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CRC PILOT PROGRAM TO INVESTIGATE THE EFFECT ON DRIVEABILITY OF INTAKE VALVE DEPOSITS AND VARIATIONS IN FUEL VOLATILITY

June 1993

COORDINATING RESEARCH COUNCIL, INC.
219 PERIMETER CENTER PARKWAY, ATLANTA, GEORGIA 30346

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CRC PILOT PROGRAM TO INVESTIGATE THE EFFECT ON DRIVEABILITY OF INTAKE VALVE DEPOSITS AND VARIATIONS IN FUEL VOLATILITY

(CRC PROJECT NO. CM-118-92)

Prepared by the

CRC Volatility Group

June 1993

Automotive Vehicle, Fuel, Lubricant, and Equipment Research Committee

of the

Coordinating Research Council, Inc.

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ABSTRACT

During the Coordinating Research Council's (CRC) program to select an engine to replace the BMW 318i as the industry standard intake valve deposit test engine, an opportunity was identified to compare the driveability performance of the engines evaluated with and without intake valve deposits. A pilot program was thus conducted by the CRC Volatility Group at Southwest Research Institute during late 1991 and early 1992 to investigate the relationship between intake valve deposits and cold-start and warmup driveability. Eight vehicles were tested using three fuels with varying T_{50} levels. Duplicate ratings were made using both the BMW Driveability Test Procedure and a modification of the CRC Cold-Start and Warmup Driveability Procedure. None of the three candidate engines were as good as the BMW 318i reference engine in discriminating valve deposit effects on driveability. Rater differences obscured other possible effects.

I. INTRODUCTION

The Coordinating Research Council (CRC) Intake Valve Deposit (IVD) Group conducted a program in 1991 at Southwest Research Institute (SwRI) to identify one or two high-volume automotive engines that: 1) develop deposits representative of those found in the US fleet; 2) are sensitive to fuel quality; and 3) develop deposits of sufficient quantity allowing for further development of fuels and additives[1]. The engine(s) and results were to be used to develop an industry-accepted test for defining the intake valve deposit characteristics of a gasoline. An opportunity was recognized to expand upon the IVD Group's program to investigate the relationship between intake valve deposits and cold-start and warmup driveability using the same vehicles.

The CRC Volatility Group thus conducted a program at the end of the original intake valve deposit program to collect data relating driveability to intake valve deposits and variations in fuel volatility on the eight vehicles tested in the CRC IVD program, and to gather information to guide a possible full-scale driveability/IVD program in the future. Mileage accumulation was accomplished in late 1991; testing was conducted in January and February 1992.

Members of the Data Analysis Panel are given in Appendix A. The program proposal is outlined in Appendix B.

II. SUMMARY AND CONCLUSIONS

Large differences in rater severity and large differences in response to planned variables (driving procedure, fuel volatility, intake valve deposits) led to large rater/procedure interactions. These interactions prevent any statistically significant conclusions regarding the effects of fuel volatility and/or intake valve deposits and the ability of each procedure to judge either volatility or intake valve deposit effects. Since this test was only a small pilot program, it was not surprising that fuel volatility and valve deposits were not shown to have statistically significant effects on driveability. Significant effects may be demonstrated in a large full-scale program, and in fact volatility effects have been demonstrated in previous programs. [2,3]

On the basis of average data, the following observations can be made:

- Of the vehicles tested, the BMW's exhibited the largest differentiation in driveability with and without intake valve deposits. The difference was about 46 and 100 demerits as measured by the CRC and BMW procedures, respectively.

- None of the three candidate engines displayed driveability problems resulting from intake valve deposits as well as the BMW.

- In general, vehicles with the same engine type responded similarly.

- The combination of the BMW 318i vehicles with the BMW procedure provided the strongest measure of the effect of intake valve deposits on driveability.

- SAS General Linear Model (GLM) analysis showed no significant difference among the candidate engines in their driveability response to intake valve deposits.
- The combination of intake valve deposits and low volatility fuel increased driveability demerits in both procedures with both raters.

III. TEST VEHICLES

The same eight test cars that were used in the CRC Intake Valve Deposit Program[1] were used in the driveability program. The fleet is described in Table 1.

The BMW's had known performance records to allow them to serve as baselines. Two rater comparison cars were also rented to assist in the assessment of driver variability.

Prior to beginning the mileage accumulation, the vehicles were prepared according to the SwRI/BMW Intake Valve Deposit Test Procedure[4]. This preparation included a cooling system pressure check, a leakdown test, and a blowby reading at 1000 rpm. A full array of computer diagnostic tests was also performed on each vehicle to ensure the vehicles met manufacturer's specifications.

IV. TEST FUELS

The CRC composite base fuel used for the mileage accumulation fuel was the same fuel used in the CRC IVD Program. This composite base fuel was made up of five fuels donated by five suppliers. The CRC composite base fuel did not contain an intake valve deposit control additive, and was shown in the IVD Program to produce intake valve deposits in all the vehicles; therefore, it was selected for use in this program. Table 2 presents inspections on this composite base fuel.

The driveability test fuel set contained four hydrocarbon-only fuels blended at 7.5±0.3 psi Reid vapor pressure. The 50 percent distillation temperatures (T_{50}) were targeted at 200°F, 225°F, 250°F, and 270°F for the four fuels, with tolerances of ±5°F. The 90 percent distillation temperatures (T_{90}) were targeted at 340°F ±10°F for all fuels. The fuels did not contain any detergent or additive package. The fuels contained an antioxidant and a corrosion inhibitor. The fuels were unleaded and had a minimum (R+M)/2 octane rating of 92. The fuels had a maximum endpoint of 415°F. The 270°F T_{50} test fuel was only to be used in the unlikely case that insignificant driveability demerits were obtained with the 250°F T_{50} test fuel. Table 3 contains the average test fuel inspection data as reported by three laboratories, while Appendix C summarizes individual laboratory fuel properties.

V. TEST SITE

The program was conducted by CRC under contract at Southwest Research Institute in San Antonio, Texas. SwRI provided a suitable test track for driveability testing, mileage accumulation, and the necessary labor for conducting the test program. One of the two driveability rating teams was provided by EG&G Automotive Research, Inc.

VI. TEST CONDITIONS

The preferable temperature range for overnight soaks and testing was between 40°F and 50°F. The maximum range was set between 32°F and 60°F.

In the first half of the program, during which testing was conducted with deposited valves, all testing was accomplished with a mean temperature of 48.5°F and a range of 37°F to 54°F. In the second half of the program, during which testing was conducted with clean valves, the mean test temperature was 53.8°F with a range of 48°F to 65°F.

Some tests had to be rescheduled because of rain or because the temperatures were not within the acceptable limits.

VII. TEST DESIGN

Upon completion of the IVD engine-selection program[1], the engines from all eight test vehicles were disassembled to allow inspections and measurements of the intake valve deposits. The deposited valves were saved for further analysis by the IVD Group, and new valves were installed for the driveability work. Cylinder heads were cleaned and checked for proper specifications prior to installation of the new valves. Mileage was accumulated on the clean engines using the composite base fuel and the standard BMW mileage accumulation cycle to generate deposits for the driveability testing.

After the vehicles accumulated 20,000 miles, each rater performed driveability ratings on each fuel/procedure combination using each of the vehicle types. Upon completion of the driveability ratings with the deposited valves, the engines were disassembled for inspections and measurements of intake valve deposits. New valves were then installed in each of the vehicles, and clean driveability ratings were performed. This minimized the time lapse and temperature differences between the "clean" and "dirty" ratings.

To meet the time constraints necessary to make this program useful, it was necessary to make duplicate ratings, rather than triplicate tests as had been originally proposed. All vehicles were tested on all three conventional fuels (nominal 200°F, 225°F, and 250°F T_{50}) with duplicate ratings on both the BMW procedure and a modification of the CRC cold-start and warmup procedure. This was a balanced (4 engine types x 2 vehicles per engine type x 3 fuels x 2 test procedures x 2 raters) experiment comparing driveability with clean and dirty intake valves (20,000 deposit miles).

Two rater/observer teams were used for all ratings, with SwRI and EG&G each providing a team. Each team rated one car of each make/model; the duplicate rating was made by the other rating team. Each rating team thus saw each car/fuel combination once during each phase of the program (once with deposited valves and once with clean valves). Two additional vehicles were utilized for rater comparison cars. These were rental cars with at least 10,000 miles on them, and were tested each day on the 250°F T_{50} fuel to provide comparison data on the raters.

VIII. TEST PROCEDURE

All vehicles were tested on the three fuels using both the standard BMW cycle and a modification of the CRC Cold-Start and Warmup Procedure. Test procedures are detailed in Appendices D and E, respectively. The normal BMW and CRC demerit calculation methods as defined in Appendices D and E were used for the respective test procedures.

The modified CRC Cold-Start and Warmup Procedure was developed on-site with this test fleet by several members of the CRC Volatility Group. The test procedure was modified to maximize sensitivity to deposits. Accelerations and braking were more aggressive. Surge was not included among the malfunctions rated.

IX. DISCUSSION OF RESULTS

A complete listing of the driveability data is given in Appendix F. The data were analyzed using SAS General Linear Models (GLM) and Least Squares (LS) Means. The analysis was also t'ed using square root of TWD as the analyzed variable, but no improvement was found. The following results are thus based upon analysis of total weighted demerits.

1. Intake Valve Deposit Weights

The results of duplicate 5,000-mile IVD deposit tests on the BMW and three candidate engines from the IVD program[1] are presented in Table 4 along with 20,000-mile deposit weights from independent tests using the same vehicles, fuel, and mileage accumulation cycle. These 20,000-mile test engines were used for this driveability test. On average, deposit weights for CRC-3/CRC-4 and CRC-5/CRC-6 did not increase from 5,000 miles (measured during the previous IVD testing) to 20,000 miles (measured during this driveability program), while deposits for CRC-1/CRC-2 and S-49/S-50 were much higher in this 20,000-mile test than in the previous 5,000-mile test. The average deposit weights ranged from 287 for CRC-1/CRC-2 to 919 for S-49/S-50 (See Table 4). Deposit weights for each of the eight driveability test vehicles ae shown in Table 5.

2. Vehicle Response - Driveability Demerits versus Deposits

Twelve driveability tests were conducted on each vehicle at 20,000 miles (3 fuels x 2 procedures x 2 raters). Dirty valves were then replaced with clean valves and the twelve run matrices repeated on each vehicle. Using all the data from both procedures, the difference in driveability demerits with and without deposits shows a strong deposit affect for the BMW 318i vehicle. The three candidate engines show a smaller overall response to IVD. These data are shown in Figure 1. Data listings and SAS General Linear Model Procedure (GLM) runs supporting this work are available on request.

3. CRC Driveability Procedure

The bar graphs in Figure 2 show the average of six runs (3 fuels x 2 raters) for valves with and without deposits using the CRC Driveability Procedure. The graph shows that similar vehicles with the same engine configuration had similar demerit levels both with and without deposits. The difference in driveability due to deposits between the BMW and candidate engines was significant at the 95 percent confidence level. Figure 3 shows that the other three engines exhibit no consistent degradation in driveability due to deposits as measured by the CRC Driveability Procedure. None of the differences between the candidate engines were statistically significant.

4. BMW Driveability Procedure

The bar graph in Figure 4 shows the average of six runs (3 fuels x 2 raters) for intake valves with and without deposits using the BMW Driveability Procedure. As in the CRC procedure, similar vehicles with the same engine configuration had similar demerit levels which allow the models to be averaged as shown in Table 6. Again, the BMW vehicles had the highest demerits with and without deposits and showed the largest increase in demerits. Average demerits across the other three engines increased approximately 30 demerits which is significant at the 95 percent confidence level. As shown in Figure 3, the degradation of driveability due to deposits in these three engines is also significantly different from the BMW 318i at the 95 percent confidence level; however, the candidate engines are not significantly different from each other.

5. Comparison of Driveability Procedures

Since both vehicles of the same engine configuration appear to respond similarly for each of the test procedures, the differences in demerits between clean and dirty engines were averaged and are shown in Table 6. This table shows that the BMW vehicles had the highest increase in driveability demerits with deposits in the BMW Driveability Procedure. The BMW also had the largest degradation in driveability due to IVD (46 total weighted demerits) in the CRC Driveability Procedure.

The BMW 318i vehicle shows degraded driveability with deposits using either procedure; however, the change in demerits using the BMW Procedure is twice as large as the demerit increase is in the CRC Driveability Procedure. With the other three vehicles, there is no degradation in driveability due to deposits using the CRC Procedure. Using the BMW Procedure, there is a modest increase in driveability demerits due to IVD. Neither procedure shows that any one of the three candidate engines are more responsive to deposit induced driveability problems than the other two. This information is shown in Figure 3.

The success of the BMW Procedure in correlating driveability malfunctions with IVD is not surprising, since the BMW procedure was developed explicitly for this purpose.

6. Volatility

Figure 5 shows the demerits observed using the BMW procedure with the BMW 318i vehicles with (dirty) and without (clean) valve deposits on each of the three test fuels. T_{50} is used to characterize the difference between fuels. Each data point is the average of four runs (2 vehicles x 2 raters). The curves indicate increasing demerits with increasing T_{50} (decreasing volatility) as expected. The dirty valve condition generated larger demerits than the clean condition and showed greater response to fuel volatility. The increase in demerits with dirty valves due to increasing T_{50} from 200°F to 250°F is about the same as the overall increase in demerits due to valve deposits; however, the effect of valve deposits on demerits varies with T_{50} level.

Figure 6 shows the driveability demerits for the other three vehicle models using the BMW procedure. These vehicles had much lower demerits than the BMW vehicles. In order to show the responses to fuel volatility and deposits, it was necessary to expand the demerit scale on the plot, compared to the previous figure. Each of the three vehicle models show increased demerits with deposits on each of the three fuels and increasing demerits with increasing T_{50} except for CRC-5 and CRC-6 with the most volatile fuel; however, all demerits are very low.

