EPA-650/2-74-060

July 1974

Environmental Protection Technology Series

DEVELOPMENT OF A METHODOLOGY FOR THE ASSESSMENT OF THE EFFECTS OF FUELS AND ADDITIVES ON CONTROL DEVICES

Office of Research and Development
U.S. Environmental Protection Agency
Washington, DC 20460

EPA-650/2-74-060

DEVELOPMENT OF A METHODOLOGY FOR THE ASSESSMENT OF THE EFFECTS OF FUELS AND ADDITIVES ON CONTROL DEVICES

by

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Contract No. 68-02-0581
ROAP No. 26AAE-12
Program Element No. AA002

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Prepared for

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

July 1974

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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FOREWARD

This report was prepared by the Transportation Chemicals Research Group, Ag-Organics Department, The Dow Chemical Company, Midland, Michigan, under Contract 68-02-0581. The work reported herein was administered under the direction of the Office of Air and Water Programs, Environmental Protection Agency, with John E. Sigsby, Jr. serving as Project Officer.

The report covers work performed from June 1, 1973 to July 31, 1974.

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The authors wish to acknowledge the significant contributions of the following individuals.

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ABSTRACT

This report describes work carried out to develop a methodology for the determination of the effect of fuel additives on exhaust particle size, concentration, and composition, from light duty vehicles.

In order to determine the best methodology, particulate emissions were examined using a 350 CID Chevrolet engine, and several 350 CID Chevrolet vehicles. The engines and vehicles were operated under steady state cruise conditions, and under the federal 23 minute cycle. Particulate mass measurement techniques have included tailpipe measurement methods and air dilution sampling methods using impaction separators, and filters.

Two different fuel additives as well as a baseline fuel were used to determine the validity of the methods employed. The engine dynamometer runs were correlated with vehicles using the same fuel and additives. Engine runs were made using both manufacturer's suggested and higher than suggested additive concentrations.

The data collected suggests that the methods employed do allow the determination of any adverse effects on particulate emissions due to the inclusion of an additive in the fuel.

In addition, a study was made of probable trends in fuel additive chemistry. An additional task of this study was the collection and analyses of exhaust gas condensate, to be used in animal health studies.

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ABSTRACT

This report describes work directed at the development of methodology for determining the effect of fuel additives on the efficiency and durability of oxidation catalysts.

In addition to evaluating the effect of fuel additives on catalysts, and the subsequent effect on hydrocarbons and carbon monoxide emissions, during this study analyses were made of particulate matter emitted from the catalyst equipped engines and vehicles.

In order to determine the best methodology, emissions were examined using a 350 CID Chevrolet engine, and three 350 CID Chevrolet vehicles. The engines and vehicles were operated under steady state cruise conditions, and under the Federal cycle.

Two different fuel additives as well as a baseline fuel were used to determine the validity of the methods employed. The engine dynamometer runs were correlated with vehicles using the same fuels and additives.

The data collected suggests that the methods employed do allow the determination of any adverse effects on catalytic devices and subsequent emissions due to the inclusion of an additive in the fuel.

I. INTRODUCTION

The advent of oxidation catalysts as control devices for the removal of hydrocarbon and carbon monoxide emissions from vehicle exhaust necessitates a completely new look at fuels and fuel additives, with respect to the effect these additives will have on the durability and efficiency of the catalysts. While it is generally recognized that tetraethyl lead (TEL) and the additives necessary for the proper functioning of TEL have a long range detrimental effect on catalyst efficiency, very little is known about the effect of other additives on catalysts. Since fuel additives must be registered with the Federal government and data presented as to the effects on emission that these fuel additives might have, a series of government contracts were written directed toward the collection of fuel additive emission data, and the subsequent development of methodology for further data collection.

This report describes work directed at the development of methodology for determining the effect of fuel additives on the efficiency and durability of oxidation catalysts. Other contracts in the EPA fuel additive study program included contracts on the effect of fuel additives on the composition of the total hydrocarbon exhaust portion (Bureau of Mines), the effect of fuel additives on particulate emissions (Dow Chemical Co.), the effect of fuel additives on exhaust visibility (Cornell Aeronautics Lab), and development of a model for fuel additive emissions determinations (Dow Chemical Co.).

In addition to evaluating the effect of fuel additives on catalysts, and the subsequent effect on hydrocarbons and carbon monoxide emissions, during this study analyses were made of particulate matter emitted from the catalyst equipped engines and vehicles.

The study was divided into two basic approaches: 1) Engine dynamometer durability runs were made, measuring emissions before and after both beaded and monolith type noble metal catalysts. Three fuels were used. The baseline fuel was Indolene O, while the two test fuels consisted of Indolene O plus the manufacturer's recommended level of a polybutene amine additive (hereafter referred to as Additive A), and Indolene O plus the manufacturer's recommended level (at the time of the study) of methylcyclopentadienylmanganese tricarbonyl (hereafter referred to as Additive B). 2) The second part of the study was the evaluation of three vehicles equipped with beaded type catalysts and run on the three test fuels described above. These three vehicles were driven by three different drivers under a variety of normal highway and city driving conditions.

The gaseous emissions were measured using a Heath International Constant Volume Sampler to sample over the 41 minute Federal Cycle. In the case of the particulate studies, 60 mph steady state runs were used as well as Federal Cycle.

The final result of the study described in this report was the development of a method for determining the short and long range effects of fuel additives on catalytic devices. This methodology is described in Section II of the report, with the data used to support the method presented in detail in Section III.

A general conclusion of the study was that although an engine stand test procedure is adequate for catalyst evaluations as it relates to fuel additives, such procedure offers no great benefits over vehicle testing in regards to ease of data generation or data reproducibility and, in fact, is disadvantageous from a cost standpoint. The availability of catalyst equipped vehicles as of the 1975 model year eliminates the need for any special technology which would be necessary for equipping an engine with a catalyst.

II. METHODOLOGY

A. GENERAL CONCLUSIONS

The basic purpose of this study was to gather data from both engine and chassis dynamometer durability runs for use in setting up a proposed methodology for determining the effect of fuel additives on catalytic devices. It is recognized that an inexpensive and reproducible test sequence is needed in order to evaluate the many materials which will find use as functional fuel additives.

The studies which were made included 140 hour durability runs on an engine dynamometer, using both monolith and beaded catalysts. Three fuels were used, consisting of an indolene baseline, indolene fuel with 1.84 grams/gallon of polybutene amine, designated Additive "A", and indolene fuel with .26 grams/gallon of Mn, added as methycyclopentadienylmanganese tricarbonyl, designated Additive "B". Both additives were used at the manufacturer's recommended levels. Both catalyst types tested were noble metals on inert substrates. A 350 CID Chevrolet engine, modified according to the manufacturer's specification to accept the catalysts, was used for these studies.

In addition to the engine dynamometer runs, three vehicles were equipped with beaded catalysts and operated under normal driving conditions, using the same three fuels mentioned above. The three vehicles were Chevrolets, with 350 CID engines, modified to accept 1973 EGR controls, and tuned to operate according to the manufacturer's recommendations for catalyst equipped vehicles. The vehicles were broken in for approximately 2000 miles before the catalysts were installed, to eliminate any aberations due to normal engine breakin. During the first 2000 miles, blowby measurements were made to ascertain proper ring and valve seating. (The procedure for blowby measurements is described in Section II-B-1 and Table 1).

The vehicles were tested at 2000 mile intervals after catalyst installation. Gaseous measurements were made using a Heath International 5 Bag Constant Volume Sampling System. In addition to gaseous measurements, particulates were also collected and analyzed. (See Government Report EPA-650/2-74-061 for complete details on particulate testing techniques.)

Many conclusions from specific sets of data for each engine and vehicle run can be drawn. These specific comments are included in the body of the report with the different data sets. Some of the pertinent major conclusions which can be drawn from the various runs, both engine and vehicle, are as follows:

1. There did not appear to be any greater reproducibility or less scatter of data when testing on the engine stand than was noted while testing using vehicles. This is significant since the engine stand tests are generally more expensive than the corresponding vehicle tests both in terms of operating costs and capital equipment. In addition, catalyst equipped vehicles are readily available with supplemental equipment such as EGR, air pumps, etc., already in place. The location of the catalyst itself in the downstream exhaust is thereby also specified (Tables 9-22).

2. Wherever conversion effectiveness appeared to decrease as a function of time or miles, the trend was more pronounced in the vehicle tests than it was in the 140 hour engine durability tests. This might be due in part to the fact that the vehicles saw slightly more severe operating conditions (70 mph expressway driving, for example) than did the engine stand catalysts. In any event, a negative effect due to an additive seems to be more pronounced in a vehicle than on an engine stand (Figures 113-118).

3. The use of a 41 minute Federal Cycle Modified (meaning in this study that the test sequence was initiated with the engine and exhaust systems fully warmed up, rather than at the end of the 12 hour soak period) gave more consistent and repeatable data than did the corresponding Cold Start Federal Cycle, as measured by gaseous emissions. Recognizing that a Modified Federal Cycle is of limited value as far as gaseous emissions certification is concerned, it does seem that starting the Federal Cycle with a fully warmed up engine eliminates variables which might otherwise be present in the Cold Start Federal Cycle, allowing a more true reading of the actual state of the catalyst. In addition, Modified Federal Cycles can be repeated with no undo time delay as would be necessary for the Federal Cycle requirement specifying a 12 hour soak period (Figures 57-88).

4. Although in several instances the two additives tested appeared to have some negative effect on catalyst efficiency, in no case was the negative effect dramatic enough to state categorically that the additive under test was unsatisfactory. Unfortunately, time limitations did not permit longer mileage accumulations on the vehicles to determine if the long range effects would continue in the same direction. The engine durability studies were terminated after 140 hours of operation. This test length appears to be inadequate for determining any fuel additive effect on catalysts for any additive other than those which would be extremely harmful.

The effect of oxidative catalytic converters was studied during both the engine stand and vehicle tests. Only very small changes in NO_x values were noted during the vehicle tests which were of relatively longer duration. As noted in 2, whenever conversion efficiency appeared to decrease as a function of time or mileage, the trend was more pronounced in the vehicle tests than it was in the 140 hour engine durability tests.

B. RECOMMENDATIONS FOR PROPOSED FUEL ADDITIVE/CATALYST METHODOLOGY

In view of the conclusions stated above, a proposed methodology for fuel additive testing as regards catalyst life and efficiency has been developed containing the following key points: 1. Vehicles are superior to engine dynamometer for these tests. 2. The Federal Cycle, with the 12 hour cold soak, introduces variables which the Federal Cycle Modified would elminate, such as low temperature spark plug misfire and air/fuel difference due to the choke. 3. Artifical means of inducing catalyst degradation, such as cold shocking or high temperature aging are felt to be generally unreliable in determining an additive effect on the catalyst. These techniques may be valuable, however, for determining the relative merits of different catalysts. A bibliography of papers and articles on catalyst studies, including some on artifical aging, is included in Appendix A. 4. In order to determine the effect of fuel additives on catalysts and the subsequent effect on particulate, more sophisticated and expensive analytical and collection techniques are needed than for only gaseous exhaust measurements. The methodology for particulate emission studies, as relates to fuel additives, is presented in Government Report #EPA-650/2-74-061 titled "Determination of Effect on Particulate Exhaust Emissions of Additives and Impurities in Gasoline". For particulate studies an engine dynamometer is a more appropriate method of emission generation than is a vehicle, since the variables of operation can be more easily controlled on an engine stand. In addition, the dilution tube apparatus necessary for particulate collection is more easily adopted to engine stand studies than to a chassis dynamometer. The details of particulate collection and measurement are also described in Government Report EPA-650/2-74-061.

1. Vehicle Selection

In the study described in this report, 350 CID Chevrolet engines were used. It is suggested that this engine be specified as the test engine of choice, if for no other reason than that much data already exists for comparative purposes. It is recognized, however, that any standard engine could be used, and that the engine choice itself should have little effect on catalyst durability as a function of fuel additives.

The vehicles chosen for the test should be equipped with catalysts, installed by the manufacturer, and containing all supplemental control devices necessary for the proper function of the catalysts. Since catalyst equipped cars will be readily available as of the 1975 model year, it is recommended that purchased or leased vehicles be used with no additional modifications to the emission control system.

As of this writing, it appears that both beaded and monolith type noble metal catalysts will be used to meet the Federal emissions requirements. Our studies did not show any significant differences between the two types which could be attributed to a fuel additive effect. If base metal catalysts find commercial application, however, it would be appropriate to test both catalyst types since the chemical effect of a given additive on a base metal catalyst could be significantly different than on a noble metal catalyst.

The vehicles used for the tests should be tested for blowby flow every 1000 miles by the procedure outlined in Table 1. Blowby flow is a measurement of the exhaust gas which is escaping past the piston rings, and is measured via pressure on the crankcase and valve train cover.

Blowby flow tests are necessary to determine when and if the engine is properly broken in and stabilized. It is obvious that poor ring seating or valve seating will result in emission levels not representative of a normal engine. The need for ascertaining proper break-in is even more important when testing fuel additives, since it is conceivable that certain additives may lengthen or shorten the normally expected break-in period.

TABLE 1

BLOWBY TEST PROCEDURE

Clayton CT-200 Chassis Dynamometer Used

1. Thermocouples installed as follows to record accurate temperatures:
    a. Top radiator hose
    b. Carburetor venturi
    c. Oil pan
    d. Ambient air
    e. Blowby gas flow tube
2. Close oil dip stick tube
3. Close rocker cover vent to carburetor (right side on 350 CID Chevrolet)
4. Install tube from PCV (left side) to Sharp orifice meter intake (1/4" port)
5. Install Venier band throttle
6. Place wind fan in front of car
7. Connect accurate tachometer
8. Connect blowby apparatus as follows (see diagram for details):
    a. Use cooling water to maintain 75-85°F blowby
    b. Connect condensate trap to tube from PVC
    c. Connect outlet from condensate trap to Sharp orifice meter (use 1/4" orifice)
    d. Connect incline water monometer across orifice meter
    e. Connect mercury monometer to engine vacuum
9. All tests run at 2000 rpm
10. Collect the following data at each load condition:
    a. MPH
    b. RPM (maintain at 2000)
    c. Load
    d. Intake manifold pressure
    e. Ambient air
    f. Carburetor air
    g. Coolant temperature
    h. Oil temperature
    i. Barometer reading
    j. Wet and dry bulb temperatures
    k. Blowby temperature before orifice meter
    l. Pressure drop observed across water monometer
    m. Observed cfm blowby - read from Sharp orifice meter chart relating pressure drop to cfm

TABLE 1 (Cont'd)

1. CFM at standard conditions was calculated using a dfm correction factor to compensate for barometric pressure and a standard conversion factor to bring the final result to cfm at standard conditions.
2. The initial reading was taken at the lowest horsepower load measurable. Subsequent readings at multiples of 10 hp.
3. See attached data collection sheet for an example of a typical blowby run.

BLOW BY MEASUREMENTS

TABLE 1 (Cont'd) SHEET NO. 34

OBSERVER WT DATE July 10, 1973

VEHICLE MAKE Chevrolet YEAR 1972 NUMBER D2549

MILES ON VEHICLE 16.352 DISPL. 350 NO. OF CYL. V8 C.R. 8-5-1

IGNITION TIMING 6° AT 600 RPM CARB RP BBL 2

TRANSMISSION 350 Th VAC. IDLE ____ HP ____ RPM ____

BAROMETER IN Hg 29.40 at 82 WET BULB 66.0 °F DRY BULB 82.0

CORRECTED BAROMETER(DRY) 28.79 at 28.5°F ABS. HUMIDITY .470 GR/LB

INERTIA WEIGHT 4500 LBS

VALVE COVER PRESSURE ± 0"

SPARK PLUG TYPE R44T DWELL 30° HP ____ RPM ____

REMARKS: Corr Wet Bar = 29.26

BLOW-BY MEASUREMENTS TEMPERATURES

SPEED	57	56	55	53	52	
RPM	2000	2000	2000	2000	2000	
LOAD	3.4	10	20	30	40	
ENGINE VACUUM	18.9	17.5	15.0	11.0	8.3	
AMB. AIR	90	94	98	99	99	
CARB. AIR	118	120	120	120	122	
WATER	206	208	212	214	222	
OIL	242	246	250	256	265	
BLOW-BY AIR	85	85	85	85	85	
OBS. PRESS DROP	.65	.86	1.38	2.00	2.42	
OBS. CFM	.65	.81	1.01	1.23	1.35	
CFM CORR. FACTOR	.9963	.9963	.9963	.9963	.9963	
CORR CFM	.647	.807	1.006	1.225	1.345	
STD. CONV. FACTOR	1.078	1.078	1.078	1.078	1.078	
CFM at STD COND.	.697	.869	1.084	1.320	1.449	

Once the blowby has stabilized, indicating proper break-in of the engine, the frequency of the tests can be lengthened to every 4000 miles. It is important to continue periodic blowby tests as a check for abnormal ring or valve wear.

B. Test Procedures

The basic test sequence for evaluating the effect of a fuel additive on a catalyst is the Federal Cycle, 41 Minute Cold Start Test. As mentioned previously, this test does seem to give more scatter of the data than does the same test sequence after the engine and exhaust system has been warmed up (Federal Cycle Modified). The recommended procedure, therefore, is to run a Federal Cycle test, followed by two or more 41 Minute Federal Cycle Modified (Hot Start) tests. The Federal Cycle data will be useful in determining the actual emissions level as necessary for the Federal certification procedures, while the modified tests will be more representative of the actual state of the catalyst.

A series of steady state tests at 20, 30, 40 mph, etc. measured along with catalyst temperature, would be valuable in giving a profile of the catalyst after aging with an additive. Steady state testing procedures, while valuable for collection of particulate matter, are of little use for gaseous analyses. The only area where steady state might be of value is in determining if a given additive has changed the temperature at which the catalyst begins to function. A change in the light-off temperature would show up in the cold or hot start tests, but would not be as easily quantified as it would be in a series of steady state runs.

The equipment necessary for vehicle testing according to the Federal Cycle procedure is readily available. A chassis dynamometer such as the Clayton used in this study is sufficient. If the tests are run manually, using a test driver to follow the 41 minute cycle, it is suggested that the same driver be used for all tests, if possible. It has been our experience that different drivers, due to slightly different driving techniques, can introduce enough variance into the cycle to result in some data scatter. An automatic cycling procedure will obviously eliminate this problem.

The mileage accumulation procedures will have an effect on the longevity of a given catalyst even without the added variable of a fuel additive. Recommended procedures for mileage accumulation are as follows:

1. A test track procedure for accumulating mileage is the optimum. This allows for reproducible and repetitive operation of the vehicle. High speed driving will obviously put the most miles on the catalyst in the shortest period of time. However, low temperature, low speed driving is necessary to simulate city driving conditions. Any catalyst aging will be more a function of engine hours than miles. It is important under all circumstances to monitor the temperature of the catalyst to ascertain that any catalyst degradation is not due to a high temperature burnout of the catalyst. In addition, temperature monitoring will immediately pinpoint any mechanical failures such as fouled spark plug or choke sticking. The best mechanism for temperature monitoring is a direct readout temperature meter mounted on the dashboard of the vehicle, and a strip chart recorder mounted elsewhere in the vehicle to record the actual catalyst temperatures as a function of engine hours. Any high temperature due to mechanical failure or overload would be readily noted, and aberations in the data would be explained. Our studies did not utilize a temperature recorder, but in retrospect it would have been valuable to have such data.

2. If test track mileage accumulation is not possible, normal highway and city driving can be used. The best way to make sure that the mileage is accumulated in a representative fashion is to set up a driving sequence which includes an appropriate amount of urban, suburban and expressway type operation. While recognizing that flexibility is necessary in developing a driving sequence, a suggested format would be for a minimum of 50% of the engine hours to be accumulated in urban and suburban type driving, and for no more than 50% of the hours to be accumulated at expressway speeds.

Since ambient temperature and humidity conditions will have some effect on gaseous emissions, and since the statistical significance of a fleet test is already low unless several vehicles are used for each of the additives and the baseline, it is important that the vehicles start and finish the test period at about the same time.

The testing interval of the vehicles should be no less frequent than 2000 miles for the first 10,000 miles, and 4000 miles thereafter. Since normal catalyst life is expected to be 50,000 miles, any negative effect showing up dramatically within the first 10,000 miles would be reason enough to terminate the test at 10,000 miles. If no effect is noted during this period, the tests should be extended to 25,000 miles. Discussions with auto company personnel have led to the conclusion that catalyst performance shows little consistency past 25,000 miles. It is felt that tests lasting longer than this would contribute little in the way of data which could be attributed to a fuel additive effect.

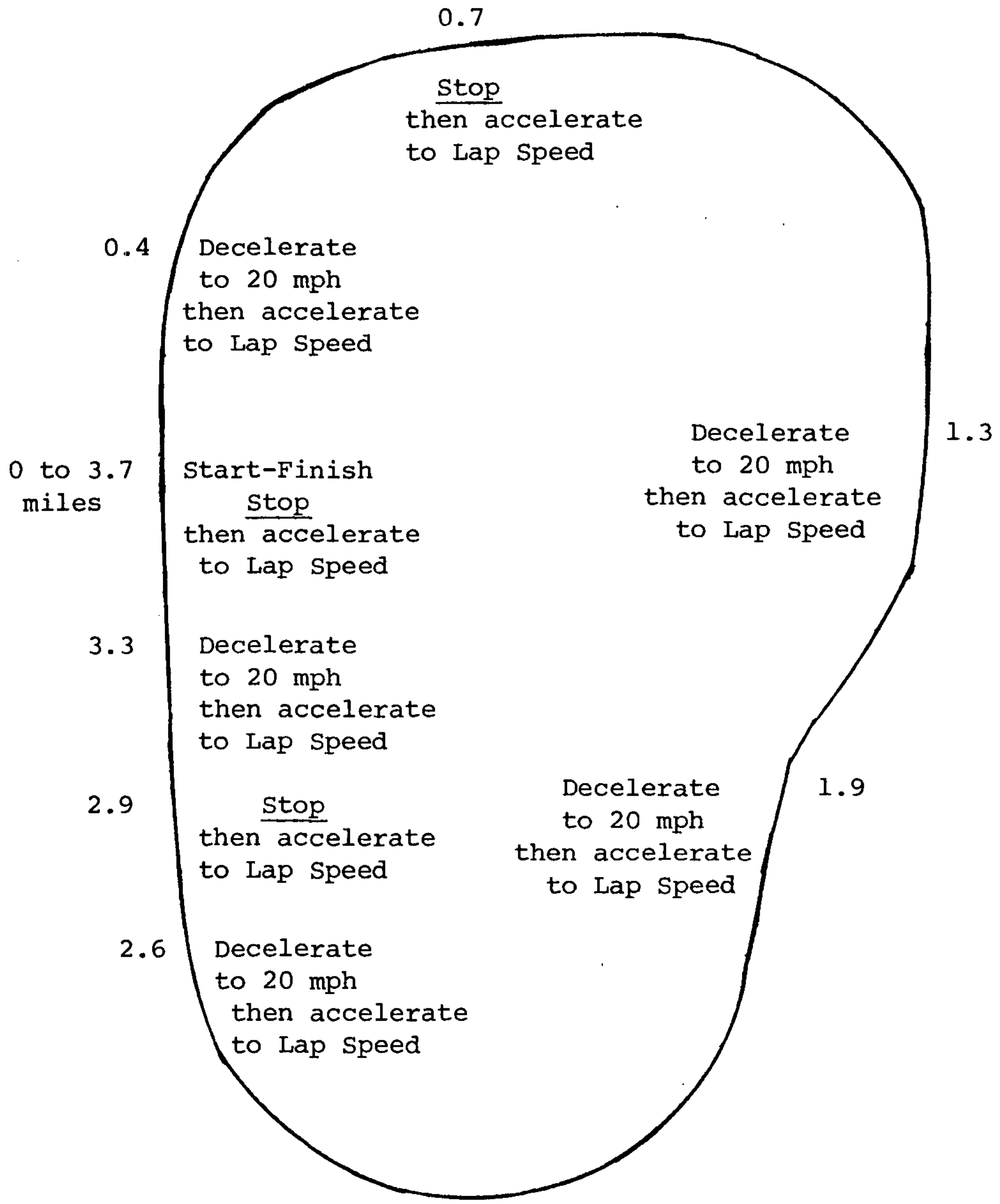
Although we recommend that vehicles be used as the primary test source, it is recognized that some manufacturers of additives are well equipped to run multi-engine dynamometer studies. This technique is satisfactory, but for the reasons previously described cannot be recommended as the method of choice. If engines are to be used, however, several criteria are necessary.

It is extremely important that the engines be equipped with catalysts in a way which very closely simulates the given catalyst system as it would exist on a vehicle. Accessory emission control devices are necessary, as well as verifying that the placement of the catalyst downstream from the exhaust header be the same as the placement on a vehicle. If a given test catalyst is used on a vehicle to catalyze the exhaust stream from eight cylinders, than it must also be used on all eight cylinders of the test engine exhaust.

The engine dynamometer cycle is an extremely important part of the data collection process. Previous work (Government Report EPA 650/2-74-061) involving particulate studies, used the 23 Minute Federal Cycle which was repeated over and over until the required number of hours were accumulated on the engine. For the catalyst studies described in this report, the sequence of 23 minute runs was felt to be unsatisfactory. Basically, the average speed of approximately 19 miles per hour was not felt to be adequate for promoting any severe additive effect on the catalyst. In addition, the accelerations in the Federal Cycle (23 minutes) do not severely enough load the engine. Higher loads will cause short duration catalyst temperature increases which more closely simulate severe driving conditions such as wide open accelerations or trailer towing.

The durability cycle of choice for the fuel additive effect engine runs is described in detail on page 24319, Volume 37, Number 221, Wednesday, November 15, 1972 of the Federal Register. This cycle is summarized in Table 2. The pertinent factors in this cycle include rapid acceleration

TABLE 2. ENGINE DURABILITY TEST CYCLE



All Stops are 15 sec.

Lap	Speed-m.p.h.
1	40
2	30
3	40
4	40
5	35
6	30
7	35
8	45
9	35
10	55
11	70

ENGINE DYNAMOMETER DURABILITY TEST SCHEDULE

Accumulated Days	With Converter	Without Converter	Federal Cycle	Federal Cycle Modified	Particulate Test 60 MPH	Particulate Test 23 Min.	Accumulated Hours on Test	Sequence of Test	Test Pairs	Remarks
1	X		X					1	1&4	The engine was operated on the Federal Durability Driving Cycle for 19 hours and then stopped for 4 hours to simulate a cold start test.
	X			X			6	2	2&5	
	X				X			3		
2		X	X					4		The engine was operated on the Federal Durability Driving Cycle for 24 hours with no engine shut down as no simulated cold start is called for before emission test.
		X		X			25	5		
	X					X		6		
	X					X		7		
3	X			X				8	8&9	
		X		X			48	9		
4	X		X					10	10&13	Same as Day #1
	X			X			67	11	11&12	
		X		X				12		
5		X	X					13		Same as Day #1
		X		X			86	14	14&15	
	X			X				15		
6		X		X			109	16	16&17	Same as Day #2
	X			X				17		
7		X	X					18	18&21	Same as Day #1
		X		X			128	19	19&20	
	X			X				20		
8	X		X					21		Engine shut down at end of day when the accumulated hours total 137 hours.
	X			X			137	22	22&23	
		X		X				23		
9	X					X	140	24		Particulate test on this day.
	X					X		25		
	X				X			26		

and deceleration, with a top speed of 70 mph, and an overall average speed of about 40 mph. It is basically a cycle adapted from test track driving. A 3.7 mile test course was used, with a total of 11 laps. During the first 9 laps, there are 4 stops with 15 seconds idle. Normal accelerations and decelerations are used. In addition, there are 5 light decelerations each lap from the base speed to 20 mph followed by light accelerations to the base speed. The 10th lap is run at a constant 55 mph. The 11th lap is begun with a wide open throttle acceleration from stop to 70 mph. A normal deceleration to idle followed by a second wide open throttle acceleration occurs at the midpoint of the lap.

The durability schedule was transcribed onto computer tape, which was used on a mode monitor manufactured by Northern Ampower Corporation to control the engine and the dynamometer. There are probably many ways in which a cycle can be transcribed to control an engine dynamometer, but since all of the work on this contract was done using the Northern Ampower Mode Monitor, no attempt will be made to discuss other systems. It is important, however, to use a cycle and not a series of long steady state runs, since the effect on a catalyst of a steady state run will not be the same as the fuel additive effect which will occur as a result of frequent acceleration and deceleration.

C. Analyses of Data

The gaseous emission data collected during this study was determined using the Heath International 5 bag CVS system. The procedures followed in all cases were those outlined in the Federal Register for gaseous determinations.

The single most important piece of data generated from each specific test is the total grams/mile hydrocarbon and carbon monoxide figure for the weighted average of the segments of the Federal Cycle. This number will be directly comparable to the figures obtained during certification of a given engine or control system. The change, over time, in the total grams/mile number is an accurate assessment of the effect of a given additive on the control system under test.

The various segments of the Federal Cycle, however, as measured by the 5 bag system, can be used individually to give more detailed information about the specific effects of any fuel additive under test. The cold start portion is the least reproducible of the three segments, but when compared to the stabilized or hot start segment can not only give information about the relative durability of catalysts, but is also a good check point for determining very quickly if any mechanical malfunctions are occurring.

For example, if the cold start portion shows an increase in grams/mile hydrocarbon or carbon monoxide as a function of time, while the stabilized and hot start portion remains relatively constant, this could be an indication that the light-off temperature of the catalyst is increasing, while the efficiency, once light-off temperature is reached, is not affected. On the other hand, if the cold start portion remains relatively constant while the stabilized segment goes up, either sharply or as a function of time, this could be an indication of high speed spark plug misfiring due to mechanical ignition problems or an additive effect on the spark plugs themselves. An overall rise in the weighted averages, per the Federal Cycle procedure, can be more easily relied on as an indication of catalyst degradation if the same general effect is noted in the various segments of the cycle. In Section III, the data from both the engine runs and the vehicle tests are presented, and in each case the effect of the additive fuels is discussed for the weighted average and the individual segments.

As mentioned previously, the raw data from the CVS system was converted into grams/mile using the Federal Register procedure outlined in the Wednesday, November 15, 1972 edition, Volume 37, Number 221. A computer program, obtained from EPA, was used to perform the calculations. For gaseous emission testing it is convenient that computer capacity and an appropriate program be available for these calculations. It would be virtually difficult to do them any other way.

In addition to the gaseous emission data, it is appropriate to also determine a fuel additive effect on a catalyst relative to particulate emissions. No attempt was made in this study to further refine particulate collection and analysis methodology. The methods described in report EPA-650/2-74-061 are sufficient for these studies relative to particulate mass and composition (carbon, hydrogen, nitrogen, benzo(a) pyrene, and trace metals). However, since oxidation catalysts are suspected of increasing the ratio of SO_3/SO_2 compared to non-catalyst systems, measurement of these particular species is appropriate. Some preliminary work was done using a modification of Method 8, described in Federal Register, Volume 36, page 24893. Basically, this method involves sampling a direct exhaust gas stream from before and after the catalyst, and running the stream through a series of impingers, collecting the SO_2 in a peroxide solution and the SO_3 in an isopropyl alcohol solution. From the initial attempts at ascertaining any shift in SO_3/SO_2 ratio, it appears that this method can be used. However, not enough work was done to warrant a detailed explanation as part of the methodology of this contract.

Filtration techniques described in report EPA-650/2-74-061 can also be used to determine any shift in the SO_3/SO_2 ratio, since in diluted exhaust the SO_3 will exist in the hydrated form as H_2SO_4. This can be collected on the millipore filter media, and analyzed by one of several techniques specific for the $SO_4^=$ ion. Barium precipitation is one such method, and is described in Method 8. A technique used on occasion in other studies involved induced electron emission spectroscopy, and is specific for a given valence state of sulfur. Total sulfur in the particulate can be measured using readily available pyrolitic techniques. Samples for $SO_4^=$ analyses were collected from each run and forwarded to EPA for analyses. The results of these analyses are not reported in this study.

In analyzing the data generated both on the engine stand and the vehicles, it is recognized that the statistical significance is low. For each test, there are enough uncontrollable variables present, such as minor undetected mechanical malfunctions or ambient weather conditions, so that in each durability run there always seemed to be one or two points unexplainably higher or lower than the observed trend from the rest of the data points. Where possible, an attempt has been made to rationalize what the cause might have been. However, in many cases there does not appear to be any plausible explanation. It is suggested that any test on an additive system that is expected to see widespread usage be run with at least two vehicles on the baseline fuel and two or more on the given additive fuel. A statistically significant multi-engine or vehicle test can be set up using one of any number of mathematical models.

Table 4 is an example of how a statistical test can be set up by making certain assumptions about the repeatability and closeness with which the engines or vehicles match. The horizontal axis of the table is the standard deviation, or the difference, plus or minus, which one would expect between engines or vehicles in a normal situation. The vertical axis, p, is the difference in the average emission levels which is expected to be significant. The numbers in the body of the table are the numbers of vehicles or engines needed to show the difference p. For example, if it is assumed that a set of matched engines will show a normal 25% variation from the average on hydrocarbon or carbon monoxide emissions when equipped with a catalyst and run on a baseline fuel, and that an increase in emissions of 50% ($p = 1.5$), compared to a baseline, is expected, than 15 engines would be necessary for both baseline and test fuel in order to be assured that the 50% increase is statistically significant at the 95% confidence level, and not a result of the normal variations expected between engines. If the engines are felt to be closely enough matched so that a deviation of 15% is expected, and a 150% ($p = 2.5$) increase in emissions due to an additive is significant, than 4 engines or vehicles can be used.

The graph on Table 4 shows the importance of the duration of the test. Obviously, if an additive causes catalyst degradation with time, the longer the test runs, the greater the difference will become between the baseline and the test fuel, until at some point a plateau is reached. If a test is terminated before the plateau is reached, then p will be smaller than necessary, and the statistical significance will be lower for a given number of engines or vehicles than would be expected.

In setting up a statistically significant test sequence, as much prior information on the expected behavior of the engines as can be obtained is quite helpful. For example, if it has already been established that a given engine on a given test sequence (either engine stand or vehicle) would show a normal variance of 15% from the average, then a fewer number of vehicles or engines can be used for the tests than if the assumption was erroneously made that the engines would show a 25% variance.

Table 5 is a summary of some of the gaseous data obtained from engine dynamometer runs, measured before the catalyst via CVS. The intent is to show the variability in hydrocarbon and carbon monoxide emissions which is present in the same engine during a single run and also the variability in the same engine from run to run. Although a slight increase in both hydrocarbons and carbon monoxide might be expected to occur as a result of engine hours, the deviations from the average which occur apparently in a random fashion indicate that a range of 15% to 40% deviation from the average is not unlikely. For example, with the baseline fuel, tested 7 times on a Federal Cycle modified with no catalyst, the average hydrocarbon emission was .43 grams/mile, with a low of .2 grams/mile (perhaps spurious, but if so, no reason was readily apparent) and a high of .56 grams/mile, or -53% and +30%, respectively. Another example, using fuel Additive A, with no convertor, showed a range of +22% and -10% for hydrocarbons and +6% and -9% for carbon monoxide. It is apparent from this data that before a statistically significant test can be set up, some assumptions on the expected repeatability of the data must be made, and the repeatability will most likely be in the 15-40% range.

D. Expected Results

In light of the statistical significane of the data which was just discussed, it is apparent that using a relatively small (less than 10 vehicles) fleet test will give statistically sound results only if the additive under test shows differences in gaseous emissions of around 2 times the emissions measured under baseline conditions.

Since there are numerous additives used in fuel which will need to be tested, and since many of these additives are all organic compounds used at low percentages, it is reasonable to assume that different sized fleet tests will be necessary to generate the data needed to make reliable conclusions as to the effect of a given additive on catalysts. For example, a low molecular weight organic material such as methyl alcohol, used as an anti-icer, would be expected to have little or no effect on a catalyst. Therefore, a large number of test vehicles would be necessary to statistically verify the exact magnitude of any change in emission rates. However, since methyl alcohol is expected to have little effect on catalyst life, and since it is also readily oxidized and should have little effect on regulated gaseous emissions, and also since the value of this additive in fuel is such that a large expenditure for data generation might be felt unreasonable, the argument could be reversed so that a small fleet test would be enough to validate a qualitative conclusion.

In the case of an additive used for octane improvement, such as Additive "B" in this study, which will have a widespread usage and which can also be expected to have some chemical or physical effect on a catalyst, the cost and time necessary to generate statistically sound data would be justified.

The point being made is that there should be some flexibility in the proposed fleet tests (or engine stand runs) to allow for expected differences in various additives with respect to catalyst efficiency and longevity, and should also take into account the value of the given additive to the industry or consumer.

Another consideration which was not looked at in this study but which could be significant is a cummulative effect when more than one additive is present in a given fuel. A fully formulated gasoline containing an octane improver, a dye, an antioxidant and a detergent could have a larger or smaller cummulative effect on catalyst efficiency than any of the additives by themselves. The use of a detergent by itself could conceivably show a decrease in hydrocarbon emissions compared to a baseline fuel containing no additives just as a result of forming lower engine and intake manifold deposits, whereas in combination with other additives this effect would be negated. It is suggested that where feasible, tests be run on fully formulated fuels to determine any effects on the catalysts. If negative effects are noted, then the individual additives can be tested via the same procedure.

This study primarily involved testing for the regulated gaseous emissions (carbon monoxide and unburned hydrocarbons) which would be affected by oxidation catalysts. Analysis of particulate emissions was also looked at, but in general, showed so much scatter that meaningful conclusions are difficult to draw. In analyzing the data collected from a test on a given additive, there are several key points to consider. First, an increase in carbon monoxide or hydrocarbons as a function of miles is significant as an absolute measurement only if the increase takes the emission level past the Federal Standard in effect at the time. For example, if carbon monoxide in a given test goes from 1 g/mile to 3 g/mile, the absolute numbers are not of much value in terms of drawing conclusions about the additive since both the start and finish numbers are below the 3.4 g/mile standard.

The second point, which logically follows from the example just stated, is that catalyst efficiency is the most important measurement. Following the previous example, if the baseline test showed an increase in carbon monoxide from 1.0 g/mile to 2.0 g/mile over the same time period that the test fuel showed a 1.0 g/mile to 3.0 g/mile increase, then the conclusion would have to be that although the additive shows some negative effect on the catalyst, the effect is not significant in terms of an overall reduction in air quality.

The third point to consider is that any additive which causes an increase in emissions which takes the levels above the regulated standard should be considered suspect. This point has to be tempered somewhat, however, with the recognition that a baseline fuel can also show an increase to a point above the standard as a result of normal catalyst attrition. The data presented in this study in Section III shows that the baseline as well as the two additives ended up above 3.4 g/mile carbon monoxide at the conclusion of the 17,000 mile vehicle tests.

F. <u>Summary</u>

To summarize, the methodology suggested for testing fuel additives for the effect on catalyst operation with respect to gaseous emissions is as follows:

1. Select a statistically significant fleet size (or engine runs, if so desired) based on assumed parameters of reproducibility and precision, and based on whether prior data is available on the given additive system and engines used for the tests.

2. Break in the vehicles, testing for blowby every 1,000 miles until stabilized, and every 4,000 miles after test.

3. Run the vehicles according to a prescribed test sequence (test trade or road), testing for gaseous emissions every 2,000 miles for the first 10,000 test miles, and 4,000 miles thereafter, using the Federal Test Cycle (both modified and cold start).

4. Collect and tabulate the data in such a way that the catalyst efficiency at the end of each test sequence is the prime consideration. Apply statistical methods of analysis to the results to verify statistical significance.

