19, NTIS PB 82128018, August 1981.

4. "The Determination of a Range of Concern for Mobile Source Emissions of Hydrogen Cyanide", EPA/AA/CTAB/PA/81-13, NTIS PB 82120098, August 1981.

5. "Determination of a Range of Concern for Mobile Source Emissions of Ammonia", EPA/AA/CTAB/PA/81-20, NTIS PB 82120056, August 1981.

6. "The Determination of Range of Concern for Mobile Source Emissions of Sulfuric Acid", EPA/AA/CTAB/PA81-21, NTIS PB 82117870, August 1981.

7. "An Approach for Determining Levels of Concern for Unregulated Toxic Compounds from Mobile Sources", EPA/AA/CTAB/PA/81-2, NTIS PB 82118167, July 1981.

8. "Nitrosamines and Other Hazardous Emissions from Engine Crankcase", EPA/AA/CTAB/PA/81-15, NTIS PB 2127960, June 1981.

9. "Review of the Literature and On-going EPA Projects Comparing Portable Dosimeters & Fixed Site Monitors as Accurate Indicators of Exposure to Carbon Monoxide", EPA/AA/CTAB/PA/81-14, NTIS PB 82123712, May 1981.

10. "A Review of the Compatibility of Methanol/Gasoline Blends with Motor Vehicle Fuel Systems", EPA/AA/CTAB/PA/81-12, NTIS PB 82117904, May 1981.

11. "Brief Synoposis of EPA Office of Research and Development and the Health Effects Institute Mobile Source Work", EPA/AA/CTAB/PA/81-10, NTIS PB 82124421, May 1981.

12. "Mobile Source Emissions of Formaldehyde and Other Aldehydes", EPA/AA/-CTAB/PA/81-11, NTIS PB 82118159, May 1981.

13. "Comparison of Gas Phase Hydrocarbon Emissions from LD Gasoline Vehicles and LD Vehicles Equipped with Diesel Engines", EPA/AA/CTAB/PA/80-5, September 1980.

14. "Summary of Responses from Manufacturers EPA Letter Requesting Car Interior/Nitrosamine Information", EPA/AA/CTAB/PA/80-4, August 1980.

15. "Changes in Automotive Sulfate Emissions with Extended Mileage, CTAB-2/ASE-FY 79-1, January 1979.

Some Recent CTAB Extramural Contract Reports

1. "Estimating Mobile Source Pollutants in Microscale Exposure Situations", EPA-460/3-81-021, NTIS PB 82101114, July 1981.

2. "Nitrosamines in Vehicle Interiors", EPA-460/3-81-029, NTIS PB 82125014 September 1981.

3. "Unregulated Exhaust Emissions from Non Catalyst Baseline Cars Under Malfunction Conditions", EPA-460/3-81-020, NTIS PB 82101130, May 1981.

4. "Emission Characterization of an Alcohol/Diesel-Pilot Fueled Compression-Ignition Engine and Its Heavy-Duty Diesel Counterpart", EPA-460/3-81-023, NTIS PB 82154113, August 1981.

5. "Characterization of Exhaust Emissions from High Mileage Catalyst-Equipped Automobiles", EPA-460/3-81-024, NTIS PB 82131566, September 1981.

6. "Sulfuric Acid Health Effects", EPA-460/3-81-025, NTIS PB 82113135, September 1981.

7. "Hydrogen Cyanide Health Effects", EPA-460/3-81-026, NTIS PB 82116039, September 1981.

8. "Ammonia Health Effects", EPA-460/3-81-027, NTIS PB 82116047, September 1981.

9. "Hydrogen Sulfide Health Effects", EPA-460/3-81-028, NTIS PB , September 1981.

10. "Formaldehyde Health Effects", EPA-460/3-81-033, NTIS PB 82162397, December 1981.

11. "Acrolein Health Effects", EPA-460/3-81-034, NTIS-PB 82161282, December 1981.

12. "Methanol Health Effects", EPA-460/3-81-032, NTIS PB 82160797, December 1981.

13. "Nitrosamine Analysis of Diesel Crankcase Emissions", EPA-460/3-81-008, NTIS PB 81212458, March 1980.

14. "Characterization of Diesel Emissions as a Function of Fuel Variables", EPA-460/3-81-015, NTIS PB 81244048, April 1981.

15. "Characterization and Research Investigation of Methanol and Methyl Fuels", EPA-460/3-77-015, NTIS PB 2718998, August 1977.

16. "Impact of Coal and Oil Shale Products on Gasoline Composition 1976-2000", EPA-460/3-76-035, NTIS PB 265478, December 1976.

17. "Assessment of Automotive Sulfate Emission Control Technology", EPA-460/3-77-008, NTIS PB 270263, June 1977.

18. "Gasohol, TBA, MTBE Effects On Light Duty Emissions", EPA-460/3-79-012, NTIS-PB 80224082, October 1979.

19. "Characterization of Gaseous and Particulate Emissions from Light-Duty Diesels Operated on Various Fuels", EPA-460/3-79-008, NTIS PB 80122443, June 1979.

20. "Hydrogen Cyanide Emissions from a Three-way Catalyst Prototype", EPA-460/3-77-023, NTIS PB 279037, December 1977.

21. "Preliminary Investigation of Light Duty Diesel Catalysts", EPA-460/3-80-002, NTIS PB 81240327, January 1980.

22. "Regulated and Unregulated Exhaust Emissions from Malfunctioning Non-catalyst and Oxidation Catalyst Automobiles", EPA-460/3-80-003, NTIS PB 80190473, January 1980.

23. "Regulated and Unregulated Exhaust Emissions from Malfunctioning Three-Way Catalyst Gasoline Automobiles", EPA-460/3-80-004, NTIS PB 8019084, January 1980.

24. "Regulated and Unregulated Exhaust Emissions from a Malfunctioning Three-way Catalyst Gasoline Automobile", EPA-460/3-80-005, NTIS PB 80187446, January 1980.

25. "Characterization of Sulfates, Odor, Smoke, POM and Particulates from Light and Heavy Duty Engines-Part IX", EPA 460/3-79-007, NTIS PB 80121551, June 1979.

26. "Characterization of Tire Wear Particulates", EPA-460/3-81-036, NTIS PB 821153586, November 1981.