Figures 7 and 8 show the demerits on the same vehicles using the CRC driveability procedure. The comparisons are not as clear using this procedure. The BMW still has higher demerits than any of the other cars and the valve deposits increase demerits. The increase in demerits due to deposits on the low T_{50} fuel is very minor, however, compared to the differences with the other two fuels. Also, the driveability of the BMW either with or without deposits did not degrade when T_{50} was increased from 225°F to 250°F. With the other three vehicles, there appears to be a lack of uniformity in response to either volatility or deposits. CRC-5/CRC-6 show almost no driveability response to either deposits or volatility. The differences in driveability in CRC-1/CRC-2 due to either volatility or deposits are generally less than five demerits. Only the data with deposits for CRC-3/CRC-4 indicate any appreciable driveability response to fuel volatility.

7. Test Temperature

Based on the rater comparison vehicles, statistical analysis shows no significant effect for each rater or temperature between the dirty phase of the program (average soak temperature = 48°F) and the clean phase of the program (average soak temperature = 54°F) excluding reruns. Reruns were conducted between February 17, 1992 and February 25, 1992, with an average soak temperature of 58°F.

8. Analysis for Individual Raters

The vast difference in demerit levels between raters leads to an analysis problem. Because the demerits issued by Rater R are five to ten times higher than those issued by Rater S (Appendix F), with an accompanying level of variability, the data reported by Rater S are masked by the magnitude of the noise in Rater R's data. Thus, the preceding conclusions are to a great extent based only on the appraisals by Rater R. This is tantamount to discarding half the data. Without prior knowledge, there is no way of knowing which rater, if either, is doing the better job of detecting and consistently evaluating driveability malfunctions. The low ratings might be appropriate, the high ratings might be appropriate, or both raters might respond well to fuel parameters, but at different absolute levels. Consequently, the data analyzed separately for each rater follows.

Each point for each volatility level on the graphs of data from the three candidate engines (Figures 9-12) represents the average of six tests, one test on each of the pair of vehicles representing each of the three candidates. The graphs of results from the BMW vehicles (Figures 13-16) represent the average of two tests, one on each car. Statistical significance defined in terms of 95 percent confidence limits is not a useful tool in this case due to the variability introduced by model-to-model and car-to-car (within a given model) differences. Instead, the data from this pilot program should be taken merely as averages, with the knowledge that these results are indicative, not proof.

Each figure is plotted versus volatility. The correct measure of volatility to use is not clear at this point. Since this is a pilot study, choosing a volatility scale prematurely has been avoided; instead, the fuels are presented evenly spaced along the abscissa. Fuel 809 is the most volatile and Fuel 811 is the least volatile. It should be noted that the relative distances are not meant to be representative of volatility differentials, even though the volatility does decrease going from left to right.

A. The CRC IVD/Driveability Test Procedure

With these points in mind, Figures 9-12 depict the data generated by the CRC procedure. Figures 9 and 10 present the data from Rater S, while Figures 11 and 12 present the data from Rater R. The data from each rater are further subdivided into results from the six vehicles with the candidate engines (which were not significantly different, and so were pooled) and the results from the two BMW vehicles.

Figure 9 shows that Rater S found very few malfunctions (fewer than 25 demerits) and little difference between fuels when evaluating the candidate vehicles with clean valves using the CRC procedure. Rater S did differentiate the lowest volatility fuel from the two higher volatility fuels when the same vehicles had dirty valves. An alternate view is that with higher volatility fuels, IVD was not detected by this rater; yet with the least volatile fuel, dirty and clean valves could be distinguished. The overall low demerit levels are in keeping with the latest cold start and driveaway results for PFI vehicles[5].

Figure 10 shows Rater S's evaluations of the BMW vehicles using the CRC procedure. As in discussion sections 2 - 6, the BMW vehicles were evaluated separately because their response level was five to ten times higher than the mean for the candidate vehicles. In the BMW vehicles, dirty valves caused a near doubling in mean demerits at <u>all</u> fuel volatilities. Additionally, for both clean and dirty valves, there is a continuous trend of decreasing volatility leading to degraded driveability. In the case of valves with IVD, this is in contrast to the nonlinear results seen in the candidate vehicles.

In Figure 11, the results from the candidate vehicles as evaluated by Rater R using the CRC procedure are presented. Compared with Figure 9, the roughly order-of-magnitude difference in rater response is immediately obvious. Paradoxically, with higher volatility fuel, IVD leads to only two-thirds the demerits seen when the valves are clean. Only with the least volatile fuel do the clean valves generate fewer demerits than those with IVD. Another unusual feature is that the dirty valves have a continuous degradation of driveability with decreasing volatility, while the clean valves show no response, and possibly an improvement on the worst fuel. Possible explanations for the apparent paradoxical results will be discussed in the "Comparison of Procedures" section.

The results with the BMW vehicles (Figure 12) are somewhat similar in that for higher volatility fuels, the best driveability is found when IVD is present, but clean valves give better driveability with the least volatile fuel. In this case, however, the trend of clean results is unclear. It may be strongly nonlinear, or the apparent curvature may be an artifact of the high variability. The tests with IVD present show no difference between the two least volatile fuels, but much better results on the most volatile fuel.

B. <u>The BMW IVD Test Procedure</u>

The final four figures show the results of the BMW procedure broken down in the same way. The results provided by Rater S on the candidate vehicles using the BMW procedure show little difference between clean and dirty valves except with the worst fuel (see Figure 13). In that case, more demerits were observed when valves were dirty. The clean valves show only a slight response to fuel volatility, while the cars tested with dirty valves show a stronger response due to the high demerit level found with the least volatile fuel. This compares well with the CRC procedure results.

When the BMW's were tested by Rater S using the BMW procedure, the driveability was three to five times worse with IVD present, regardless of volatility (see Figure 14). Again, the magnitude of the demerit levels was much higher than for the candidate vehicles. Driveability always decreases with decreasing volatility for both clean and dirty valves. Again, the results parallel the CRC procedure results.

In Figures 15 and 16, Rater R's results for the candidate vehicles and for the BMW's are presented. The results are very similar to each other except that the magnitude of the demerits generated by the BMW's is roughly three times that of the candidate vehicles. Both sets of cars generate more demerits when IVD is present, and both sets of cars always respond with decreasing driveability as volatility decreases. The results of the BMW procedure are not consistent with those of the CRC procedure.

C. Comparison of Procedures

The two procedures compare differently depending upon the rater generating the data. Rater S obtains similar results in both procedures. In the CRC procedure, Rater S finds a small, degradation in the driveability of the candidate vehicles with clean valves. This degradation may not have physical significance, since its magnitude is small relative to the noise level. Rater S also found virtually no difference between Fuels 809 and 810 with dirty valves. Rater S found the most demerits with the combination of dirty valves and the lowest volatility fuel. The same results are obtained in the BMW procedure except that the magnitude of the results is roughly half that in the CRC procedure. Thus, the case of dirty valves and low volatility fuel is distinguished in the same way by either procedure.

Rater S also generates the consistent results for the BMW vehicles for both the CRC and BMW procedures. In both procedures, the dirty valves cause a five-to-ten fold increase in observed demerits relative to clean valves. The only difference is that the BMW procedure produces roughly half the demerits of the CRC procedure, in accordance with the results from the candidate vehicles. In contrast to the candidate vehicle results, the response to volatility is roughly linear over the range studied (always degrading as volatility decreases).

Judging by the results from Rater S, the two procedures are roughly equivalent in sorting fuels and finding IVD-related problems. Only the magnitude of the numbers changes between procedures, with the CRC procedure's being the more severe. Based upon Rater S's data, the BMW vehicles appear continuously dependent upon fuel volatility, while the candidate vehicles respond to fuel volatility only at quite low volatility and only when IVD is present.

The results from Rater R are more troublesome to analyze. There is a great deal of difference between results from the two test procedures. The BMW procedure results indicate that both candidate and BMW vehicles respond to volatility over the entire range, and vehicles with IVD always have appreciably more driveability problems than vehicles with clean valves. The results from the CRC procedure are confusing, however, with improvements in driveability accompanying decreases in volatility, vehicles with dirty valves performing better than those with clean valves when the high volatility fuel is used, and apparent unusual nonlinearities. Rater R finds the BMW procedure more severe.

These conflicts may be due in part to the fact the CRC procedure is new and not as well learned by the raters as the established BMW procedure. The severe nature of the CRC procedure may have caused a great deal of noise in Rater R's results, leading to the physically hard-to-understand results. It is also possible that Rater S may have missed malfunctions at the trace level, leading to artificially low results, and possibly inducing the nonlinear behavior observed in the CRC procedure. The results in that procedure are so low that if the rater's sensitivity was either "no fault" or "moderate malfunction," then trace problems at intermediate volatility might go unrecorded, leading to nonlinearity in the small data set. It is impossible to state unambiguously that one or the other, or both, raters are "right" or "wrong."

The point of the pilot program was to evaluate the potential of the new cycle to discriminate between dirty and clean valves, to discriminate fuel effects and their relation to IVD, and to indicate if any or all of the candidate engines could be used as a replacement for the BMW engine which currently serves as the standard. While the mixed results in this pilot study do not allow definitive conclusion, both procedures may well be able to discriminate between dirty and clean valves based upon driveability, and may also serve to search for fuel properties that interact with IVD to degrade driveability. Only a full-scale evaluation with more vehicles and fuels could have provided answers as to which procedure more accurately correlates to IVD-induced problems experienced in real-world driving. Furthermore, it seems likely there is no major difference between the candidate engines in their driveability response to IVD. The candidate engines perform very well, so their response volatility is not as strong as that of the BMW engine, but it appears that testing with very low volatility fuel should allow discrimination of IVD effects on driveability.

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TABLES

AND

FIGURES

TABLE 1

TEST VEHICLES

Vehicle Management Number	Engine Configuration
CRC-1/CRC-2	4 valves per cylinder Multiport fuel injection I-4 - normally aspirated
CRC-3/CRC-4	2 valves per cylinder Multiport fuel injection I-4 - normally aspirated
CRC-5/CRC-6	2 valves per cylinder Multiport fuel injection V-6 - normally aspirated
S-49/S-50	1985 BMW 1.8L OHC 318i

TABLE 2

CRC Composite Base Fuel

Test Methods	Results
Distillation, °F, % Evaporated (ASTM D 86)	
IBP	92
5	118
10	134
15	142
20	150
30	169
40	194
50	216
60	237
70	261
80	294
90	333
95	366
FBP	402
Recovered %	98.5
Residue %	0.5
Loss	1
Sulfur, XRF, Wt. % (ASTM D 2622)	0.015
Oxidation Stability (ASTM D 525)	No Break @ 24 Hr
FIA (ASTM D 1319)	
Aromatics, Vol %	26.2
Olefins, Vol %	11.0
Saturates, Vol %	62.8

Test Methods	Results
Reid Vapor Pressure, PSI (ASTM D 323)	7.9
API Gravity (ASTM D 4052)	58.4
NACE, Rust Rating (TM0172-86)	A
Lead (Pb), g/Gal. (ASTM D 3237)	<0.001
RON (ASTM D 2699)	93.9
MON (ASTM D 2700)	83.4
Oxygenates, Vol % (ASTM D 4815)	
MTBE	0.18
Bromine Number (ASTM D 1159)	29.6
Existent Gums (ASTM 381)	
Date: 7/5/91	
Unwashed, mg/100 ml	3.8
Washed, mg/100 ml	2.6
CU Corrosion (ASTM D 130)	1A

TABLE 3

TEST FUEL DISTILLATIONS

Distillation, °F, % Evaporated ASTM D 86	GA-809	GA-810	GA-811	GA-812
IBP	93	87	91	92
5	116	117	118	115
10	130	136	135	130
20	145	163	164	161
30	164	190	196	206
40	186	212	227	251
50	204	226	248	275
60	214	239	271	298
70	224	260	304	313
80	245	306	332	324
90	332	355	349	335
95	355	379	370	346
FBP	384	411	415	385
Recovered %	97.8	97.3	98.7	98.6
Residue %	0.7	1.5	0.8	0.7
Loss %	1.5	1.25	0.5	0.7

TABLE 4

AVERAGE INTAKE VALVE DEPOSITS

FOR EACH ENGINE

5,000 and 20,000 Miles

Vehicle Model	Deposit Weight, mg 5,000[1] Miles	20,000[2] Miles	% Increase
CRC-1/CRC-2	107.9	287.4	166.4
CRC-3/CRC-4	434.0	435.4	0.3
CRC-5/CRC-6	724.6	728.4	0.5
S-49/S-50	271.6	919.2	238.4

(1) 5,000-mile deposit weights were obtained during the IVD program conducted immediately before this driveability program.

(2) 20,000-mile deposit weights were obtained during this driveability program.

TABLE 5

AVERAGE INTAKE VALVE DEPOSITS

FOR EACH VEHICLE

20,000 Deposit Miles

Vehicles	Deposit Weight, mg
CRC-1	368.8
CRC-2	206.1
CRC-3	475.2
CRC-4	395.6
CRC-5	698.2
CRC-6	758.5
S-49	869.0
S-49	969.4

TABLE 6

**INCREASE IN DRIVEABILITY DEMERITS
WITH DEPOSITS**

Driveability Demerits
Averaged Across Three Test Fuel Volatilities

Vehicle	Delta CRC Cycle TWD	n	Delta BMW Cycle Total Demerits	n
CRC-1/CRC-2	-9.9*	12	32.9*	12
CRC-3/CRC-4	-8.7*	12	22.5*	12
CRC-5/CRC-6	-0.1*	12	35.2*	12
S-49/S-50	46.3	12	100.2	12

* The candidate engines respond differently from the BMW 318i at 95% confidence, but not differently from each other.