TABLE 4. STATISTICAL TEST EXAMPLE

Standard Deviation

p	.15	.20	.25	.30	.40
1.5	7	10	15	22	37
2.0	4	5	6	7	11
2.5	≤4	≤4	4	5	6
3.0	≤4	≤4	≤4	≤4	4

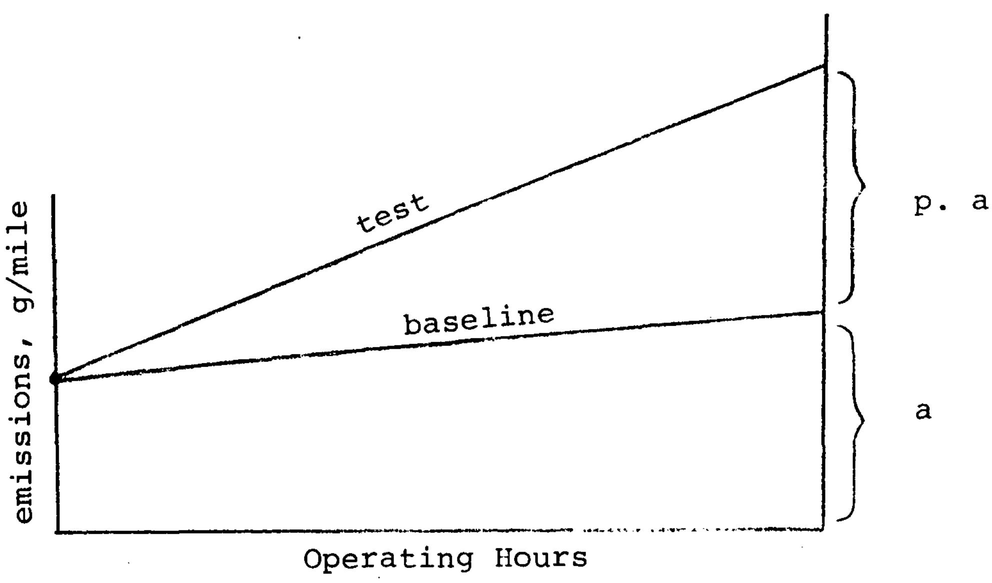


TABLE 5. VARIABILITY OF DATA

Engine Runs												
Baseline Fuel No Catalyst, g/mile				Additive A No Catalyst, g/mile				Additive B No Catalyst, g/mile				
HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	
.53	22.1	.58	17.3	.59	17.3	.37	22.6	1.03	24.1	1.37	17.6	
.56	25.8	.56	17.3	.62	17.4	.39	21.8	.99	25.3	1.44	17.6	
.53	29.9	.58	17.7	.57	17.6	.38	23.2	1.12	21.1	1.43	17.6	
.44	24.8	.61	17.7	.66	17.6	.39	19.9	1.16	22.8	1.83	15.9	
.20	11.4	.63	17.6	.88	17.2	.50	21.9	1.28	23.9			
.38	22.2			.58	17.4	.45	21.8	.94	15.4			
.40	23.9			.74	17.2			1.02	17.0			
.43	22.3	.59	17.5	.66	17.4	.41	21.9	1.08	21.4	1.52	17.2	Average
+30%	+33%	+7%	+1%	+33%	+1%	+22%	+6%	+19%	+18%	+20%	+2%	Max. Deviation from Average
-53%	-49%	-5%	-1%	-14%	-1%	-10%	-9%	-13%	-28%	-10%	-8%	Min. Deviation from Average

III. EXPERIMENTAL DATA, GASEOUS EMISSION

This section consists of the raw data from all of the engine and vehicle tests which was used to verify conclusions regarding the methodology. The data is presented in eight sections, with comments and conclusions for each section. The eight sections are:

A. Raw Data, Engine Stand, Monolithic Catalyst, Three Fuels.
B. Comparison of Three Fuels, Engine Stand, Monolithic Catalyst.
C. Raw Data, Engine Stand, Beaded Catalyst, Three Fuels
D. Comparison of Three Fuels, Engine Stand, Beaded Catalyst.
E. Comparison of Beaded and Monolithic Catalysts, Engine Stand, Three Fuels
F. Raw Data, Chassis Dynamometer, Beaded Catalyst, Three Fuels
G. Comparison of Three Fuels, Chassis Dynamometer, Beaded Catalyst
H. Comparison of Chassis Vs. Engine Dynamometer, Beaded Catalyst, Three Fuels

The data is presented in tabular form, with graphs of grams/mile or efficiency versus time or miles for comparative purposes. The term "Federal Cycle" refers in all cases to the 41 Minute Cycle as described in the Federal Register. Modified Federal Cycle refers to the 41 Minute Cycle, starting with a completely warmed up engine. Cold transient, stabilized, and hot transient refer to the respective segments of the Federal Cycle. The weighted figure is the total grams/mile calculated via the Federal Cycle procedures.

Physical data on the fuel used in each test is presented in Tables 6, 7, 8. The same batch of Indolene fuel was used for all three fuels, with the only difference being the test additives in two of the fuels.

TABLE 6

INDOLENE No.15214 91 OCTANE FUEL
BASE FUEL

API Gravity	58.7
IBP	84
5	106
10	118
20	142
30	164
40	186
50	204
60	230
70	252
80	278
90	316
95	390
EP	
% Residue	0.2
RON	90.0
MON	80.6
RVP	9.3
% Saturates	66.0
Olefins	6.4
Aromatics	27.6
Carbon	86.2%
Hydrogen	13.3%
Sulfur	355 PPM

Trace Metals	Fe	Ni	Cu	Al	Ca	Mg	Mn	Pb	Cr	Sn	Zn	Ti
PPM	1.	<1.	0.2	2	7	<1.	<0.5	12.	<1.	<1.	<3.	<1.

Lead by Atomic Absorption = 12.PPM

Phosphorus by Colormetric Data = <1.PPM

Bromine by X-ray Fluorescence = 4.PPM

TABLE 7

INDOLENE No.15214 91 OCTANE FUEL
+ ADDITIVE "A"

API Gravity	59.7
Distillation:	
IBP	96
5	114
10	126
20	148
30	166
40	188
50	208
60	226
70	244
80	270
90	304
95	378
EP	
% Residue	0.2
RON	90.6
MON	80.4
RVP	8.0
Saturates	68.4
Olefins	3.8
Aromatics	27.8
Carbon	86.1%
Hydrogen	13.4%
Sulfur	460. PPM

Trace Metals	Fe	Ni	Cu	Al	Ca	Mg	Mn	Pb	Cr	Sn	Zn	Ti
PPM	3.	<1.	<0.2	1.	2	<1.	<0.5	--	<1.	<1.	<3.	<1.

Lead by Atomic Absorption = 66 ppm

Phosphorus = <2.PPM

Bromine by X-ray Fluorescence = 25 ppm

TABLE 8

INDOLENE No.15214 91 OCTANE FUEL
+ ADDITIVE "B"

API Gravity	59.5
Distillation:	
IBP	102
5	126
10	136
20	154
30	174
40	194
50	212
60	230
70	248
80	272
90	314
95	380
E.P.	
% Residue	0.2
RON	93.0
MON	81.0
RVP	8.0
Saturates	68.2
Olefins	4.8
Aromatics	26.8
Carbon	85.8%
Hydrogen	13.4%
Sulfur	480. PPM

Trace Metals	Fe	Ni	Cu	Al	Ca	Mg	Mn	Pb	Cr	Sn	Zn	Ti
PPM	3.	<1.	<0.2	<1.	2	<1.	82.	--	<1.	<1.	<3.	<1.

Lead by Atomic Absorption = 74 ppm

Phosphorus = <2.PPM

Bromine by X-ray Fluorescence = 25 ppm

A. Raw Data, Engine Stand, Monolithic Catalyst, Three Fuels

The following set of data and graphs consists of the measurements, via CVS, of carbon monoxide and hydrocarbon emissions and the corresponding conversion efficiencies for monolithic catalysts. For the study, an engine was equipped with a catalytic converter coupled to an engine dynamometer and operated on a Federal Durability Cycle as described in the November 15, 1972, Volume 37, Number 221, Federal Register. Three different fuels were used: baseline, Additive "A", and Additive "B".

The exhaust gases were collected using a Heath International CVS 5 Bag System. They were analyzed using the following analytical instruments:

1. Unburned hydrocarbons - Beckman Flame Ionization.
2. Carbon monoxide - 0-280 ppm, 0-3000 ppm range, Beckman Infrared Analyzer, Model 1R315.

The durability or conversion effieicney was measured by the analysis of the exhaust gases at the start and periodically during the test via the CVS method, using the Federal Cycle and Modified Federal Cycle test sequence. Exhaust gas was analyzed both before and after the catalytic converter.

The raw data is reported as well as shown graphically. The cycle is broken down into the cold, hot, and stabilized segments, and also the weighted average of each segment. The most meaningful is the weighted average, which is the number that certification procedures are based on. The cold transient segment is the first 505 seconds of the 41 Minute test, and is likely to be the least reproducible due to differences in air/fuel ratio as a result of the choke opening during this period. The catalysts were run for approximately 140 hours on each fuel, using a fresh catalyst for each 140 hour run. In addition to gaseous emission data, particulate measurements were made at various points during the run. The particulate data is reported in Section IV.

COMMENTS - Baseline Fuel

1. All three portions of the cycle (cold, stabilized, and hot) sampled before the converter, remained constant, as measured by the Federal Cycle test procedure, for the duration of each run.

2. With respect to carbon monoxide, all three portions as above, sampled after the converter, showed some variation; however, no significant reduction in conversion efficiency was observed.

3. During the Modified Federal Cycle, before the converter, the carbon monoxide emission levels were constant while the emission levels after the converter showed a downward trend. This is shown in the converter efficiency curves which show an improvement with time.

4. With respect to hydrocarbon emissions, during the Federal Cycle, except for the cold start portion, the grams/mile for both before and after the converter remains relatively constant, with a slight downward trend developing after the converter. This is shown graphically in the conversion efficiency curve.

5. With respect to hydrocarbons, data from the Modified Federal Cycle show smaller differences and less scatter between the before and after converter measurements than does the data from the Federal Cycle. The after converter data shows a downward trend, which indicates an improvement in conversion efficiency, with time.

TABLE 9. BASE FUEL, MONOLITHIC CATALYST, ENGINE STAND, RAW DATA, GRAMS/MILE *

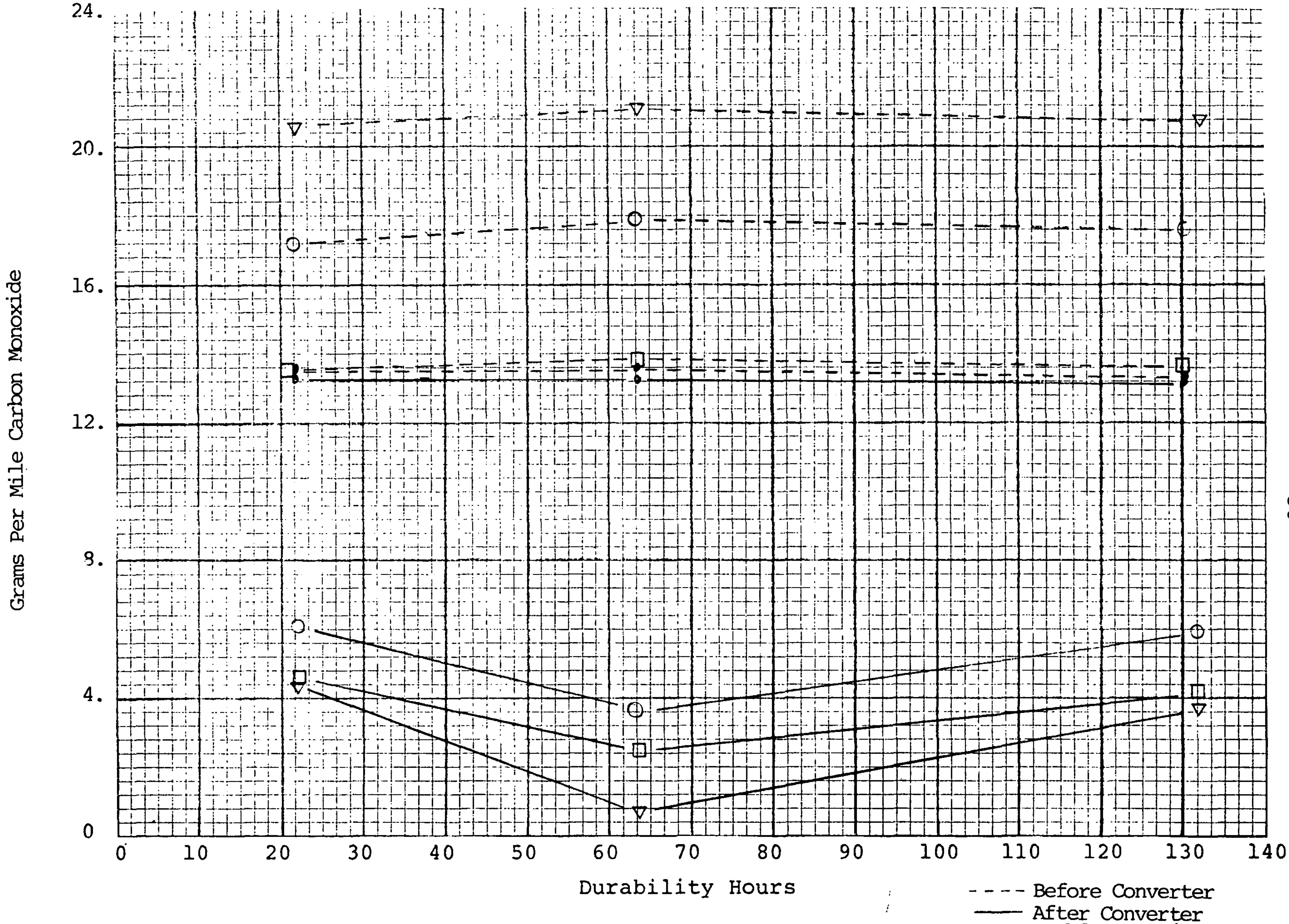
Cold		Hot		Cold		Hot		Hot		Hot		Cold		Hot		
HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	
21.7		22.5		64.1		65.2		86.8		108		131.8		131.8		Durability Hours
With Converter																
.94	13.6	.88	7.6	1.25	13.56	.35	5.68	.54	5.95	.20	5.36	4.2	13.5	.39	5.07	Cold Transient
.11	4.6	.13	3.84	.47	.84	.16	.81	.13	1.04	.17	.68	.26	1.3	.19	1.43	Stabilized
.23	4.5	.24	4.16	.19	2.45	.24	7.63	.16	3.11	.17	4.61	.19	2.8	.20	4.43	Hot Transient
.31	6.4	.31	4.69	.55	3.82	.22	3.60	.22	2.58	.17	2.66	1.04	4.16	.23	2.95	Weighted
Without Converter																
2.62	13.54	.85	13.6	1.51	13.8	.42	13.6	.57	13.8	.58	13.88	1.85	13.7	.80	13.74	Cold Transient
.74	20.61	.53	20.6	.64	21.1	.63	20.6	.62	21.1	.66	21.1	.67	20.87	.62	20.9	Stabilized
.48	13.46	.46	13.46	.53	13.8	.53	13.4	.50	13.8	.53	13.8	.53	13.76	.52	13.76	Hot Transient
1.05	17.29	.58	17.31	.78	17.72	.56	17.32	.58	17.69	.61	17.7	.87	17.55	.63	17.6	Weighted
% Efficiency																
64.1	0	0	44.1	17.2	1.7	16.6	58.2	5.2	56.8	65.5	61.4	62.1	0	51.2	63.1	Cold Transient
85.1	77.6	75.4	81.3	26.5	96.0	74.6	96.0	79.0	95.0	74.2	96.7	95.9	80.9	69.3	93.1	Stabilized
52.0	66.5	47.8	69.0	64.1	82.2	54.7	43.0	68.0	77.4	67.9	66.5	62.9	69.4	61.5	67.8	Hot Transient
70.4	62.9	46.5	72.9	29.5	76.7	60.7	79.2	62.0	85.4	72.1	84.9	77.0	65.8	63.4	83.2	Weighted

*Corrected for ambient conditions.

TABLE 10. AMBIENT CONDITIONS

BASE FUEL - MONOLITH CATALYST ENGINE DYNAMOMETER

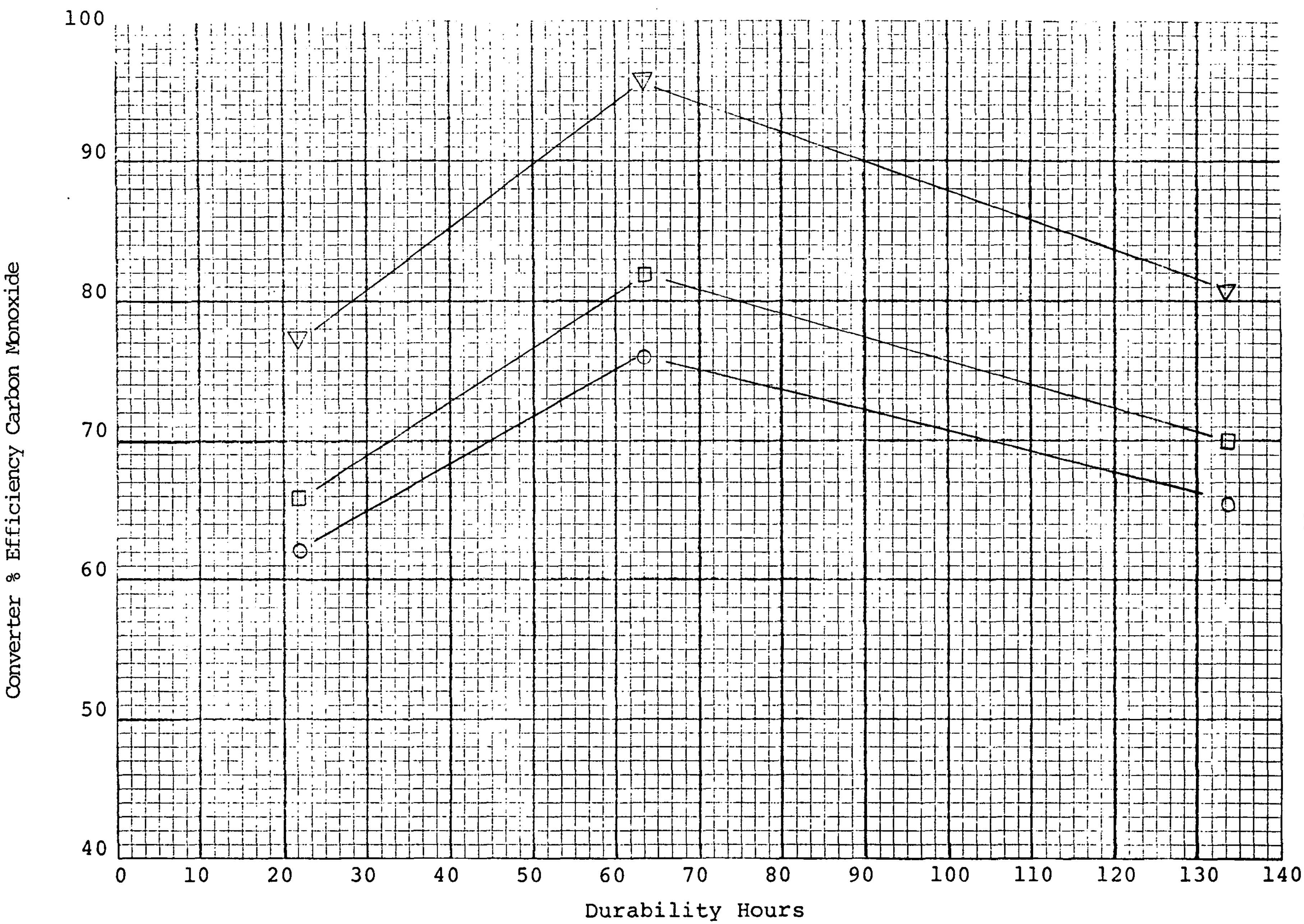
Modified Federal Cycle		X		X	X	X		X
Federal Cycle	X		X				X	
Durability Hours	0	22.5	64.1	65.2	86.8	108	131.8	131.8
<u>WITHOUT CONVERTER</u>								
Barometer	29.32	29.32	29.18	29.18	29.60	29.63	29.33	29.60
Corrected Barometer	29.19	29.19	29.08	29.08	29.48	29.48	29.19	29.46
Ambient Air °F	77.	77.	62.	62.	74.	82.	81.	87.
Wet Bulb °F	60.	60.	51.	51.	52.5	55.5	58.	59.
Dry Bulb °F	77.	77.	62.	72.	74.	82.	80.	88.
Humidity %	35.89	35.89	45.91	45.91	19.05	13.74	21.84	13.83
<u>WITH CONVERTER</u>								
Barometer	29.18	29.18	29.60	29.18	29.60	29.63	29.62	29.60
Corrected Barometer	29.05	29.05	29.48	29.08	29.48	29.48	29.49	29.46
Ambient Air °F	78.	78.	74.	64.	74.	82.	77.	87.
Wet Bulb °F	61.	61.	52.5	52.	52.5	55.5	53.	59.
Dry Bulb °F	78.	78.	74.	64.	74.	82.	76.5	88.
Humidity %	36.84	36.84	19.05	43.34	19.05	13.74	16.03	16.03



CVS EMISSIONS FEDERAL CYCLE

Monolithic Catalyst
Base Fuel

FIGURE 1

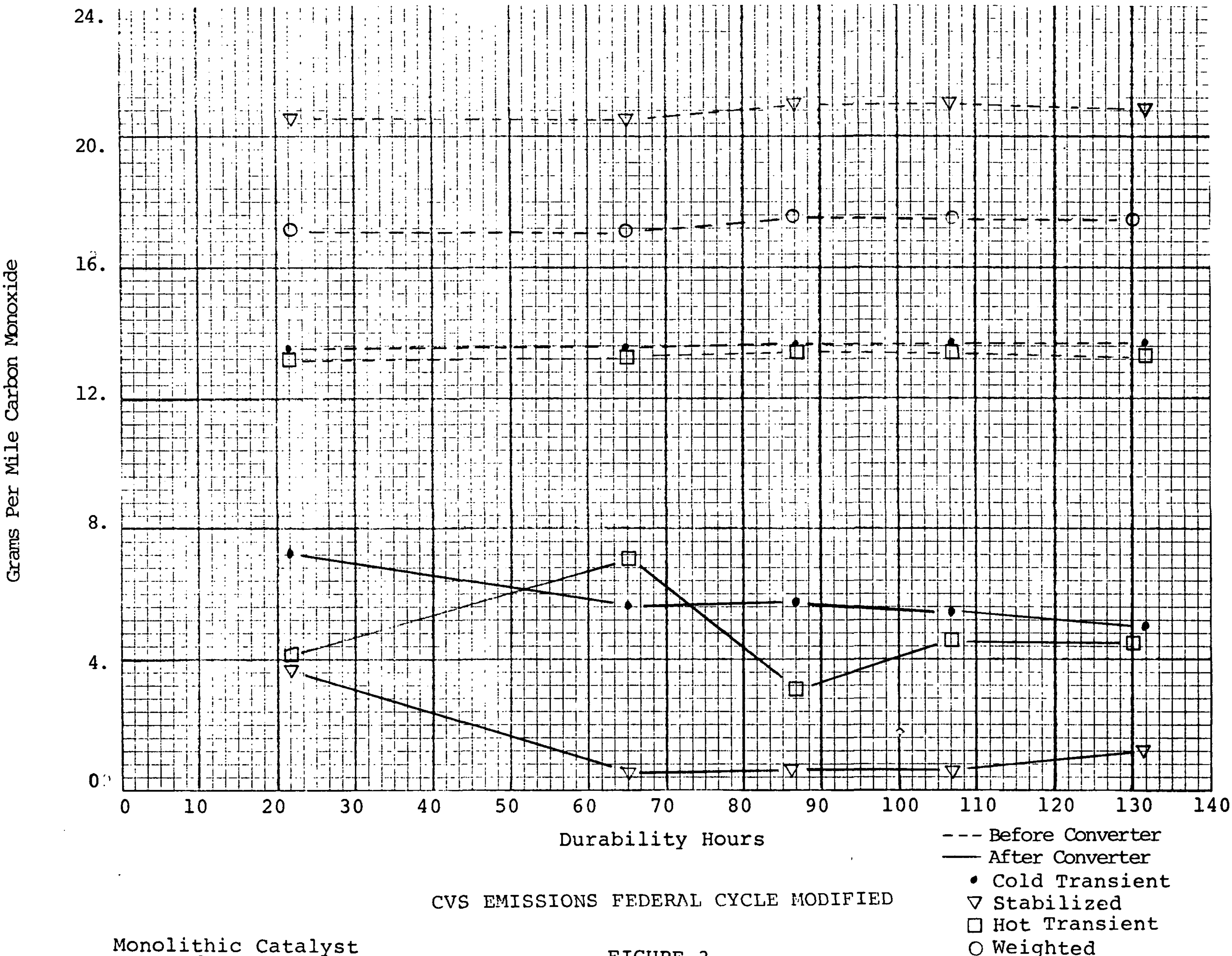


CVS EMISSIONS FEDERAL CYCLE

● Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Monolithic Catalyst
Base Fuel

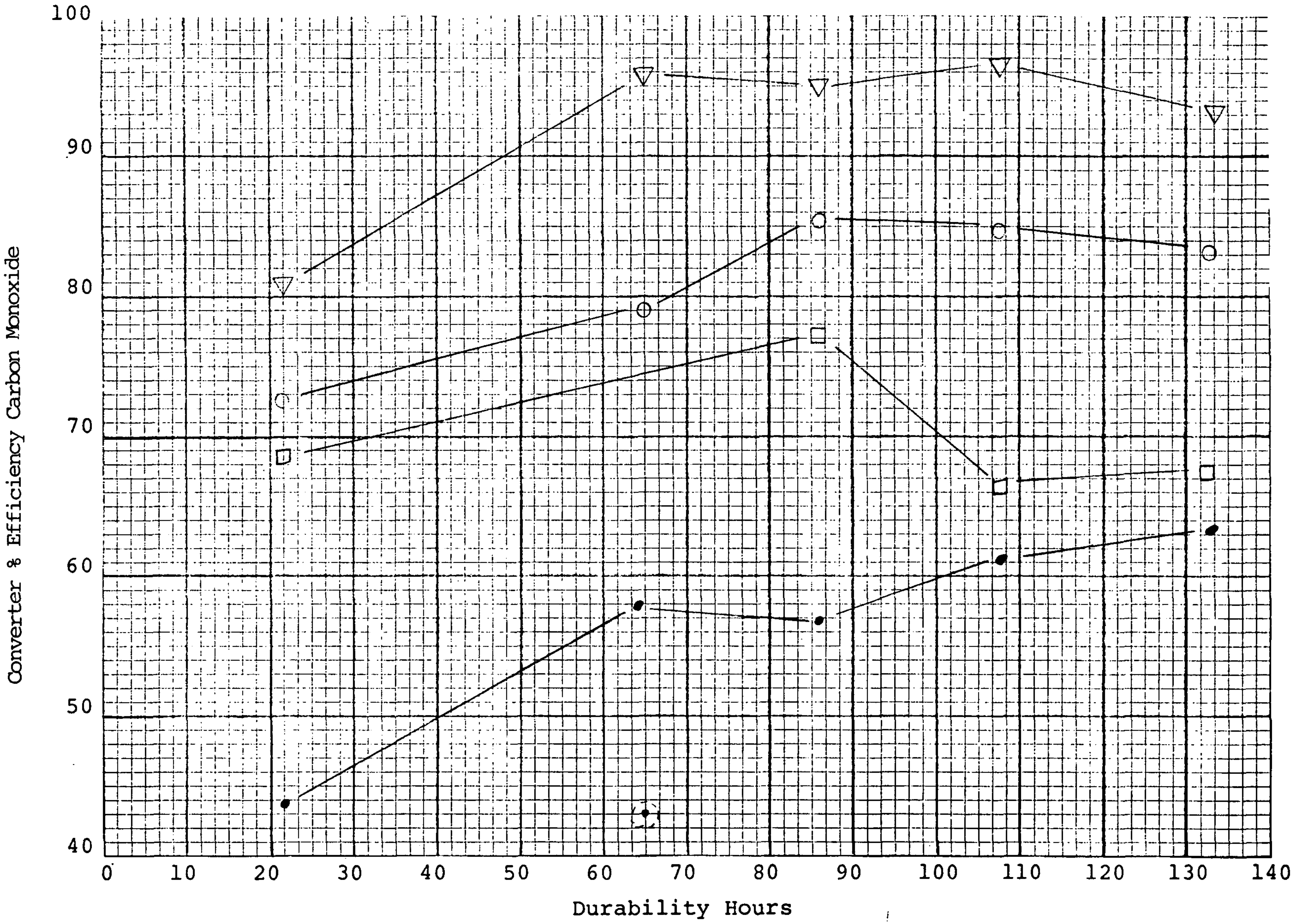
FIGURE 2



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Monolithic Catalyst
Base Fuel

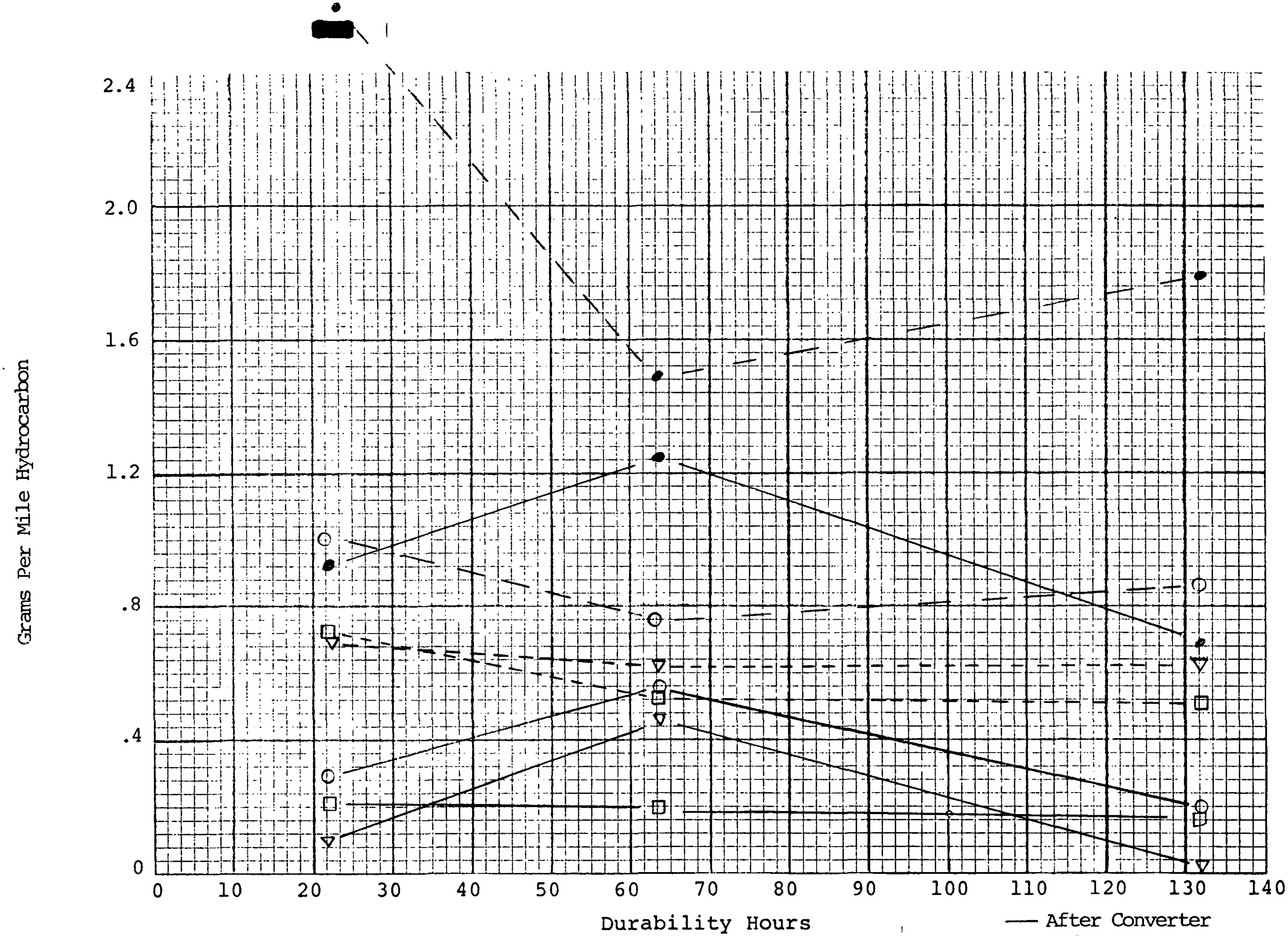
FIGURE 3



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Monolithic Catalyst
Base Fuel

FIGURE 4

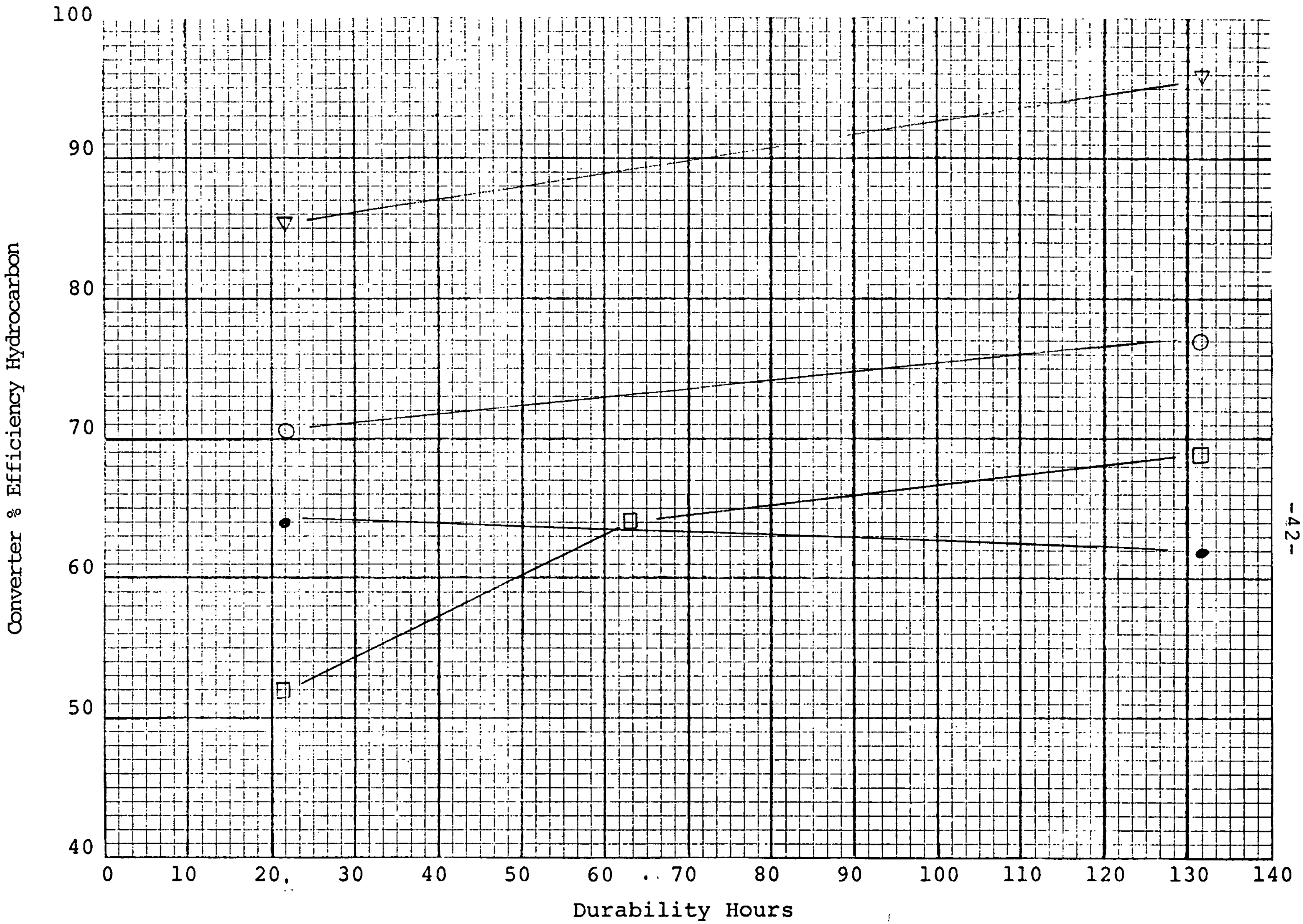


— After Converter
---- Before Converter
• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

CVS EMISSIONS FEDERAL CYCLE

Monolithic Catalyst
Base Fuel

FIGURE 5

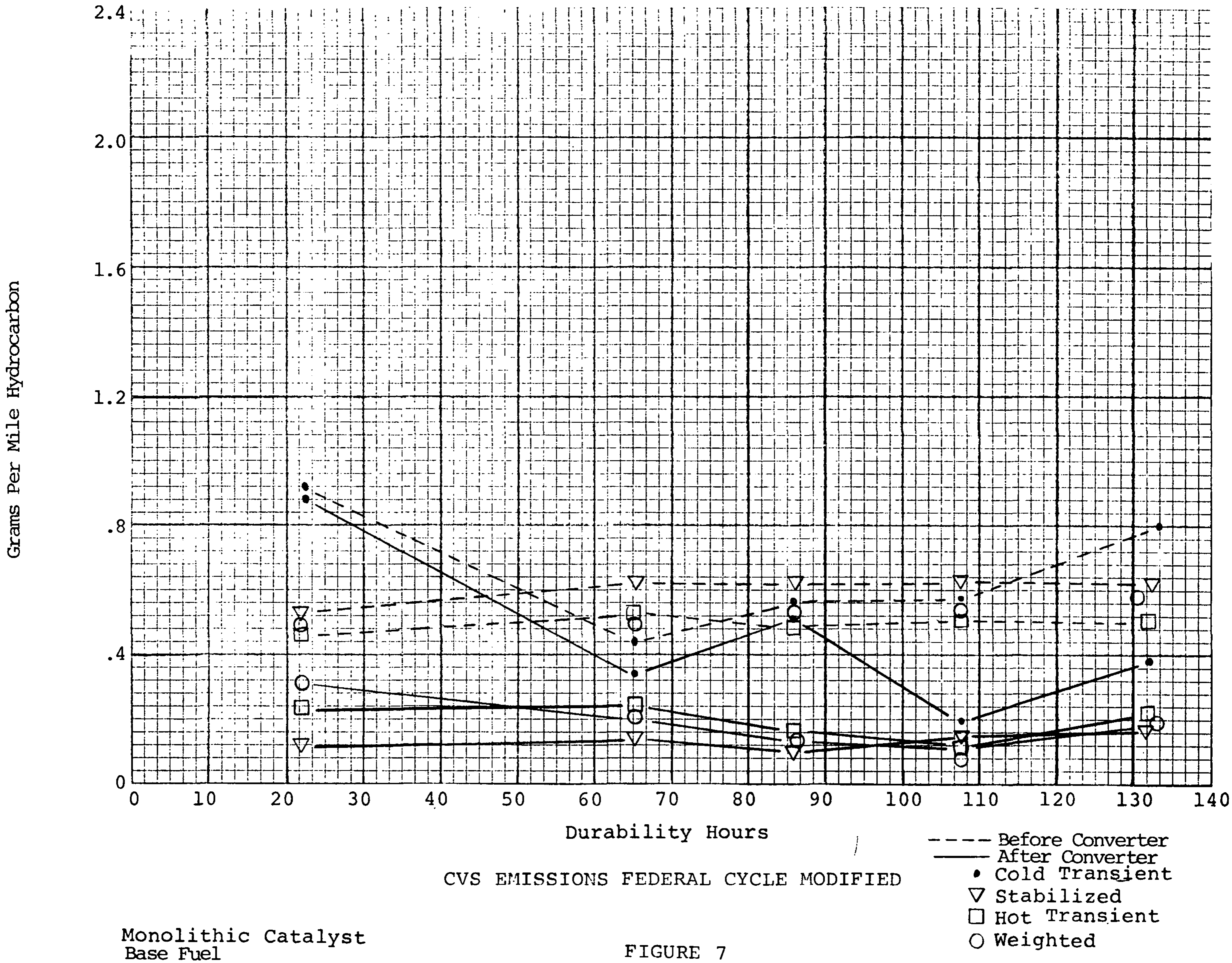


CVS EMISSIONS FEDERAL CYCLE

● Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Monolithic Catalyst
Base Fuel

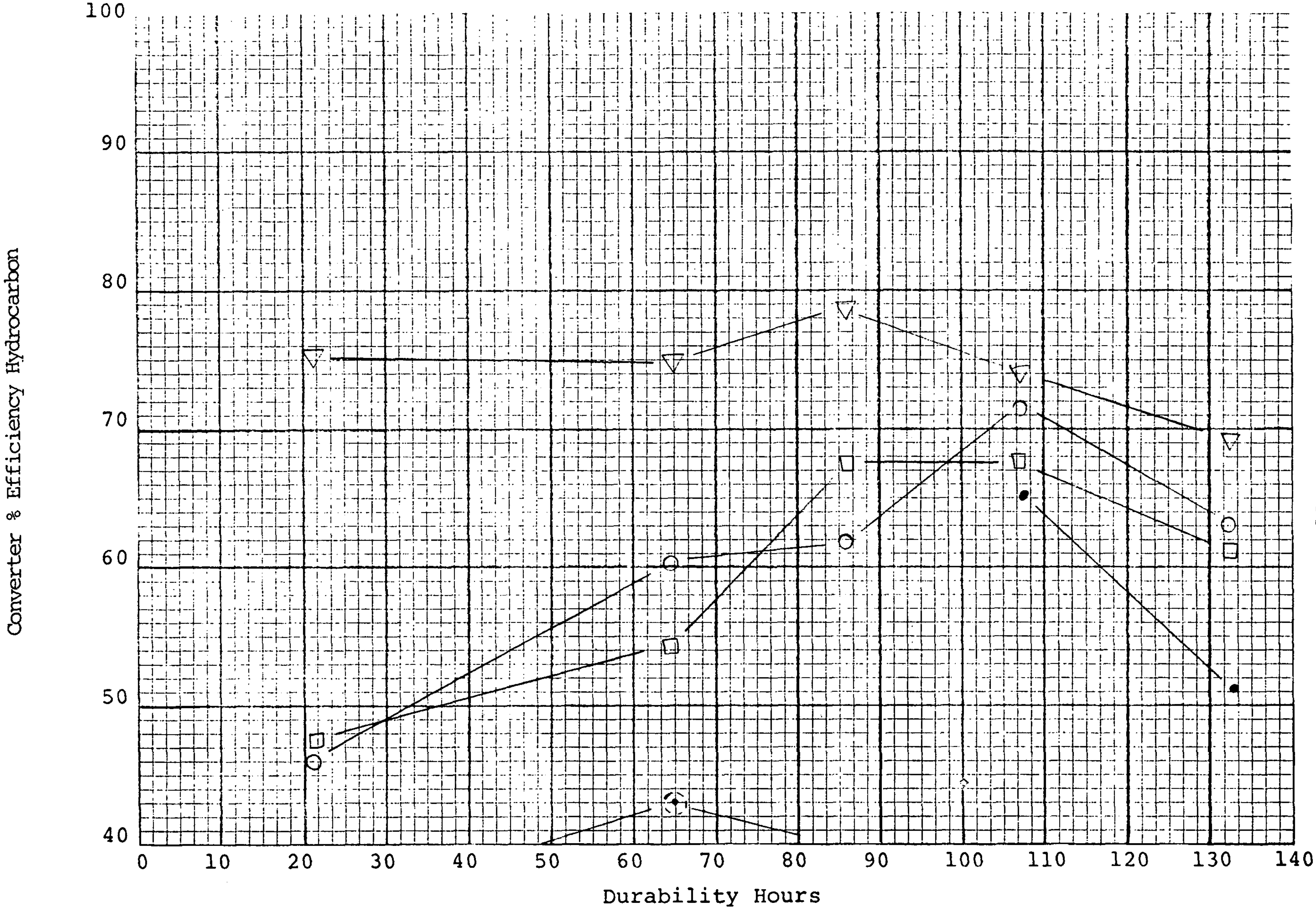
FIGURE 6



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Monolithic Catalyst
Base Fuel

FIGURE 7



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Monolithic Catalyst
Base Fuel

FIGURE 8

COMMENTS - Additive "A"

1. Due to a dead band in the range capability of the two instruments used to measure carbon monoxide, the data points which fell between 3000 ppm and 3500 ppm are estimates. This does not appear to have a significant effect on the validity of the data as far as identifying trends.