FIGURE 1
INCREASE IN DRIVEABILITY DEMERITS WITH DEPOSITS
BY VEHICLE MODEL

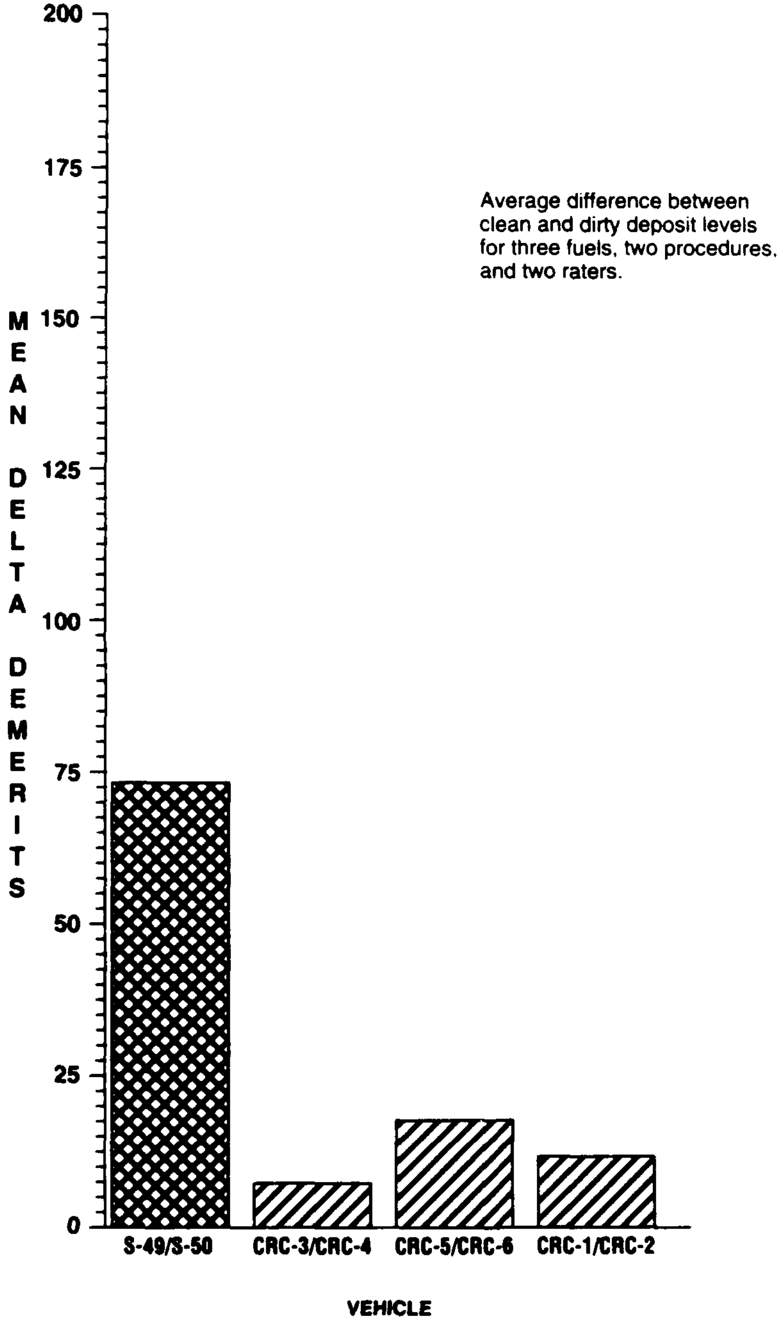


FIGURE 2
CRC DRIVEABILITY TEST RESPONSE TO IVD
BY VEHICLE AND TEST PHASE

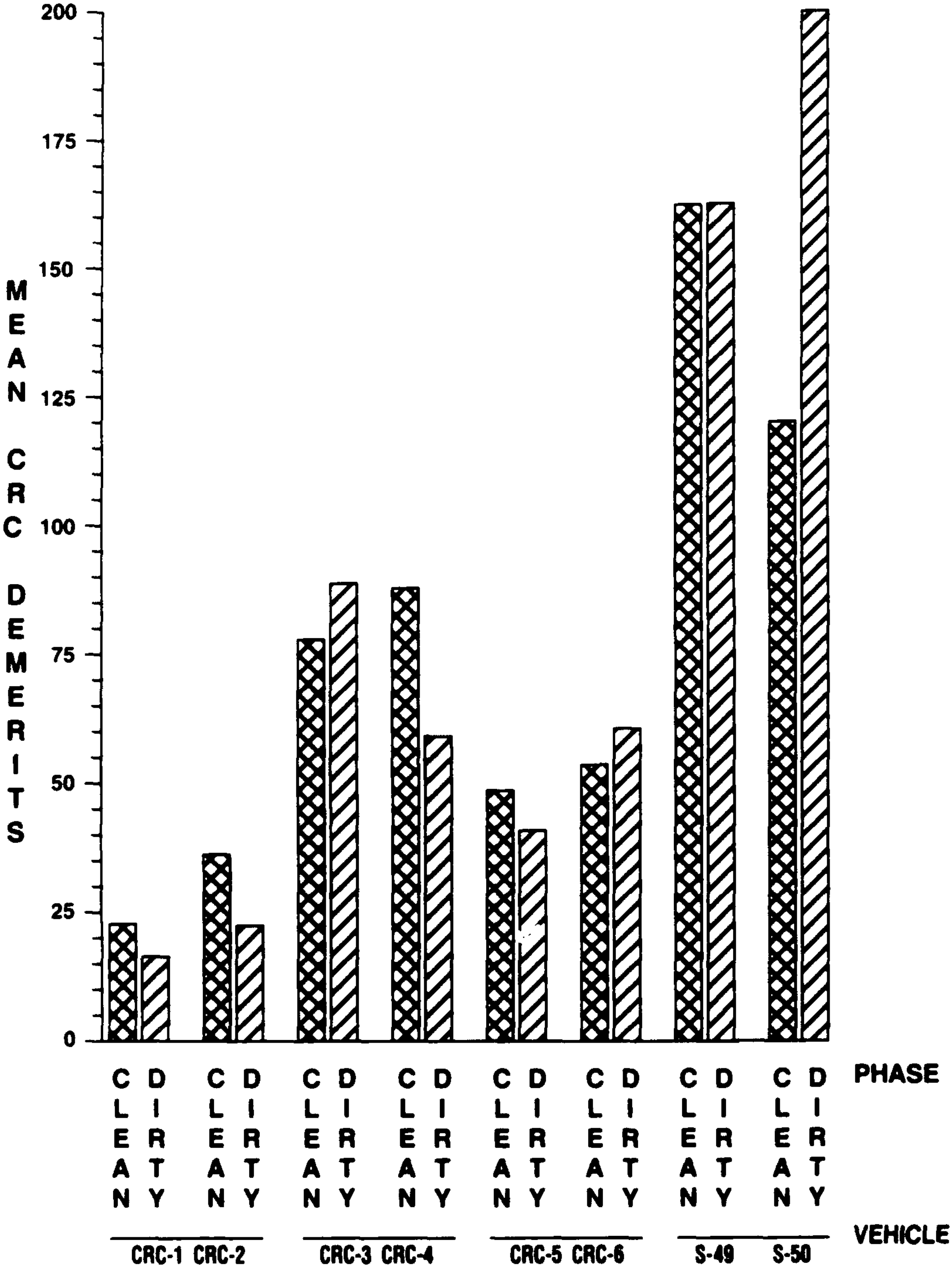


FIGURE 3
CHANGE IN DRIVEABILITY DEMERITS WITH DEPOSITS
BY VEHICLE AND TEST PROCEDURE

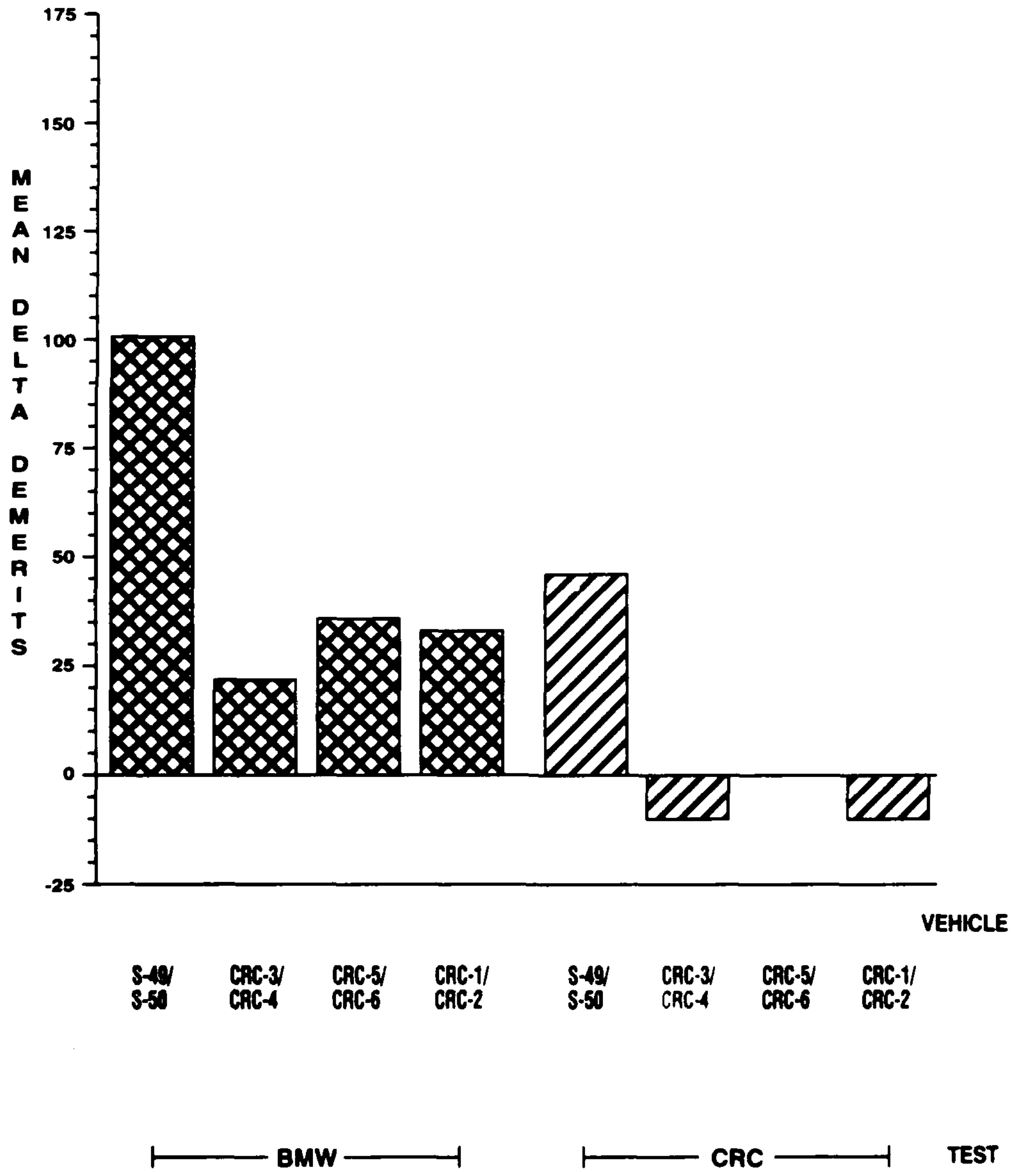


FIGURE 4
BMW DRIVEABILITY TEST RESPONSE TO IVD
BY VEHICLE AND TEST PHASE

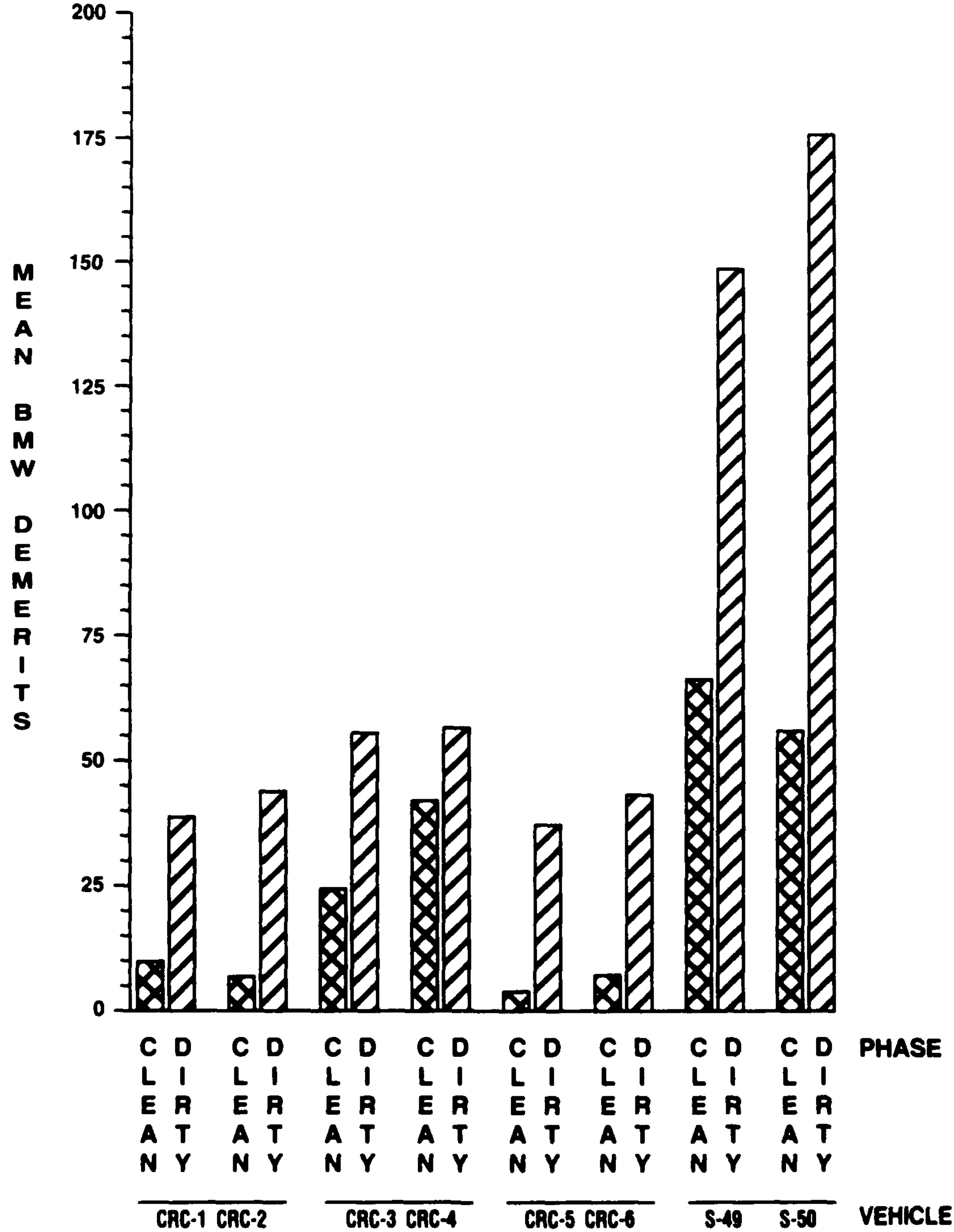


FIGURE 5
BMW DRIVEABILITY PROCEDURE DEMERITS
vs FUEL VOLATILITY (T_{50})

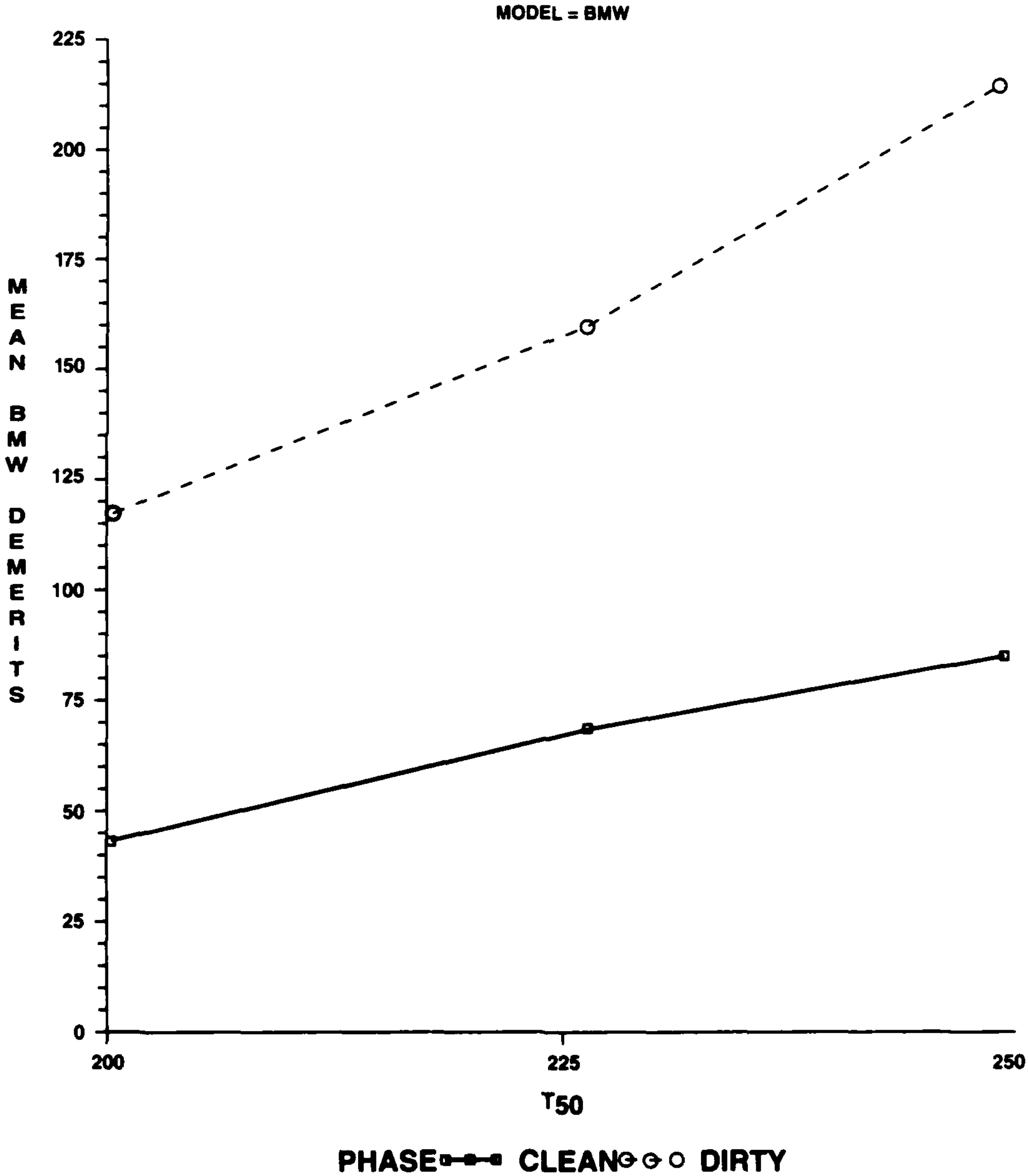


FIGURE 6
BMW DRIVEABILITY PROCEDURE DEMERITS
vs FUEL VOLATILITY (T_{50})
BY TEST PHASE
MODEL = CANDIDATES

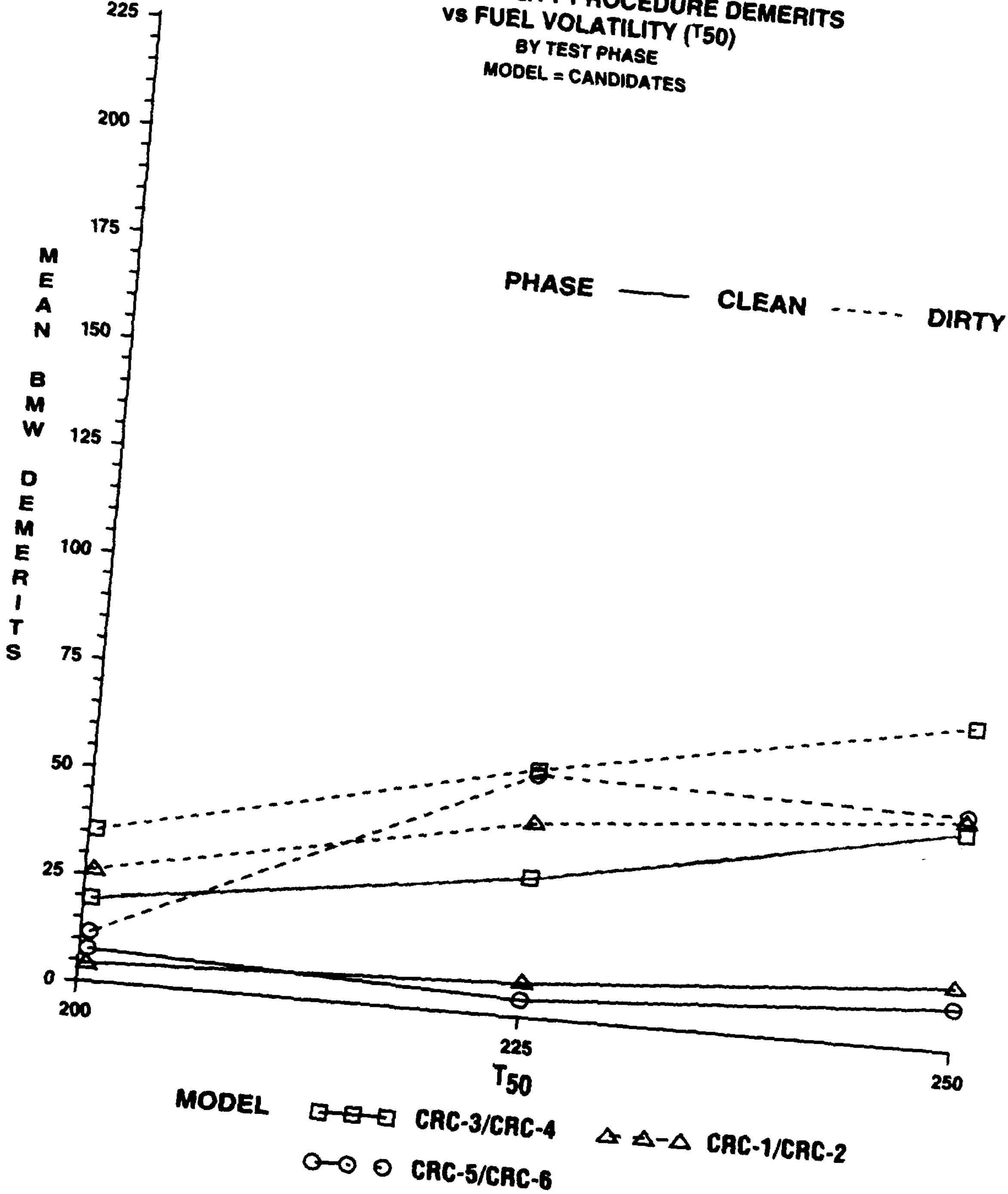


FIGURE 7
CRC DRIVEABILITY PROCEDURE DEMERITS
vs FUEL VOLATILITY (T_{50})