2. The data obtained from the Federal Cycle shows a slight drop in overall conversion efficiency with this same trend a little more pronounced for the Modified Federal Cycle test run.

3. With respect to hydrocarbons as measured by the Federal Cycle test procedure, the differences between before and after converter are quite small. When calculated to a percentage basis, this leads to an apparent significant drop in conversion efficiency. However, the steep slope in the efficiency curve is due to the relatively low hydrocarbon levels seen before the converter, and as such the apparent conversion efficiency drop takes on less significance.

4. The data for the Modified Federal Cycle hydrocarbon emissions shows the same trends, however, they are less pronounced.

TABLE 11. "A" ADDITIVE, MONOLITH CATALYST, ENGINE STAND, RAW DATA, GRAMS/MILE. *

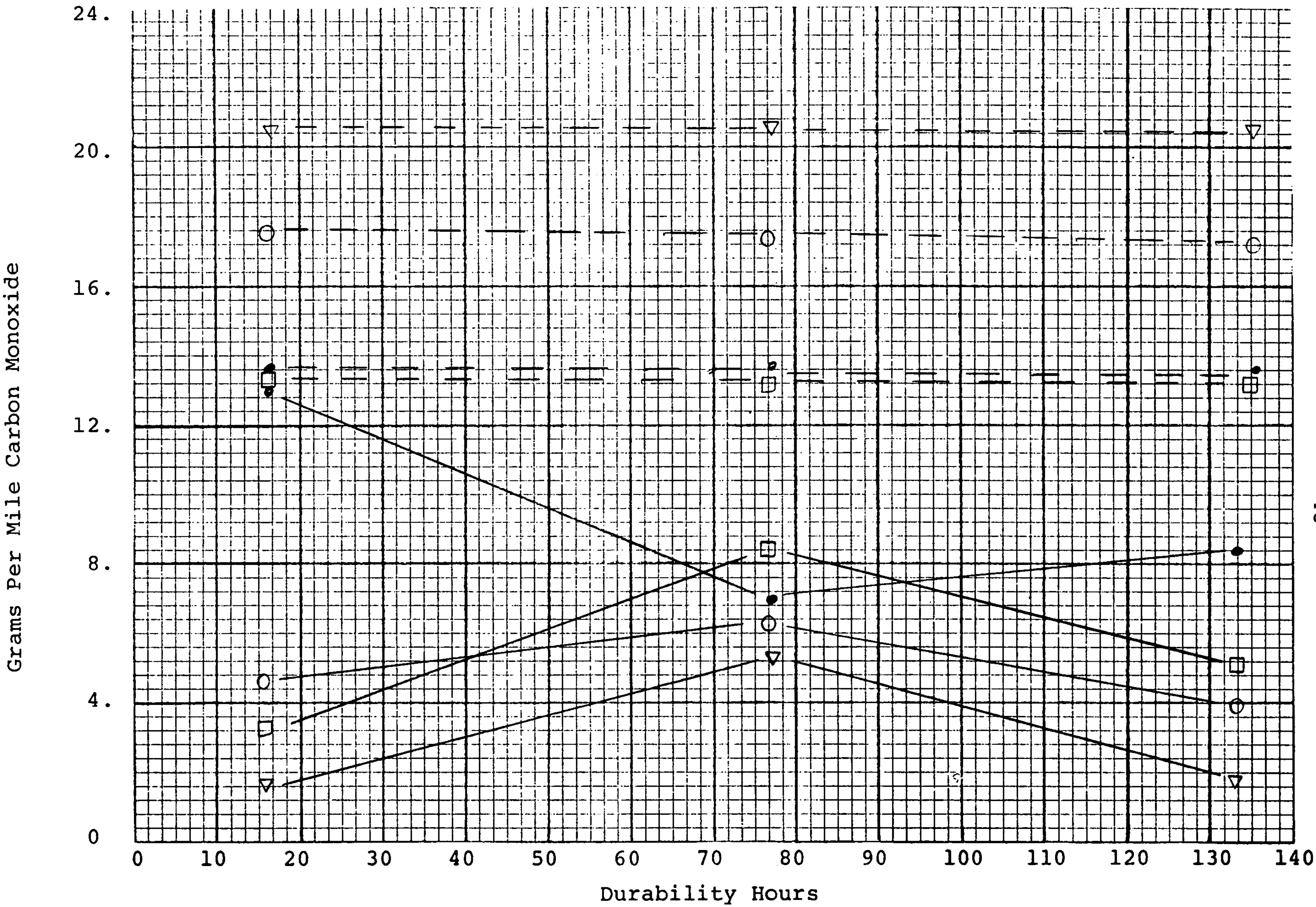
Cold		Hot		Hot		Hot		Cold		Hot		Hot		Hot		Cold		Hot		
HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	
1		17		38		60		77		77		99		116		134		134		Durability Hours
With Converter																				
.35	13.59	.21	4.41	.21	2.91	.28	5.90	.44	7.34	.26	5.90	.23	5.05	.26	8.42	.91	12.2	.40	8.08	Cold Transient
.11	1.69	.12	1.67	.20	1.37	.21	3.69	.45	5.34	.22	3.18	.31	3.45	.24	2.49	.30	4.02	.28	1.90	Stabilized
.11	3.64	.10	1.64	.20	3.03	.19	3.10	.21	8.74	.21	5.41	.25	5.05	.23	4.39	.30	5.79	.29	5.36	Hot Transient
.16	4.60	.13	2.21	.20	2.12	.22	3.98	.38	6.65	.23	4.32	.28	4.20	.24	4.19	.42	6.15	.30	4.06	Weighted
Without Converter																				
1.46	13.54	.64	13.53	.68	13.64	.51	13.78	.67	13.44	.73	13.45	.51	13.82	.53	13.62	.95	13.71	.87	13.44	Cold Transient
.63	20.51	.62	20.57	.65	20.74	.65	20.95	.68	20.42	1.05	20.49	.77	20.96	.65	20.71	.49	20.78	.76	20.43	Stabilized
.51	13.53	.50	13.51	.50	13.62	.46	13.79	.52	13.48	.66	13.41	.56	13.77	.48	13.60	.46	13.67	.59	13.49	Hot Transient
.77	17.25	.59	17.28	.62	17.42	.57	17.61	.64	17.17	.88	17.20	.66	17.61	.58	17.40	.58	17.47	.74	17.18	Weighted
% Efficiency																				
76.0	0	67.1	67.4	69.1	78.6	45.0	57.2	34.3	45.4	64.4	56.1	54.9	63.5	50.9	38.2	4.2	11.0	54.0	39.8	Cold Transient
82.5	91.7	80.6	91.8	69.2	93.3	67.7	82.4	33.8	73.8	79.0	84.5	59.7	83.5	63.1	87.9	38.7	80.6	63.1	90.7	Stabilized
78.4	73.0	80.0	87.8	56.0	77.7	58.7	77.5	59.6	35.2	68.2	59.5	55.3	63.2	52.1	67.7	34.7	57.6	50.8	60.2	Hot Transient
79.2	73.3	77.9	87.2	67.7	87.7	61.4	77.4	40.6	61.3	73.8	74.8	57.6	76.1	58.6	75.9	27.6	64.8	59.5	76.3	Weighted

*Corrected for ambient conditions.

TABLE 12. AMBIENT CONDITIONS

"A" ADDITIVE - MONOLITH CATALYST ENGINE DYNAMOMETER

Modified Federal Cycle		X	X	X		X	X	X		X
Federal Cycle	X				X				X	
Durability Hours	1	17	38	60	77	77	99	116	134	134
WITHOUT CONVERTER										
Barometer	29.31	29.31	29.46	29.66	29.10	29.10	29.44	29.20	29.20	28.96
Corrected Barometer	29.16	29.16	29.35	29.53	28.98	28.98	29.30	29.08	29.08	28.84
Ambient Air °F	86.	86.	73.	78.	75.	75.	80.	74.	74.	73.
Wet Bulb °F	61.	61.	55.	57.	61.	61.	58.	57.	57.	53.
Dry Bulb °F	78.	78.	73.	79.	73.	73.	82.	75.	75.	74.
Humidity %	36.77	36.77	29.23	22.67	50.12	50.12	20.17	31.16	31.16	71.15
WITH CONVERTER										
Barometer	29.38	29.38	29.46	29.66	29.66	29.10	29.44	29.20	28.96	28.96
Corrected Barometer	29.23	29.23	29.35	29.53	29.53	28.98	29.30	29.08	28.84	28.84
Ambient Air °F	85.	85.	73.	78.	78.	75.	80.	74.	73.	73.
Wet Bulb °F	63.	63.	55.	57.	57.	61.	58.	57.	53.	53.
Dry Bulb °F	89.	89.	73.	79.	79.	73.	82.	75.	74.	74.
Humidity %	21.47	21.47	29.23	22.67	22.67	50.12	20.17	31.16	21.15	21.15

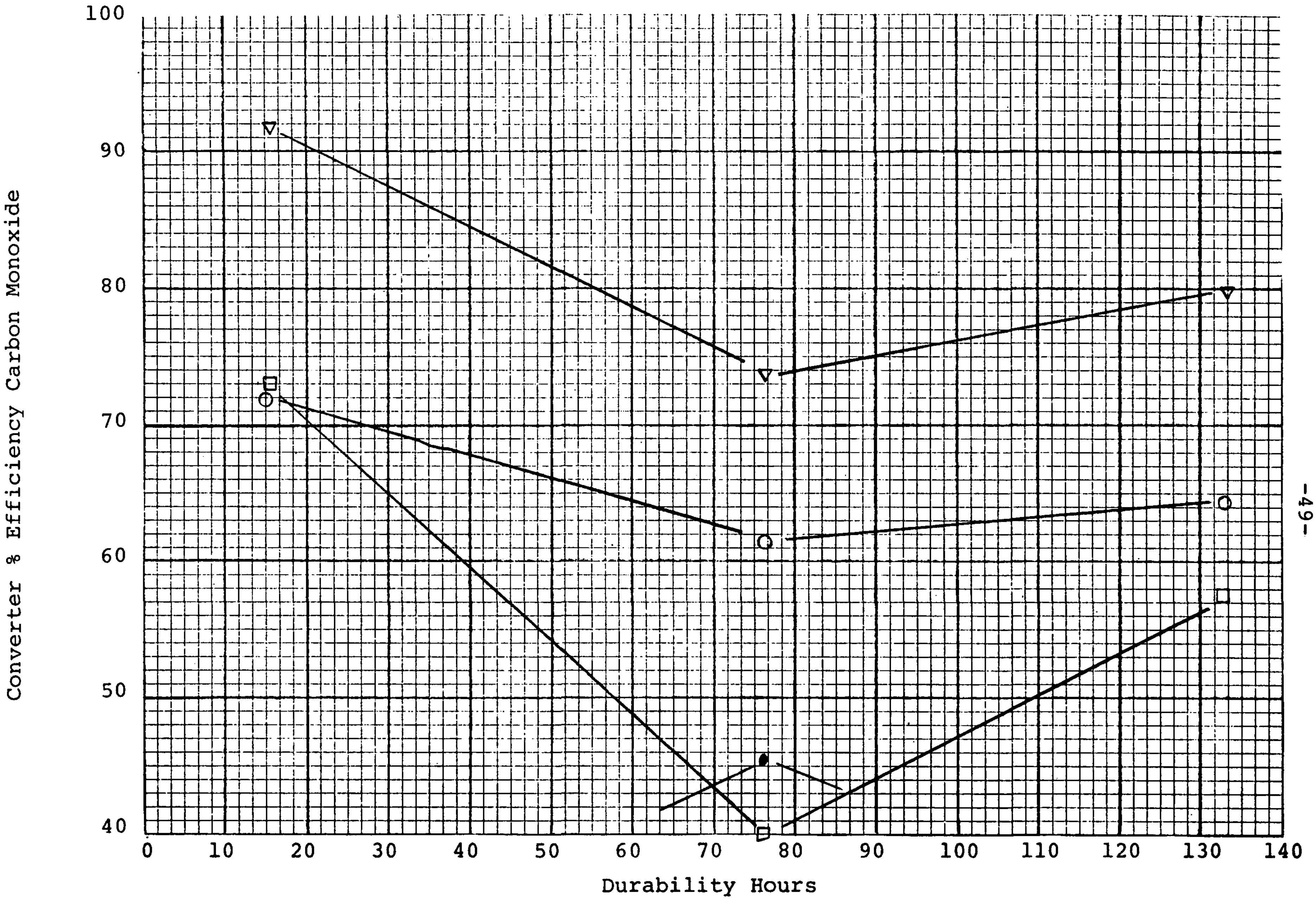


CVS EMISSIONS FEDERAL CYCLE

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted
- - Before Converter
—— After Converter

Monolithic Catalyst
"A" Additive

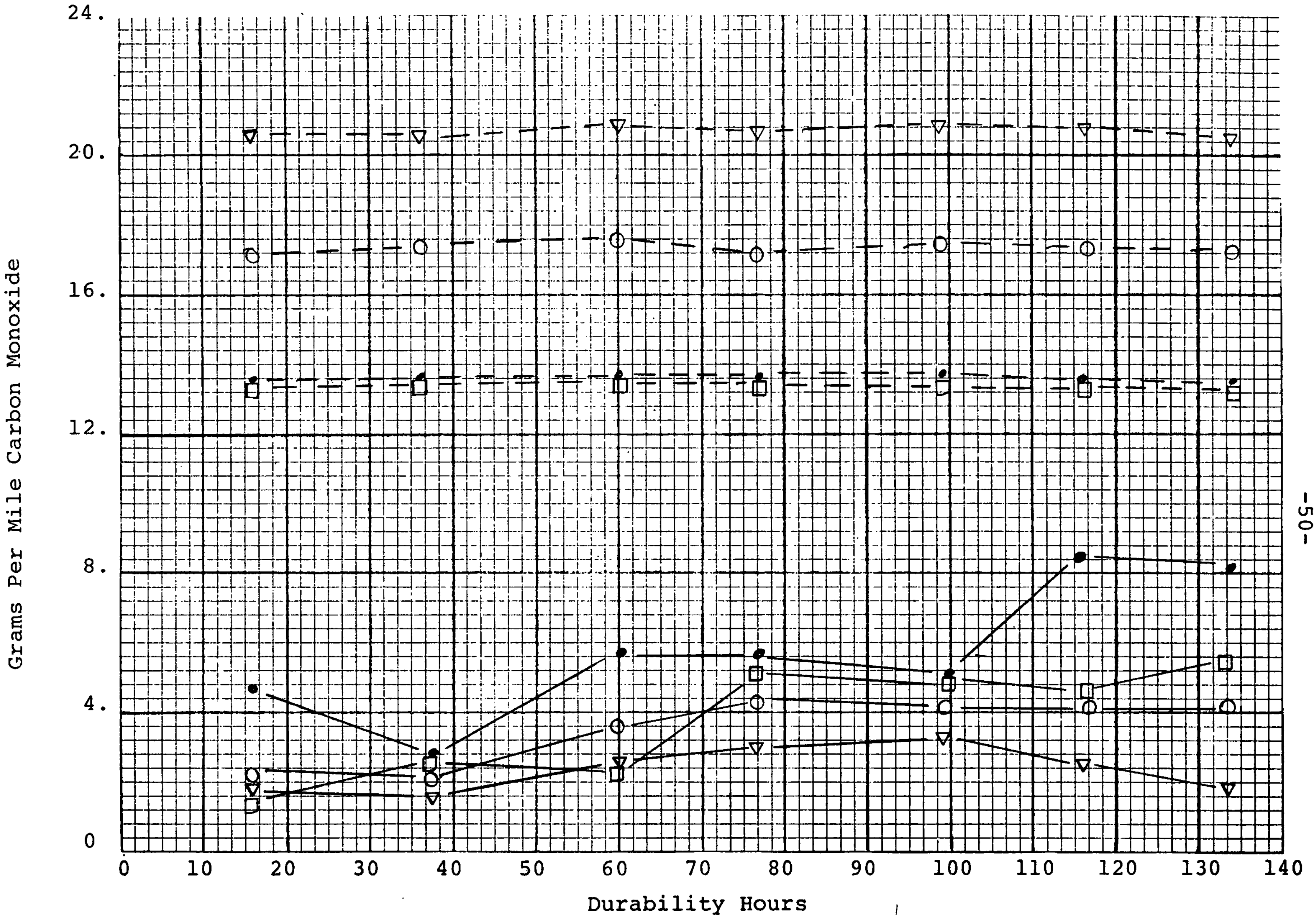
FIGURE 9



CVS EMISSIONS FEDERAL CYCLE

Monolithic Catalyst
"A" Additive

FIGURE 10

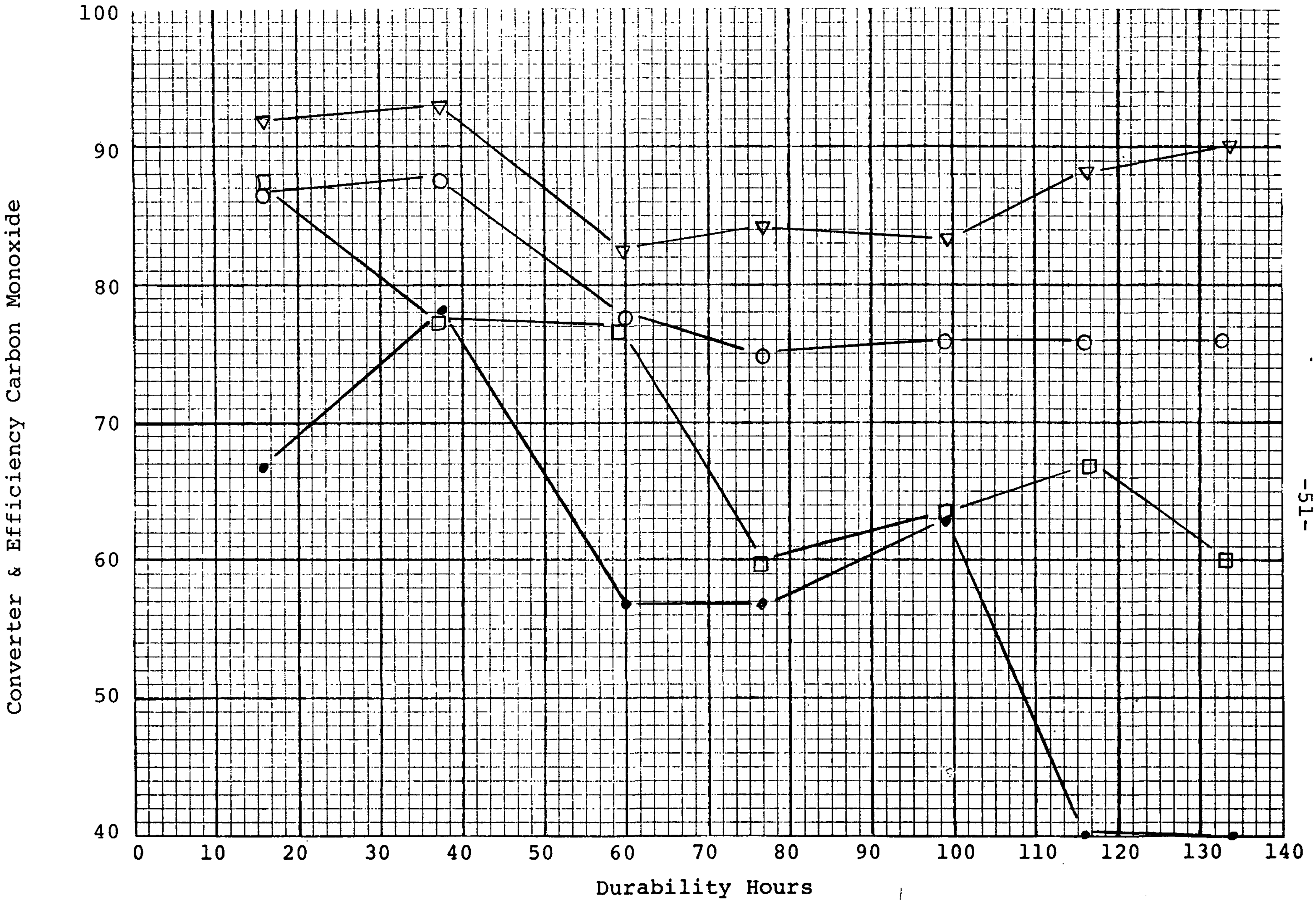


CVS EMISSIONS FEDERAL CYCLE MODIFIED

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted
– – – Before Converter
——— After Converter

Monolithic Catalyst
"A" Additive

FIGURE 11

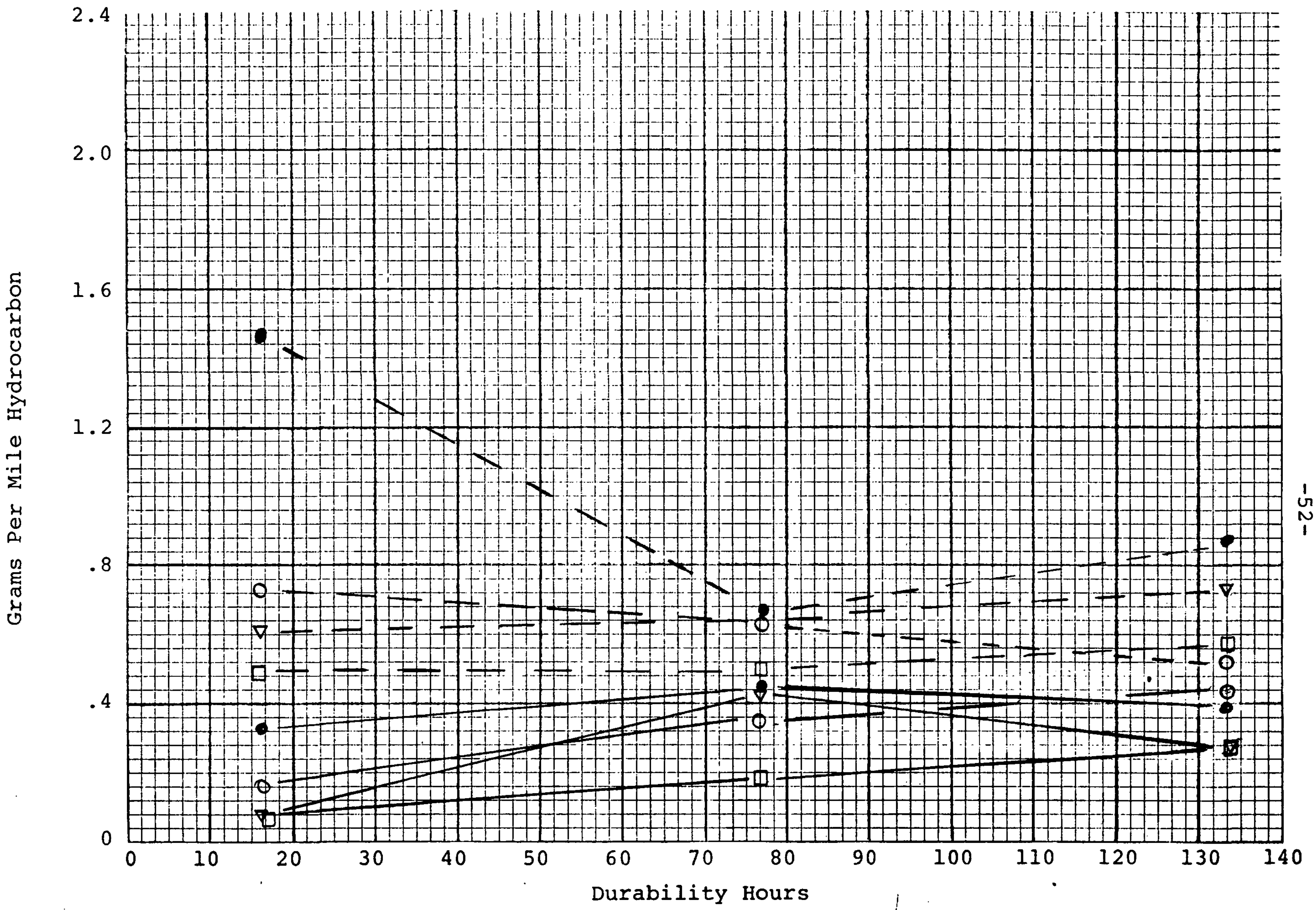


CVS EMISSIONS FEDERAL CYCLE MODIFIED

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Monolithic Catalyst
"A" Additive

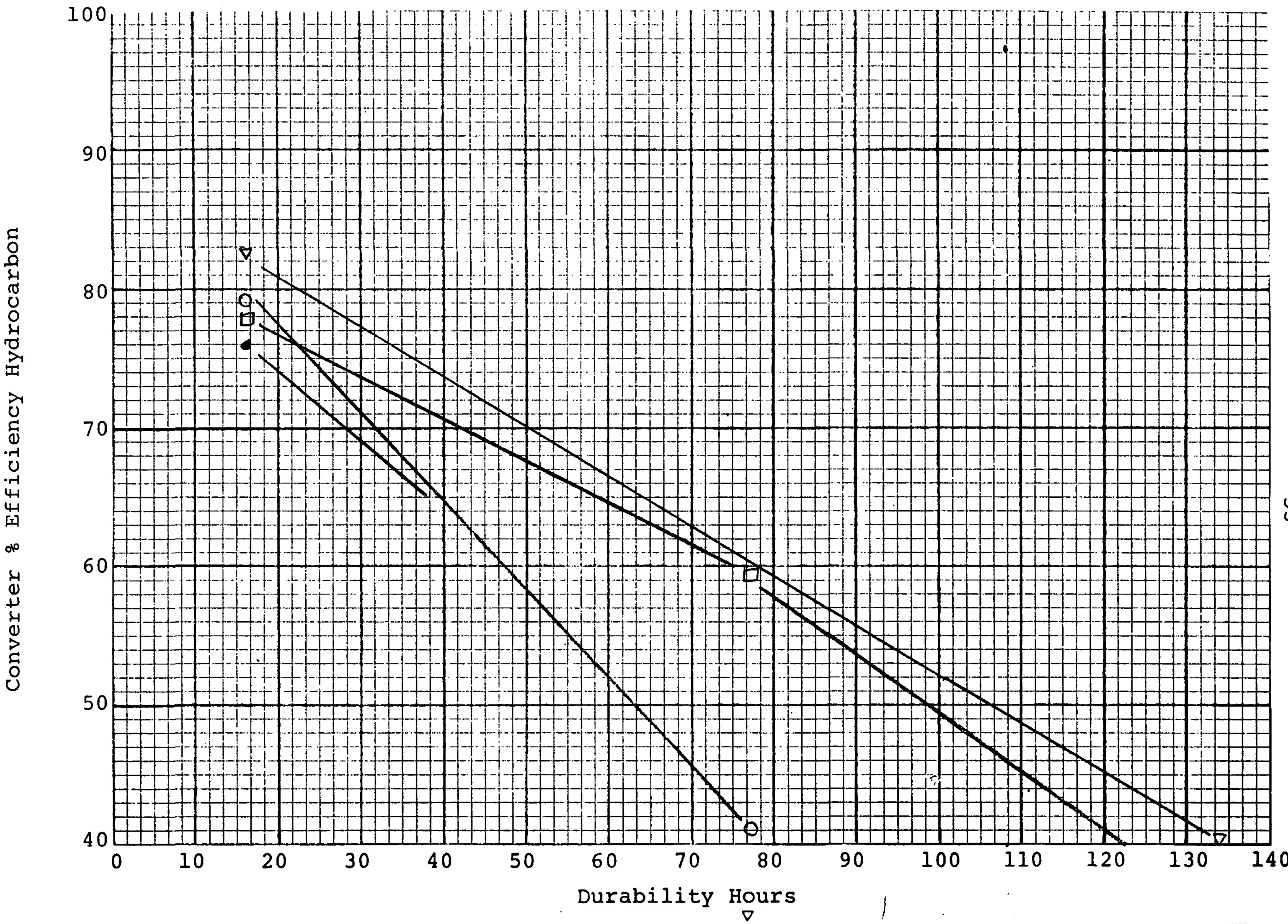
FIGURE 12



CVS EMISSIONS FEDERAL CYCLE

Monolithic Catalyst
"A" Additive

FIGURE 13

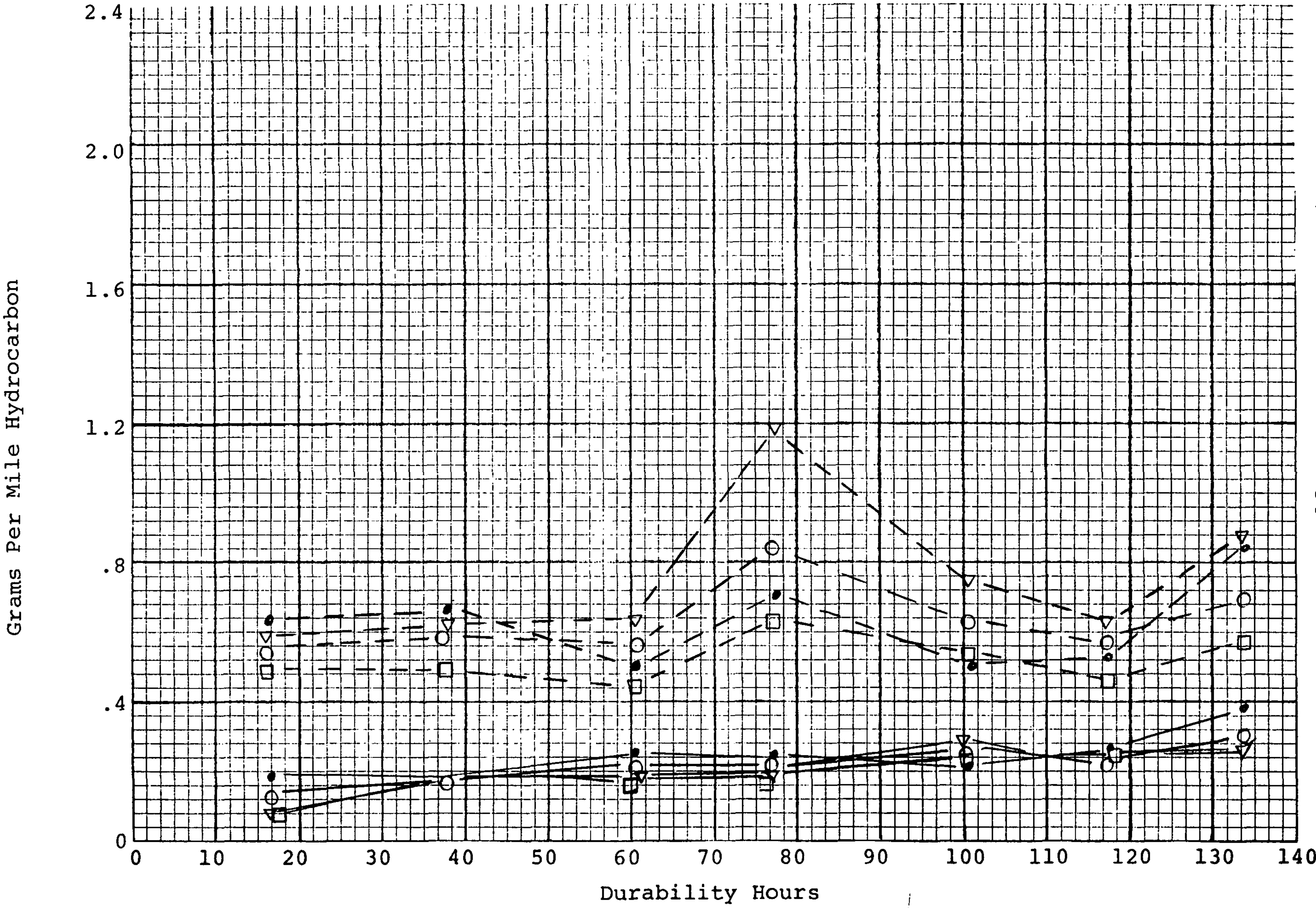


CVS EMISSIONS FEDERAL CYCLE

Monolithic Catalyst

"A" Additive

FIGURE 14

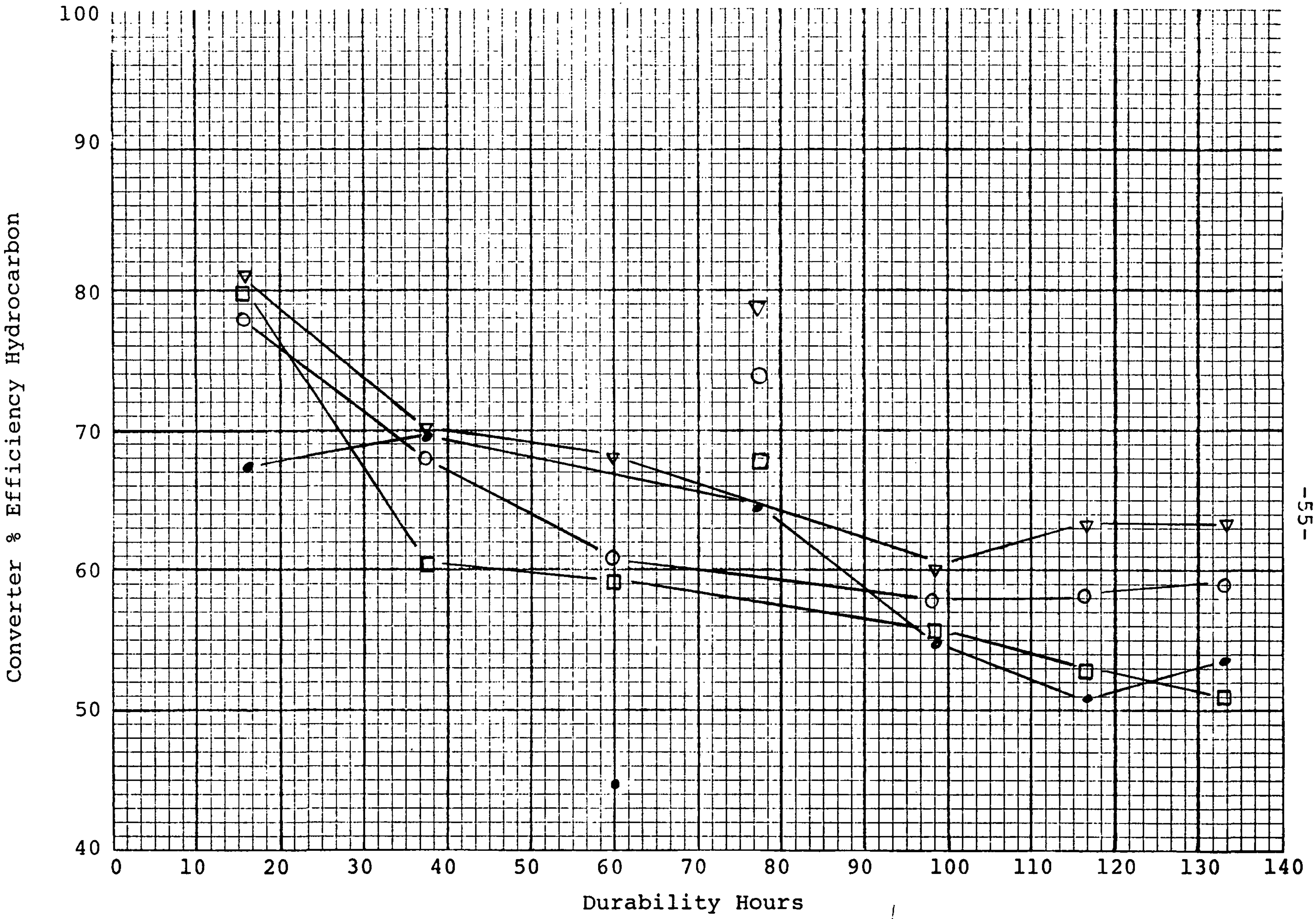


CVS EMISSIONS FEDERAL CYCLE MODIFIED

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted
— — — Before Converter
——+— After Converter

Monolithic Catalyst
"A" Additive

FIGURE 15



Monolithic Catalyst
"A" Additive

FIGURE 16

<u>COMMENTS</u> - Additive "B"

1. With respect to carbon monoxide, as measured by the Federal Cycle, both the before and after converter data points form similarly shaped curves; however, the before converter emission levels are 4-fold higher. The plots show a slight increase in emission levels with time. This effect is seen in the conversion efficiency plots, which show a slight loss in efficiency.