MODEL=BMW

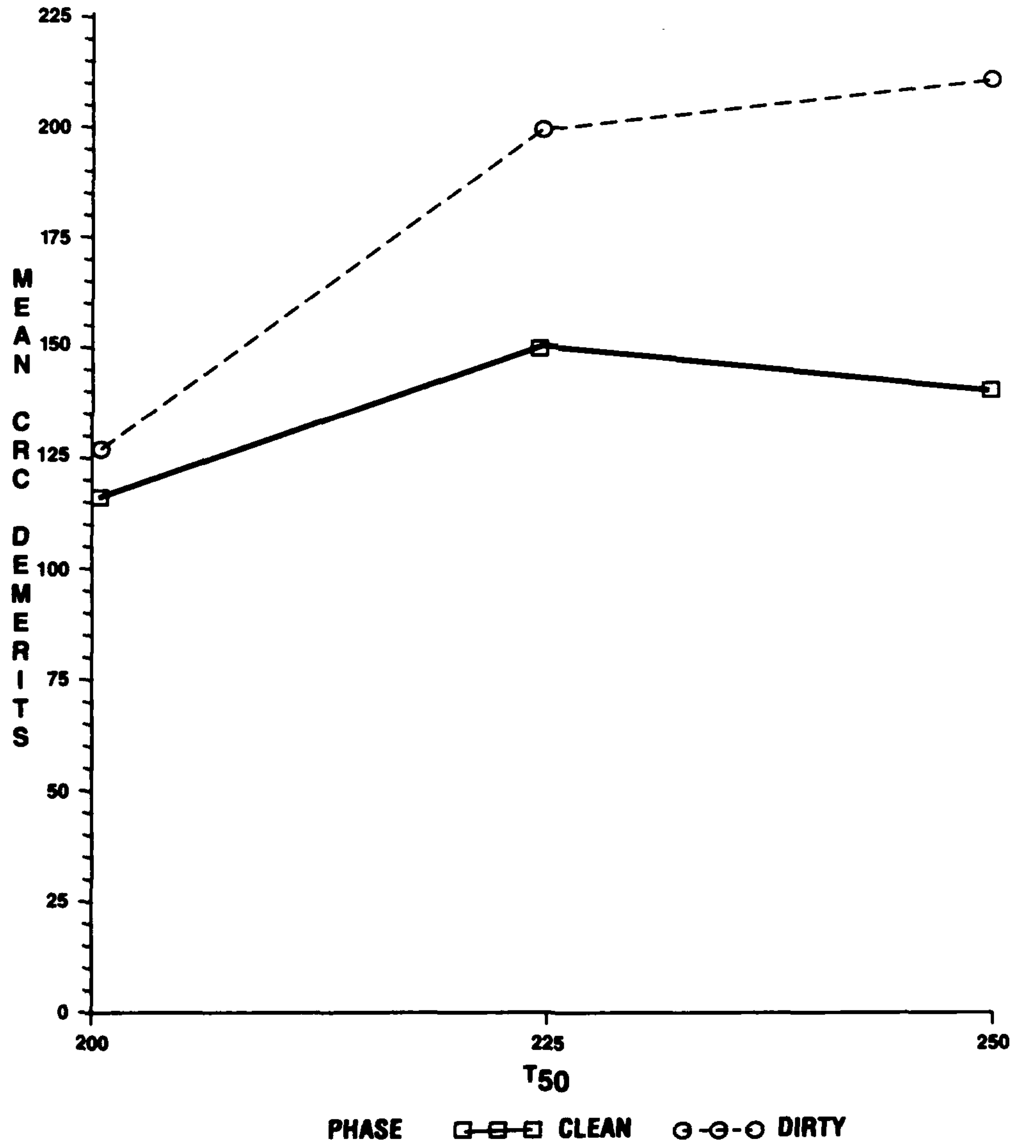


FIGURE 8
CRC DRIVEABILITY PROCEDURE DEMERITS
VS FUEL VOLATILITY (T_{50})
MODEL=CANDIDATES

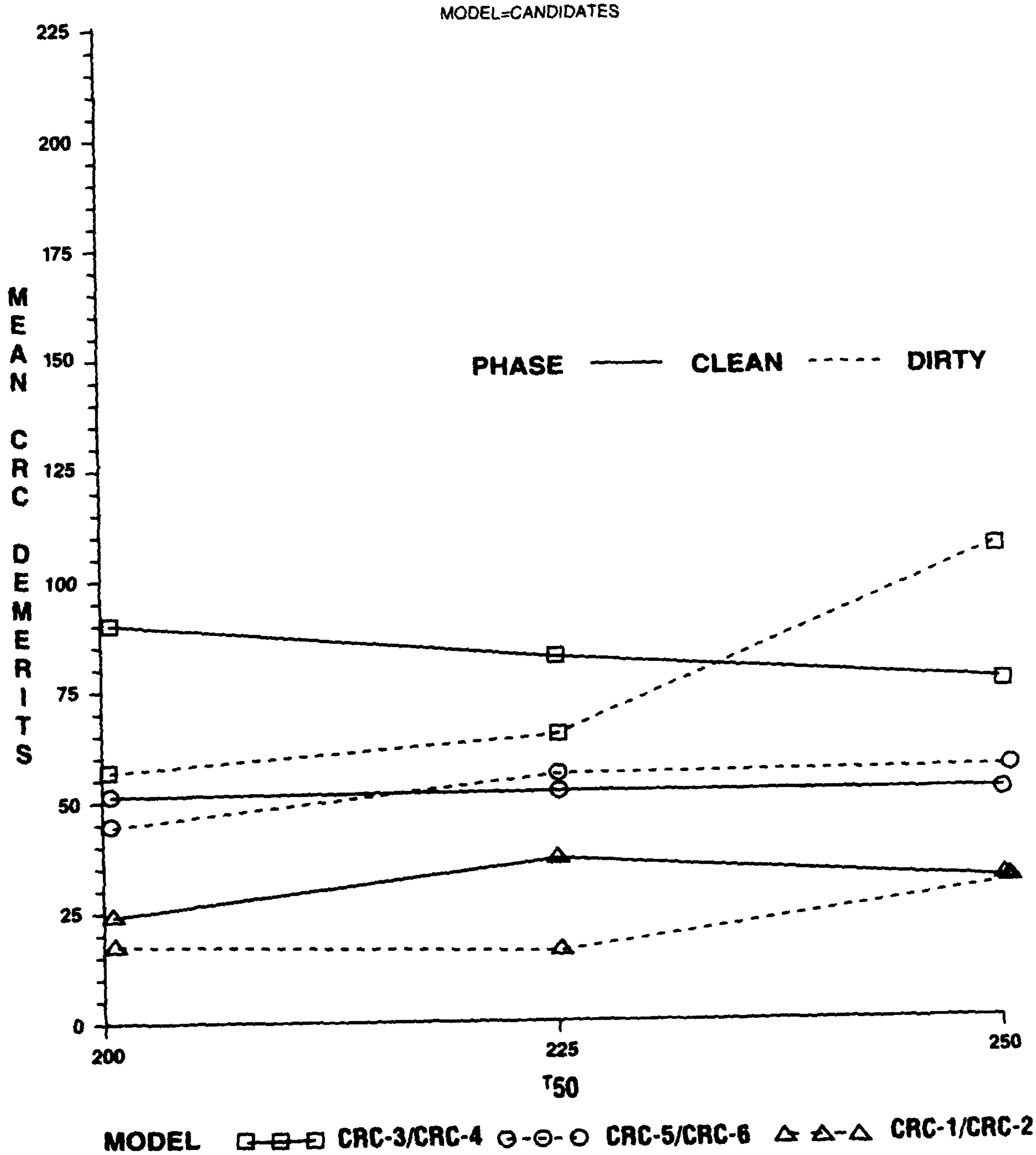


FIGURE 9
CRC TEST PROCEDURE
RATER = S 3 MODEL CANDIDATE AVERAGE

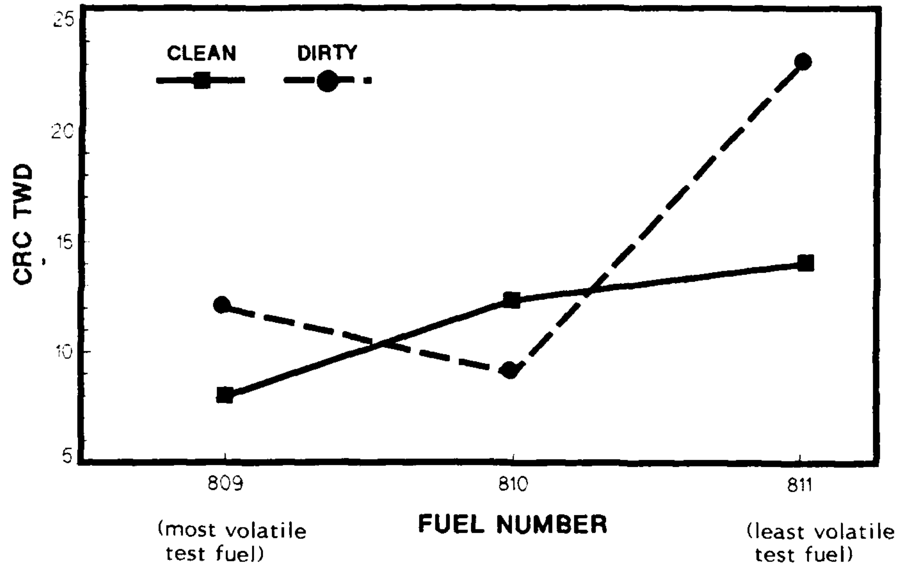


FIGURE 10
CRC TEST PROCEDURE
RATER = S BMW VEHICLE AVERAGE

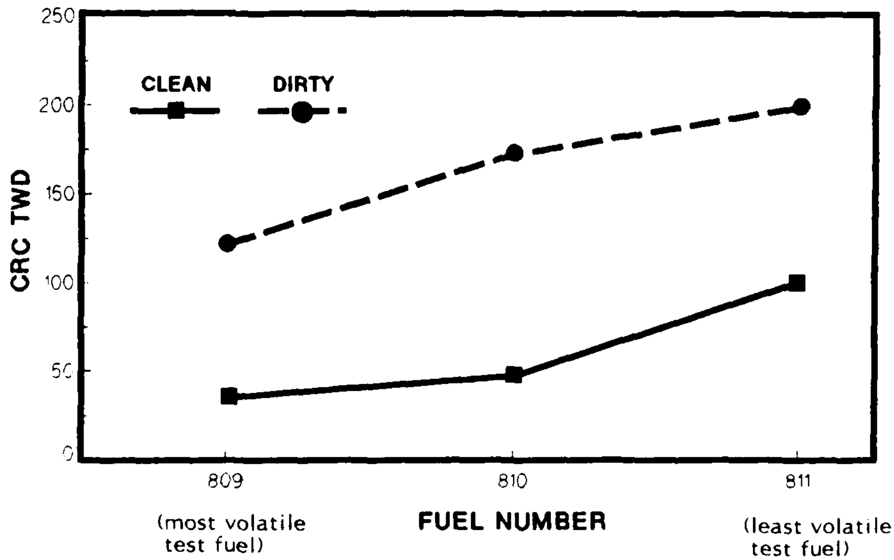


FIGURE 11
CRC TEST PROCEDURE
RATER = R 3 MODEL CANDIDATE AVERAGE

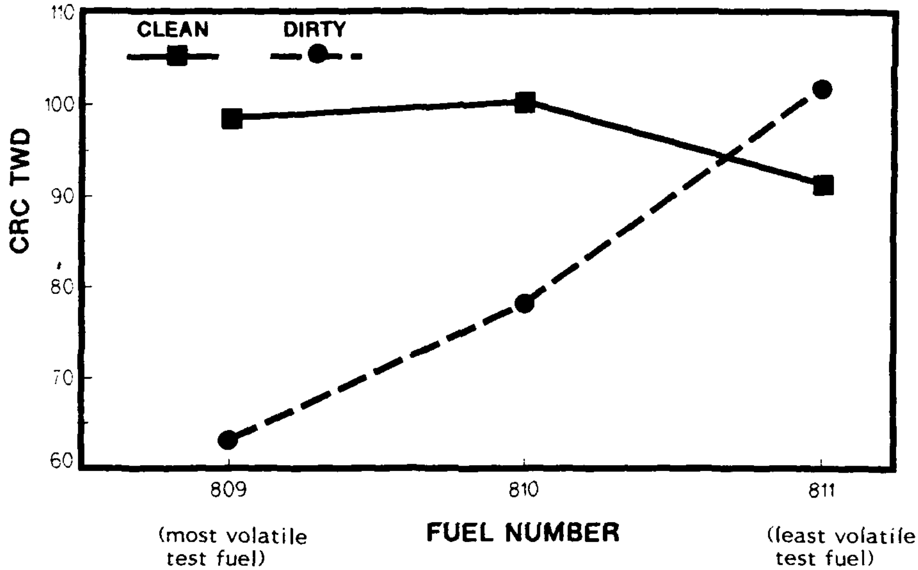


FIGURE 12
CRC TEST PROCEDURE
RATER = R BMW VEHICLE AVERAGE

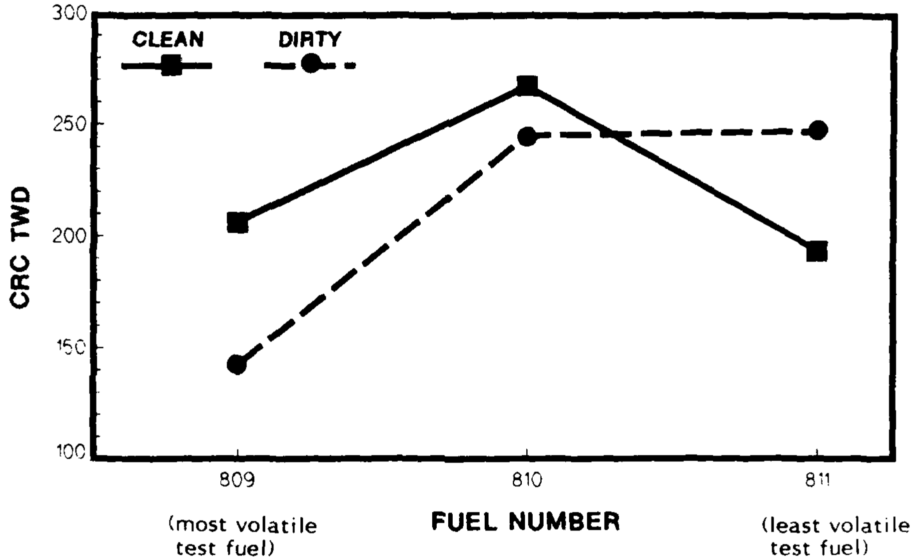


FIGURE 13
BMW TEST PROCEDURE
RATER = S 3 MODEL CANDIDATE AVERAGE

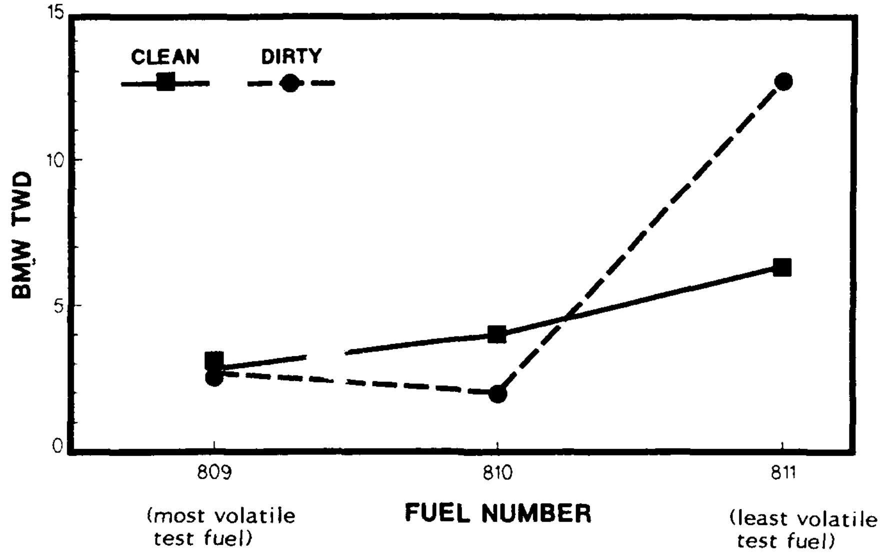


FIGURE 14
BMW TEST PROCEDURE
RATER = S BMW 318 AVERAGE

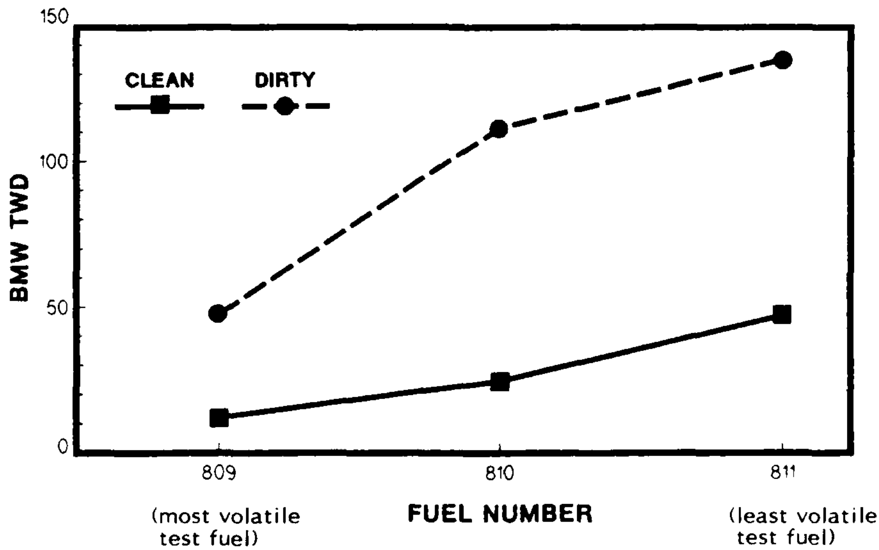


FIGURE 15
BMW TEST PROCEDURE
RATER = R 3 MODEL CANDIDATE AVERAGE

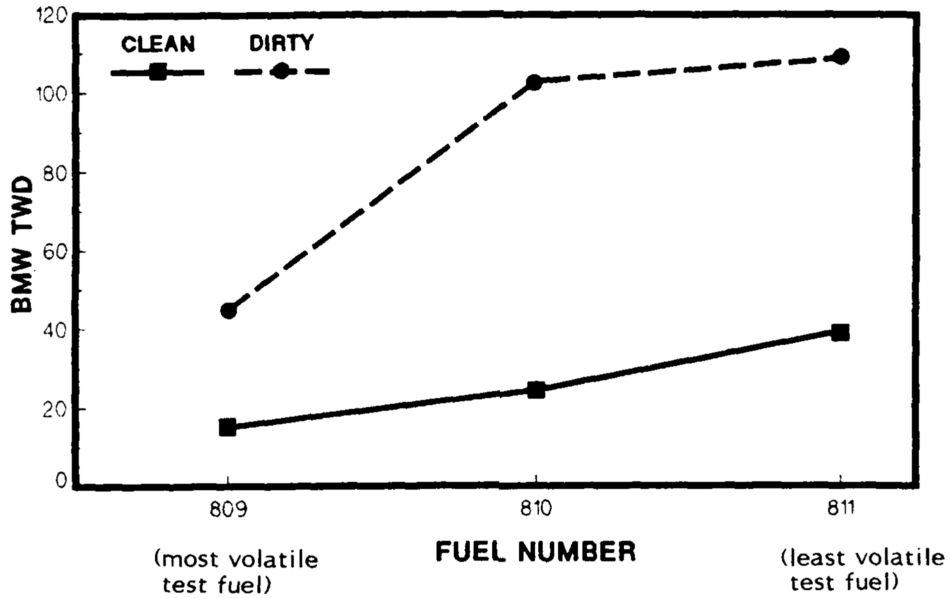
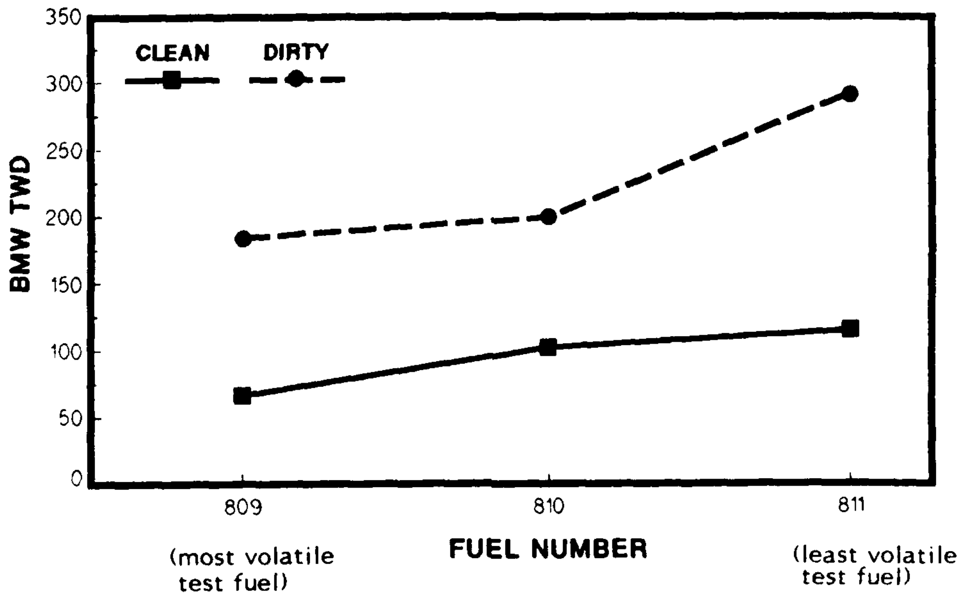


FIGURE 16
BMW TEST PROCEDURE
RATER = R BMW VEHICLE AVERAGE



APPENDIX A

MEMBERSHIP

OF THE

PROGRAM PANEL AND DATA ANALYSIS PANEL OF THE

CRC PILOT PROGRAM TO INVESTIGATE

THE EFFECT ON DRIVEABILITY OF

INTAKE VALVE DEPOSITS AND VARIATIONS IN FUEL VOLATILITY

Appendix A

Program Panel

John Graham, Leader	Chevron Research & Technology Co.
Craig Carlson	Ford Motor Company
Beth Evans	Coordinating Research Council, Inc.
Kim Sandum	Ford Motor Company
Chuck Valade	Chrysler Motors Corporation

Data Analysis Panel

John Graham, Leader	Chevron Research & Technology Co.
Carl Bonés	Mobil Research & Development Corp.
Craig Carlson	Ford Motor Company
Scott Jorgensen	General Motors Research
Bob Reuter	Texaco, Inc.
Jim Uihlein	BP Oil Company

APPENDIX B

CRC PILOT PROGRAM TO INVESTIGATE THE EFFECT ON DRIVEABILITY OF INTAKE VALVE DEPOSITS AND VARIATIONS IN FUEL VOLATILITY

CRC Pilot Program to Investigate the Effect on Driveability of Intake Valve Deposits and Variations in Fuel Volatility

Objective

The objective of this program is to collect data relating driveability to intake valve deposits (IVD) and variations in fuel volatility on the eight vehicles tested in the CRC IVD program, and to gather information to guide a possible full-scale driveability/IVD program in the future.

Background

The CRC IVD Group is conducting a program at Southwest Research Institute (SwRI) to identify one or two high-volume automotive engines that: 1) develop deposits representative of those found in the US fleet; 2) are sensitive to fuel quality; and 3) develop deposits of sufficient quantity allowing for further development of fuels and additives. The engine(s) and results will be used to develop an industry-accepted test for defining the intake valve deposit characteristics of a gasoline. Some participants recognized an opportunity to expand upon the IVD program to investigate the relationship between intake valve deposits and cold-start and warmup driveability using the same cars.

Test Site

CRC will conduct the program under contract at Southwest Research Institute in San Antonio, Texas. SwRI will provide a suitable test track for driveability testing, mileage accumulation, and the necessary labor for conducting the test program.

Test Dates

CRC will conduct the program during the fourth quarter of 1991. The ambient overnight temperatures must be below 65°F, and preferably 50°F or below. Weather data indicate that the overnight lows for San Antonio will be within an appropriate range after mid-October.

Test Fuels

The test fuel set will contain four hydrocarbon-only fuels blended at 7.5±0.3 psi Reid vapor pressure. The 50 percent distillation temperature (T_{50}) will be targeted at 200°F, 225°F, 250°F and 270°F for the four fuels, with tolerances of ±5°F. The 90 percent distillation temperature (T_{90}) will be targeted at 340°F ±10°F for the two endpoint fuels. The two middle-volatility fuels will be cross-blended from the two endpoint fuels. The fuels will not contain any detergent or additive package. The fuels will contain an antioxidant and a corrosion inhibitor. The fuels will contain no more than 3 percent benzene, and no more than 40 percent aromatics. The fuels will be unleaded and have a minimum (R+M)/2 octane rating of 92. The fuels will not exceed 437°F endpoint. The 270°F T_{50} test fuel will only be used in the unlikely case that insignificant driveability demerits are obtained with the 250°F T_{50} test fuel. These test fuels are only used for driveability testing.

Mileage accumulation will be performed using the same composite base fuel being used for mileage accumulation for the IVD engine-selection program being conducted at SwRI. This composite base fuel is made up of five fuels donated by five suppliers. The IVD study used a composite fuel to assure that the base fuel would form deposits.

Test Cars

The same eight test cars being used in the IVD program will be used in the driveability program. The test fleet is composed of two cars each of the following models:

- 1991 Ford 2.3-liter I-4 (dual spark plug model)
- 1991 GM 3.1-liter V-6
- 1991 GM 2.3-liter I-4 Quad Four
- 1985 BMW 1.8-liter 318i

The BMW's will have known performance records to allow them to serve as baselines.

Program Description

After the IVD engine-selection program, the test engines will be disassembled to allow inspections and measurements of the intake valve deposits. The deposited valves will be saved for further analysis by the IVD Group, and new valves will be installed for the driveability work. The heads will be cleaned and checked for proper specifications prior to installation of the new valves. Mileage will be accumulated on the clean engines using the composite base fuel and the standard BMW mileage accumulation cycle.

Each of the vehicles will accumulate 20,000 miles, at which time triplicate driveability ratings will be performed. Test duration will be reduced to 10,000 or 15,000 miles if the current IVD program indicates that deposit level is sufficient to affect driveability at lower miles. The current concensus is that 20,000 miles will be necessary. Upon completion of the driveability ratings with the deposited valves, the engines will be disassembled for inspections and measurements of intake valve deposits. New valves will then be installed in each of the vehicles, and clean driveability ratings will be performed. This will minimize the time lapse between the "clean" and "dirty" ratings.

The cars will be tested using both the standard BMW cycle and a modification of the CRC cold-start and warmup procedure. The CRC procedure will basically consist of:

- start
- idle neutral - 5 seconds
- idle drive - 5 seconds
- light-throttle acceleration 0-10 mph - 10 seconds
- cruise - 10 seconds
- light-throttle acceleration 10-25 mph
- cruise - 5 seconds
- light-throttle acceleration 25-35 mph
- stop
- idle drive - 10 seconds

This cycle will be repeated three times. There will be no distance specification associated with these maneuvers as there is in the normal CRC procedure. All accelerations will be performed at constant throttle.

Between the first and second CRC cycle, five accelerations will be made to 20 mph with the throttle half-open; decelerations will be made by applying the brake in the normal manner to 0 mph for automatic transmissions and 10 mph for manual transmissions.

All overnight soaks will be under 65°F and preferably at 50°F or lower. Several members of the Program Panel will be on-site at the start of testing to refine the driving cycle and to ensure that it can be performed consistently.

Because the deposits should not be allowed to become dry or flaky, the cars must still be operated at least six days a week for approximately 3-5 miles even if no mileage accumulation or testing is being performed.

After the final driveability ratings, the engines will be disassembled for inspections and measurements of intake valve deposits. These measurements will serve to complement the tests on the base fuel conducted by the IVD Group in their engine-selection program.

CRC Program Panel

A program panel organized under the CRC Volatility Group will oversee this study. They will analyze the data and prepare a technical report.

APPENDIX C

INDIVIDUAL LABORATORY FUEL PROPERTY DATA

APPENDIX C

INDIVIDUAL LABORATORY FUEL PROPERTY DATA

Fuel:	GA-809			GA-810		
Lab:	1	2	3	1	2	3
API Gravity	65.9	65.6	-	61.4	61.7	-
RVP, psi	7.8	7.5	-	7.4	7.3	-
Distillation, °F						
IBP	86	99	93	78	99	83
T_5	114	123	110	118	127	107
T_{10}	128	133	129	135	142	130
T_{20}	143	148	144	163	167	158
T_{30}	162	166	164	190	194	186
T_{40}	184	188	187	213	214	209
T_{50}	202	206	204	227	228	222
T_{60}	212	215	214	241	242	235
T_{70}	222	225	224	260	264	256
T_{80}	242	246	246	303	310	306
T_{90}	327	343	327	352	359	354
T_{95}	350	-	361	374	-	384
EP	386	381	385	428	380	424
% Recovered	-	98.7	97.0	-	97.1	97.5
% Residue	-	0.8	0.5	-	2.0	1.0
% Loss	-	0.5	2.5	-	0.9	1.5
FIA, vol %						
Aromatics	13.5	19.5	-	18.5	22.1	-
Olefins	7.5	2.7	-	4.0	5.8	-
Saturates	79.0	77.9	-	77.5	72.2	-
Benzene, vol %	0.0	-	-	0.2	0.1	-

APPENDIX C

INDIVIDUAL LABORATORY FUEL PROPERTY DATA

Fuel:	GA-811			GA-812		
Lab:	1	2	3	1	2	3
API Gravity	56.6	56.9	-	56.4	56.6	-
RVP, psi	7.5	7.4	-	7.7	7.5	-
Distillation, °F						
IBP	86	98	89	89	99	89
T_5	112	125	116	112	120	112
T_{10}	129	140	135	128	133	128
T_{20}	157	169	166	158	164	160
T_{30}	189	201	197	202	209	208
T_{40}	222	231	228	248	253	251
T_{50}	244	252	248	274	278	274
T_{60}	266	274	273	296	300	297
T_{70}	298	308	307	312	316	312
T_{80}	329	335	331	323	326	323
T_{90}	345	351	352	334	336	334
T_{95}	364	-	377	345	-	347
EP	389	438	419	364	400	391
% Recovered	-	99.4	98.0	-	99.1	98.0
% Residue	-	0.6	1.0	-	0.5	1.0
% Loss	-	0.0	1.0	-	0.4	1.0
FIA, vol %						
Aromatics	30.0	31.9	-	29.0	31.7	-
Olefins	3.5	5.8	-	1.5	3.0	-
Saturates	66.5	82.4	-	69.5	65.3	-
Benzene, vol %	0.2	0.1	-	0.3	0.2	-

APPENDIX D

BMW TEST PROCEDURE

TO EVALUATE INTAKE VALVE DEPOSIT DRIVEABILITY

(Bitting, Schwendtner, Kohlhepp, Kothe, Testroet, Ziwica
"Intake Valve Deposits - Fuel Detergency Requirements Revisited,"
SAE Paper No. 872117)

IVD - DRIVEABILITY EVALUATION PROCEDURE

I.) PROCEDURE

(Please compare with "Driveability Evaluation Sheet".)

0.) Conditioning

a) Engine should be checked beforehand (i.e. the night before), especially for: *malfunctions; performance with warm engine; proper spec. setting at warm engine like idle valve setting, CO-reading, timing, etc.*

b) Engine must be cold (8 h, overnight) before starting.

c) Make note of environmental conditions; amb. temperature should be between 50°F and 75°F.

1.) *Cold Start*

Note: After the engine has been started, wait 20 s - 30 s and let idle stabilize. Fill out sheet, make note of special occurences (stalling after start, etc.)

2.) After-Start Phase Throttle Response (out of gear).

Note: *It is important to wait after a throttle application until rpm's are down to idle and idle has stabilized* basically (° 10 - 20 seconds).

3 x wide open throttle applications

3 x part throttle application (°1/2 throttle position, fast) in case temperature gauge is still within blue field: 2 x wide open throttle application and 2 x part throttle application.

3.) After-Start Phase Acceleration, (in gear).

Note: acceleration not from stand still, but from 'creeping'.

3 x wide open throttle applications

3 x part throttle application

Make note of water temperature reading

4.) Warmup - Phase Throttle Response (out of gear).

3 x part throttle application.

3 x wide open throttle application.

In case little or no hesitation can be determined, 2 more PT applications and 2 more WOT applications should be performed. Only if severe H/S/H occurs all the time, proceed directly to step 5.