2. The emission levels of carbon monoxide as measured during the Modified Federal cycle again show a reduction of converter efficiency with time.

3. The hydrocarbon levels measured during the Federal Cycle test for both the before and after converter are consistant, with approximately 3-fold higher values for the before converter data points. The slope of the curve is upward with time, indicating a reduction of converter efficiency with time.

4. The hydrocarbon emission levels for the Modified Federal Cycle gave similar curves as the Federal Cycle and also showed a reduction in converter efficiency with time.

TABLE 13. "B" ADDITIVE, MONOLITHIC CATALYST, ENGINE STAND, RAW DATA, GRAMS/MILE**

Cold		Hot		Hot		Hot		Cold		Cold		Hot		
HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	
0		34		54		74		88		136		136		Durability Hours
With Converter														
.38	13.5	.32	2.92	.41	4.94	.51	6.0	.98	13.5	.93	13.7	.59	6.23	Cold Transient
.22	2.43	.30	1.02	.31	.67	.44	1.98	.50	3.64	.68	5.05	.56	2.16	Stabilized
.22	3.8	.34	5.25	.33	3.24	2.46*	13.8*	.56	9.74	.49	4.02	.53	5.08	Hot Transient
.25	5.0	.31	2.53	.33	2.21	.99	4.95	.61	7.25	.68	6.50	.56	3.75	Weighted
Without Converter														
1.82	13.5	1.24	13.8	1.18	13.8	1.42	13.8	2.24	15.3	2.88	12.4	1.38	12.5	Cold Transient
1.30	20.4	1.53	20.8	1.64	20.9	1.80	21.0	2.17	23.3	1.93	18.8	2.13	18.8	Stabilized
.83	13.5	1.14	13.8	1.21	13.7	1.30	13.8	1.60	15.4	2.04	12.4	1.59	12.4	Hot Transient
1.28	17.16	1.37	17.6	1.44	17.6	1.43	17.6	2.0	19.6	2.15	15.8	1.83	15.9	Weighted
% Efficiency														
79.2	0*	74.1	78.8	65.2	64.2	64.8	56.0	56.2	11.7	67.7	0*	57.2	50.1	Cold Transient
83.0	88.1	80.9	95.1	81.1	96.8	75.5	90.6	76.8	84.1	64.7	73.2	73.7	88.5	Stabilized
73.4	72	70.17	61.9	72.7	76.4	0*	0*	64.3	35.6	75.9	67.5	66.6	59.1	Hot Transient
80.4	70.7	77.3	85.6	77.1	87.3	30.7*	71.8*	69.6	63.0	68.3	58.9	69.6	76.4	Weighted

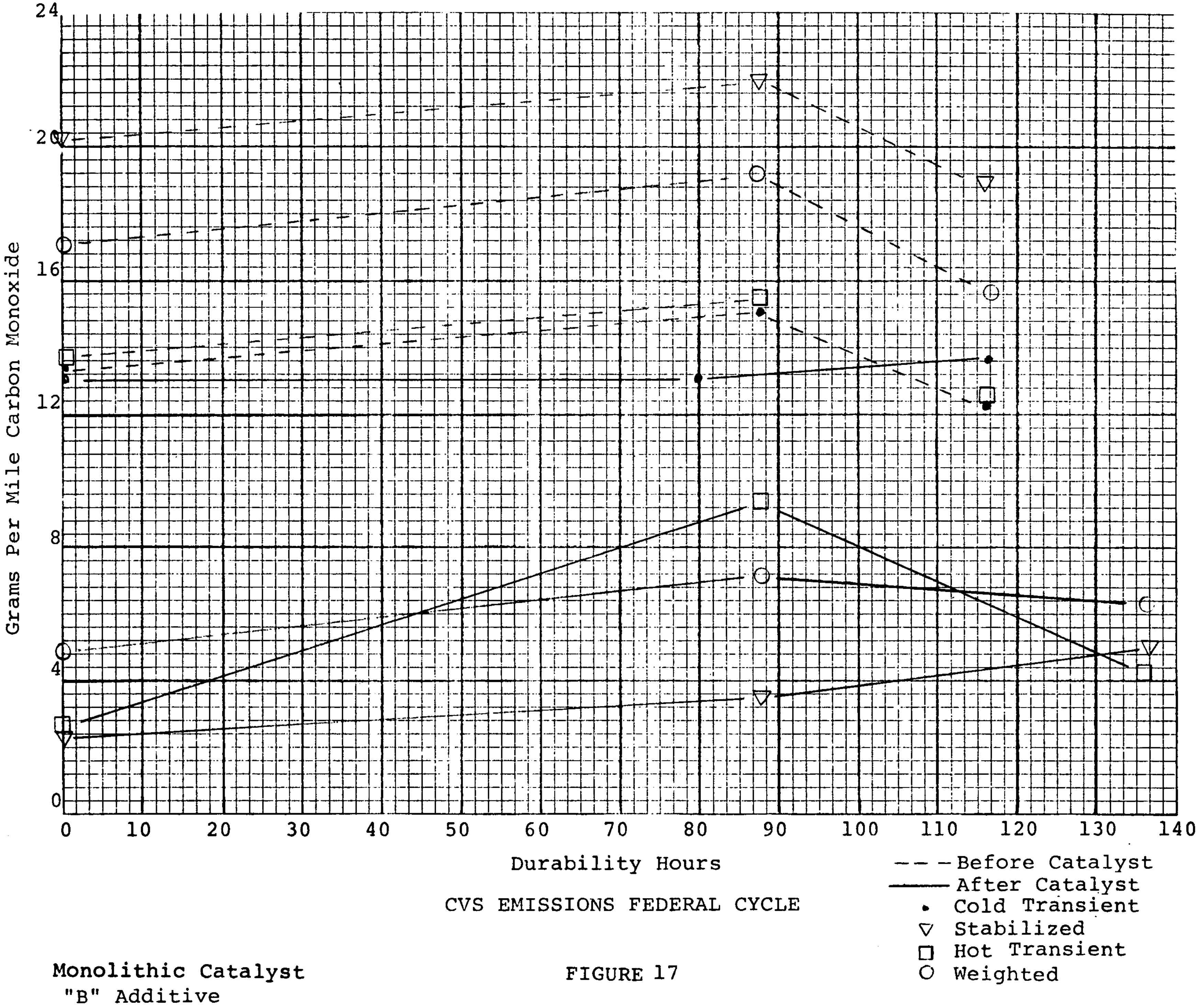
*Instrumentation error.

**Corrected for ambient conditions.

TABLE 14. AMBIENT CONDITIONS

"B" ADDITIVE - MONOLITH CATALYST   ENGINE DYNAMOMETER

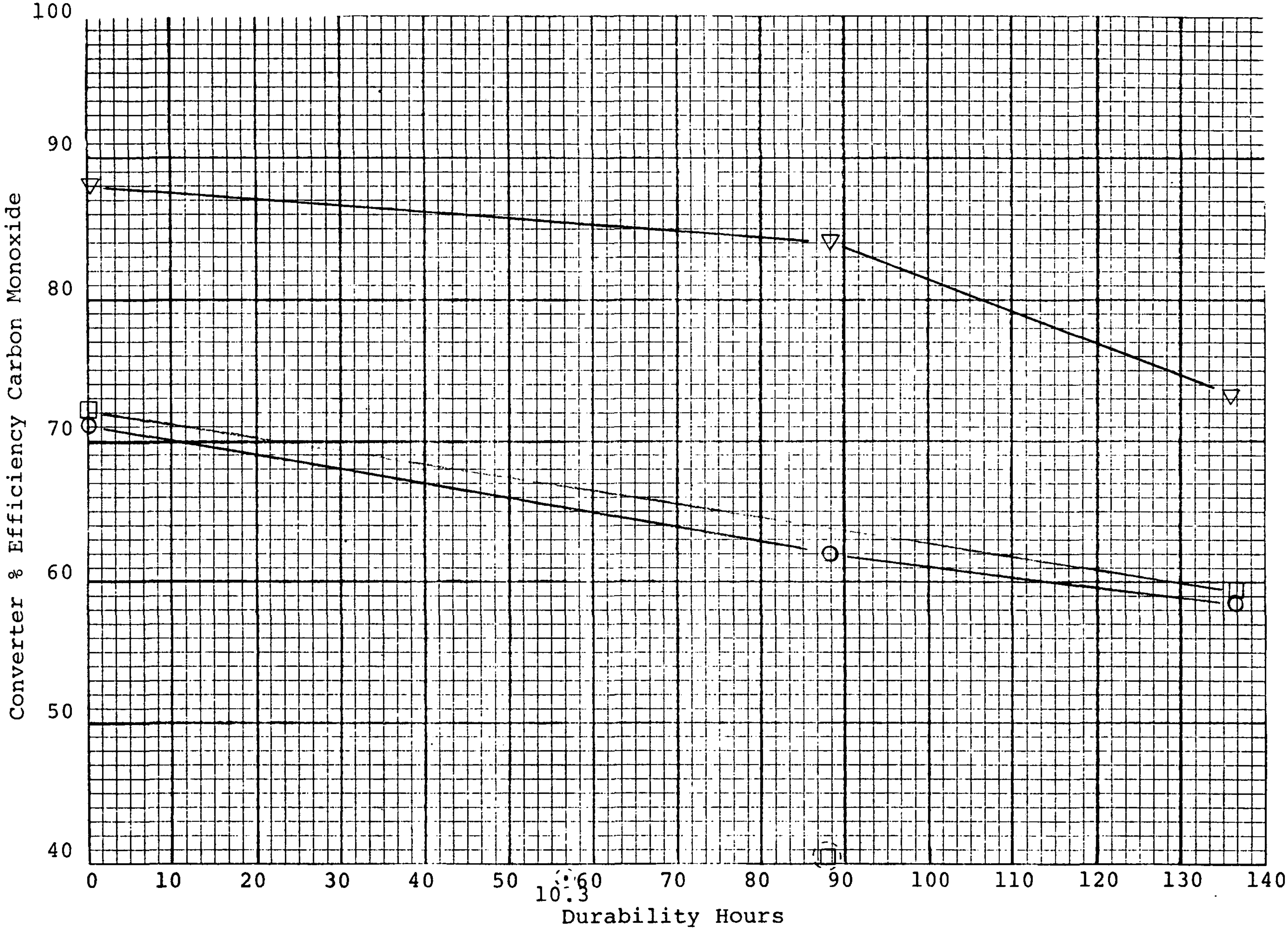
Modified Federal Cycle		X	X	X			X
Federal Cycle	X				X	X	
Durability Hours	0	34	54	74	88	136	136
<u>WITHOUT CONVERTER</u>							
Barometer	29.61	29.46	29.56	29.73	29.62	29.57	29.57
Corrected Barometer	29.47	29.31	29.42	29.59	29.48	29.41	29.41
Ambient Air °F	83.	85.	81.	80.	78.	87.	87.
Wet Bulb °F	61.5	60.	62.	58.	68.	62.	62.
Dry Bulb °F	79.0	78.5	81.	80.	78.	88.	88.
Humidity %	22.77	32.49	36.25	23.54	59.97	20.54	20.54
<u>WITH CONVERTER</u>							
Barometer	29.54	29.46	29.56	29.73	29.57	29.54	29.54
Corrected Barometer	29.42	29.31	29.42	29.59	29.42	29.40	29.40
Ambient Air °F	75.	85.	81.	80.	83.	80.	80.
Wet Bulb °F	56.	60.	62.	58.	64.	59.	59.
Dry Bulb °F	75.	78.5	81.	80.	84.	80.	80.
Humidity %	27.85	32.49	32.92	23.54	66.92	27.86	27.86



CVS EMISSIONS FEDERAL CYCLE

Monolithic Catalyst
"B" Additive

FIGURE 17

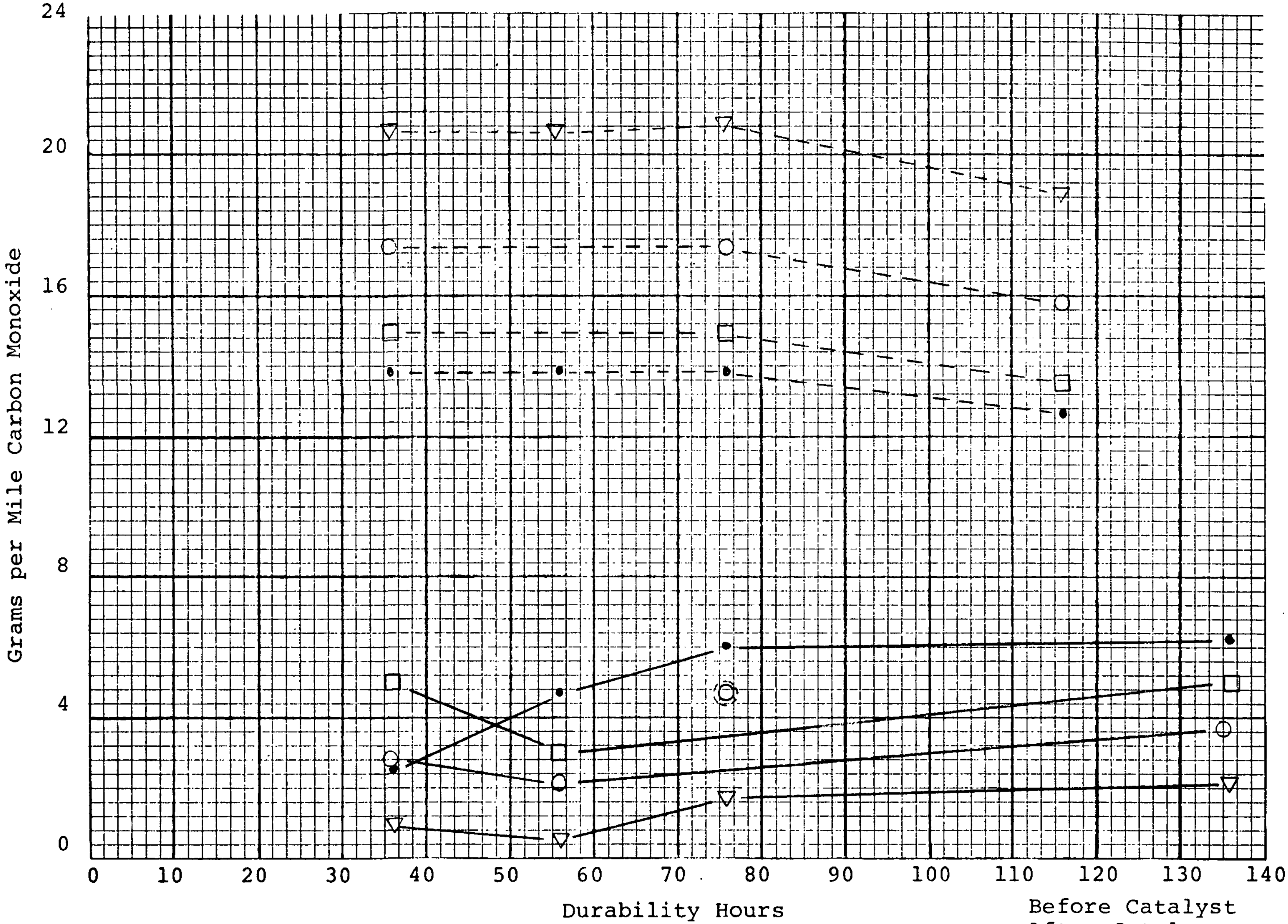


CVS EMISSIONS FEDERAL CYCLE

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Monolithic Catalyst
"B" Additive

FIGURE 18

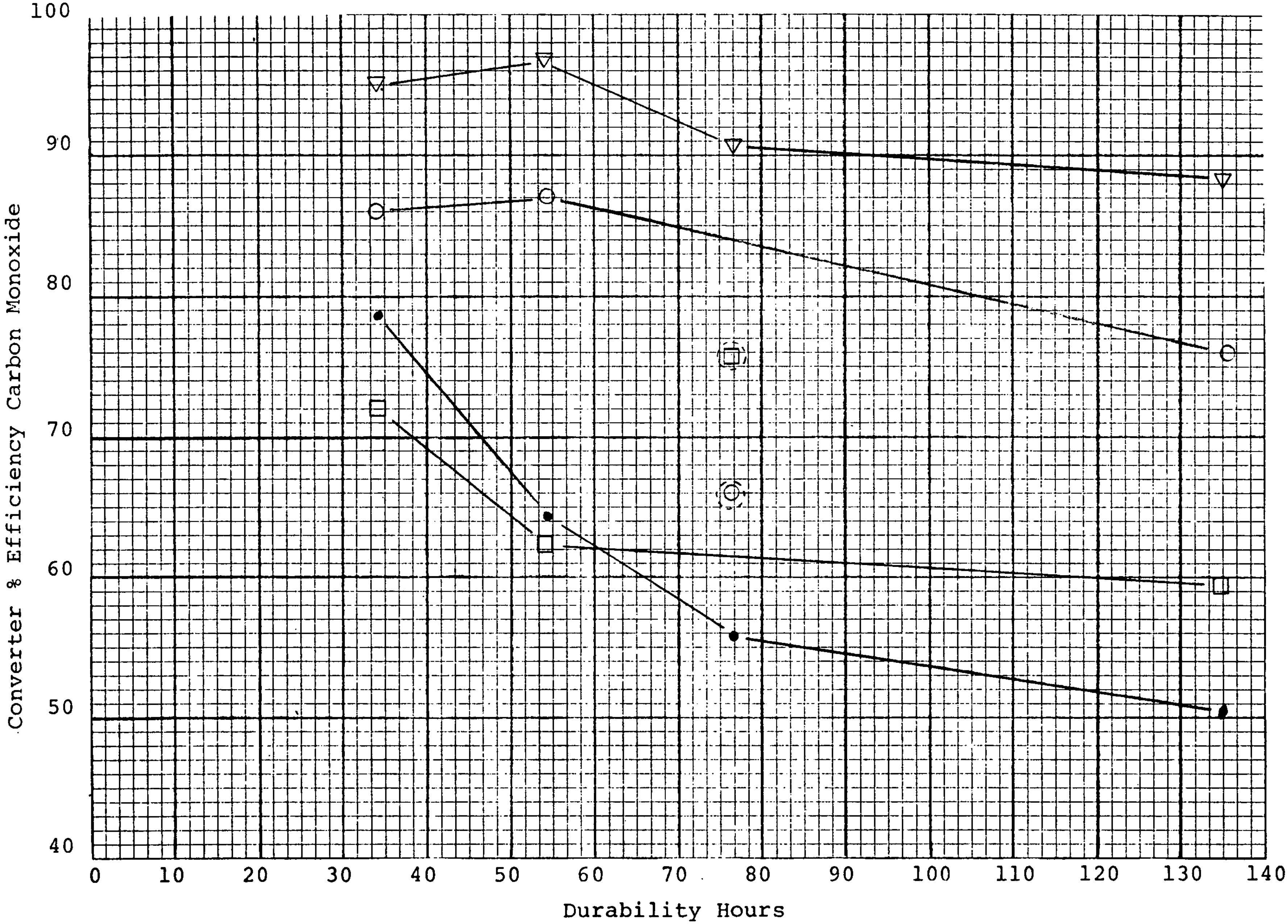


CVS EMISSIONS FEDERAL CYCLE MODIFIED

Before Catalyst
After Catalyst
• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Monolithic Catalyst
"B" Additive

FIGURE 19

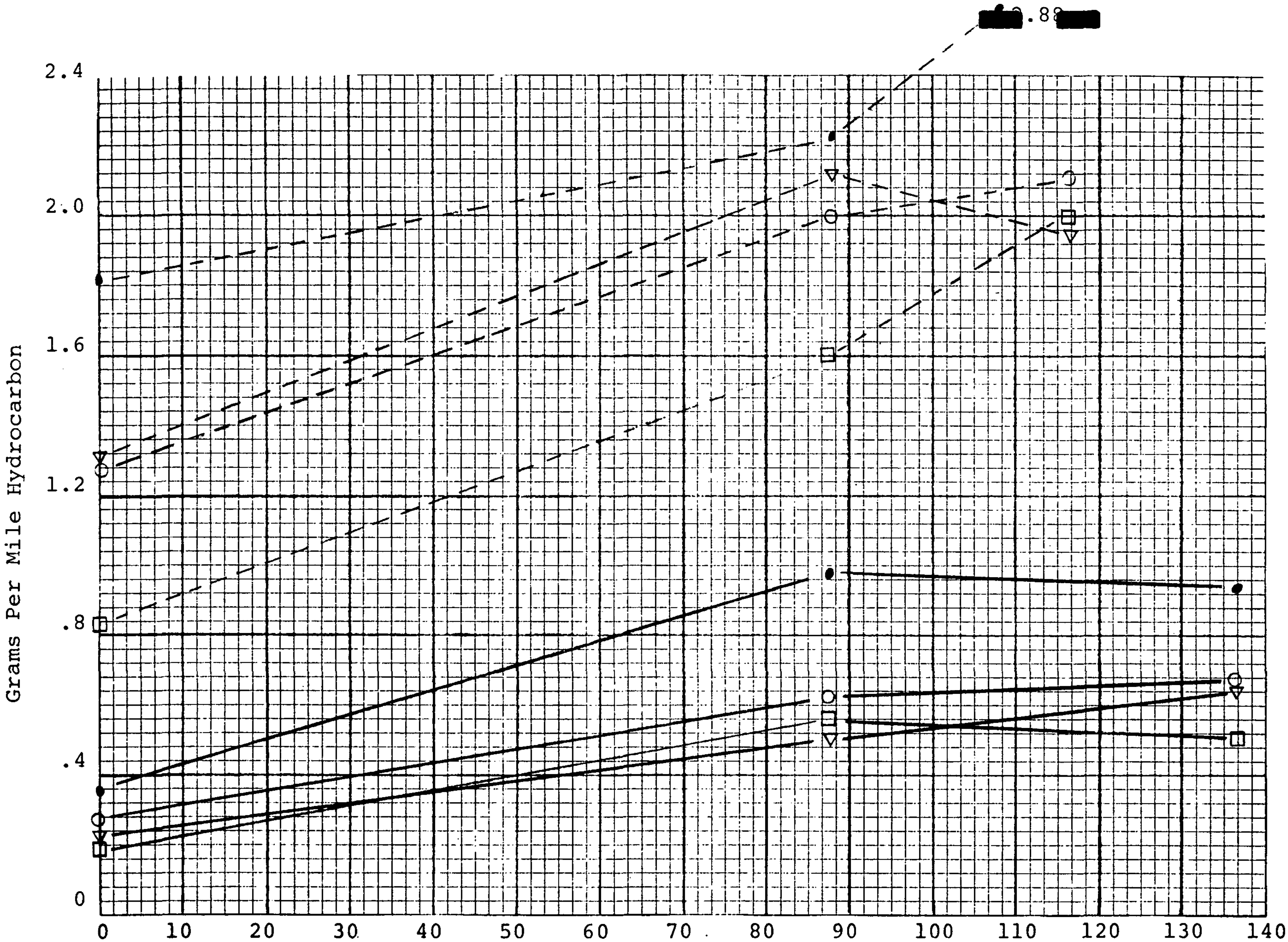


CVS EMISSIONS FEDERAL CYCLE MODIFIED

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Monolithic Catalyst
"B" Additive

FIGURE 20



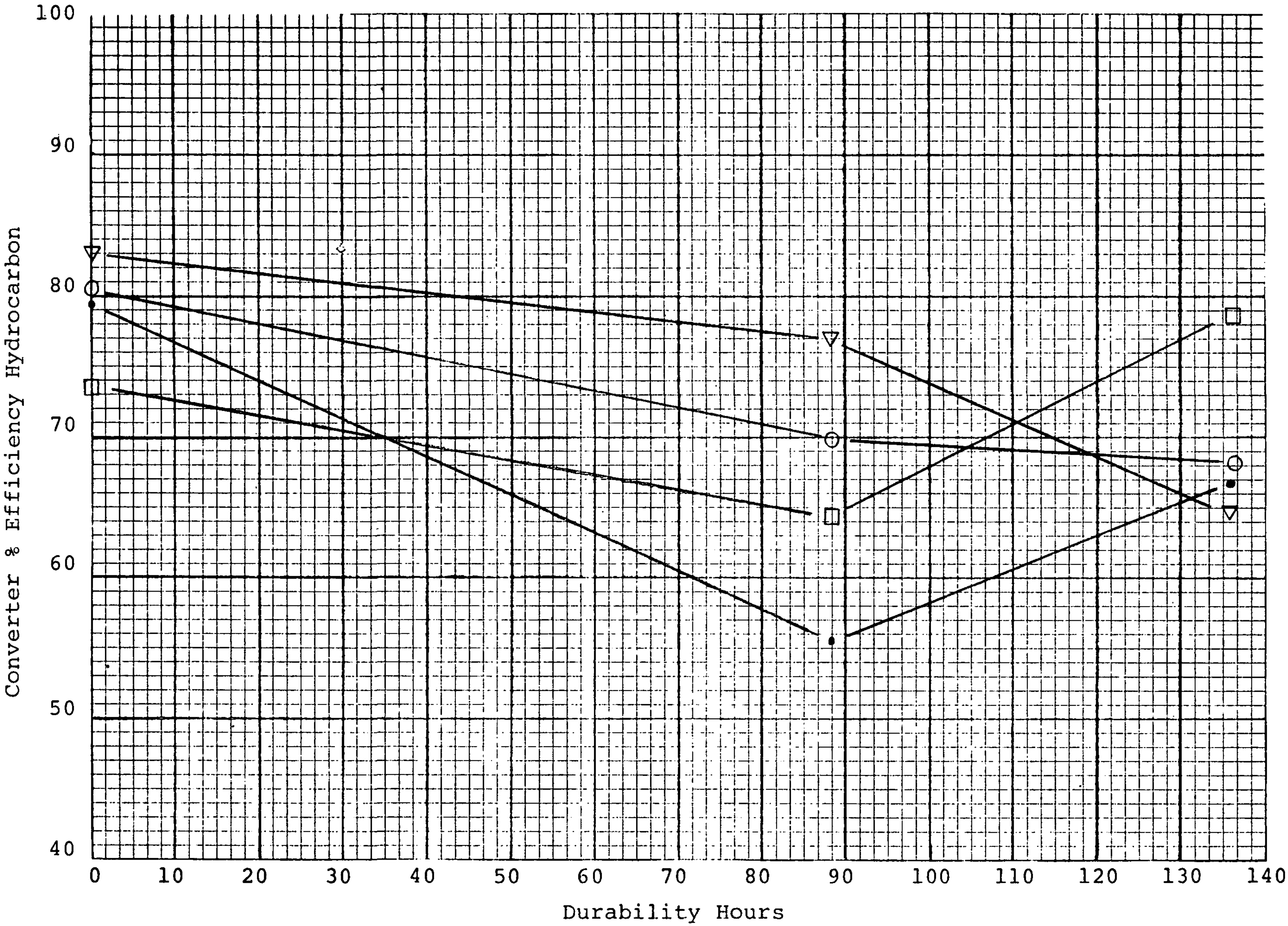
Durability Hours

CVS EMISSIONS FEDERAL CYCLE

- - - Before Catalyst
—— After Catalyst
• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Monolithic Catalyst
"B" Additive

FIGURE 21

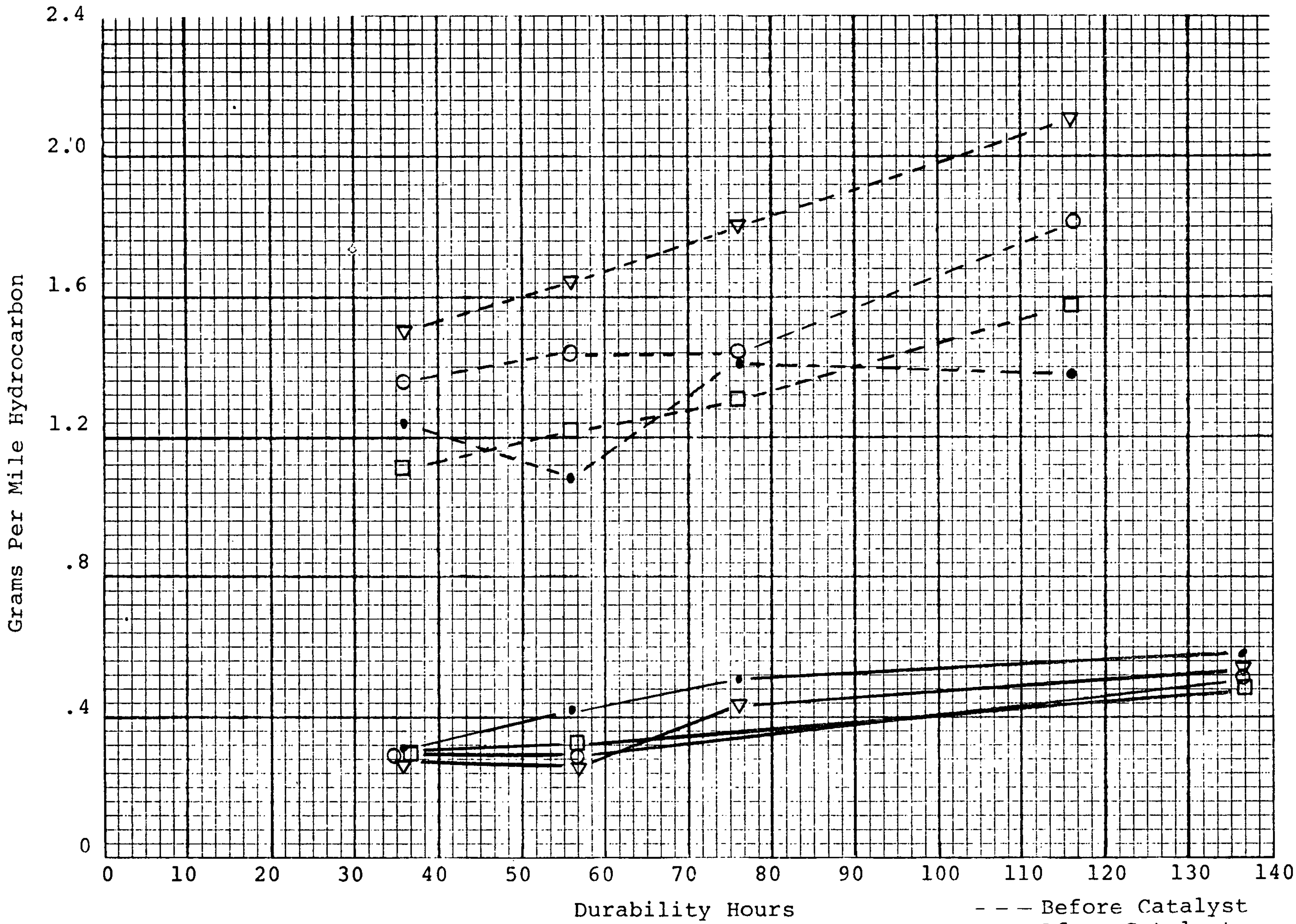


CVS EMISSIONS FEDERAL CYCLE

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Monolithic Catalyst
"B" Additive

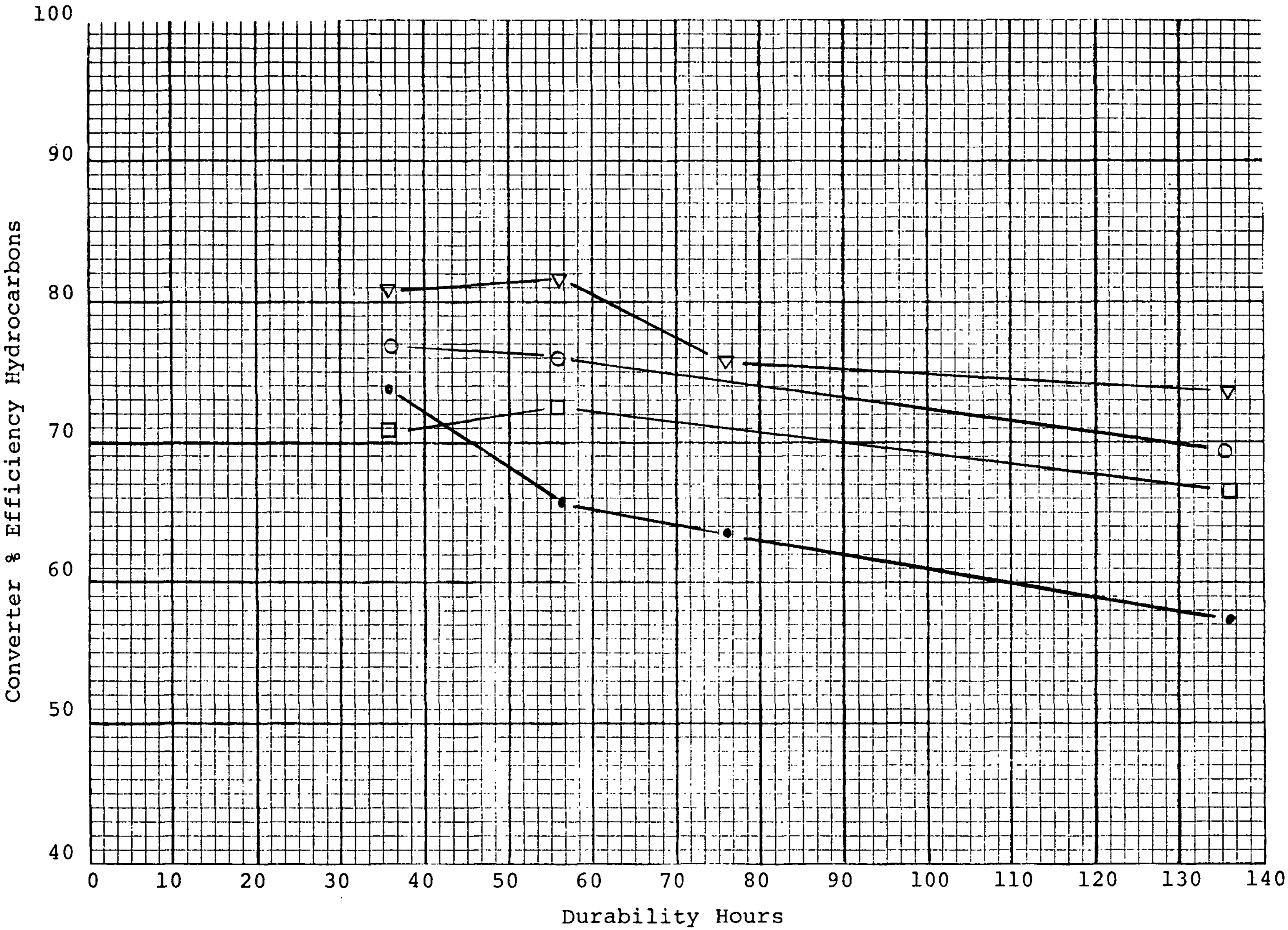
FIGURE 22



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Monolithic Catalyst
"B" Additive

FIGURE 23



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Monolithic Catalyst
"B" Additive

FIGURE 24

B. Comparison of Three Fuels, Engine Stand, Monolithic Catalyst

COMMENTS:

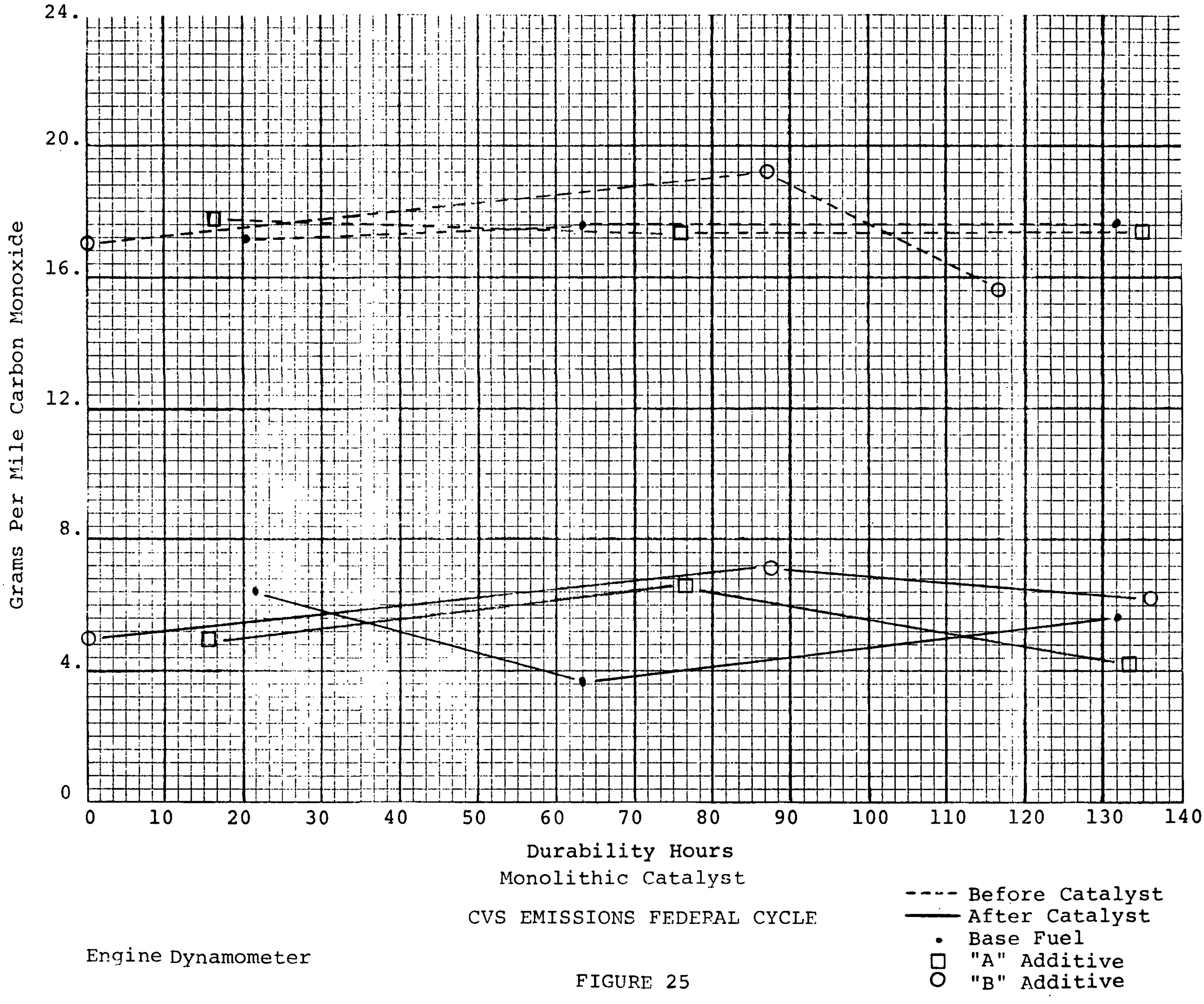
1. There was some catalyst degradation over the durability test period, although in most cases it was less than 10%. Additive A seemed to cause slightly more degradation than the baseline or Additive B.

2. With respect to carbon monoxide emissions, the base fuel started out on the durability test having the poorest conversion efficiency of the three fuels, but at the end of the test the base fuel had the best conversion efficiency.