5.) Warmup Phase Acceleration (in gear)

3 x part throttle acceleration

3 x wide open throttle acceleration

Make note of water temperature reading

6.) Evaluation of Warm Engine Driveability Incl. Idle Quality

II.) IVD DRIVEABILITY EVALUATION SHEET

VEH NO.:
DATE:
TEMP F:
BARO.:
MILE:

1) **COLD-START:**

ST TIME: MAX RPM: MIN RPM IDLE QUAL.:

2) ***AFTER-START PHASE THROTTLE RESPONSE***

WOT 3-5 =

out of gear

PT 3-5 =

3) **AFTER-START PHASE ACCELERATION**

WOT 3 =

in gear

PT 3 =

IDLE QUALITY:

4) **WARMUP PHASE THROTTLE RESPONSE**

PT 3-5 =

out of gear

WOT 3-5 =

5) **WARMUP PHASE ACCELERATION**

PT 3 =

in gear

WOT 3 =

6) **WARM ENGINE DRIVEABILITY:**

REMARKS: ____

WARM DRIVEABILITY IN GENERAL: GOOD_____ FAIR_____ BAD_____

IDLE QUALITY: ____

Note: Yet unexperienced evaluation personnel should exercise this procedure a few times before actually rating engines.

III.) LENGEND OF CODES AND RATING

a) Definition

T: = Trace   M: = Medium   H: = Heavy

Trace	=	Noticeable only by trained personnel
Medium	=	Noticeable by average driver
Heavy	=	Very troublesome
Hesitation	=	Lack of response between throttle application and PRM increase.
Stumble	=	RPM decrease before increasing
Backfire	=	RPM decrease with noticeable "popping" noise

b) Legend of codes

T - H:	=	Trace of hesitation
T - H/S:	=	Trace of hesitation and stumble
T - H/S/B:	=	Trace of hesitation and stumble with backfiring
M - H:	=	Medium hesitation, easily noticeable
M - H/S:	=	Medium hesitation and stumble
M - H/S/B:	=	Medium hesitation and stumble with backfiring
H - H:	=	Heavy hesitation
H - H/S:	=	Heavy hesitation and stumble, severe driveability compl.
H - H/S/B:	=	Heavy hesitation and stumble and backfiring, damage of sensitive components (i.e. idle valve) possible.

c) Demerit Rating

	T	M	H
H	2	6	11
H/S	3	9	18
H/S/B	4	12	24

Stalling: = 48

A:57186

APPENDIX E

MODIFIED CRC COLD-START AND
WARMUP DRIVEABILITY PROCEDURE
TO EVALUATE INTAKE VALVE DEPOSIT DRIVEABILITY

CRC COLD START AND WARMUP DRIVEABILITY PROCEDURE TO EVALUATE INTAKE VALVE DEPOSIT DRIVEABILITY

Test Procedure and Data Recording

A. Record all necessary test information at the top of the data sheet.

B. Start engine per Owner's Manual Procedure. Record start time.

C. If engine fails to start after 15 seconds of cranking, stop cranking. Follow Owner's Manual procedure for this situation. This will be called a no-start. Record NS in the initial start time box on the data sheet.

D. Record idle quality in"Neutral" immediately after start; foot should be removed from accelerator pedal.

E. If engine stalls, repeat Steps B and C. Record number of stalls and starting time of *required restarts.*

   Note that space has been provided on the data sheet for only three restarts. In the demerit calculation system, only the first three stalls add to the demerit total. If the engine stalls a fourth time, restart and proceed to the next step as quickly as possible without recording restart time.

F. Allow engine to idle 5 seconds, followed by a snap throttle maneuver. Snap throttle is wide-open-throttle in "Neutral" until tachometer passes 3,000 rpm and then accelerator pedal is side-stepped.

G. Apply brakes, shift to normal drive range at first idle after snap throttle. Do not wait for idle to settle out. Record idle quality. If engine stalls, restart immediately. Do not record restart time. Record number of stalls. Idle 5 seconds in "Drive".

   Again, the maximum number of stalls contributing to demerits is three. If the engine stalls again, restart and proceed to the next maneuver as quickly as possible. It is important to complete the start-up procedure as quickly as possible to prevent undue warm-up before the driving maneuvers and to maintain vehicle spacing on the test track.

H. After 5 seconds in "Drive" (Step G), make a 3/4-throttle acceleration from 0-20 mph.

I. Brake to a stop and idle in "Drive" for 5 seconds. After 5 seconds in "Drive", make a light-throttle acceleration from 0-10 mph. Decelerate below 10 mph and then make a light-throttle acceleration from 10-25 mph. Brake to a stop and idle in "Drive" for 5 seconds. After 5 seconds in "Drive", make two 3/4-throttle accelerations from 0-20 mph. Perform Step I five times. All braking should be moderately aggressive.

J. During the above maneuvers, observe and record the severity of any of the following malfunctions (see attached definitions):

1. Hesitation
2. Stumble
3. Stall
4. Backfire

It is possible that during an acceleration, more than one stumble or backfire may occur. Record all ratings for each performance deficiency observed. Do not record the numbers of occurrences. Also, in recording subjective ratings (T, M, or H), be sure the entry is legible. At times, M and H recordings cannot be distinguished from each other.

Recording maneuvering stalls on the data sheet in the appropriate column: accelerating or decelerating. If the vehicle should stall before completing the maneuver, record the stall and restart the car as quickly as possible. Bring the vehicle up to the intended final speed of the maneuver. Any additional stalls observed will not add to the demerit total for the maneuver, and it is important to maintain the driving schedule as closely as possible.

RATING AND CALCULATION SYSTEM - A numerical value for driveability during the CRC test is obtained by assigning demerits to operating malfunctions. Demerits for poor starting are obtained by subtracting two seconds from the measured starting time. The number of stalls which occur during idle as well as during driving maneuvers are counted separately and assigned demerits as shown in the following table.

The multiplying factors of 8 and 32 for idle and maneuvering stalls, respectively, account for the fact that stalls are very undesirable, especially during car maneuvers.

Other malfunctions, such as hesitation, stumble, idle roughness, and backfire, are rated subjectively by the driver on a scale of trace, moderate, or heavy. Since all malfunctions are not of equal importance, the demerits are multiplied by the weighting factors yielding weighted demerits.

Finally, weighted demerits, demerits for stalls, and demerits for poor starting are summed to obtain total weighted demerits (TWD), which are used as an indication of driveability during the test. As driveability deteriorates, TWD increases.

A restriction has been applied in the totaling of demerits to ensure that a stall results in the highest possible number of demerits within a given maneuver. When more than one malfunction occurs during a maneuver, demerits are counted for only the malfunction which had the largest number of weighted demerits. Another restriction is that for each idle period, no more than three idle stalls are counted.

Definitions for malfunctions and severity factors:

Malfunctions

Start Time:	The cumulative total of seconds necessary to start the engine and have it run for a prescribed idle period prior to transmission engagement.
Stall:	The engine stopping with ignition on during any segment of the driveability driving schedule and/or test condition. There are three types of stalls -- accel, decel, and idle.
Idle Roughness:	An evaluation of the idle quality or degree of smoothness while the engine is idling.
Hesitation:	A temporary lack of initial response in acceleration rate.
Stumble:	A short, sharp reduction in acceleration rate.
Backfire:	An explosion in the induction or exhaust system.

Severity Factors

Trace (T)	A level of malfunction severity that is just discernible to a test driver but not to most laymen.
Moderate (M)	A level of malfunction severity that is probably noticeable to the average layman.
Heavy (H)	A level of malfunction severity that is pronounced and obvious to both test driver and layman.

Method for Calculating TWD

Demerits for Poor Starting:

Demerits = Starting Time(s) - 2

Demerits for Stalls:

Demerits = (No. of Idle Stalls) x 8 + (No. of Maneuvering Stalls) x 32

Demerits for Malfunctions Rated Subjectively:

Demerits for Subjective Ratings:

Trace = 1
Moderate = 2
Heavy = 4

Weighting Factors for Each Malfunction:

Idle Roughness = 1
Backfire, Stumble, Hesitation = 6

Weighted Demerits = Demerits x Weighting Factor

Calculation:

TWD = Weighted Demerits + Demerits for Stalls + Demerits for Poor Starting

CRC IVD/DRIVEABILITY DATA SHEET

Run no.	Car	Fuel	Rater	Date	Time	Temperature		Odometer	Deposit Miles
						Soak	Run		

Starting time, sec.				Idle N.	Snap Throttle	Idle Dr.	0 - 20 3/4 - Th
							Stalls
Initial	Restart 1	Restart 2	Restart 3	Ruf. stalls	Hes. Stm. Bkf. Ac Dc	Ruf. stalls	Hes. Stm. Bkf. Ac Dc

Idle Dr.	0 - 10 Lt Th	10 - 25 Lt Th	Idle Dr.	0 - 20 3/4 - Th	0 - 20 3/4 - Th
	Stalls	Stalls		Stalls	Stalls
Ruf. Stalls	Hes. Stm. Bkf. Ac Dc	Hes. Stm. Bkf. Ac Dc	Ruf. Stalls	Hes. Stm. Bkf. Ac Dc	Hes. Stm. Bkf. Ac Dc

Notes:

- All idles are 5 seconds.
- Snap Throttle is wide-open-throttle until tachometer passes 3,000 rpm and then side step accelerator pedal.
- *For first Idle Drive, put vehicle in "Drive" at first idle after snap throttle - Don't wait for idle to settle out.*
- On 0 - 10 Light Throttles, back out of acceleration to a cruise state after reaching 10 mph prior to re-accelerating for the 10 - 25 Light Throttle.

APPENDIX F

DATA LISTING

CRC IVD DRIVEABILITY PROGRAM
BMW DRIVING CYCLE

OBS	TEST	PHASE	CAR	RUN	FUEL	RATER	DATE	TOTDEMS	STWD	TEMP
1	BMW	CLEAN	CRC-1	10	809	S	02/16/92	2	.	50
2	BMW	CLEAN		4	809	R	02/01/92	6	.	48
3	BMW	CLEAN		9	810	S	02/15/92	2	.	65
4	BMW	CLEAN		3	810	R	01/31/92	15	.	56
5	BMW	CLEAN		7	811	S	02/07/92	4	.	52
6	BMW	CLEAN		1	811	R	01/29/92	27	.	51
7	BMW	CLEAN	CRC-2	2	809	S	01/30/92	0	.	49
8	BMW	CLEAN		8	809	R	02/19/92	6	.	58
9	BMW	CLEAN		1	810	S	01/29/92	2	.	51
10	BMW	CLEAN		7	810	R	02/07/92	12	.	52
11	BMW	CLEAN		4	811	S	02/01/92	14	.	48
12	BMW	CLEAN		10	811	R	02/16/92	4	.	50
13	BMW	CLEAN	CRC-3	10	809	S	02/16/92	0	.	50
14	BMW	CLEAN		4	809	R	02/01/92	17	.	48
15	BMW	CLEAN		9	810	S	02/15/92	6	.	65
16	BMW	CLEAN		3	810	R	01/31/92	57	.	56
17	BMW	CLEAN		7	811	S	02/07/92	8	.	52
18	BMW	CLEAN		1	811	R	01/29/92	60	.	51
19	BMW	CLEAN	CRC-4	2	809	S	01/30/92	8	.	49
20	BMW	CLEAN		8	809	R	02/19/92	48	.	58
21	BMW	CLEAN		1	810	S	01/29/92	10	.	51
22	BMW	CLEAN		7	810	R	02/07/92	54	.	52
23	BMW	CLEAN		4	811	S	02/01/92	2	.	48
24	BMW	CLEAN		10	811	R	02/16/92	129	.	50
25	BMW	CLEAN	CRC-5	10	809	S	02/23/92	2	.	59
26	BMW	CLEAN		4	809	R	02/01/92	11	.	48
27	BMW	CLEAN		9	810	S	02/22/92	2	.	58
28	BMW	CLEAN		3	810	R	01/31/92	3	.	56
29	BMW	CLEAN		7	811	S	02/07/92	0	.	52
30	BMW	CLEAN		1	811	R	01/29/92	0	.	51
31	BMW	CLEAN	CRC-6	2	809	S	01/30/92	5	.	49
32	BMW	CLEAN		8	809	R	02/19/92	3	.	58
33	BMW	CLEAN		1	810	S	01/29/92	2	.	51
34	BMW	CLEAN		7	810	R	02/07/92	6	.	52
35	BMW	CLEAN		4	811	S	02/01/92	10	.	48
36	BMW	CLEAN		10	811	R	02/16/92	15	.	50
37	BMW	CLEAN	S-49	10	809	S	02/16/92	2	.	50
38	BMW	CLEAN		4	809	R	02/01/92	109	.	48
39	BMW	CLEAN		9	810	S	02/15/92	24	.	65
40	BMW	CLEAN		3	810	R	01/31/92	124	.	56
41	BMW	CLEAN		7	811	S	02/07/92	28	.	52
42	BMW	CLEAN		1	811	R	01/29/92	109	.	51
43	BMW	CLEAN	S-50	2	809	S	01/30/92	22	.	49
44	BMW	CLEAN		8	809	R	02/19/92	24	.	58
45	BMW	CLEAN		1	810	S	01/29/92	25	.	51
46	BMW	CLEAN		7	810	R	02/07/92	80	.	52
47	BMW	CLEAN		4	811	S	02/01/92	66	.	48
48	BMW	CLEAN		10	811	R	02/16/92	120	.	50
49	BMW	DIRTY	CRC-1	4	809	S	01/04/92	0	.	45