3. With respect to hydrocarbon emissions from the Federal Cycle Modified, the converter efficiency was best for fuel Additive B and poorest for fuel Additive A.

4. With respect to hydrocarbon emissions from the Federal Cycle conditions, the fuel Additive A seemed to have very poor conversion efficiencies compared to the base fuel, while Additive B was very similar to the base fuel.

5. Additive B fuel caused the engine to produce higher quantities of hydrocarbons before the catalyst, in the Federal Cycle.

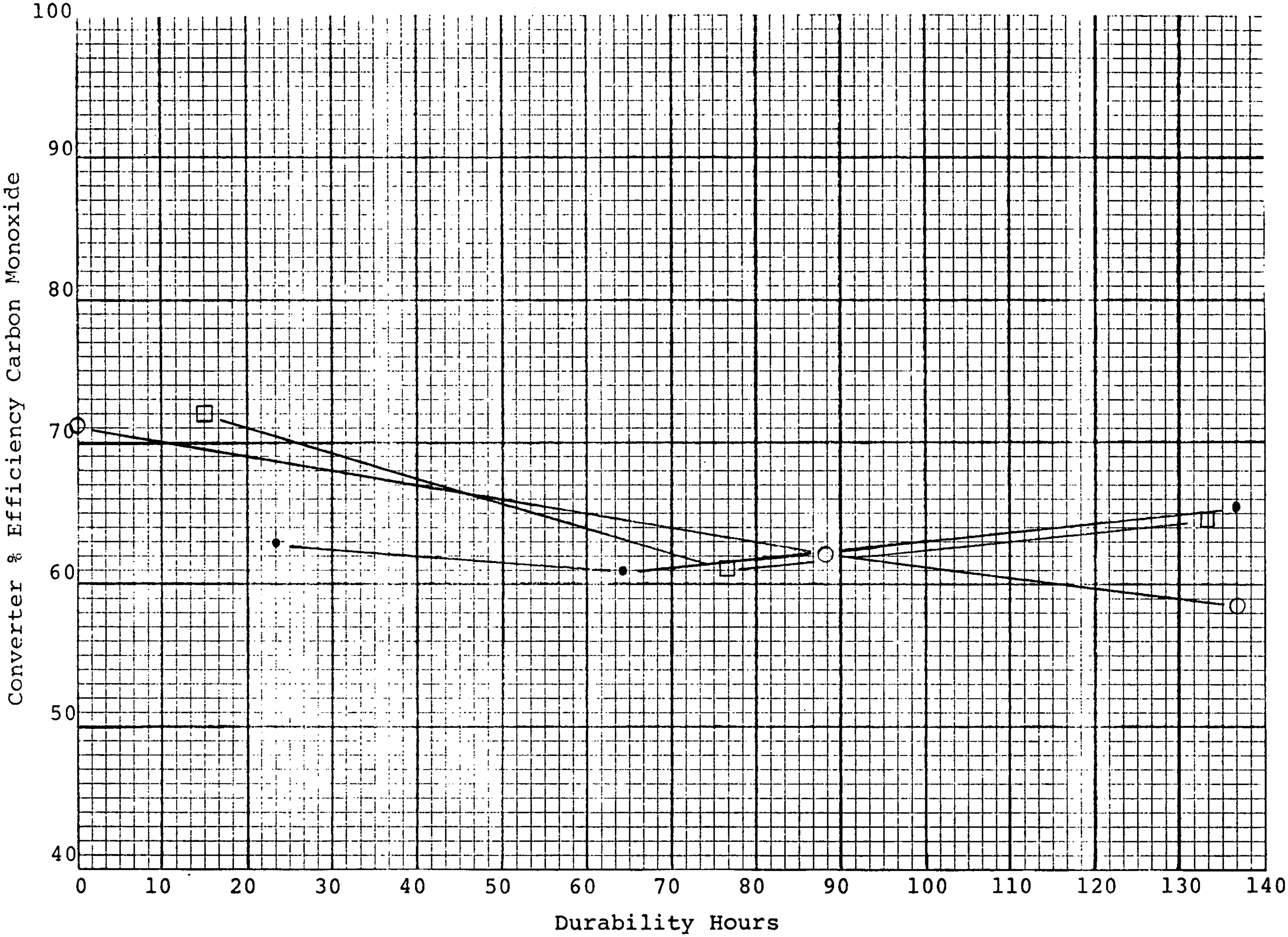


Monolithic Catalyst

CVS EMISSIONS FEDERAL CYCLE

Engine Dynamometer

FIGURE 25



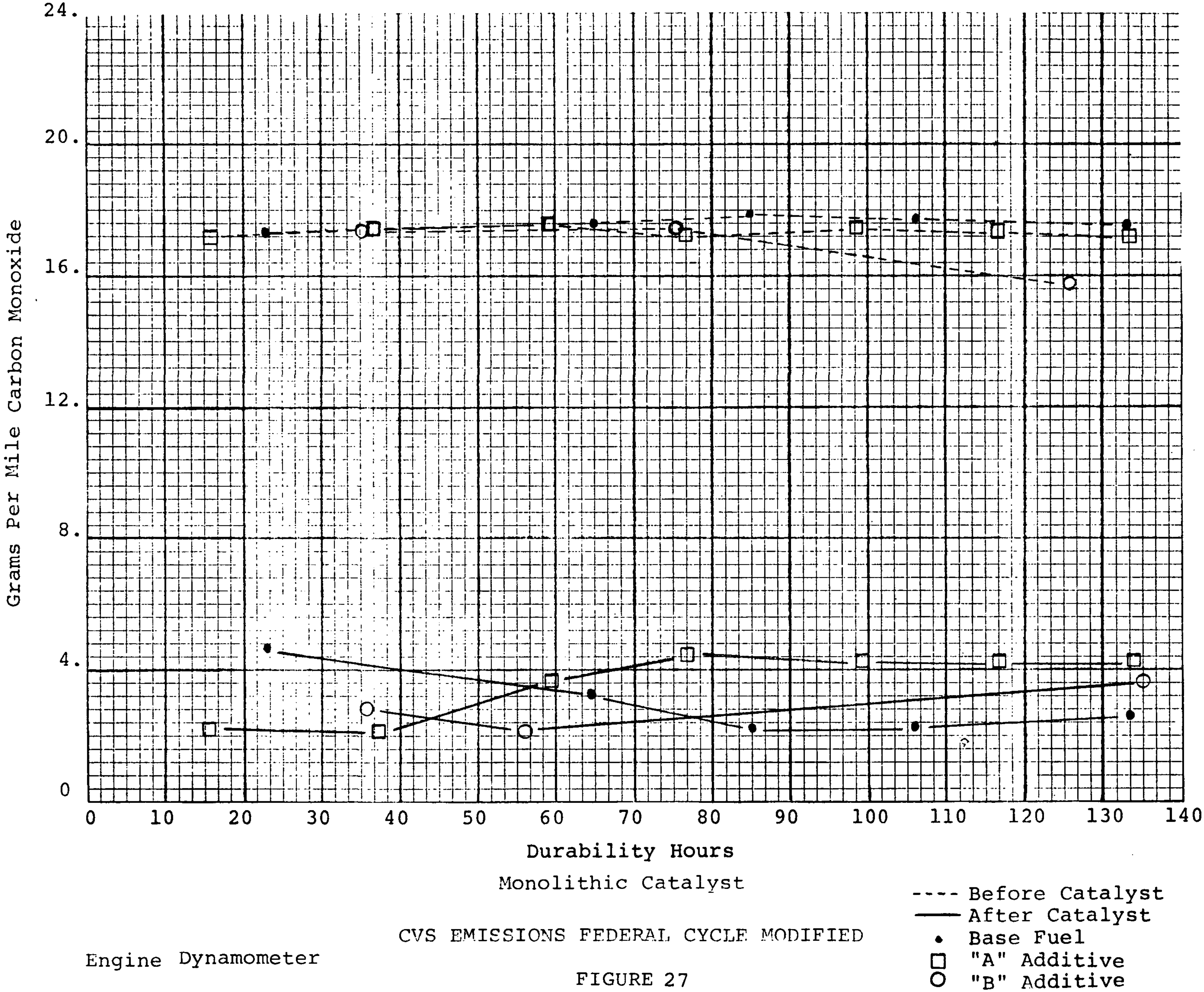
Monolithic Catalyst

CVS EMISSIONS FEDERAL CYCLE

Engine Dynamometer

FIGURE 26

• Base Fuel
□ "A" Additive
○ "B" Additive

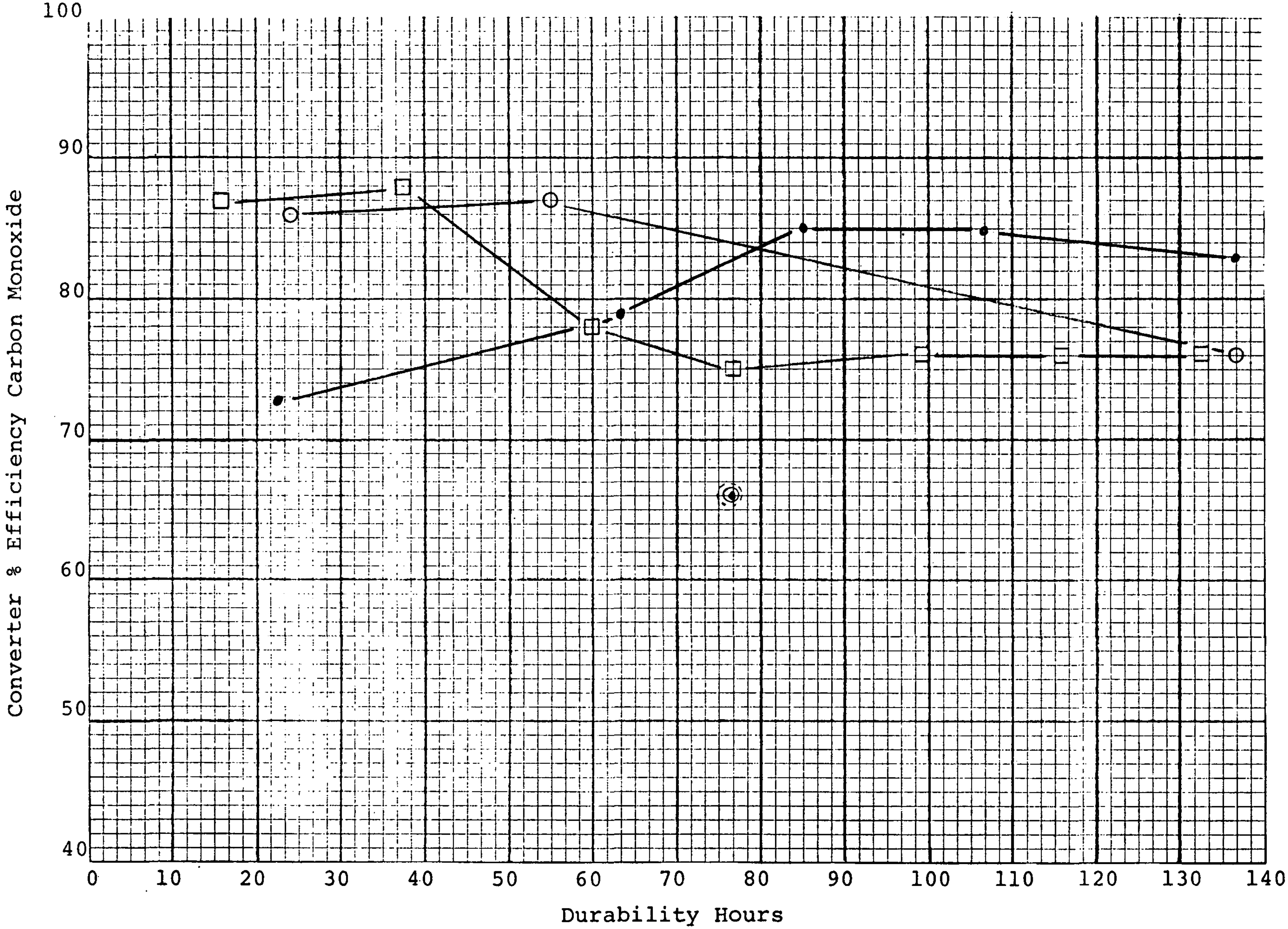


Monolithic Catalyst

Engine Dynamometer

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 27

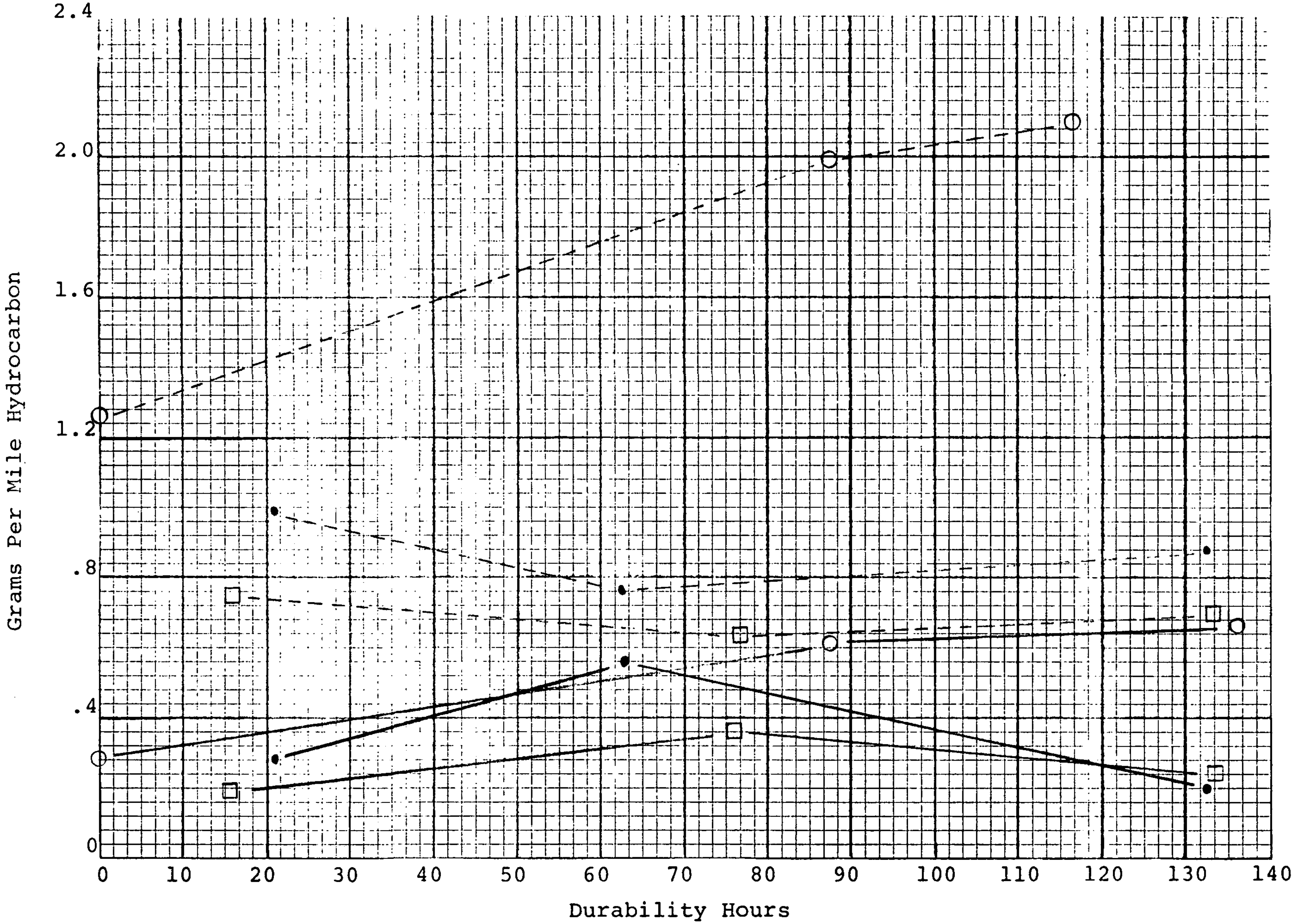


Monolithic Catalyst

Engine Dynamometer

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 28

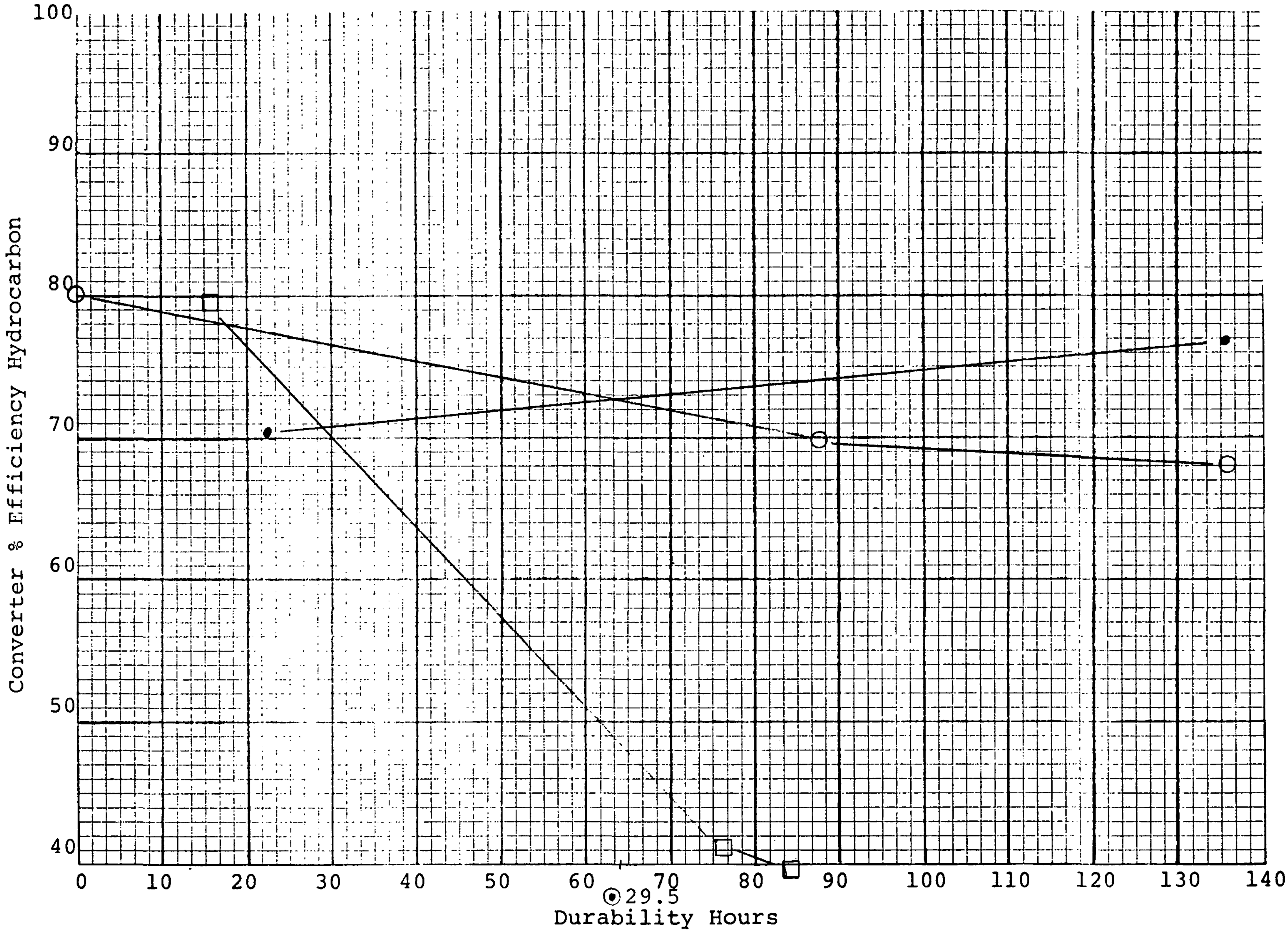


Monolithic Catalyst

CVS EMISSIONS FEDERAL CYCLE

Engine Dynamometer

FIGURE 29



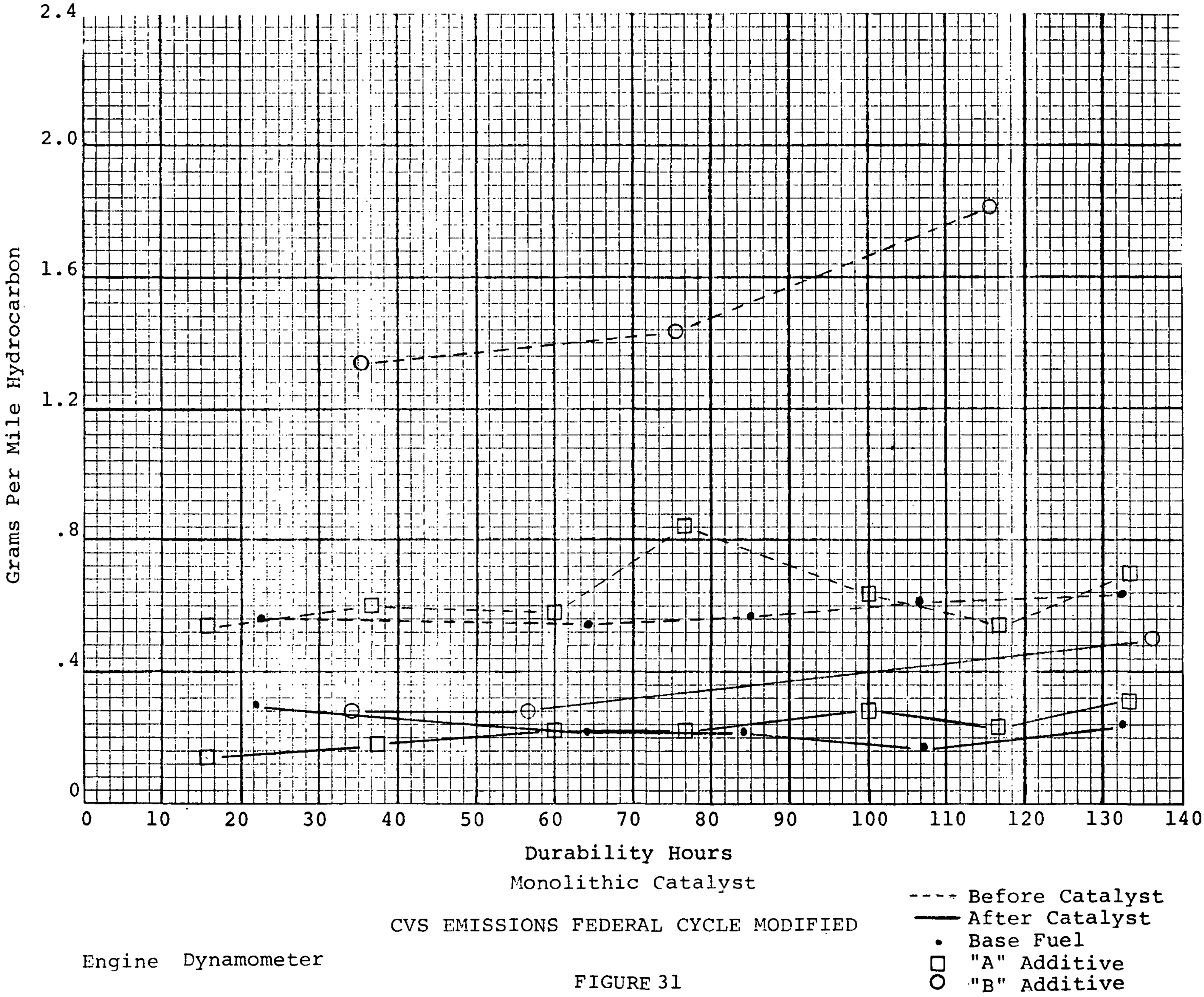
Monolithic Catalyst

CVS EMISSIONS FEDERAL CYCLE

Engine Dynamometer

• Base Fuel
□ "A" Additive
○ "B" Additive

FIGURE 30

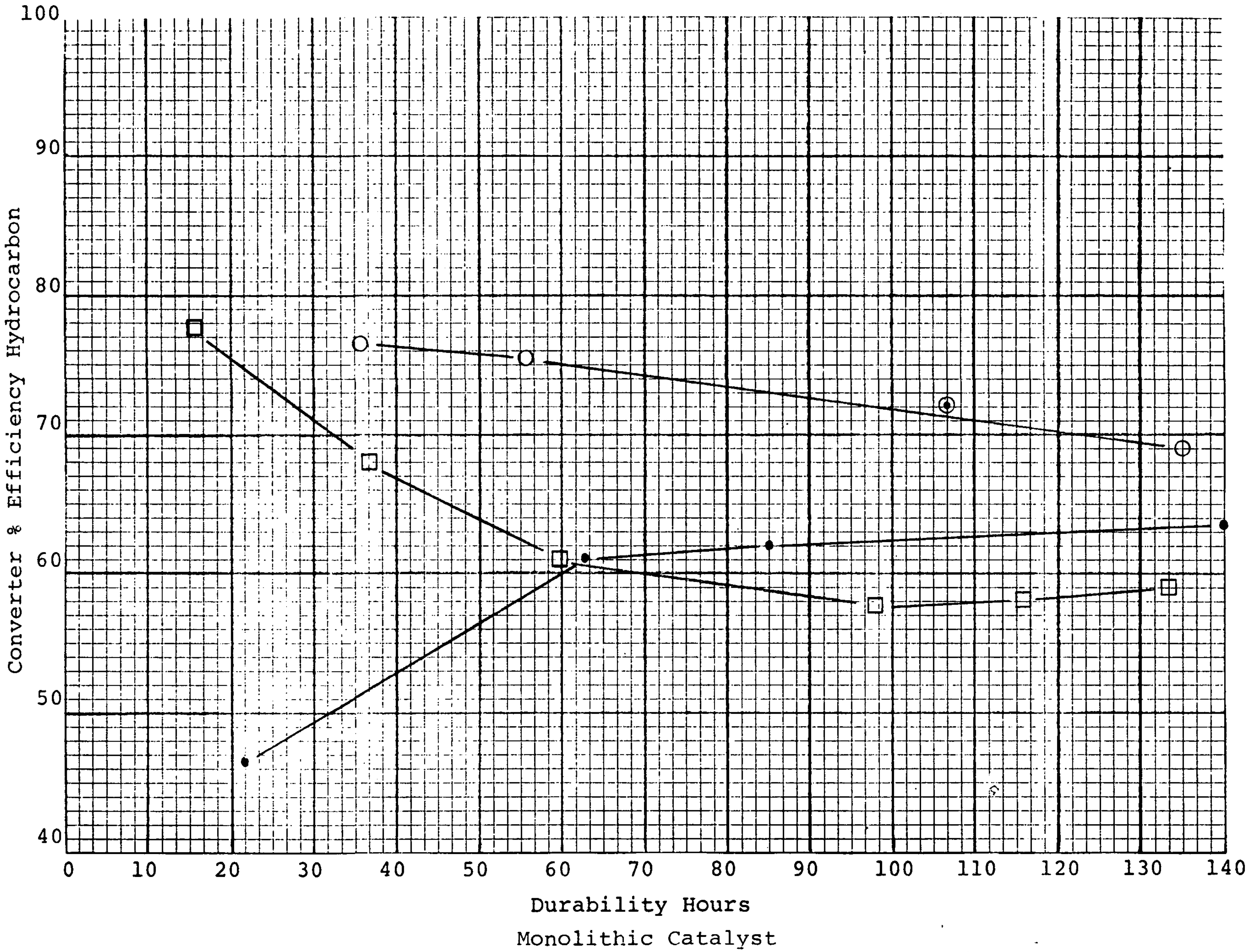


Monolithic Catalyst

CVS EMISSIONS FEDERAL CYCLE MODIFIED

Engine Dynamometer

FIGURE 31



Engine Dynamometer

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 32

• Base Fuel
□ "A" Additive
○ "B" Additive

C. Raw Data, Engine Stand, Beaded Catalyst, Three Fuels

This set of data and graphs shows the carbon monoxide emission levels and the hydrocarbon emission levels on a grams/mile basis, as well as the converter efficiency for the two gases measured. The cycle is broken down into the cold transient, hot transient, and stabilized segments of the CVS measurement, as well as the weighted average of the three.

COMMENTS - Baseline

1. The conversion efficiency appears to be slightly better for carbon monoxide than it is for hydrocarbon emissions in both the Federal Cycle and the Modified Federal Cycle tests. This observation is generally true for all three fuels and for the monolithic catalyst as well.

2. Carbon monoxide conversion efficiency was reduced during the durability test, as measured by the Federal Cycle, but not for the Federal Cycle Modified.

3. Hydrocarbon conversion efficiency was reduced during the durability test as measured by both the Federal Cycle and the Modified Federal Cycle.

4. Measured grams/mile of hydrocarbon was lower at the end of the durability test than at the beginning for both Federal Cycle and Modified Federal Cycle.

5. Data point scatter for both grams/mile measurements, and the corresponding conversion efficiencies appear to be within normal experimental ranges.

TABLE 15. BASE FUEL, BEADED CATALYST, ENGINE STAND, RAW DATA, GRAMS/MILE.*

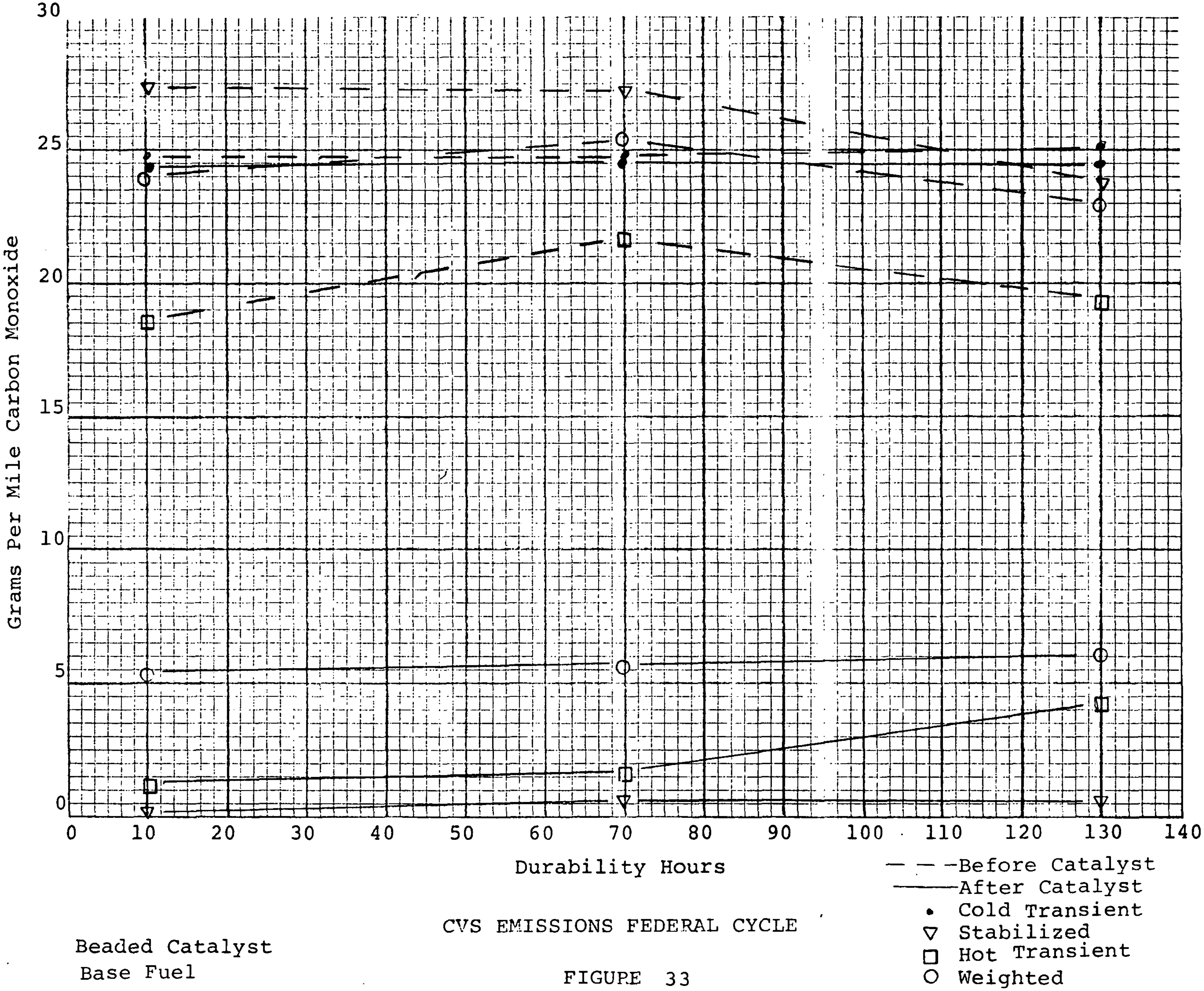
Cold		Hot		Hot		Cold		Hot		Hot		Hot		Hot		Cold		Hot		
HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	
9		9		52		70		70		88		112		130		130		140		Durability Hours
Without Converter																				
1.34	24.9	.48	17.7	.47	19.0	.91	24.8	.37	20.3	.42	23.1	.40	21.84	.39	24.1	2.68	25.1	.34	22.8	Cold Transient
.73	27.4	.61	26.7	.62	31.5	.54	27.4	.60	36.5	.47	26.7	.04	2.49	.37	23.0	.46	23.8	.41	24.9	Stabilized
.55	18.7	.41	16.2	.50	19.5	.40	21.8	.52	24.0	.41	22.4	.35	21.3	.37	19.1	.38	19.4	.41	22.7	Hot Transient
.81	24.6	.53	22.1	.56	25.8	.58	25.4	.53	29.9	.44	24.8	.20	11.4	.38	22.2	.89	22.9	.40	23.9	Weighted
With Converter																				
.80	24.6	.14	2.7	.11	1.4	1.03	24.9	.33	9.12	.20	5.9	.15	3.8	.21	6.76	.62	24.5	.17	3.51	Cold Transient
.14	.25	.10	.28	.13	.34	.17	.61	.11	.39	.47	.41	.07	.34	.09	.41	.12	.60	.10	.56	Stabilized
.11	1.28	.11	1.69	.14	1.97	.18	1.84	.38	5.0	.14	2.58	.13	2.0	.10	2.47	.17	4.13	.12	2.69	Hot Transient
.26	5.42	.11	1.14	.13	.99	.35	5.82	.23	3.39	.33	2.1	.11	1.48	.12	2.23	.23	6.3	.12	1.71	Weighted
% Efficiency																				
40.2	0	70.8	84.7	76.5	92.6	0	0	10.8	55.1	52.4	0	62.5	82.6	46.1	71.9	76.8	0	50	84.6	Cold Transient
80.8	99	83.6	98.9	79.0	98.9	68.5	97.7	81.6	98.9	0	98.4	0	86.3	75.6	98.2	73.9	92.4	75.6	97.5	Stabilized
80.0	93.1	73.1	89.5	72.0	89.8	55.0	91.5	26.9	79.2	65.8	88.4	62.8	90.6	72.9	88.4	55.2	78.7	70.7	88.1	Hot Transient
67.9	77.9	79.2	94.8	76.7	96.1	39.6	77.0	56.6	88.6	25.0	91.5	45	87.0	68.4	89.9	74.1	72.4	70.7	92.8	Weighted

*Corrected for ambient conditions.

TABLE 16. AMBIENT CONDITIONS.