CRC IVD DRIVEABILITY PROGRAM
BMW DRIVING CYCLE

OBS	TEST	PHASE	CAR	RUN	FUEL	RATER	DATE	TOTDEMS	STWD	TEMP
50	BMW	DIRTY		10	809	R	01/13/92	0	.	52
51	BMW	DIRTY		3	810	S	01/03/92	2	.	51
52	BMW	DIRTY	CRC-1	9	810	R	01/11/92	109	.	52
53	BMW	DIRTY		1	811	S	12/27/91	48	.	48
54	BMW	DIRTY		7	811	R	01/09/92	70	.	48
55	BMW	DIRTY		8	809	S	01/10/92	2	.	54
56	BMW	DIRTY		2	809	R	12/30/91	96	.	53
57	BMW	DIRTY	CRC-2	7	810	S	01/09/92	0	.	48
58	BMW	DIRTY		1	810	R	12/27/91	68	.	48
59	BMW	DIRTY		10	811	S	01/13/92	16	.	52
60	BMW	DIRTY		4	811	R	01/04/92	78	.	45
61	BMW	DIRTY		4	809	S	01/04/92	0	.	45
62	BMW	DIRTY		10	809	R	01/13/92	77	.	52
63	BMW	DIRTY	CRC-3	3	810	S	01/03/92	0	.	51
64	BMW	DIRTY		9	810	R	01/19/92	84	.	40
65	BMW	DIRTY		1	811	S	12/27/91	4	.	48
66	BMW	DIRTY		7	811	R	01/09/92	166	.	48
67	BMW	DIRTY		8	809	S	01/10/92	4	.	54
68	BMW	DIRTY		2	809	R	12/30/91	60	.	53
69	BMW	DIRTY	CRC-4	7	810	S	01/09/92	6	.	48
70	BMW	DIRTY		1	810	R	12/27/91	137	.	48
71	BMW	DIRTY		10	811	S	01/13/92	6	.	52
72	BMW	DIRTY		4	811	R	01/04/92	125	.	45
73	BMW	DIRTY		4	809	S	01/04/92	0	.	45
74	BMW	DIRTY		10	809	R	01/13/92	12	.	52
75	BMW	DIRTY	CRC-5	3	810	S	01/03/92	0	.	51
76	BMW	DIRTY		9	810	R	01/11/92	40	.	52
77	BMW	DIRTY		1	811	S	12/27/91	0	.	48
78	BMW	DIRTY		7	811	R	01/09/92	170	.	48
79	BMW	DIRTY		8	809	S	01/10/92	10	.	54
80	BMW	DIRTY		2	809	R	12/30/91	23	.	53
81	BMW	DIRTY	CRC-6	7	810	S	01/09/92	4	.	48
82	BMW	DIRTY		1	810	R	12/27/91	178	.	48
83	BMW	DIRTY		10	811	S	01/13/92	2	.	52
84	BMW	DIRTY		4	811	R	01/04/92	42	.	45
85	BMW	DIRTY		4	809	S	01/04/92	57	.	45
86	BMW	DIRTY		10	809	R	01/13/92	151	.	52
87	BMW	DIRTY	S-49	3	810	S	01/03/92	93	.	51
88	BMW	DIRTY		9	810	R	01/11/92	192	.	52
89	BMW	DIRTY		1	811	S	12/27/91	62	.	48
90	BMW	DIRTY		7	811	R	01/09/92	332	.	48
91	BMW	DIRTY		8	809	S	01/10/92	38	.	54
92	BMW	DIRTY		2	809	R	12/30/91	217	.	53
93	BMW	DIRTY	S-50	7	810	S	01/09/92	130	.	48
94	BMW	DIRTY		1	810	R	12/27/91	206	.	48
95	BMW	DIRTY		10	811	S	01/13/92	208	.	52
96	BMW	DIRTY		4	811	R	01/04/92	250	.	45

CRC IVD DRIVEABILITY PROGRAM
CRC DRIVING CYCLE

OBS	TEST	PHASE	CAR	RUN	FUEL	RATER	DATE	TOTDEMS	STWD	TEMP
1	CRC	CLEAN		12	809	S	02/18/92	.	0	57
2	CRC	CLEAN		6	809	R	02/06/92	.	46	50
3	CRC	CLEAN	CRC-1	8	810	S	02/19/92	.	0	58
4	CRC	CLEAN		2	810	R	01/30/92	.	60	49
5	CRC	CLEAN		11	811	S	02/17/92	.	0	59
6	CRC	CLEAN		5	811	R	02/05/92	.	30	51
7	CRC	CLEAN		5	809	S	02/05/92	.	0	51
8	CRC	CLEAN		11	809	R	02/17/92	.	36	59
9	CRC	CLEAN	CRC-2	3	810	S	01/31/92	.	12	56
10	CRC	CLEAN		9	810	R	02/15/92	.	72	65
11	CRC	CLEAN		6	811	S	02/06/92	.	24	50
12	CRC	CLEAN		12	811	R	02/18/92	.	70	57
13	CRC	CLEAN		12	809	S	02/18/92	.	0	57
14	CRC	CLEAN		6	809	R	02/06/92	.	185	50
15	CRC	CLEAN	CRC-3	8	810	S	02/19/92	.	6	58
16	CRC	CLEAN		2	810	R	01/30/92	.	130	49
17	CRC	CLEAN		11	811	S	02/17/92	.	6	59
18	CRC	CLEAN		5	811	R	02/05/92	.	138	51
19	CRC	CLEAN		5	809	S	02/05/92	.	6	51
20	CRC	CLEAN		11	809	R	02/17/92	.	168	59
21	CRC	CLEAN		3	810	S	01/31/92	.	8	56
22	CRC	CLEAN	CRC-4	9	810	R	02/15/92	.	185	65
23	CRC	CLEAN		6	811	S	02/06/92	.	6	50
24	CRC	CLEAN		12	811	R	02/18/92	.	153	57
25	CRC	CLEAN		12	809	S	02/25/92	.	30	53
26	CRC	CLEAN		6	809	R	02/06/92	.	80	50
27	CRC	CLEAN	CRC-5	8	810	S	02/08/92	.	24	52
28	CRC	CLEAN		2	810	R	01/30/92	.	82	49
29	CRC	CLEAN		11	811	S	02/24/92	.	12	63
30	CRC	CLEAN		5	811	R	02/05/92	.	63	51
31	CRC	CLEAN		5	809	S	02/05/92	.	12	51
32	CRC	CLEAN		11	809	R	02/17/92	.	76	59
33	CRC	CLEAN	CRC-6	3	810	S	01/31/92	.	24	56
34	CRC	CLEAN		9	810	R	02/15/92	.	73	65
35	CRC	CLEAN		6	811	S	02/06/92	.	36	50
36	CRC	CLEAN		12	811	R	02/18/92	.	94	57
37	CRC	CLEAN		12	809	S	02/18/92	.	18	57
38	CRC	CLEAN		6	809	R	02/06/92	.	182	50
39	CRC	CLEAN	S-49	8	810	S	02/19/92	.	68	58
40	CRC	CLEAN		2	810	R	01/30/92	.	342	49
41	CRC	CLEAN		11	811	S	02/17/92	.	110	59
42	CRC	CLEAN		5	811	R	02/05/92	.	256	51
43	CRC	CLEAN		5	809	S	02/05/92	.	52	51
44	CRC	CLEAN		11	809	R	02/17/92	.	231	59
45	CRC	CLEAN	S-50	3	810	S	01/31/92	.	26	56
46	CRC	CLEAN		9	810	R	02/15/92	.	192	65
47	CRC	CLEAN		6	811	S	02/06/92	.	90	50
48	CRC	CLEAN		12	811	R	02/18/92	.	131	57
49	CRC	DIRTY	CRC-1	6	809	S	01/12/92	.	0	49

CRC IVD DRIVEABILITY PROGRAM
CRC DRIVING CYCLE

OBS	TEST	PHASE	CAR	RUN	FUEL	RATER	DATE	TOTDEMS	STWD	TEMP
50	CRC	DIRTY		12	809	R	01/16/92	.	42	37
51	CRC	DIRTY		2	810	S	12/30/91	.	0	53
52	CRC	DIRTY	CRC-1	8	810	R	01/10/92	.	20	54
53	CRC	DIRTY		5	811	S	01/06/92	.	0	52
54	CRC	DIRTY		11	811	R	01/19/92	.	36	40
55	CRC	DIRTY		11	809	S	01/14/92	.	0	43
56	CRC	DIRTY		5	809	R	01/06/92	.	19	52
57	CRC	DIRTY	CRC-2	9	810	S	01/11/92	.	6	52
58	CRC	DIRTY		3	810	R	01/03/92	.	30	51
59	CRC	DIRTY		12	811	S	01/16/92	.	6	37
60	CRC	DIRTY		6	811	R	01/12/92	.	72	49
61	CRC	DIRTY		6	809	S	01/12/92	.	12	49
62	CRC	DIRTY		12	809	R	01/16/92	.	150	37
63	CRC	DIRTY	CRC-3	2	810	S	12/30/91	.	6	53
64	CRC	DIRTY		8	810	R	01/10/92	.	129	54
65	CRC	DIRTY		5	811	S	01/06/92	.	6	52
66	CRC	DIRTY		11	811	R	01/14/92	.	229	43
67	CRC	DIRTY		11	809	S	01/14/92	.	6	43
68	CRC	DIRTY		5	809	R	01/06/92	.	49	52
69	CRC	DIRTY	CRC-4	9	810	S	01/11/92	.	6	52
70	CRC	DIRTY		3	810	R	01/03/92	.	109	51
71	CRC	DIRTY		12	811	S	01/16/92	.	30	37
72	CRC	DIRTY		6	811	R	01/12/92	.	155	49
73	CRC	DIRTY		6	809	S	01/12/92	.	24	49
74	CRC	DIRTY		12	809	R	01/16/92	.	33	37
75	CRC	DIRTY	CRC-5	2	810	S	12/30/91	.	0	53
76	CRC	DIRTY		8	810	R	01/10/92	.	93	54
77	CRC	DIRTY		5	811	S	01/06/92	.	60	52
78	CRC	DIRTY		11	811	R	01/14/92	.	34	43
79	CRC	DIRTY		11	809	S	01/14/92	.	30	43
80	CRC	DIRTY		5	809	R	01/06/92	.	86	52
81	CRC	DIRTY	CRC-6	9	810	S	01/11/92	.	36	52
82	CRC	DIRTY		3	810	R	01/03/92	.	88	51
83	CRC	DIRTY		12	811	S	01/16/92	.	36	37
84	CRC	DIRTY		6	811	R	01/12/92	.	85	49
85	CRC	DIRTY		6	809	S	01/12/92	.	105	49
86	CRC	DIRTY		12	809	R	01/16/92	.	107	37
87	CRC	DIRTY	S-49	2	810	S	12/30/91	.	164	53
88	CRC	DIRTY		8	810	R	01/10/92	.	262	54
89	CRC	DIRTY		5	811	S	01/06/92	.	134	52
90	CRC	DIRTY		11	811	R	01/14/92	.	208	43
91	CRC	DIRTY		11	809	S	01/14/92	.	138	43
92	CRC	DIRTY		5	809	R	01/06/92	.	178	52
93	CRC	DIRTY	S-50	9	810	S	01/11/92	.	180	52
94	CRC	DIRTY		3	810	R	01/03/92	.	228	51
95	CRC	DIRTY		12	811	S	01/16/92	.	264	37
96	CRC	DIRTY		6	811	R	01/12/92	.	286	49

CRC IVD DRIVEABILITY PROGRAM
RATER CORRECTION CARS
CRC & BMW DRIVING CYCLE

OBS	TEST	PHASE	CAR	RUN	FUEL	RATER	TOTDEMS	STWD
1	BMW	CLEAN	CRC-7	4	811	S	2	.
2	BMW	CLEAN		7	811	S	0	.
3	BMW	CLEAN		9	811	S	0	.
4	BMW	CLEAN	CRC-8	1	811	S	6	.
5	BMW	CLEAN		2	811	S	2	.
6	BMW	CLEAN		10	811	S	0	.
7	BMW	CLEAN	CRC-7	1	811	R	18	.
8	BMW	CLEAN		3	811	R	7	.
9	BMW	CLEAN		10	811	R	30	.
10	BMW	CLEAN	CRC-8	4	811	R	0	.
11	BMW	CLEAN		7	811	R	8	.
12	BMW	CLEAN		8	811	R	6	.
13	BMW	DIRTY	CRC-7	1	811	S	0	.
14	BMW	DIRTY		4	811	S	0	.
15	BMW	DIRTY		8	811	S	4	.
16	BMW	DIRTY	CRC-8	10	811	S	2	.
17	BMW	DIRTY		3	811	S	0	.
18	BMW	DIRTY		7	811	S	2	.
19	BMW	DIRTY	CRC-7	7	811	R	33	.
20	BMW	DIRTY		9	811	R	26	.
21	BMW	DIRTY		1	811	R	179	.
22	BMW	DIRTY	CRC-8	2	811	R	6	.
23	BMW	DIRTY		4	811	R	0	.
24	BMW	DIRTY		10	811	R	17	.
25	CRC	CLEAN	CRC-7	6	811	S	.	6
26	CRC	CLEAN		11	811	S	.	0
27	CRC	CLEAN		8	811	S	.	0
28	CRC	CLEAN	CRC-8	3	811	S	.	18
29	CRC	CLEAN		5	811	S	.	12
30	CRC	CLEAN		12	811	S	.	0
31	CRC	CLEAN	CRC-7	5	811	R	.	33
32	CRC	CLEAN		12	811	R	.	21
33	CRC	CLEAN		2	811	R	.	48
34	CRC	CLEAN	CRC-8	6	811	R	.	16
35	CRC	CLEAN		9	811	R	.	57
36	CRC	CLEAN		11	811	R	.	33
37	CRC	DIRTY	CRC-7	2	811	S	.	0
38	CRC	DIRTY		6	811	S	.	0
39	CRC	DIRTY		12	811	S	.	12
40	CRC	DIRTY	CRC-8	5	811	S	.	0
41	CRC	DIRTY		9	811	S	.	18
42	CRC	DIRTY		11	811	S	.	18
43	CRC	DIRTY	CRC-7	3	811	R	.	40
44	CRC	DIRTY		5	811	R	.	8
45	CRC	DIRTY		11	811	R	.	35
46	CRC	DIRTY	CRC-8	8	811	R	.	22
47	CRC	DIRTY		6	811	R	.	40
48	CRC	DIRTY		12	811	R	.	18