BASE FUEL - BEADED CATALYST ENGINE DYNAMOMETER

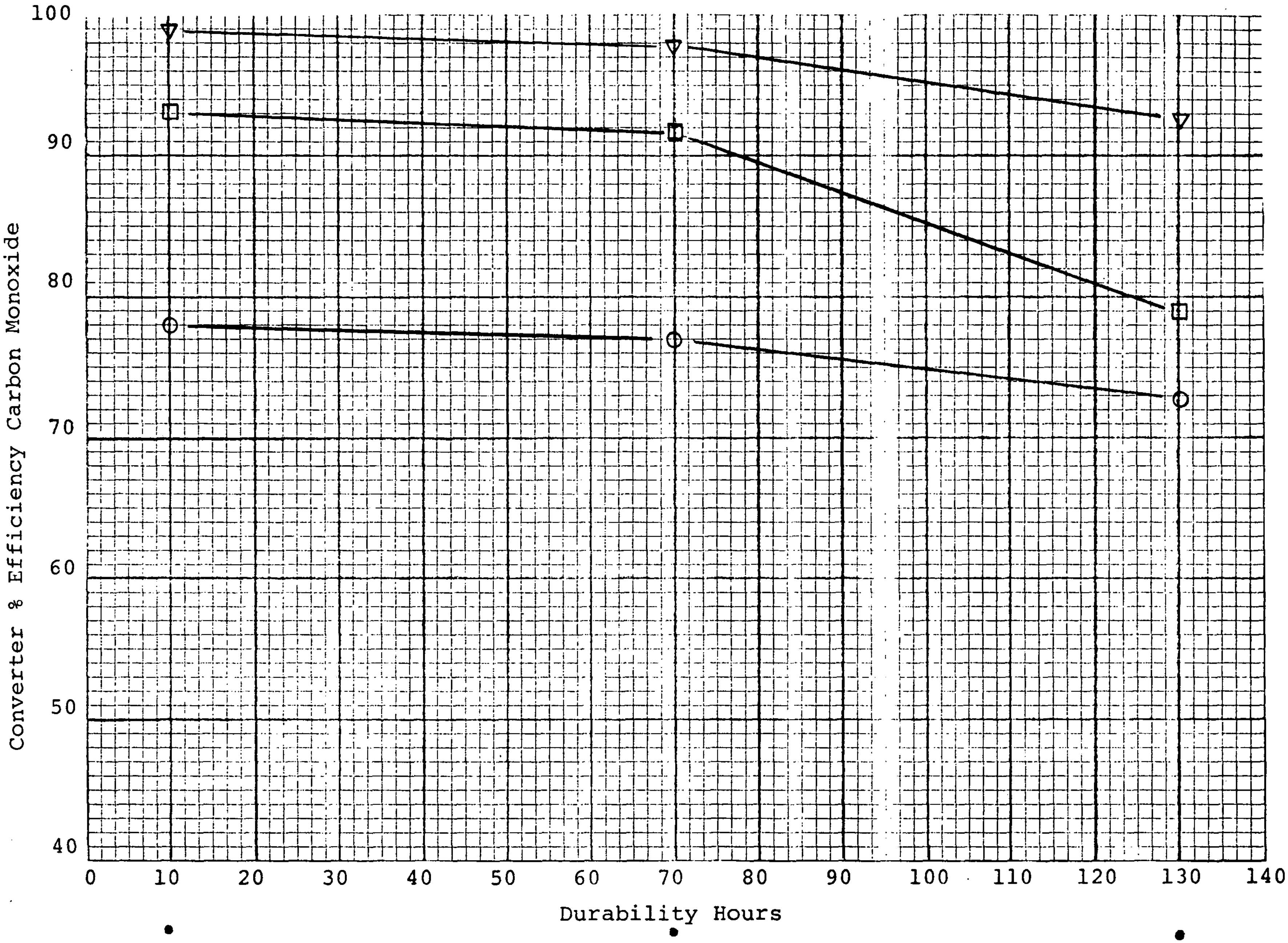
Modified Federal Cycle		X	X		X	X	X	X		X
Federal Cycle	X			X					X	
Durability Hours	9	9	52	70	70	88	112	130	130	140
<u>WITHOUT CONVERTER</u>										
Barometer	29.61	29.34	29.47	29.76	29.40	29.26	29.63	29.64	29.64	29.72
Corrected Barometer	29.47	29.21	29.33	29.11	29.26	29.11	29.51	29.50	29.50	29.08
Ambient Air °F	80.	75.	82.	86.	82.	86.	75.	83.	83.	85.
Wet Bulb °F	55.	50.5	52.5	60.5	57.	60.5	53.	58.	58.	63.
Dry Bulb °F	81.	76.0	83.0	84.	81.	84.	72.	84.	84.	85.
Humidity %	13.99	10.27	5.59	23.34	19.27	23.34	24.75	16.87	16.87	22.11
<u>WITH CONVERTER</u>										
Barometer	29.22	29.22	29.47	29.46	29.46	29.26	29.63	29.64	29.01	29.01
Corrected Barometer	29.11	29.11	29.33	29.31	29.31	29.11	29.51	29.50	28.89	28.89
Ambient Air °F	68.	68.	82.	76.5	76.5	86.	75.	83.	74.0	74.
Wet Bulb °F	47.	47.	52.5	54.	54.	60.5	53.	58.	52.	52.
Dry Bulb °F	70.	70.	83.	77.	77.	84.	72.	84.	72.	72.
Humidity %	10.29	10.29	5.59	17.98	17.98	23.34	24.75	16.87	22.11	22.11



CVS EMISSIONS FEDERAL CYCLE

Beaded Catalyst
Base Fuel

FIGURE 33

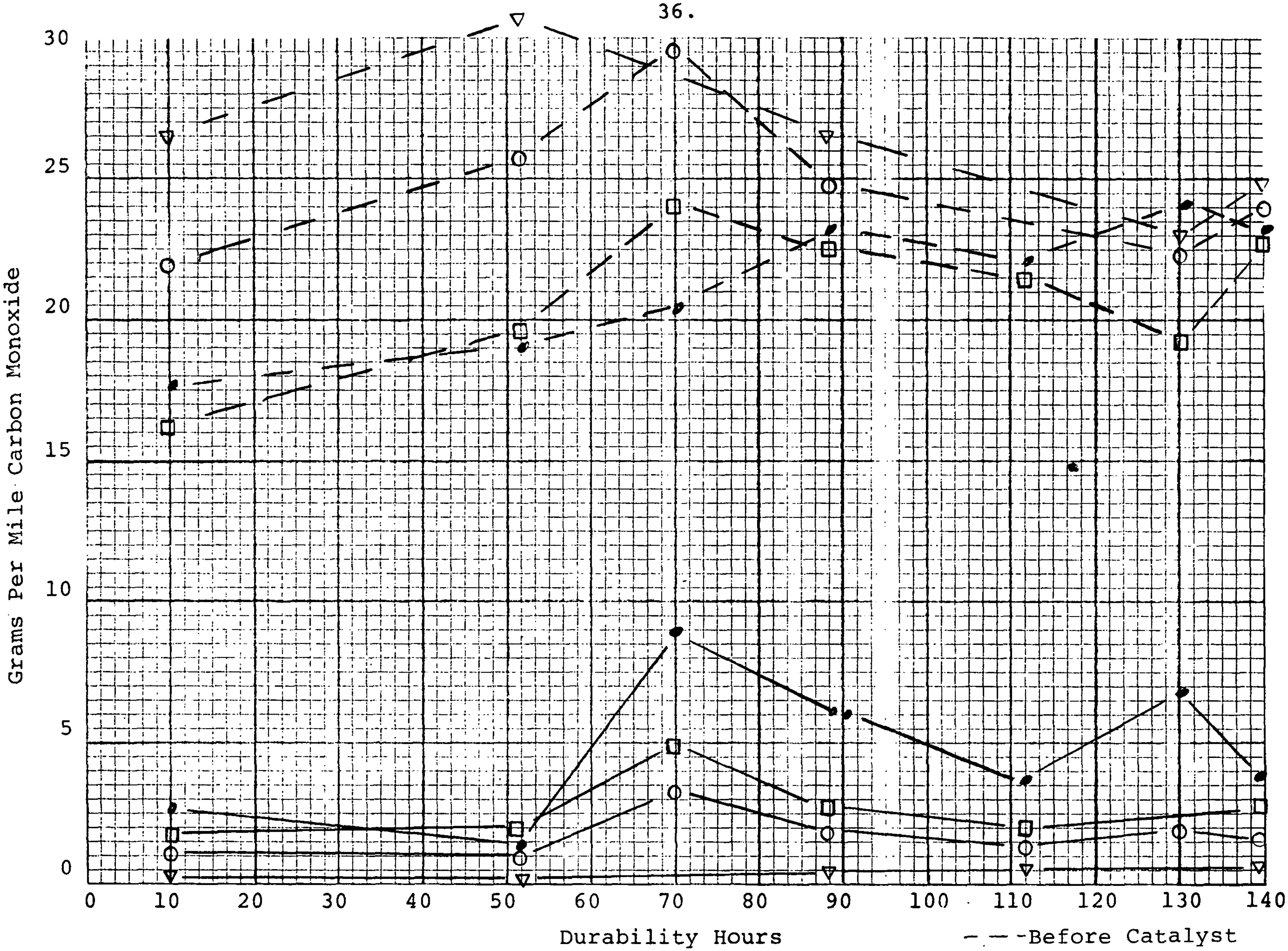


CVS EMISSIONS FEDERAL CYCLE

Beaded Catalyst

Base Fuel

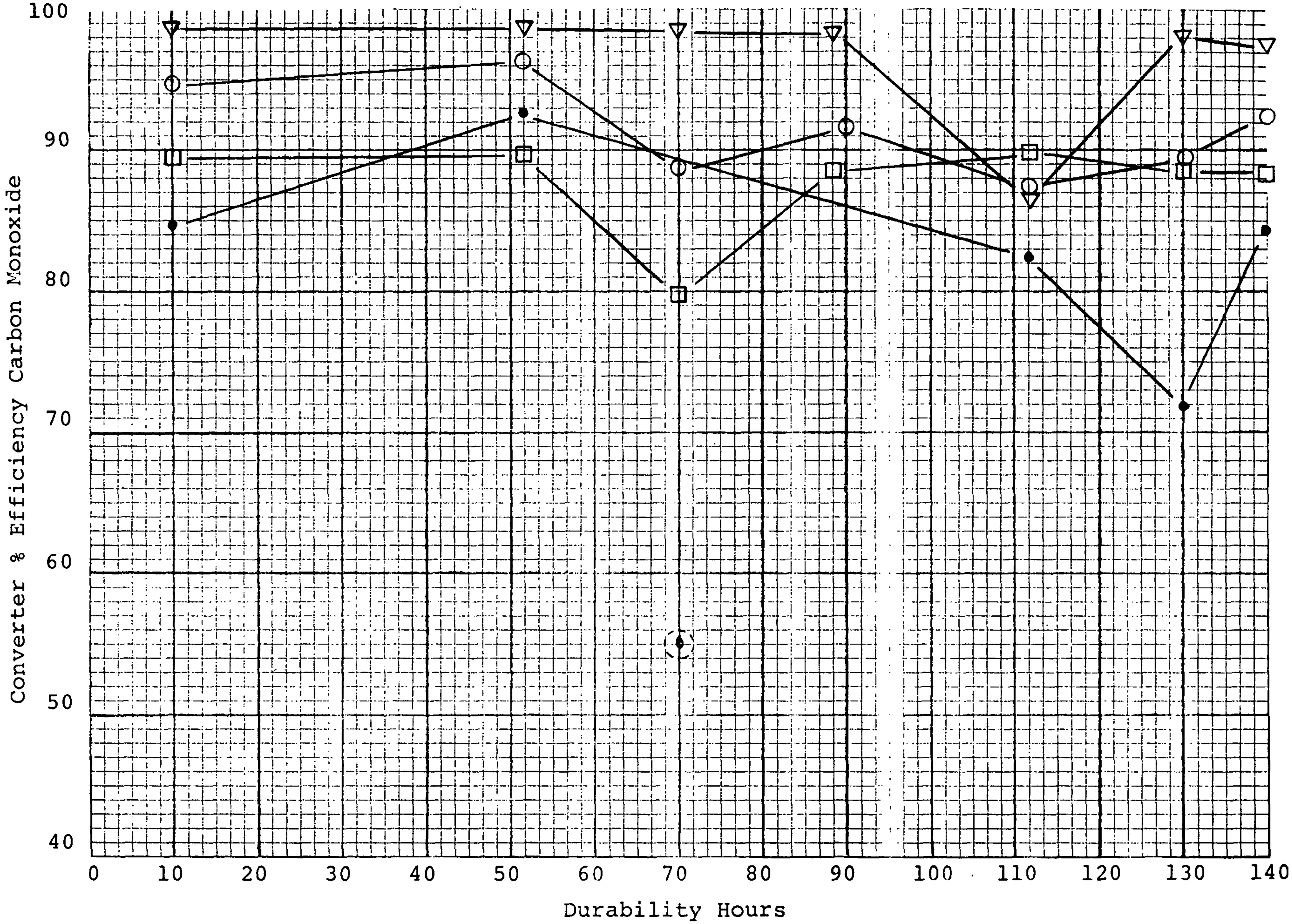
FIGURE 34



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Beaded Catalyst
Base Fuel

FIGURE 35

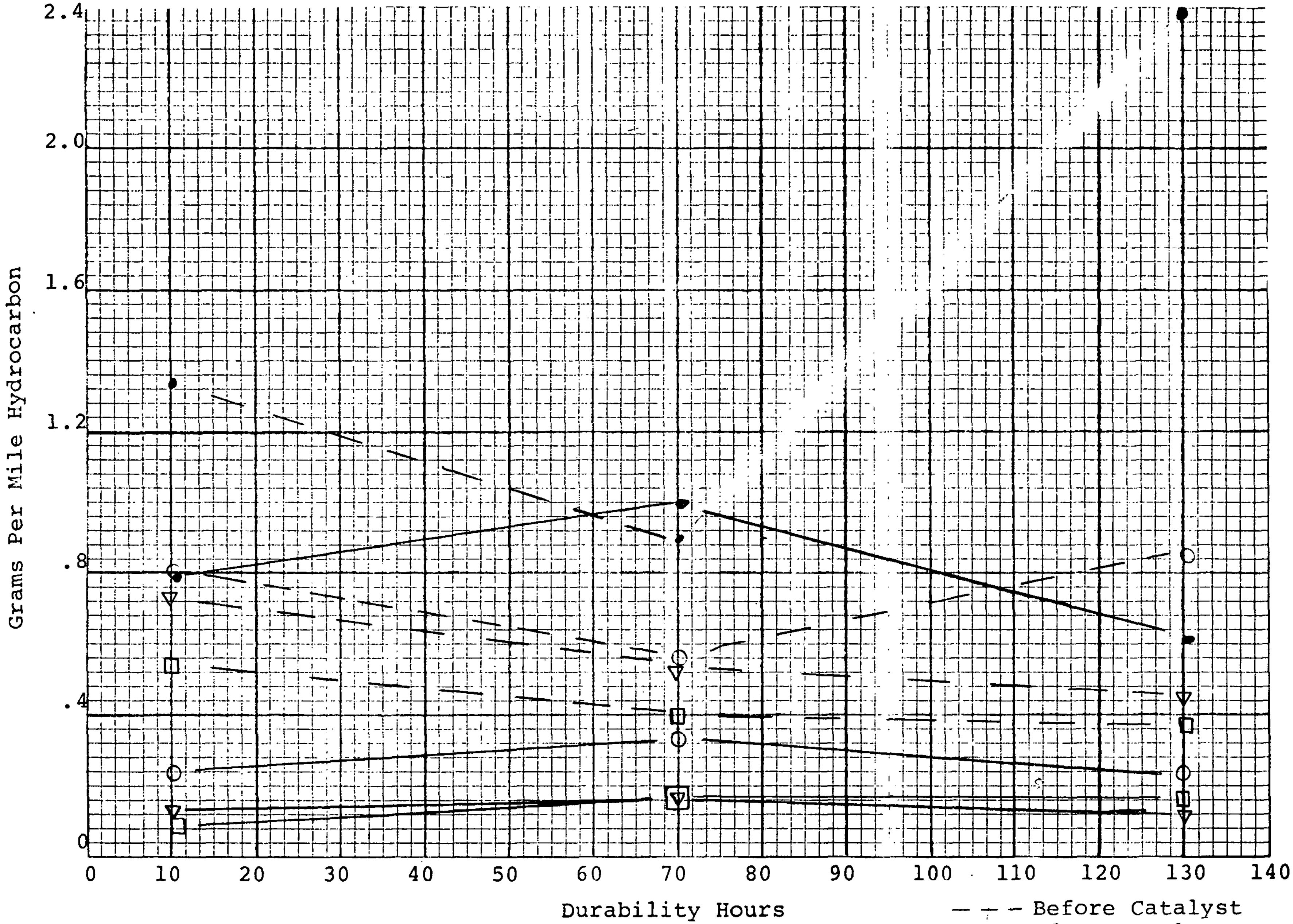


CVS EMISSIONS FEDERAL CYCLE MODIFIED

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Beaded Catalyst
Base Fuel

FIGURF 36

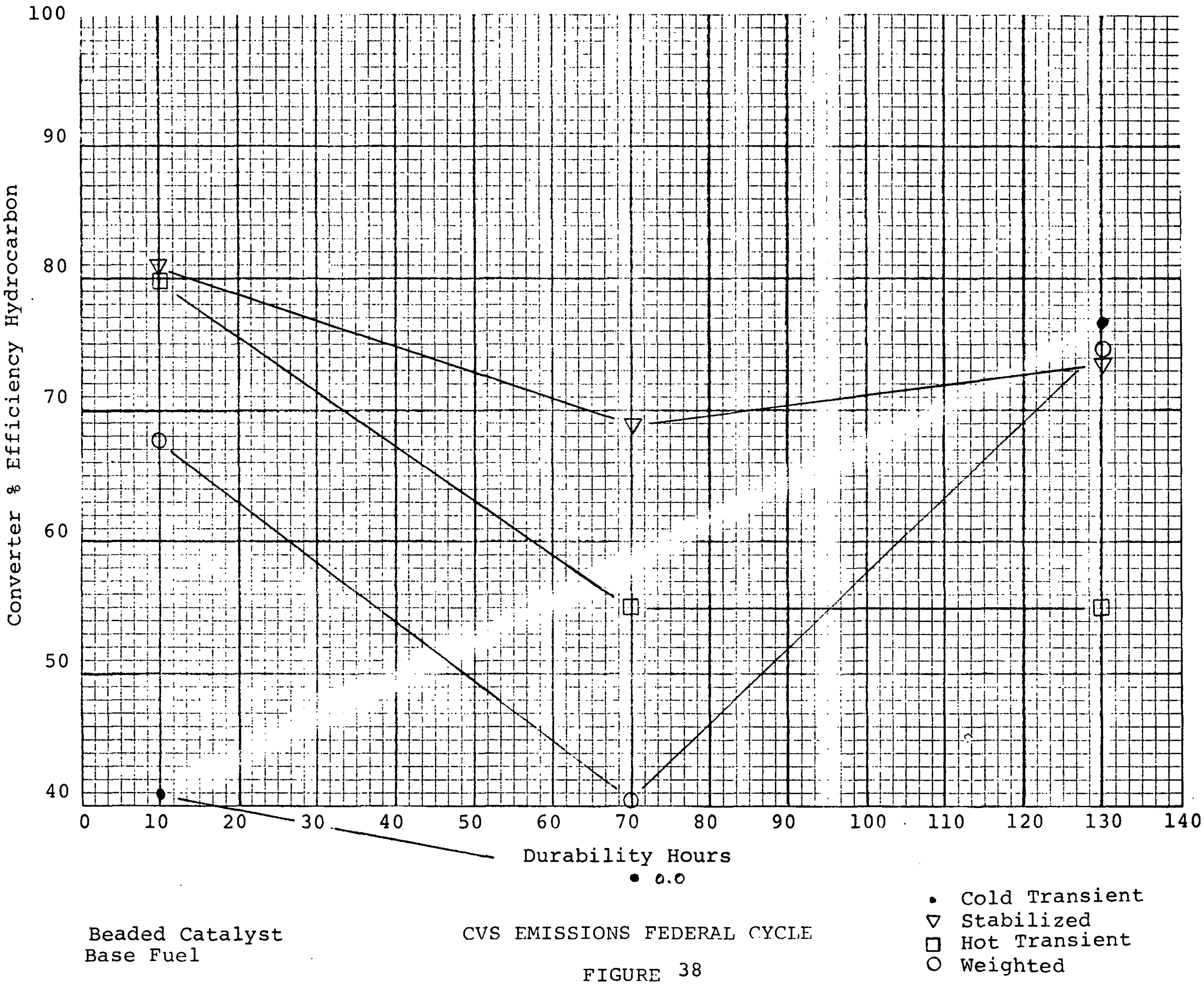


— — — Before Catalyst
——— After Catalyst
• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

CVS EMISSIONS FEDERAL CYCLE

Beaded Catalyst
Base Fuel

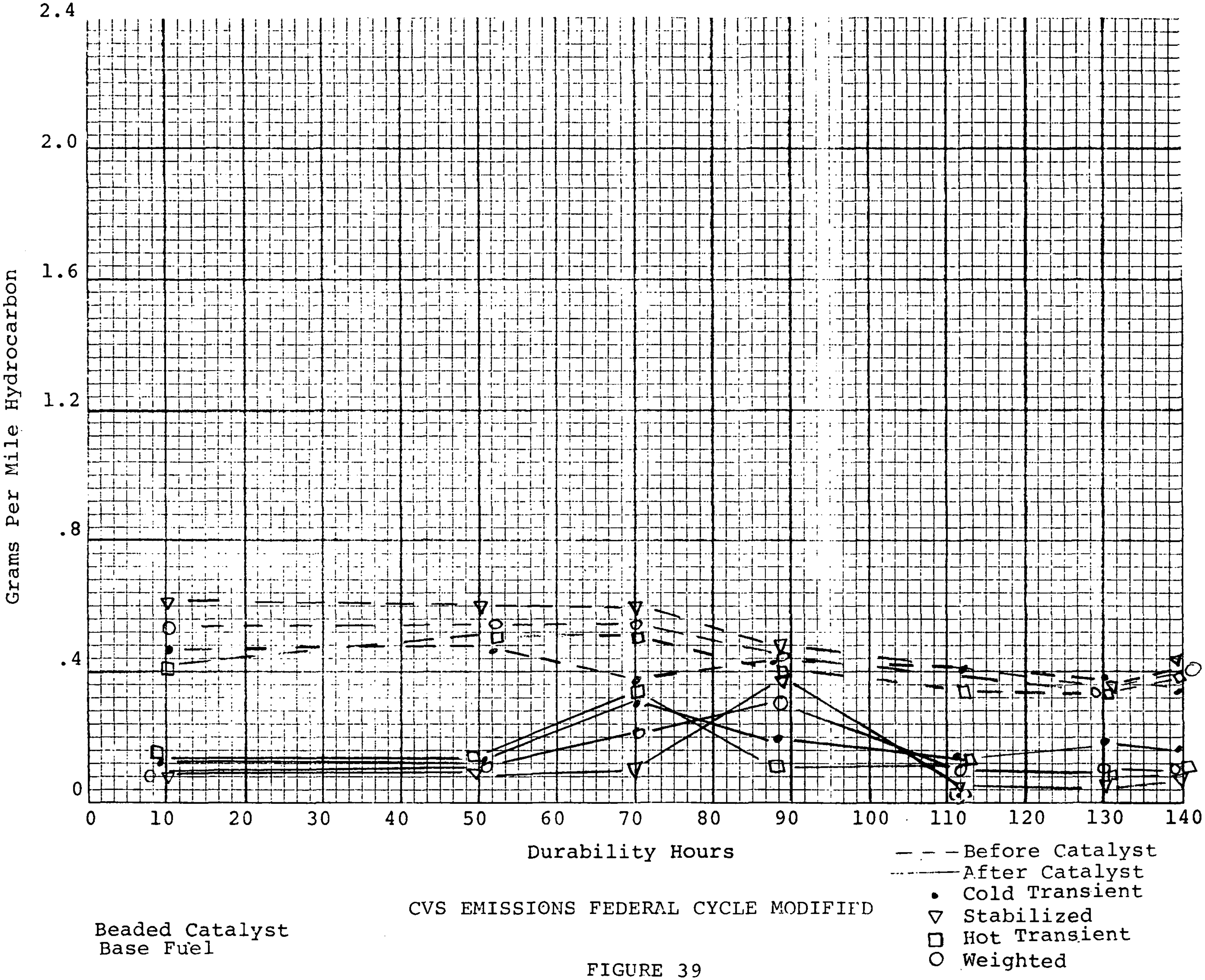
FIGURE 37



Beaded Catalyst
Base Fuel

CVS EMISSIONS FEDERAL CYCLE

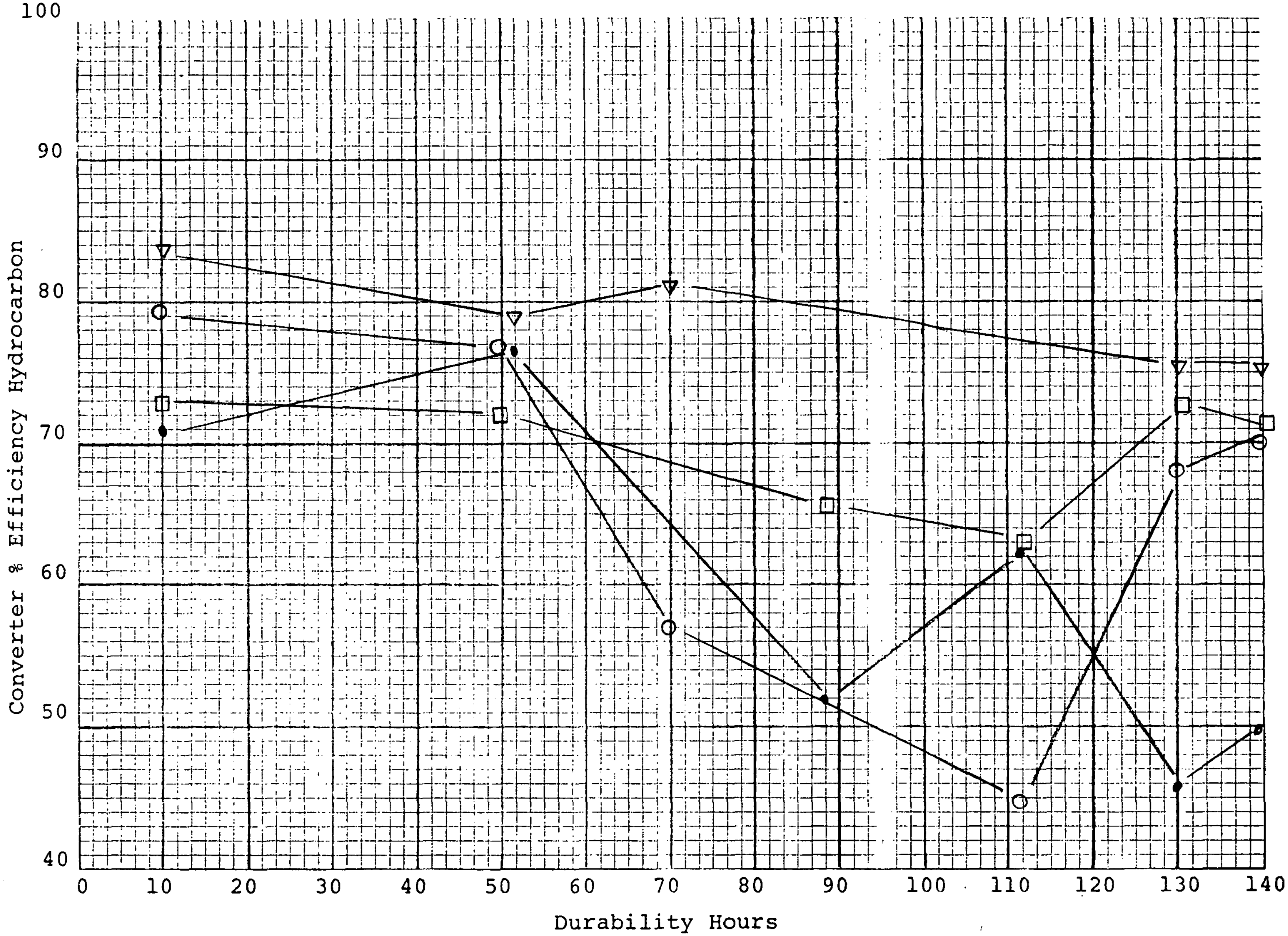
FIGURE 38



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Beaded Catalyst
Base Fuel

FIGURE 39



Beaded Catalyst
Base Fuel

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 40

COMMENTS: Additive "A"

1. The conversion of carbon monoxide is much better than the conversion of hydrocarbon emissions. This fact is generally true for all three fuels and when using the monolithic catalyst also.

2. Carbon monoxide conversion showed a drop in efficiency over the durability test for the Federal Cycle, but no drop in efficiency when tested under the Federal Cycle Modified.

3. Hydrocarbon conversion efficiency did not show any converter degradation over the durability test period.

TABLE 17. "A" ADDITIVE, BEADED CATALYST, ENGINE STAND, RAW DATA, GRAMS/MILE.*

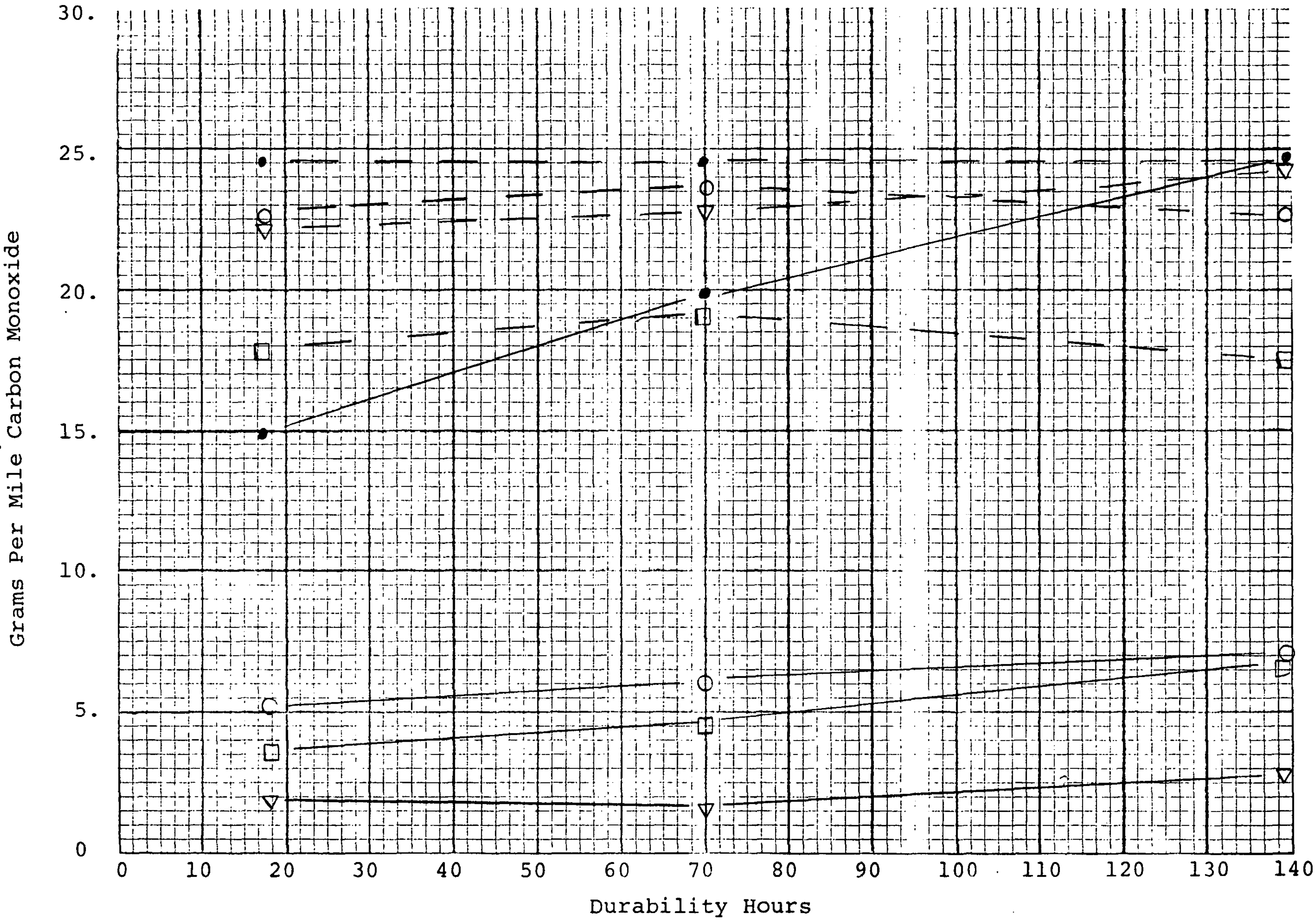
Cold		Hot		Hot		Cold		Hot		Hot		Cold		Hot		Hot		
HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	
17		17		50		69		69		103		130		130		140		Durability Hours
Without Converter																		
.72	24.7	.32	19.5	.42	20.4	.57	24.8	.38	22.9	.40	20.9	1.15	24.7	.48	19.9	.44	21.9	Cold Transient
.39	24.4	.39	24.5	.42	23.7	.41	25.8	.40	25.0	.41	21.1	.49	24.5	.54	24.4	.48	23.1	Stabilized
.34	17.4	.34	21.1	.33	19.1	.37	19.2	.34	19.9	.33	17.1	.39	17.3	.46	18.3	.39	19.4	Hot Transient
.44	22.6	.37	22.6	.39	21.8	.43	23.8	.38	23.2	.39	19.9	.60	22.7	.50	21.9	.45	21.8	Weighted
With Converter																		
.45	15.0	.14	4.59	.22	9.0	.61*	20.3	.16	7.37	.21	9.41	.71	29.9*	.12	2.63	.11	3.2	Cold Transient
.12	1.92	.11	2.27	.14	2.64	.12	1.77	.11	2.13	.11	3.11	.16	2.88	.14	2.34	.13	2.2	Stabilized
.13	3.89	.13	4.69	.16	4.94	.14	4.69	.14	4.87	.16	5.92	.19	6.91	.17	4.72	.21	6.76	Hot Transient
.19	5.08	.12	3.38	.16	4.53	.23	6.26	.13	3.91	.15	5.33	.28	8.38	.15	3.03	.15	3.61	Weighted
% Efficiency																		
37.5	39.2	56.2	22.5	47.6	55.9	0	18.1	57.9	67.8	47.5	55.0	38.3	0	75.0	86.8	75.0	85.4	Cold Transient
69.2	92.1	71.7	90.7	66.7	88.9	70.7	93.1	72.5	91.5	73.2	85.3	67.3	88.2	74.1	90.4	72.9	90.5	Stabilized
61.7	77.6	61.7	77.8	51.5	74.1	62.2	75.6	58.8	75.5	51.5	65.4	51.3	60.1	63.0	74.2	46.2	65.2	Hot Transient
56.8	77.5	67.5	85.0	59.0	79.2	46.5	73.7	65.8	83.1	61.5	73.2	53.3	63.1	70.0	86.2	66.7	83.4	Weighted

*Corrected for ambient conditions.

TABLE 18. AMBIENT CONDITIONS

"A" ADDITIVE - BEADED CATALYST   ENGINE DYNAMOMETER

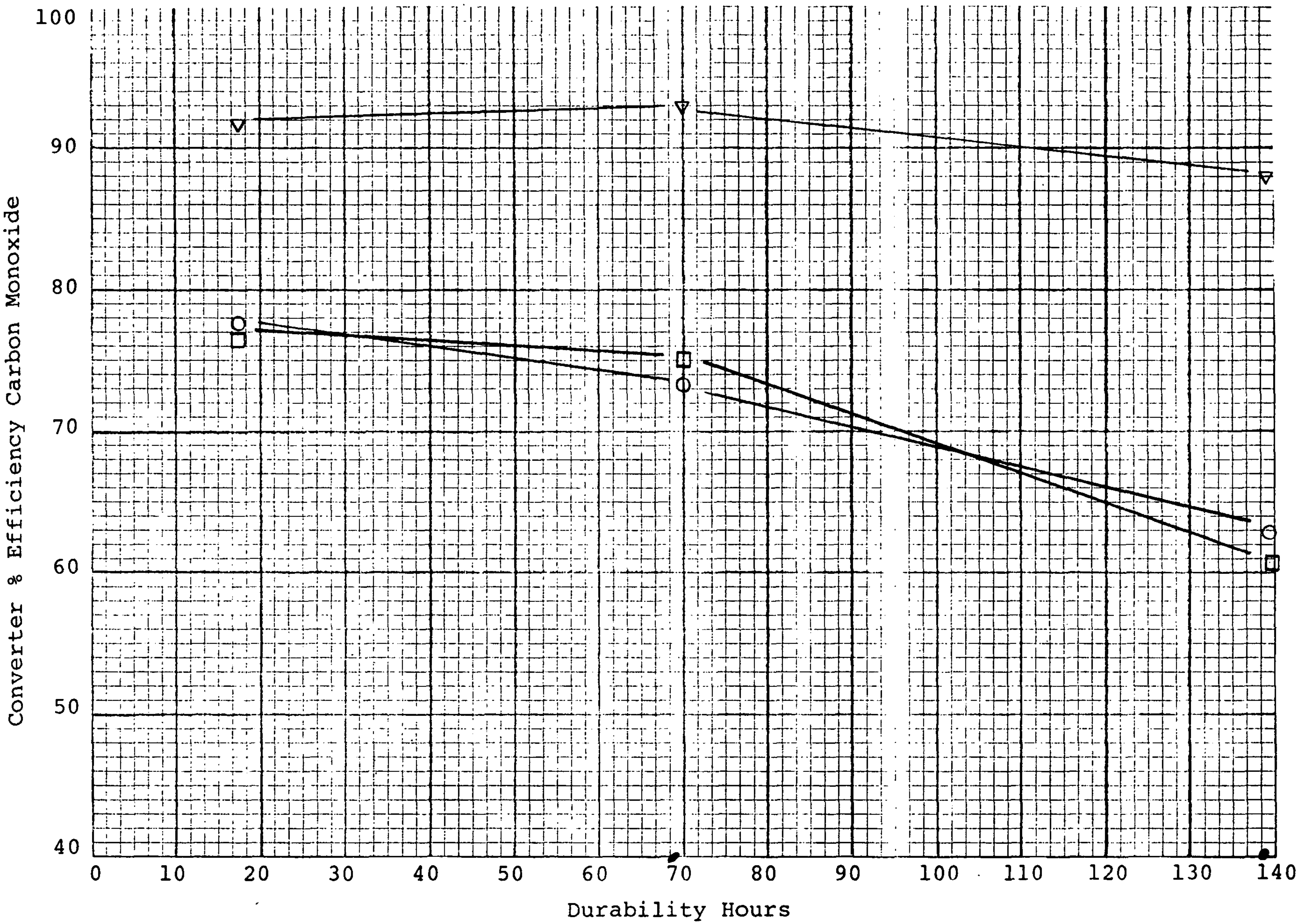
Modified Federal Cycle		X	X		X	X		X	X	
Federal Cycle	X			X			X			X
Durability Hours	17	17	50	69	69	103	130	130	140	140
WITHOUT CONVERTER										
Barometer	29.39	29.39	29.48	29.33	29.23	29.62	29.56	29.56	29.81	
Corrected Barometer	29.27	29.27	29.35	29.19	29.09	29.49	29.43	29.43	29.67	
Ambient Air °F	75.	75.	78.	80.	80.	78.	75.	75.	78.	
Wet Bulb °F	53.	53.	55.	79.	57.	52.5	52.	52.	51.	
Dry Bulb °F	72.	72.	76.	52.	79.	75.	73.	73.	75.	
Humidity %	24.96	24.96	22.7	9.77	22.91	17.27	19.65	19.65	12.64	
WITH CONVERTER										
Barometer	29.64	29.64	29.48	29.23	29.23	29.62	29.65	29.64	29.81	
Corrected Barometer	29.49	29.49	29.35	29.09	29.09	29.49	29.53	29.53	29.67	
Ambient Air °F	84.	84.	78.	80.	80.	78.	74.	70.	78.	
Wet Bulb °F	59.	59.	55.	57.	57.	52.5	50.	49.	51.	
Dry Bulb °F	86.	86.	76.	79.	79.	75.	72.	69.	75.	
Humidity %	16.34	16.34	22.7	22.91	22.91	17.27	15.23	18.24	12.64	



Beaded Catalyst
"A" Additive

CVS EMISSIONS FEDERAL CYCLE

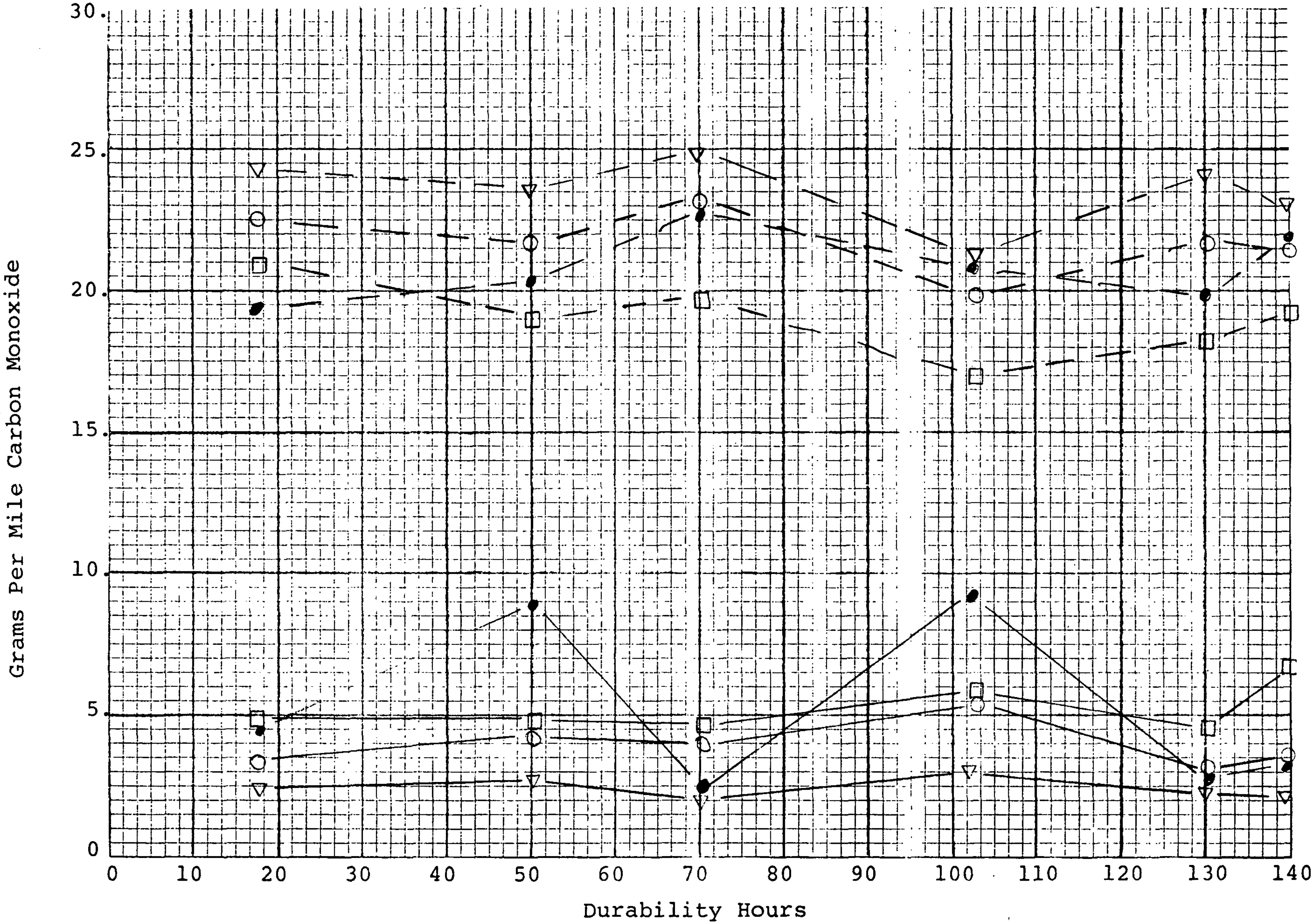
FIGURE 41



Beaded Catalyst
"A" Additive

CVS EMISSIONS FEDERAL CYCLE

FIGURE 42

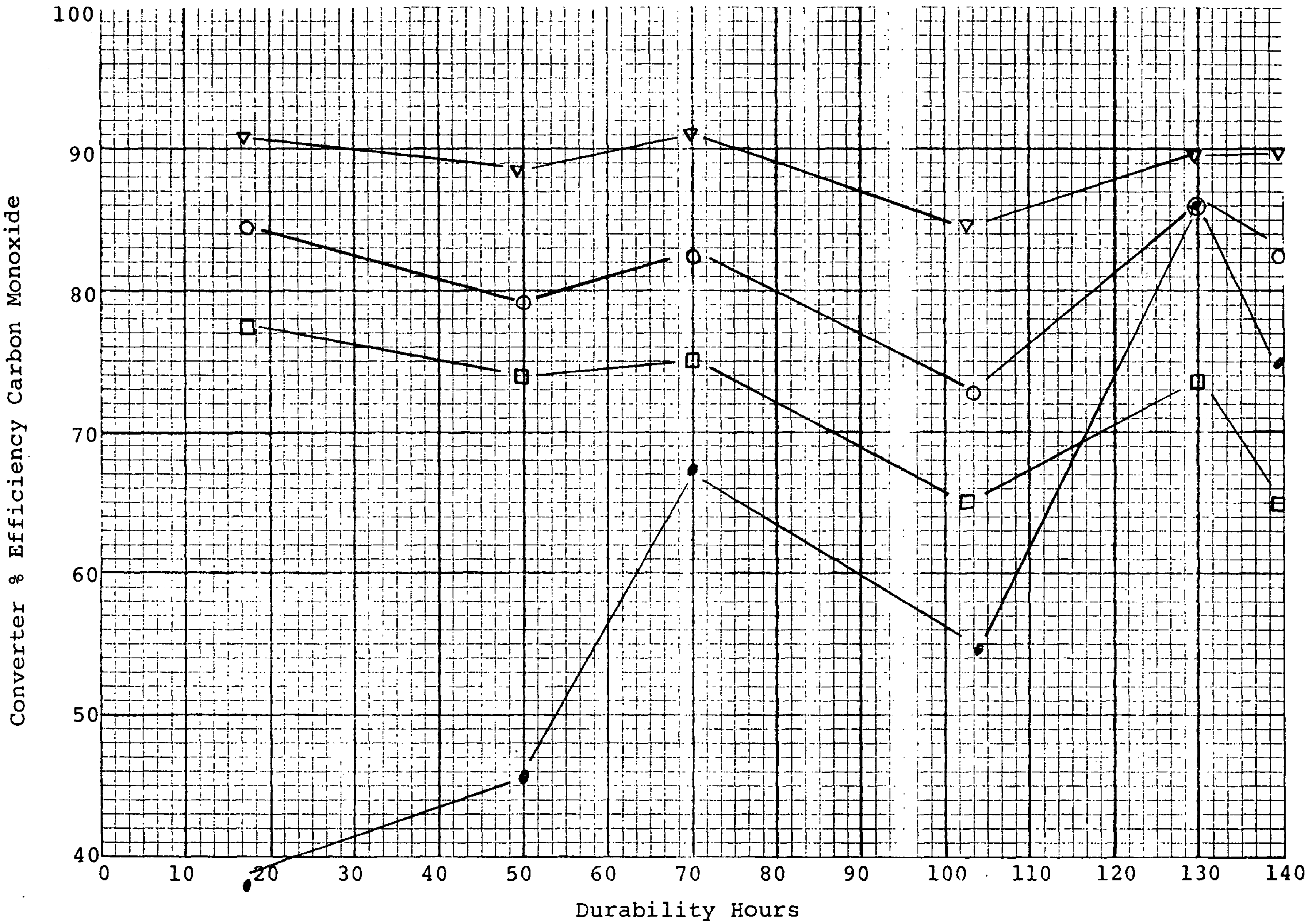


Beaded Catalyst

"A" Additive

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 43

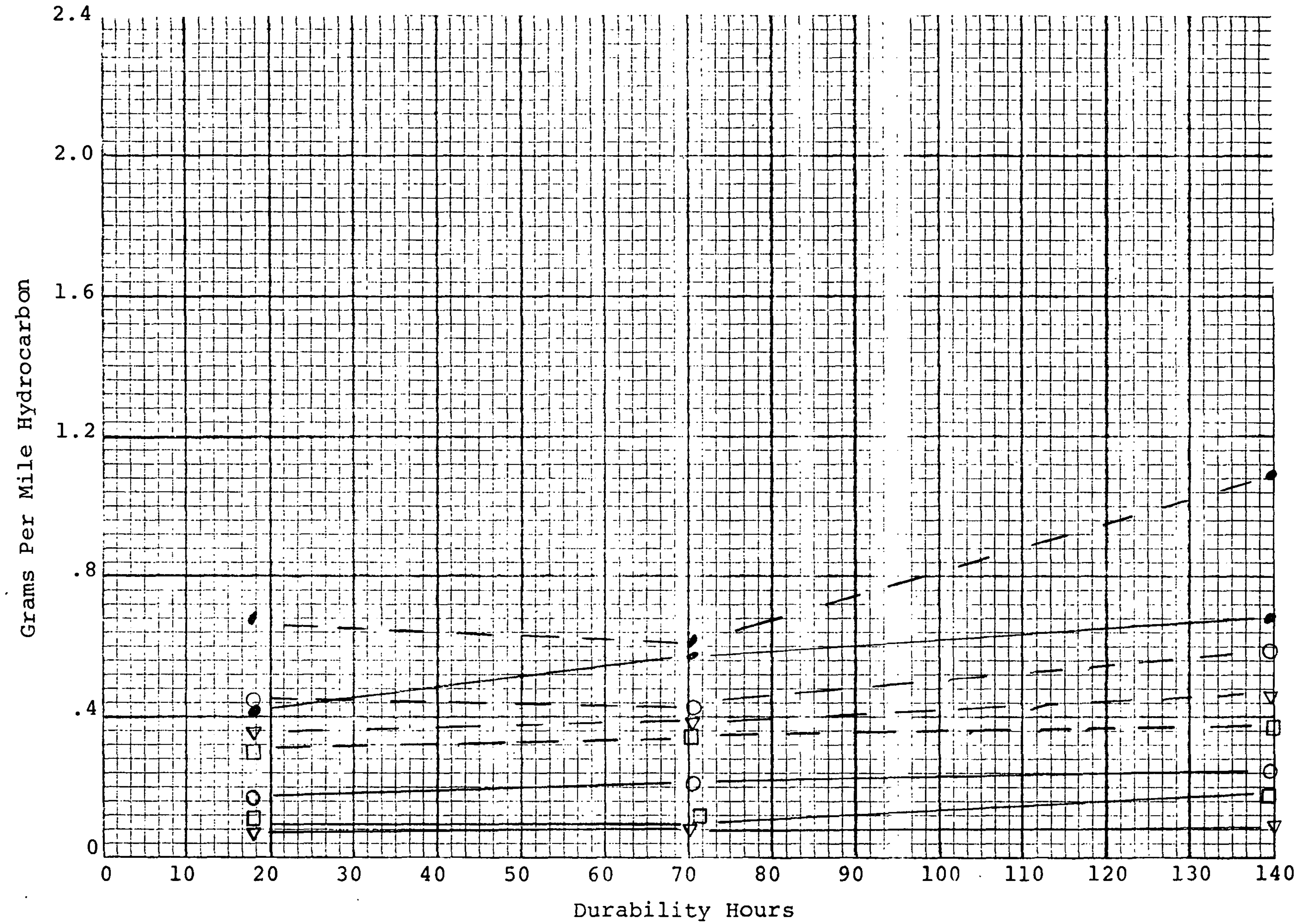


CVS EMISSIONS FEDERAL CYCLE MODIFIED

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Beaded Catalyst
"A" Additive

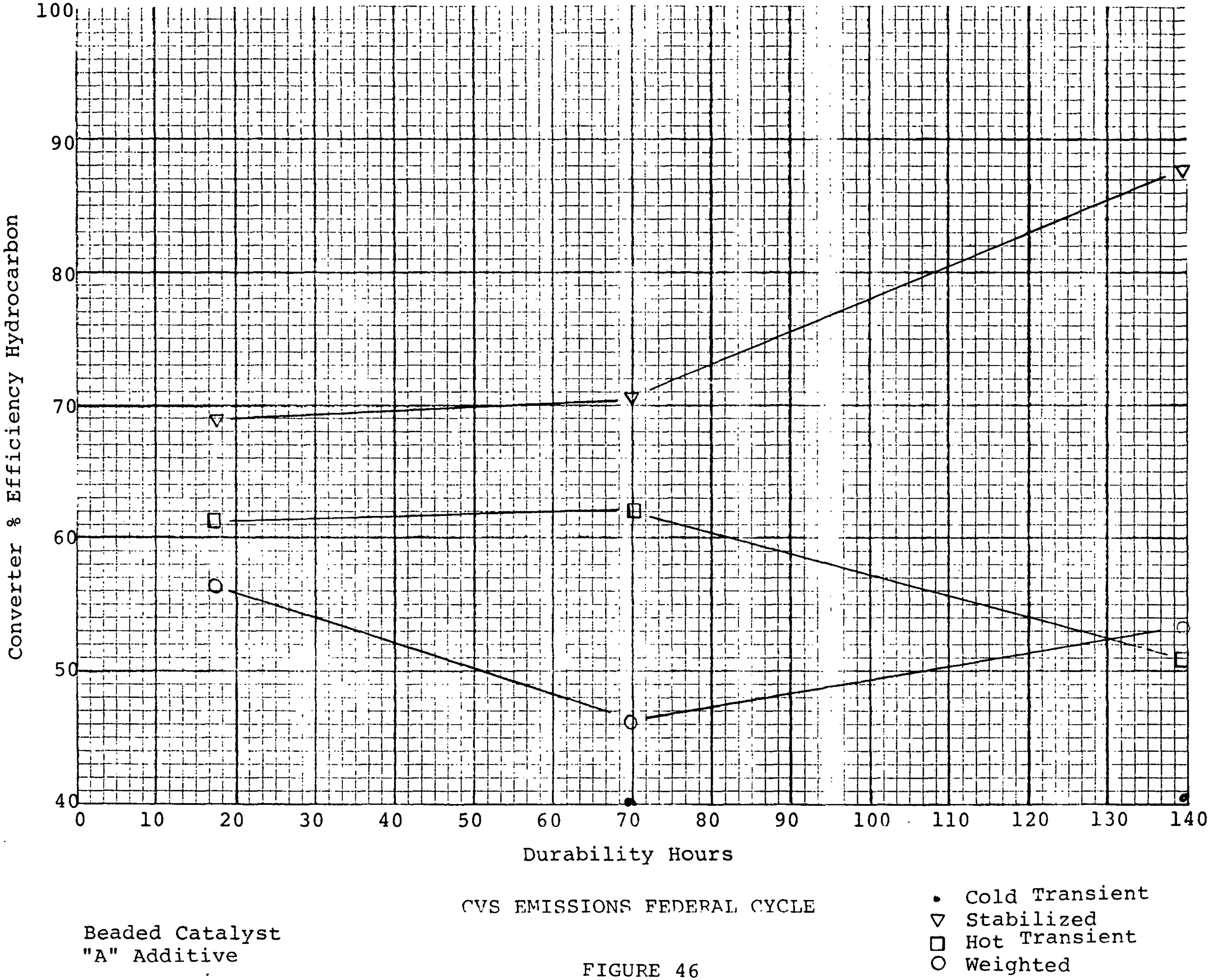
FIGURE 44



Beaded Catalyst
"A" Additive

CVS EMISSIONS FEDERAL CYCLE

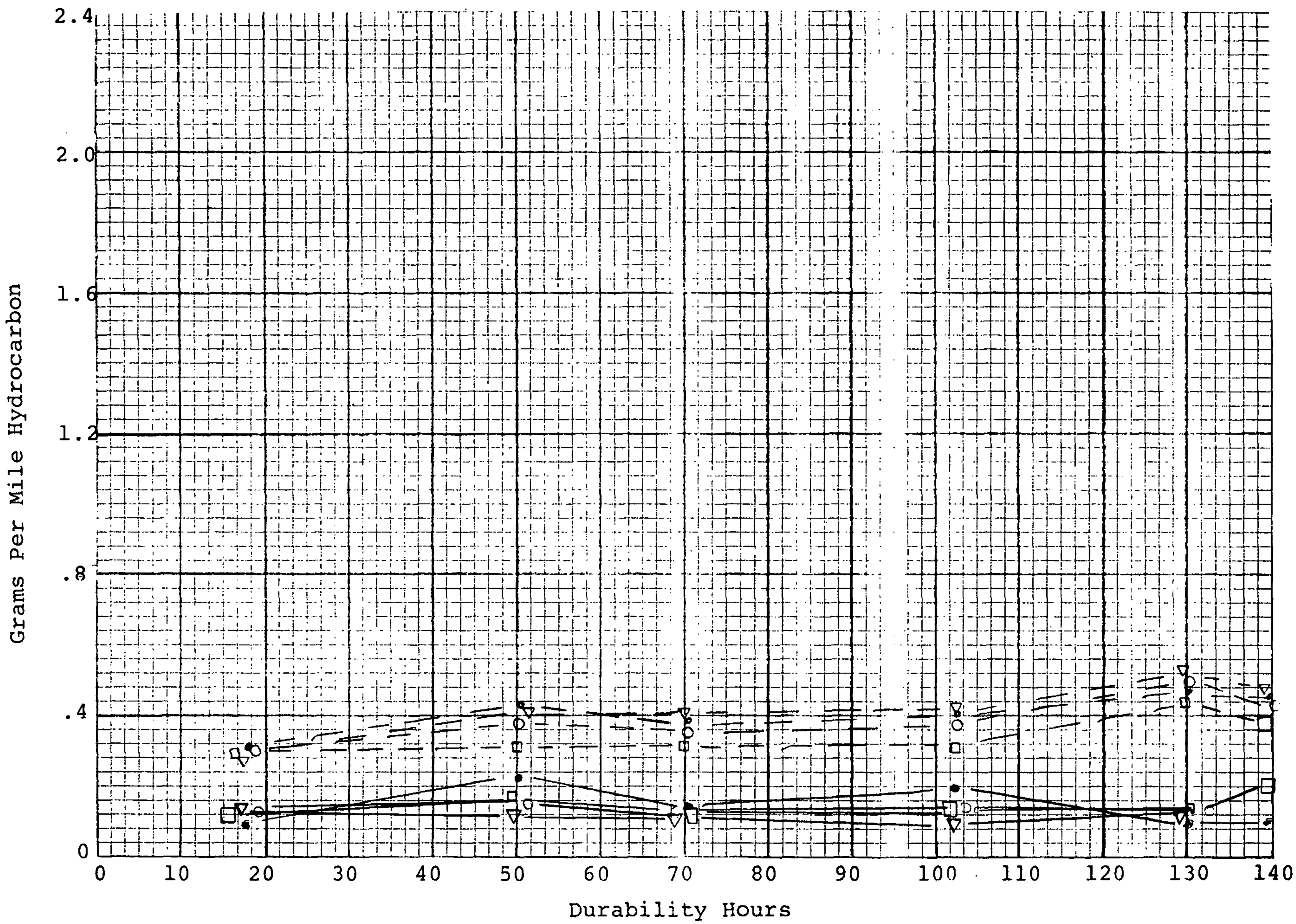
FIGURE 45



CVS EMISSIONS FEDERAL CYCLE

Beaded Catalyst
"A" Additive

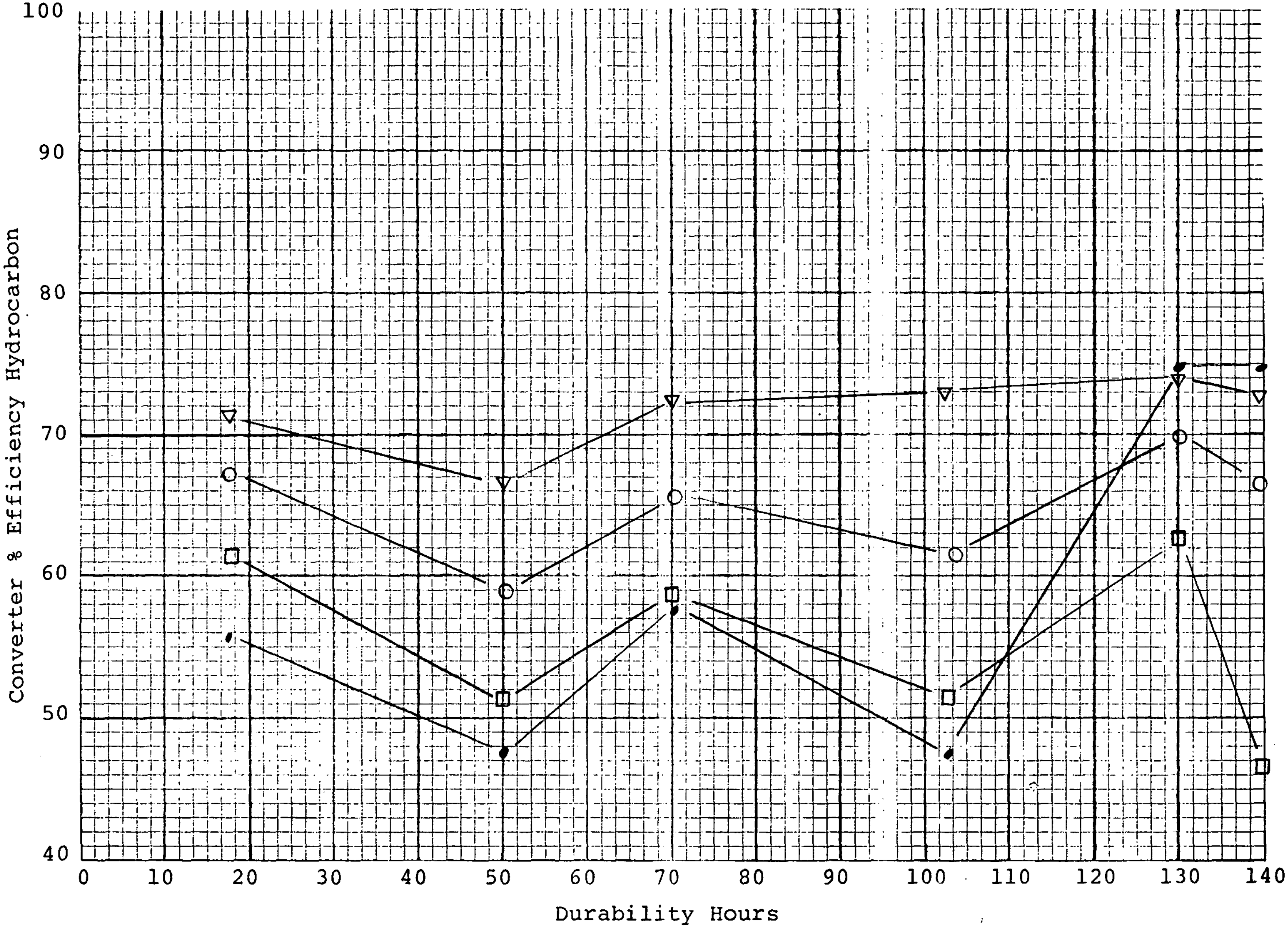
FIGURE 46



Beaded Catalyst
"A" Additive

CVS EMISSIONS FEDEPAL CYCLF MODIFIED

FIGURE 47



CVS EMISSIONS FEDERAL CYCLE MODIFIED

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Beaded Catalyst
"A" Additive

FIGURE 48

COMMENTS: Additive "B"

1. The carbon monoxide conversion efficiency appears to be much better than the hydrocarbon conversion efficiency, as measured by both Federal Cycle and Modified Federal Cycle.

2. There is no significant degradation of catalyst efficiency for carbon monoxide conversion during the durability test period.

3. There is a slight drop in converter efficiency over the durability test period as shown by the weighted data curves for both the Federal and Federal Cycle Modified test sequence. The data also shows that this drop is due largely to the cold transient portion of the test sequence which one would expect.

TABLE 19. "B" ADDITIVE, BEADED CATALYST, ENGINE STAND, RAW DATA, GRAMS/MILE.*

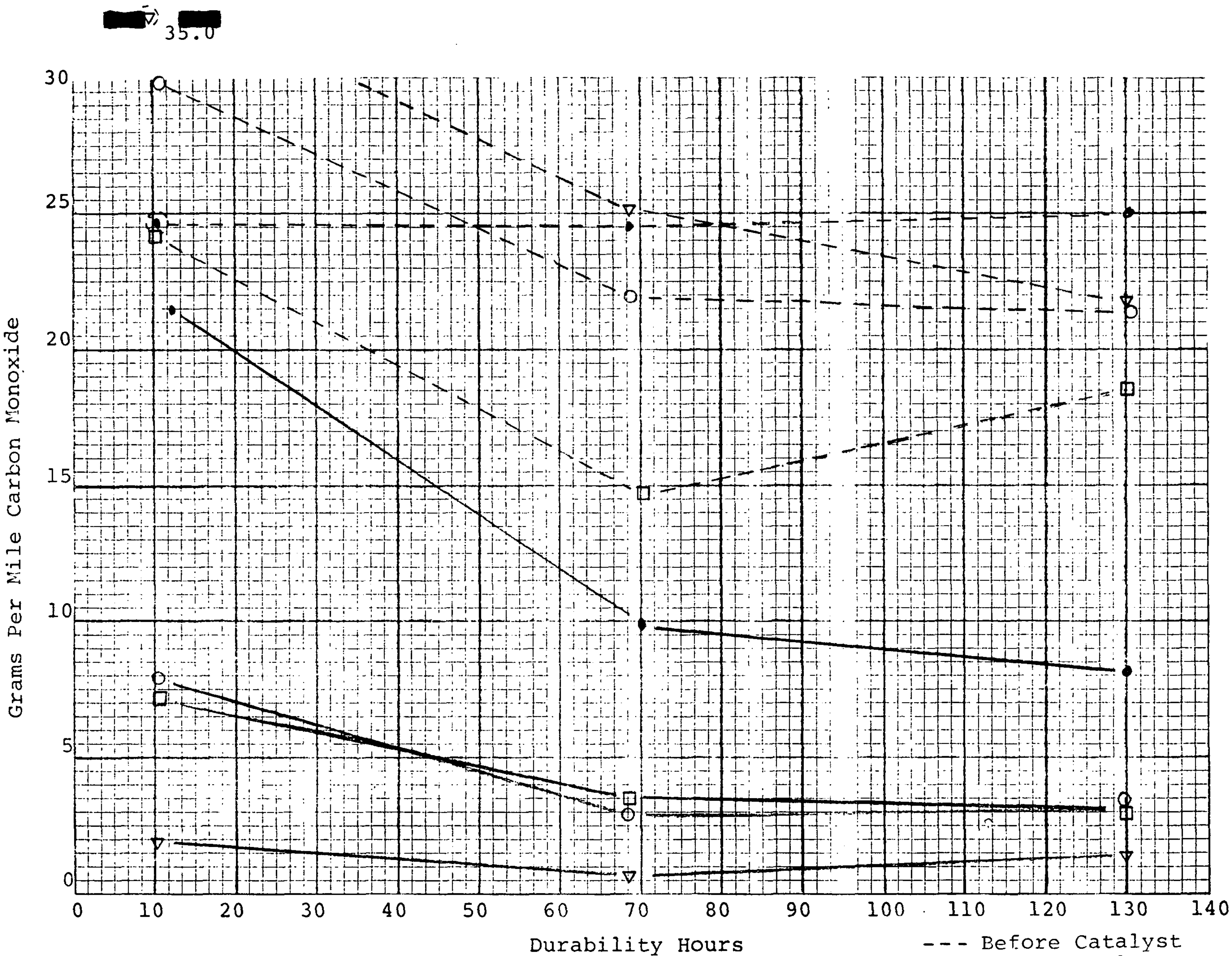
Cold		Hot		Hot		Cold		Hot		Hot		Hot		Cold		Hot		Hot		
HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	
11		11		49		68		68		84		104		130		130		140		Durability Hours
Without Converter																				
5.71	24.53	1.07	24.51	.91	21.27	1.88	24.65	1.01	19.09	.99	20.19	1.19	22.51	1.17	25.06	.78*	18.78	.85	15.96	Cold Transient
1.25	35.23	1.11	25.21	1.12	28.21	1.27	25.19	1.23	22.73	1.30	24.36	1.40	26.56	.96	21.78	1.04	13.95	1.14	17.56	Stabilized
.83	24.53	.83	21.51	.79	22.48	1.01	14.73	.99	19.46	.99	21.5	1.11	19.46	.75	18.81	.86	15.59	.91	16.77	Hot Transient
2.03	30.24	1.03	24.09	.99	25.29	1.32	22.3	1.12	21.13	1.16	22.76	1.28	23.87	.95	21.65	.94	15.36	1.02	17.03	Weighted
With Converter																				
.93	24.60	.34	10.02	.24	1.58	.57	9.92	.66	8.41	.90	15.07	.84	9.48	.74	22.27*	.46	8.27	.45	6.04	Cold Transient
.20	1.93	.22	2.92	.23	.93	.26	.50	.26	.87	.42	3.06	.38	.92	.30	1.62	.31	1.40	.29	1.52	Stabilized
.20	7.63	.21	5.21	.36	3.70	.40	3.76	.37	3.88	.51	7.08	.49	3.74	.36	4.31	.37	3.24	.49	5.68	Hot Transient
.34	8.00	.24	4.95	.27	1.80	.36	3.26	.37	3.18	.54	6.54	.50	3.39	.41	6.48	.36	3.27	.38	3.54	Weighted
% Efficiency																				
83.7	x	68.2	59.1	73.6	92.5	69.6	59.7	34.6	55.9	9.0	25.3	29.4	57.8	36.7	11.1*	41.0	56.9	47.0	62.1	Cold Transient
84.0	94.5	80.1	88.4	79.4	95.6	79.5	98.0	78.8	96.1	67.6	87.4	72.8	96.5	68.7	92.5	70.1	89.9	74.5	91.3	Stabilized
75.9	69.3	74.6	75.7	54.4	83.5	60.3	74.4	62.6	80.0	48.4	67.0	55.8	80.7	52.0	77.0	56.9	79.2	46.1	66.1	Hot Transient
83.2	73.5	76.6	79.4	72.7	92.8	72.7	85.3	66.9	84.9	53.4	71.2	60.9	85.7	56.8	70.0	61.7	78.7	62.7	79.2	Weighted

*Corrected for ambient conditions.

TABLE 20. AMBIENT CONDITIONS

"B" ADDITIVE - BEADED CATALYST ENGINE DYNAMOMETER

Modified Federal Cycle		X	X		X	X	X		X	X
Federal Cycle	X			X				X		
Durability Hours	11	11	49	68	68	84	104	130	130	140
<u>WITHOUT CONVERTER</u>										
Barometer	29.16	29.16	29.50	29.16	29.40	29.16	29.46	29.54	29.54	29.78
Corrected Barometer	29.04	29.04	29.37	29.03	29.27	29.03	29.32	29.46	29.46	29.65
Ambient Air °F	74.	74.	77.	77.	81.	77.	76.	77.	77.	76.
Wet Bulb °F	52.5	52.5	53.	54.	55.	54.	51.	53.	53.	54.
Dry Bulb °F	74.	74.	78.	78.	83.	78.	73.	78.	78.	78.
Humidity %	19.46	19.46	13.54	16.54	11.37	16.54	16.58	13.45	13.45	15.96
<u>WITH CONVERTER</u>										
Barometer	29.23	29.23	29.50	29.42	29.40	29.98	29.56	29.78	29.54	29.78
Corrected Barometer	29.11	29.11	29.37	29.30	29.27	28.85	29.42	29.65	29.46	29.65
Ambient Air °F	74.	74.	77.	75.	81.	77.	80.	76.	77.	76.
Wet Bulb °F	54.	54.	53.	50.5	55.	55.	54.	54.	53.	54.
Dry Bulb °F	75.	75.	78.	75.	83.	78.	79.	78.	78.	78.
Humidity %	21.92	21.92	13.54	11.63	11.37	19.42	16.58	15.96	13.45	15.96

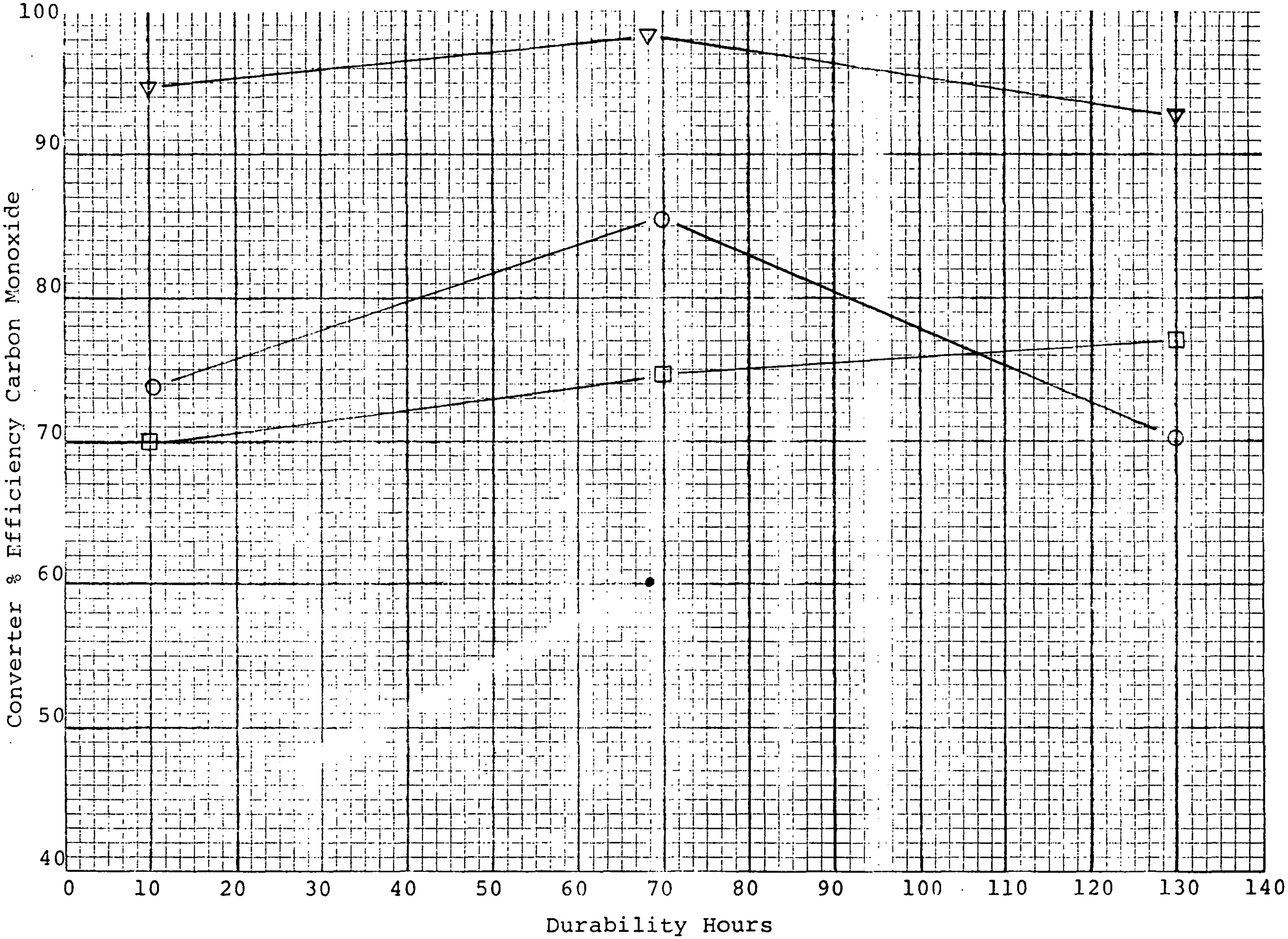


--- Before Catalyst
— After Catalyst
• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

CVS EMISSIONS FEDERAL CYCLE

Beaded Catalyst
"B" Additive

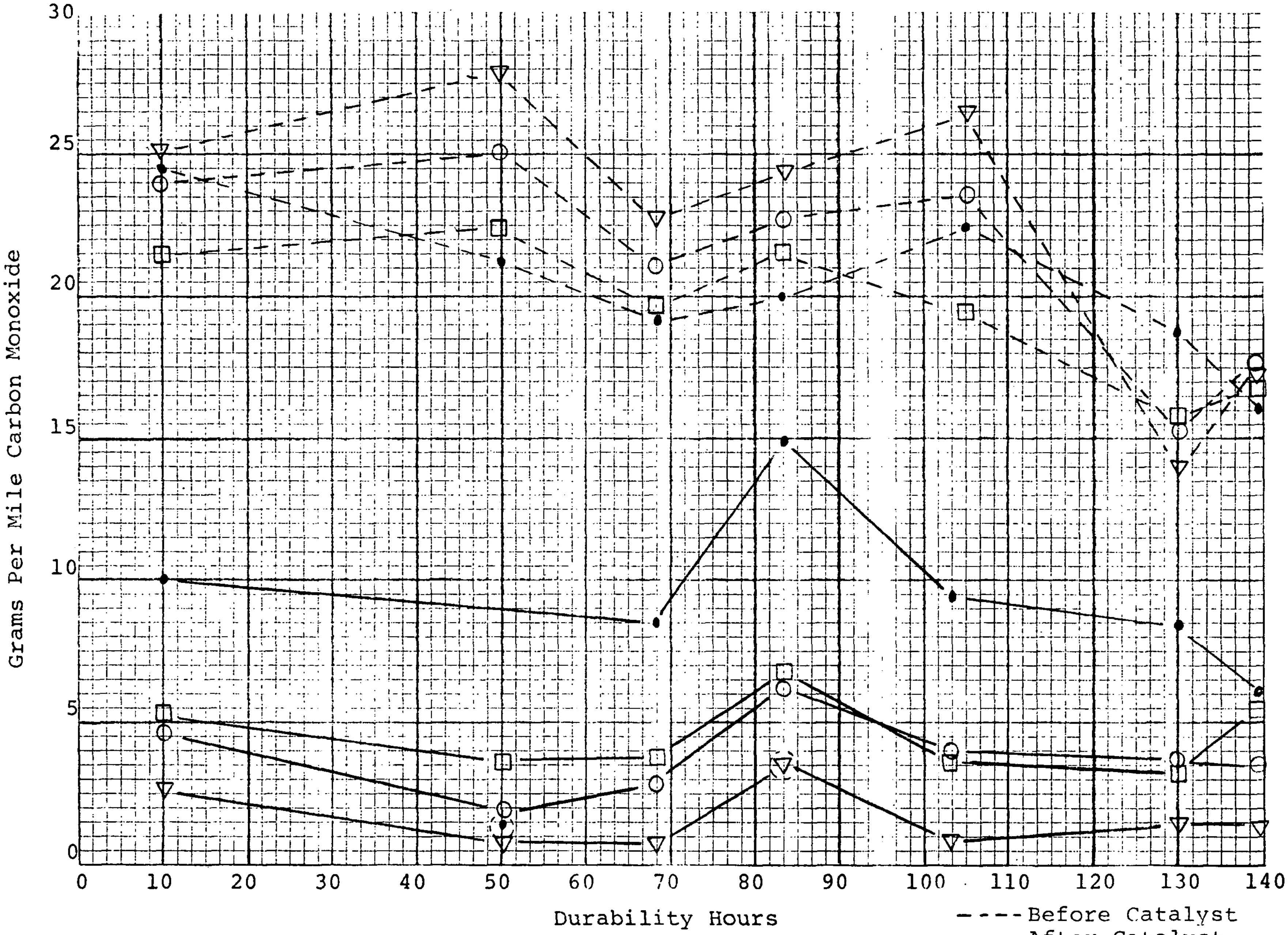
FIGURE 49



Beaded Catalyst
"B" Additive

CVS EMISSIONS FEDERAL CYCLE

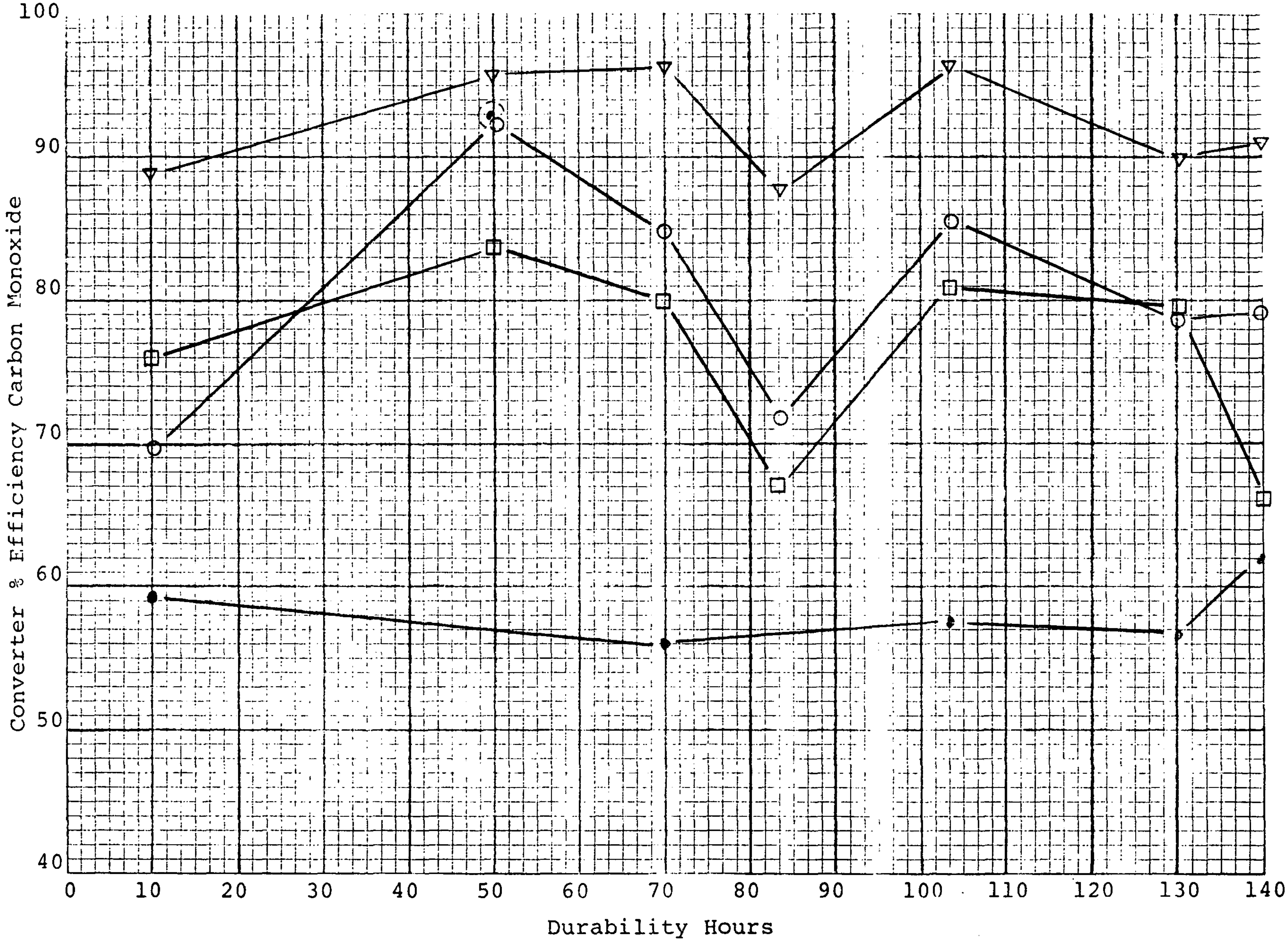
FIGURE 50



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Beaded Catalyst
"B" Additive

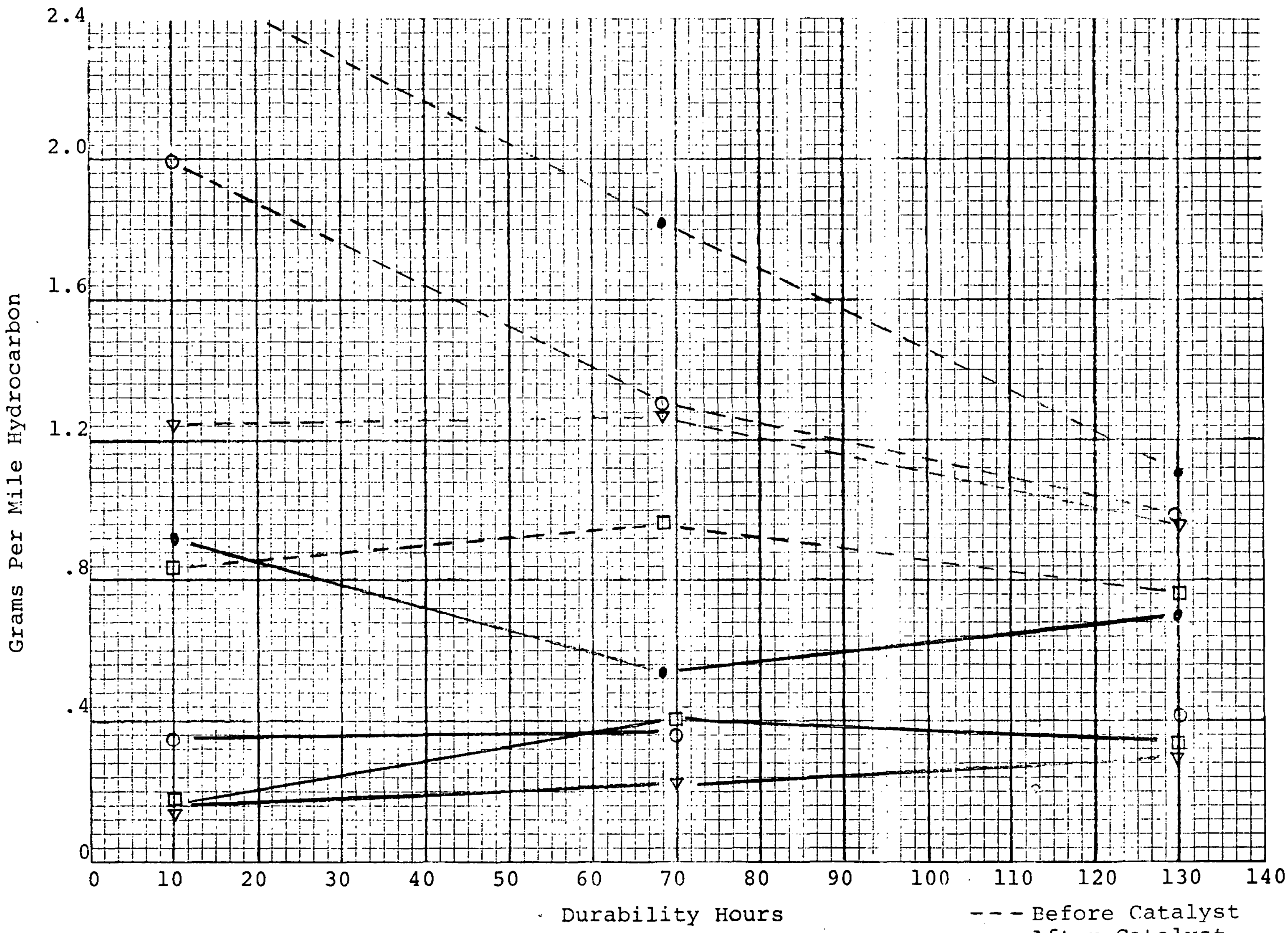
FIGURE 51



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Beaded Catalyst
"B" Additive

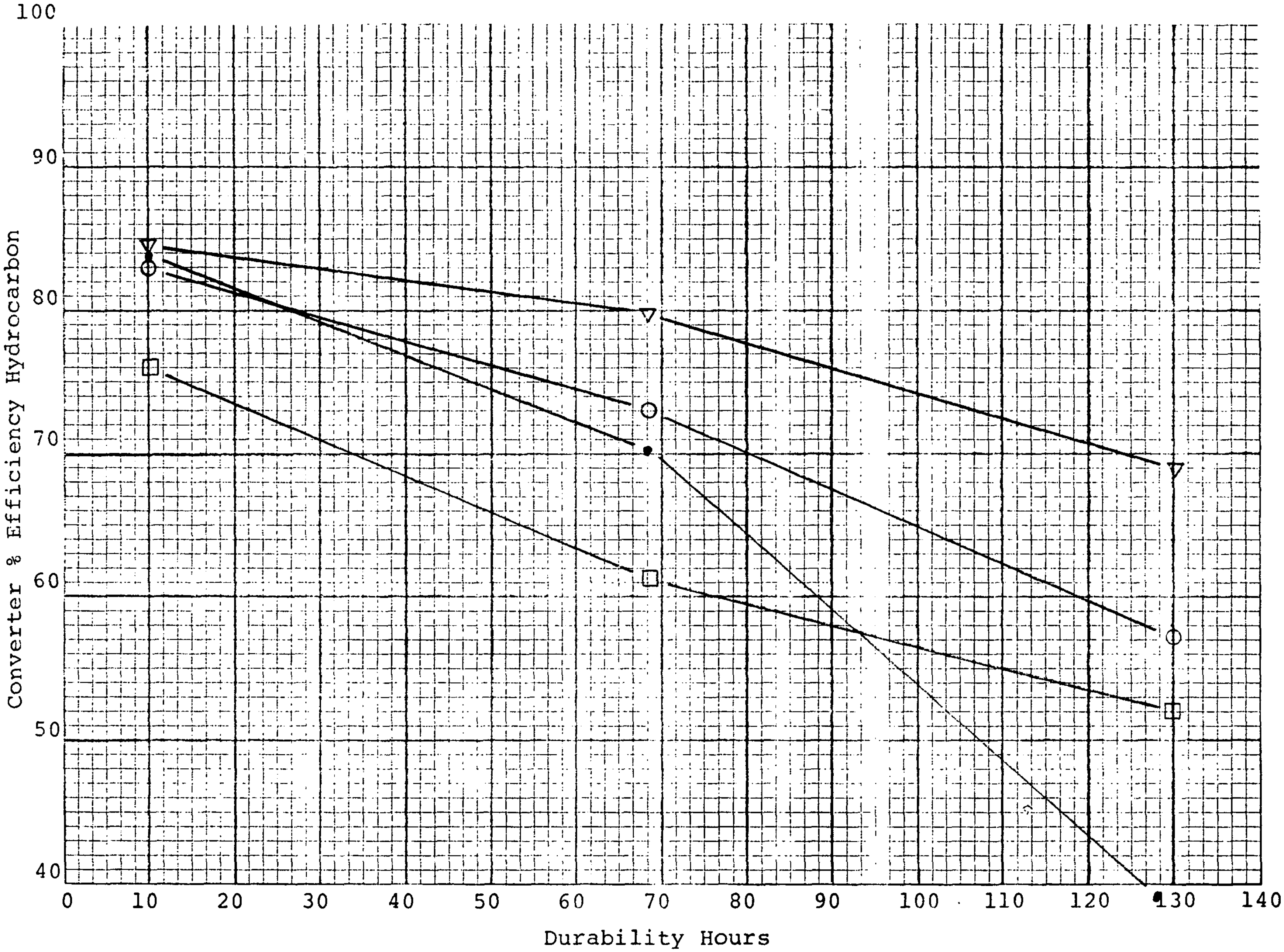
FIGURE 52



CVS EMISSIONS FEDERAL CYCLE

Beaded Catalyst
"B" Additive

FIGURE 53

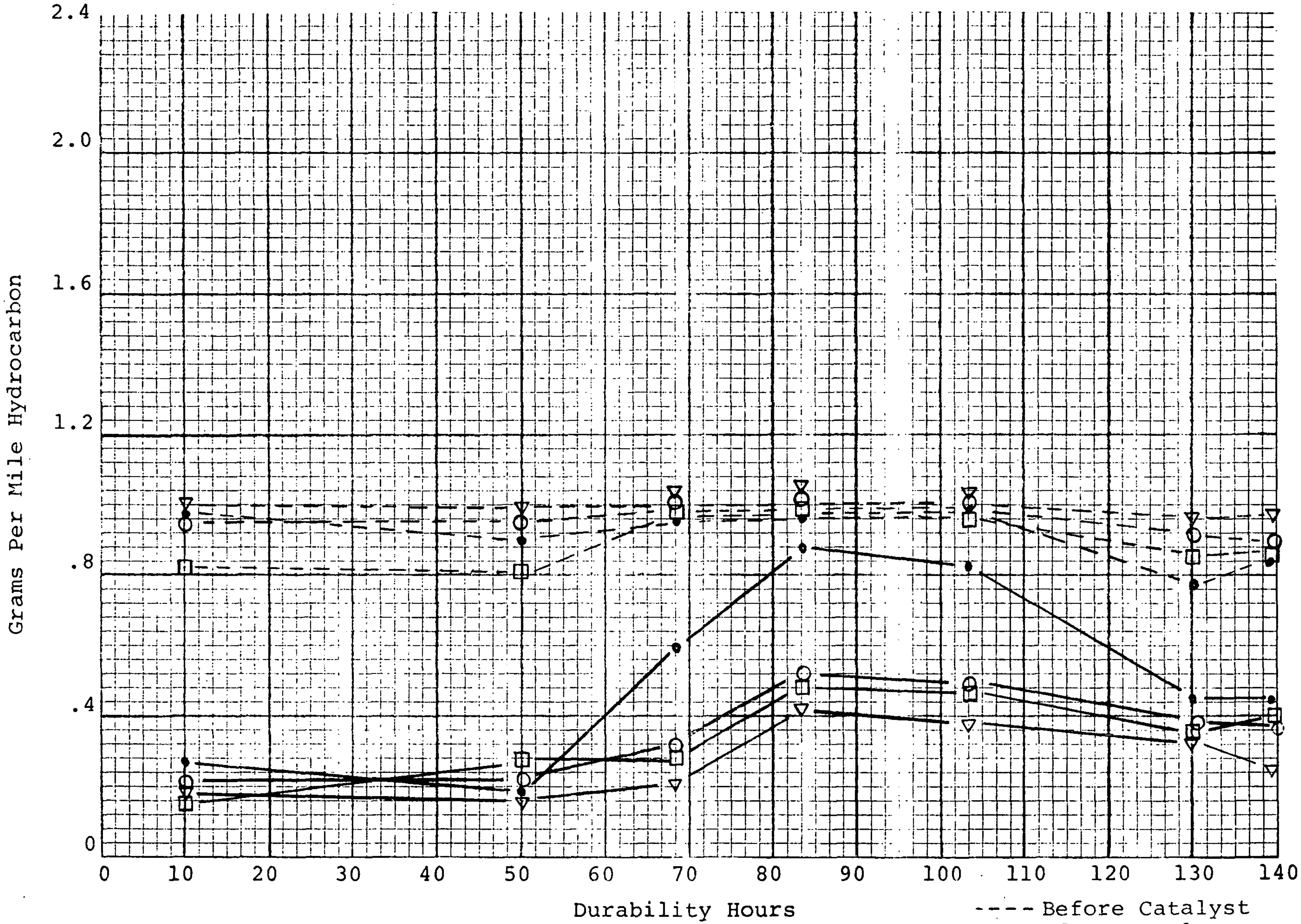


• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Beaded Catalyst
"B" Additive

CVS EMISSIONS FEDERAL CYCLE

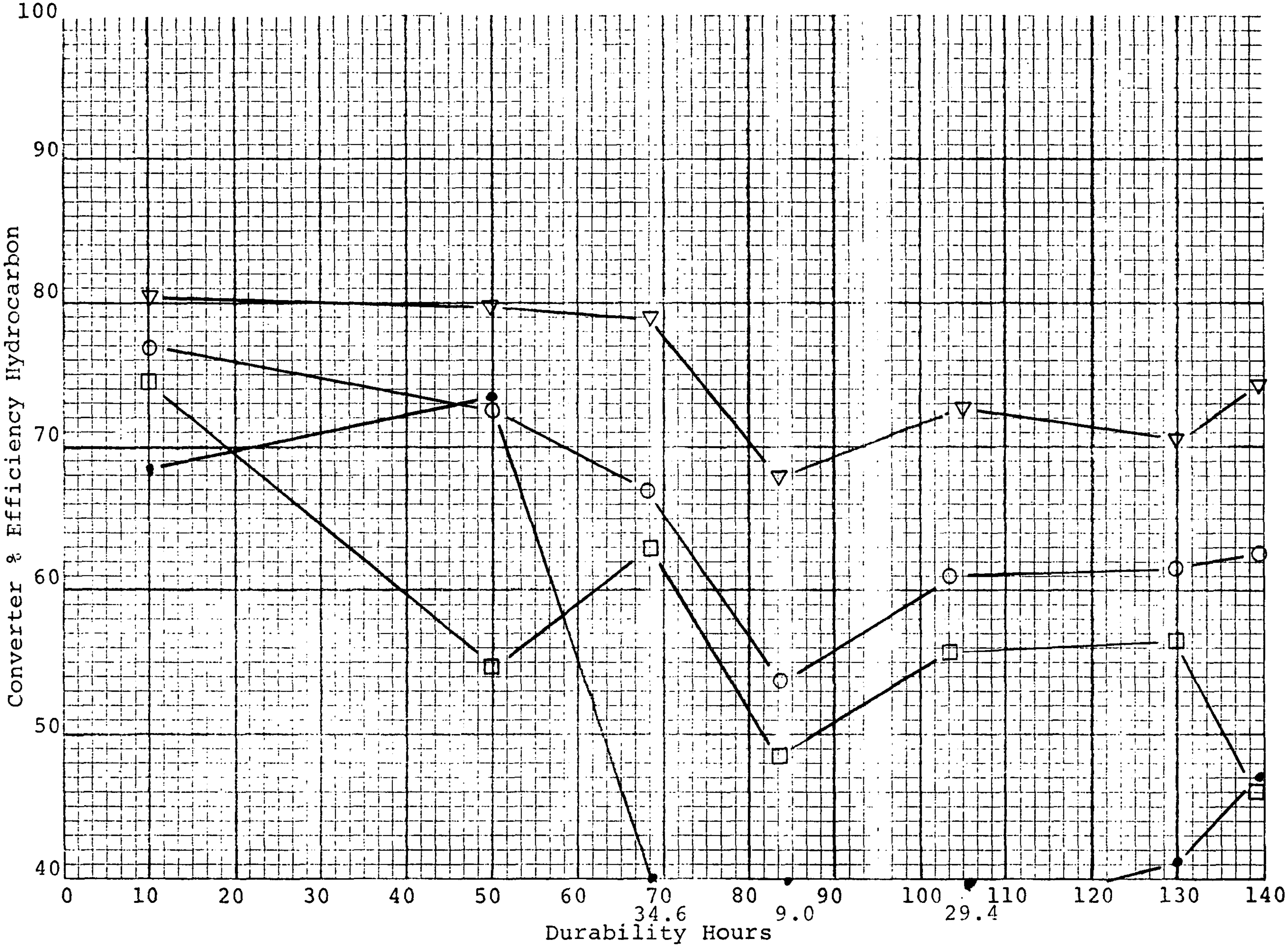
FIGURE 54



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Beaded Catalyst
"B" Additive

FIGURE 55



Beaded Catalyst
"B" Additive

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 56

D. Comparison of Three Fuels, Engine Stand, Beaded Catalyst

COMMENTS:

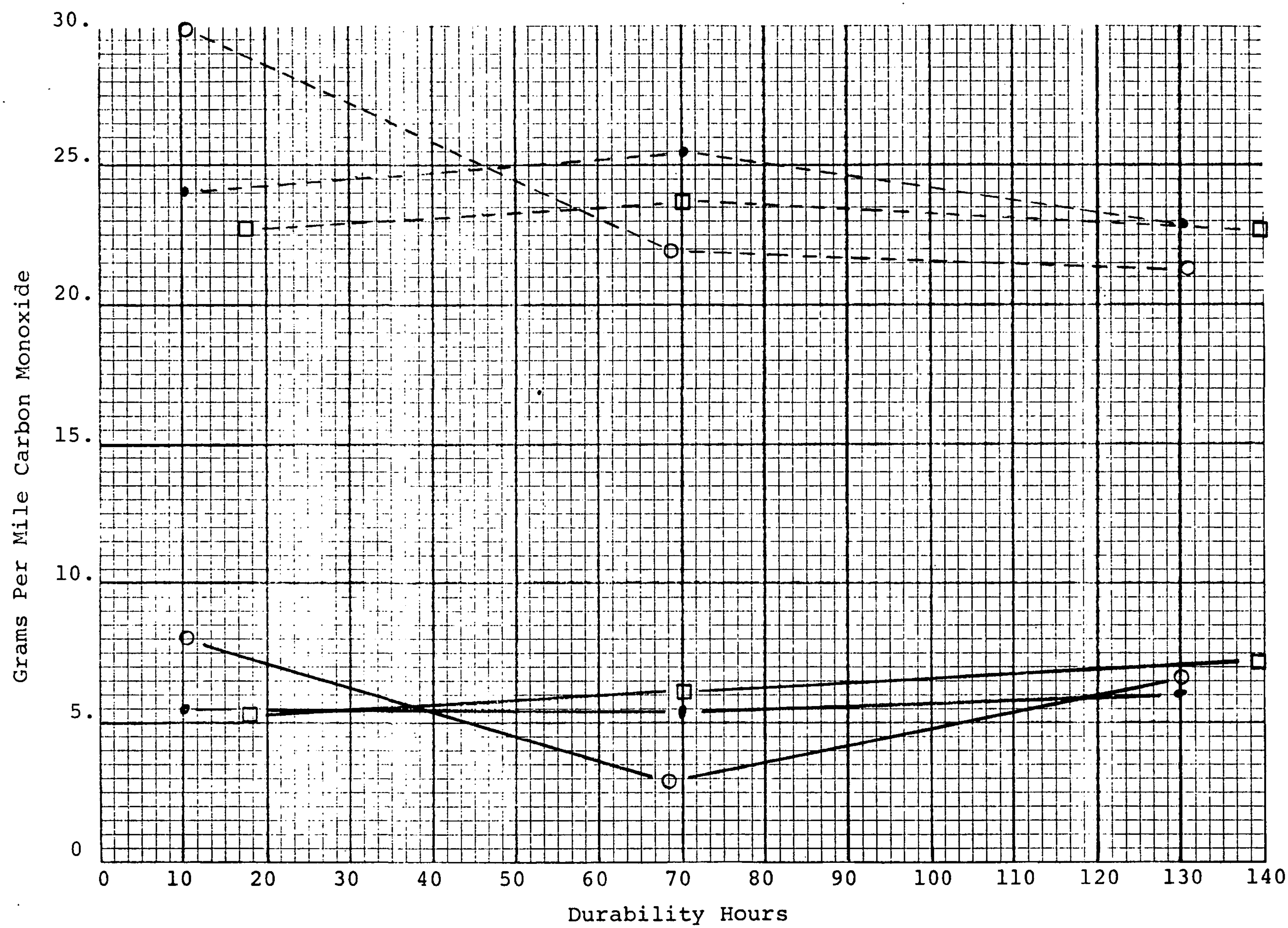
1. With respect to carbon monoxide emissions for the Federal Cycle Modified, the conversion efficiency for the base fuel is slightly better than Additive "A" or Additive "B", at the conclusion of 140 hours.

2. With respect to carbon monoxide emissions for the Federal Cycle, the conversion efficiency for the three fuels is similar with the base fuel being the best and Additive "A" fuel somewhat poorer.

3. With respect to hydrocarbon emissions, when tested under the Federal Cycle Modified, the conversion efficiency is best for the base fuel, while Additives "A" and "B" are slightly poorer.

4. With respect to hydrocarbon emissions from the Federal Cycle, Additive "A" and "B" show somewhat poorer conversion efficiency than the base fuel, as well as a decline in efficiency over time.

5. The fuel containing Additive "B" produced higher hydrocarbon emissions, as measured before the catalyst, thus the converter efficiency for Additive "B" appears to be the best. This phenomena makes it difficult to make absolute comparisons of the relative efficiencies after the converter.

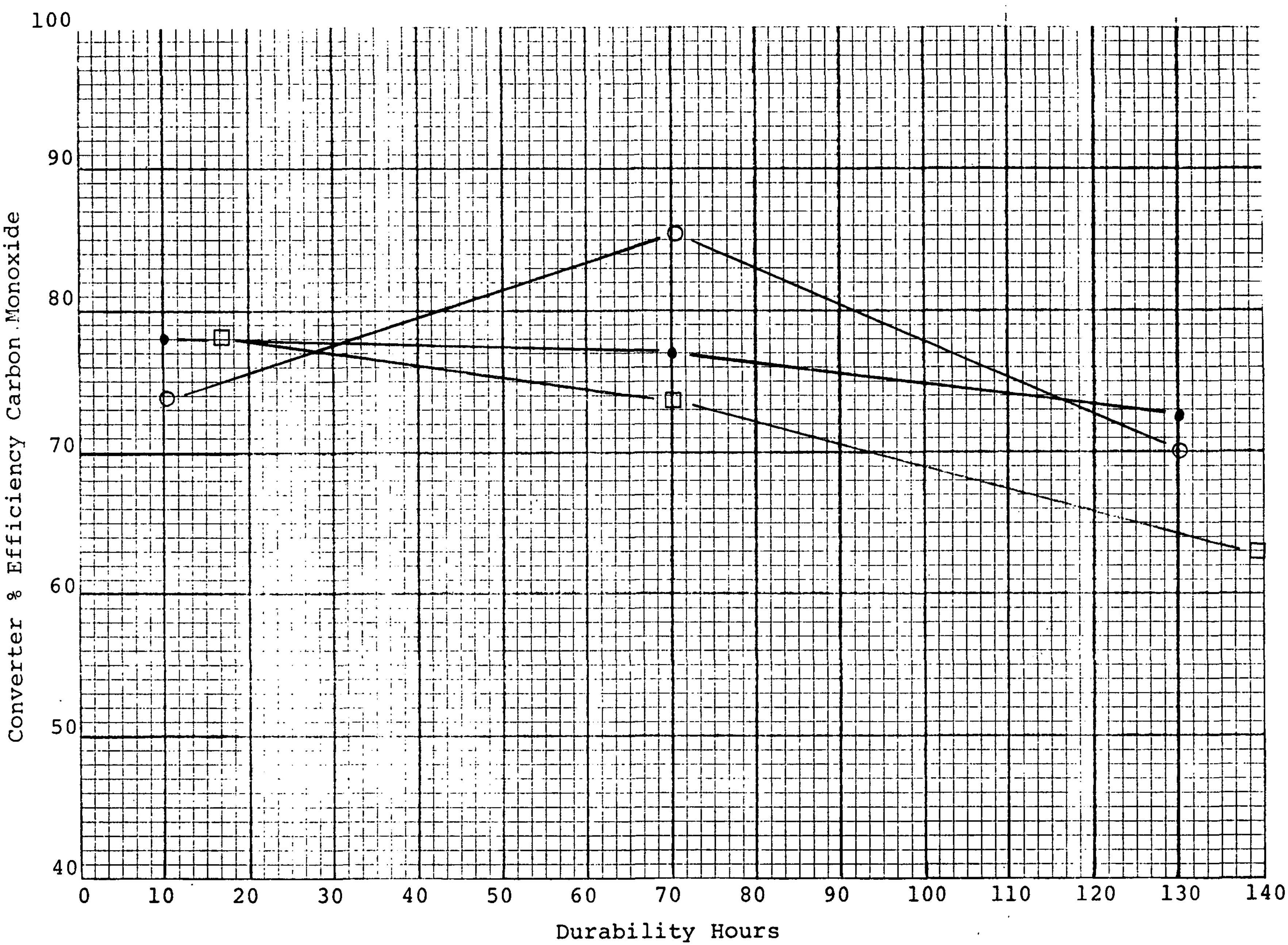


Beaded Catalyst

CVS EMISSIONS FEDERAL CYCLE

Engine Dynamometer

FIGURE 57



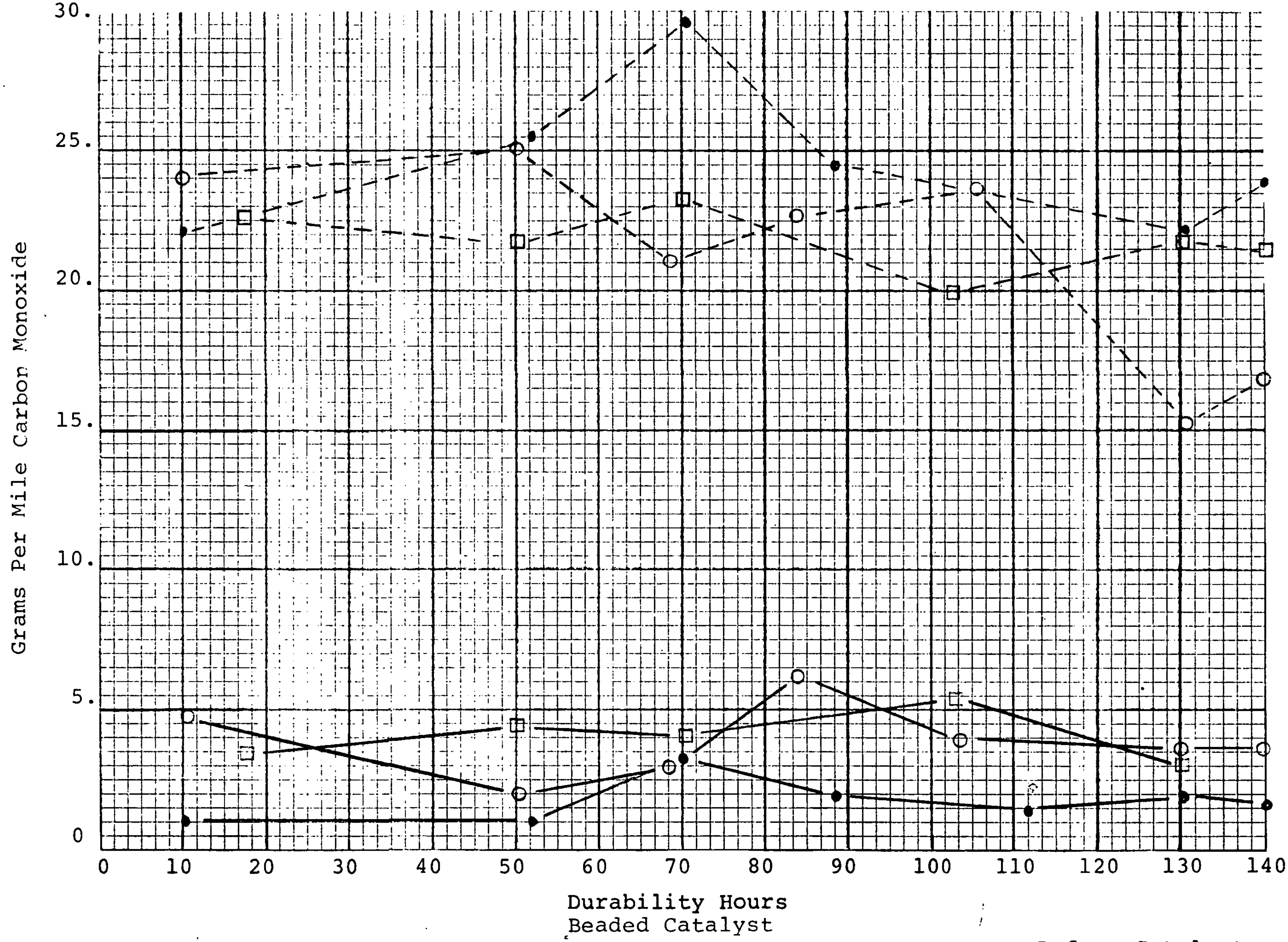
Beaded Catalyst

CVS EMISSIONS FEDERAL CYCLE

Engine Dynamometer

FIGURE 58

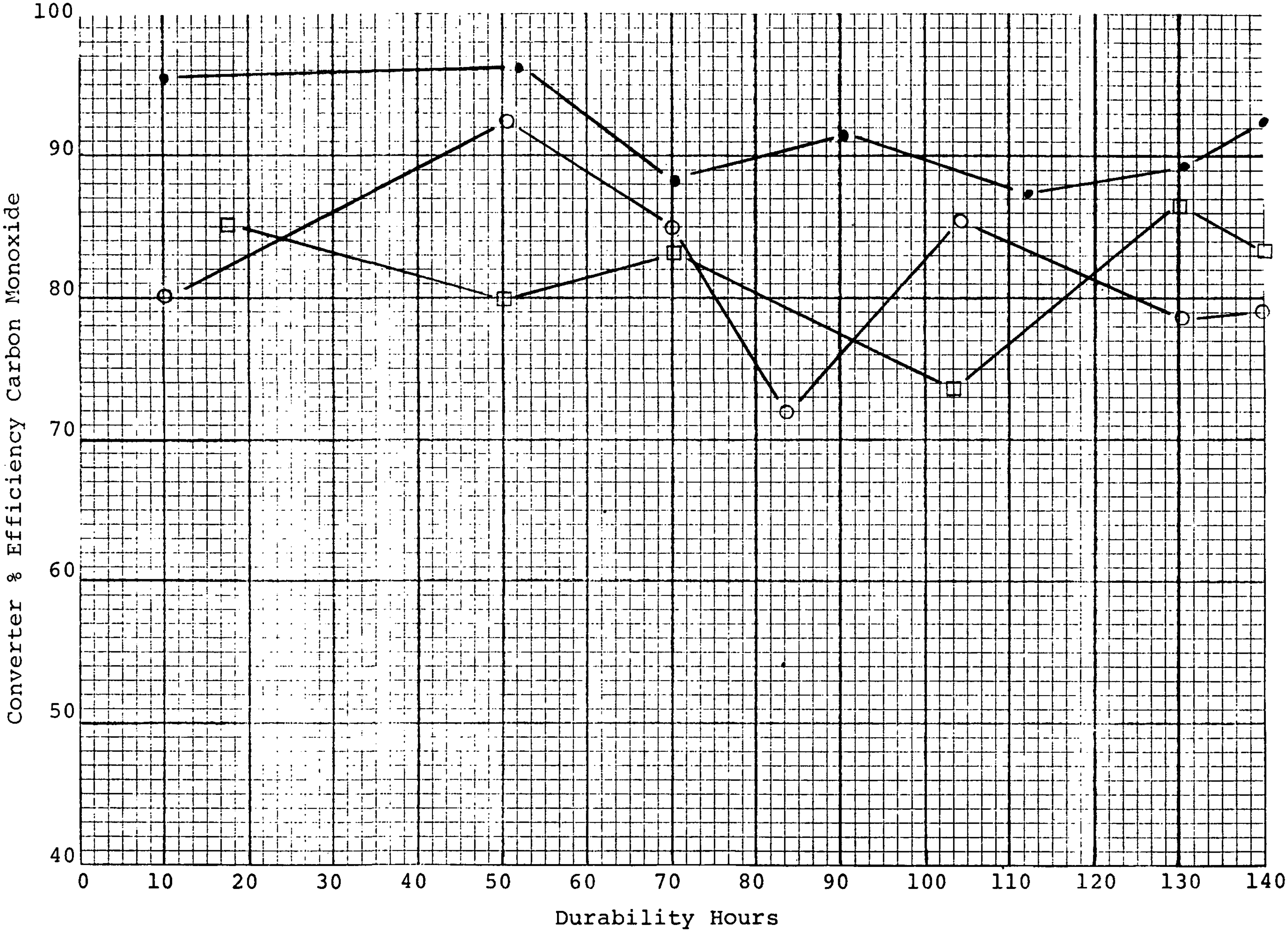
• Base Fuel
□ "A" Additive
○ "B" Additive



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Engine Dynamometer

FIGURE 59

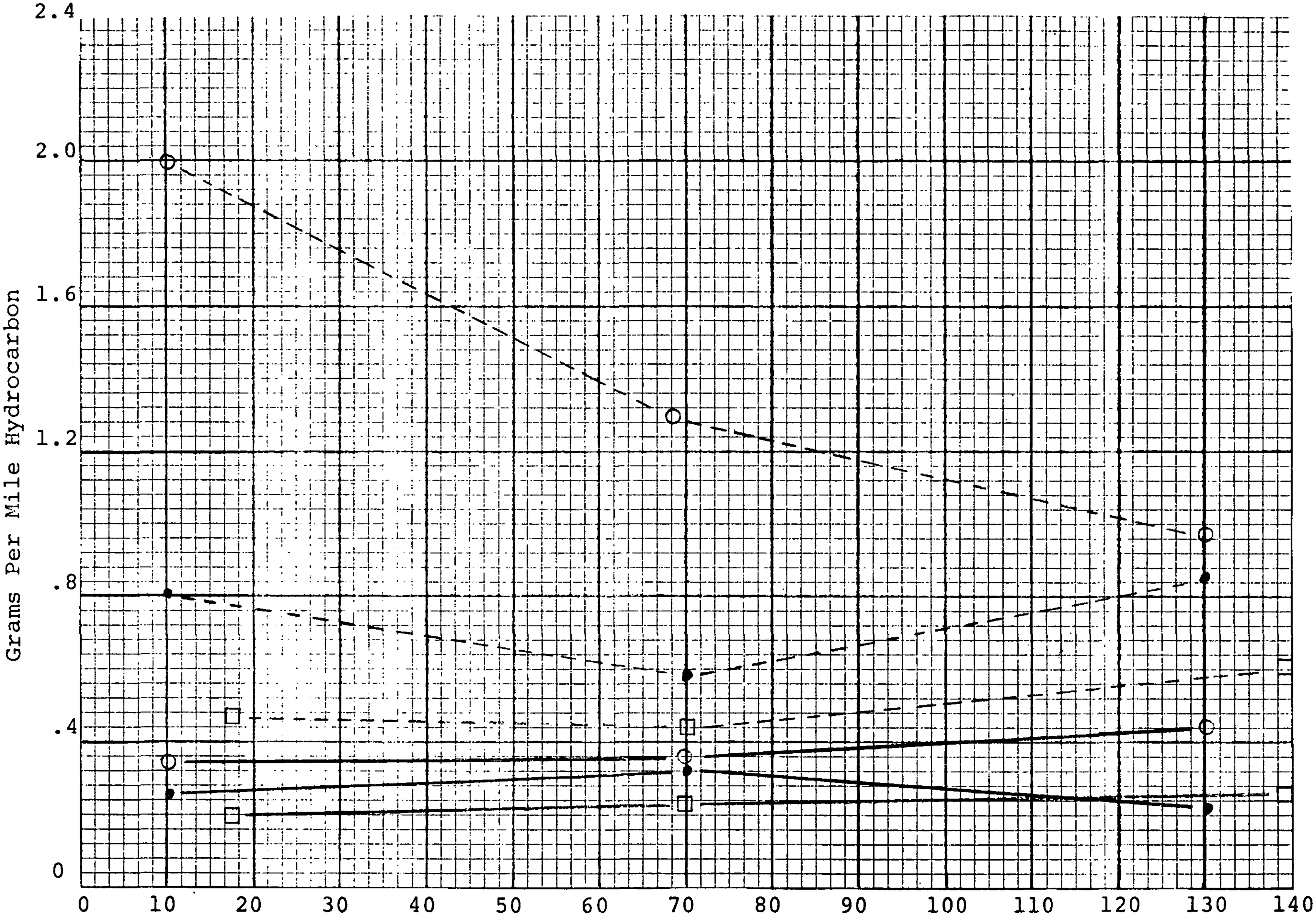


CVS EMISSIONS FEDERAL CYCLE MODIFIED

• Base Fuel
□ "A" Additive
○ "B" Additive

Engine Dynamometer

FIGURE 60



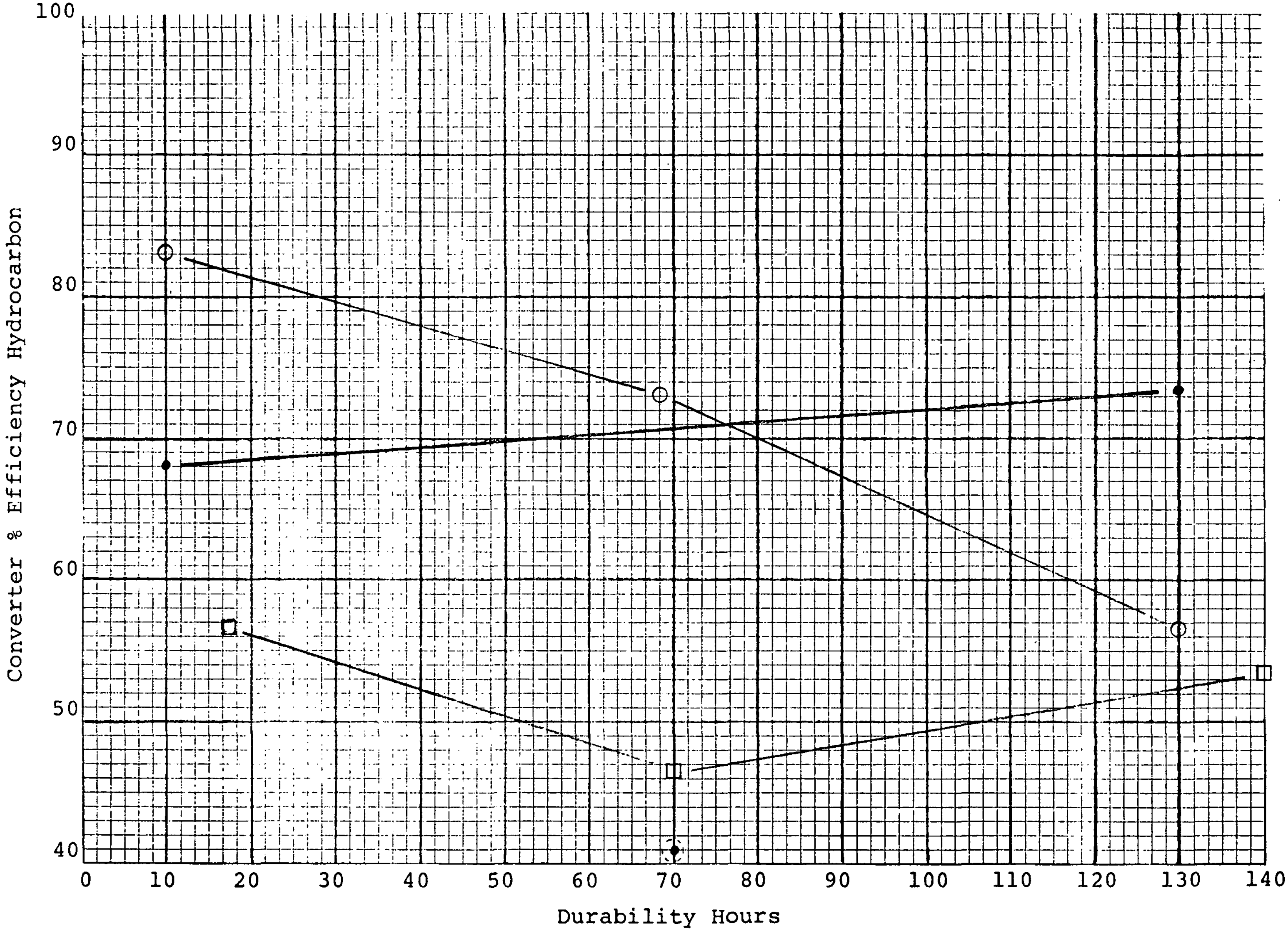
Beaded Catalyst

Before Catalyst
After Catalyst
• Base Fuel
□ "A" Additive
O "B" Additive

CVS EMISSIONS FEDERAL CYCLE

Engine Dynamometer

FIGURE 61



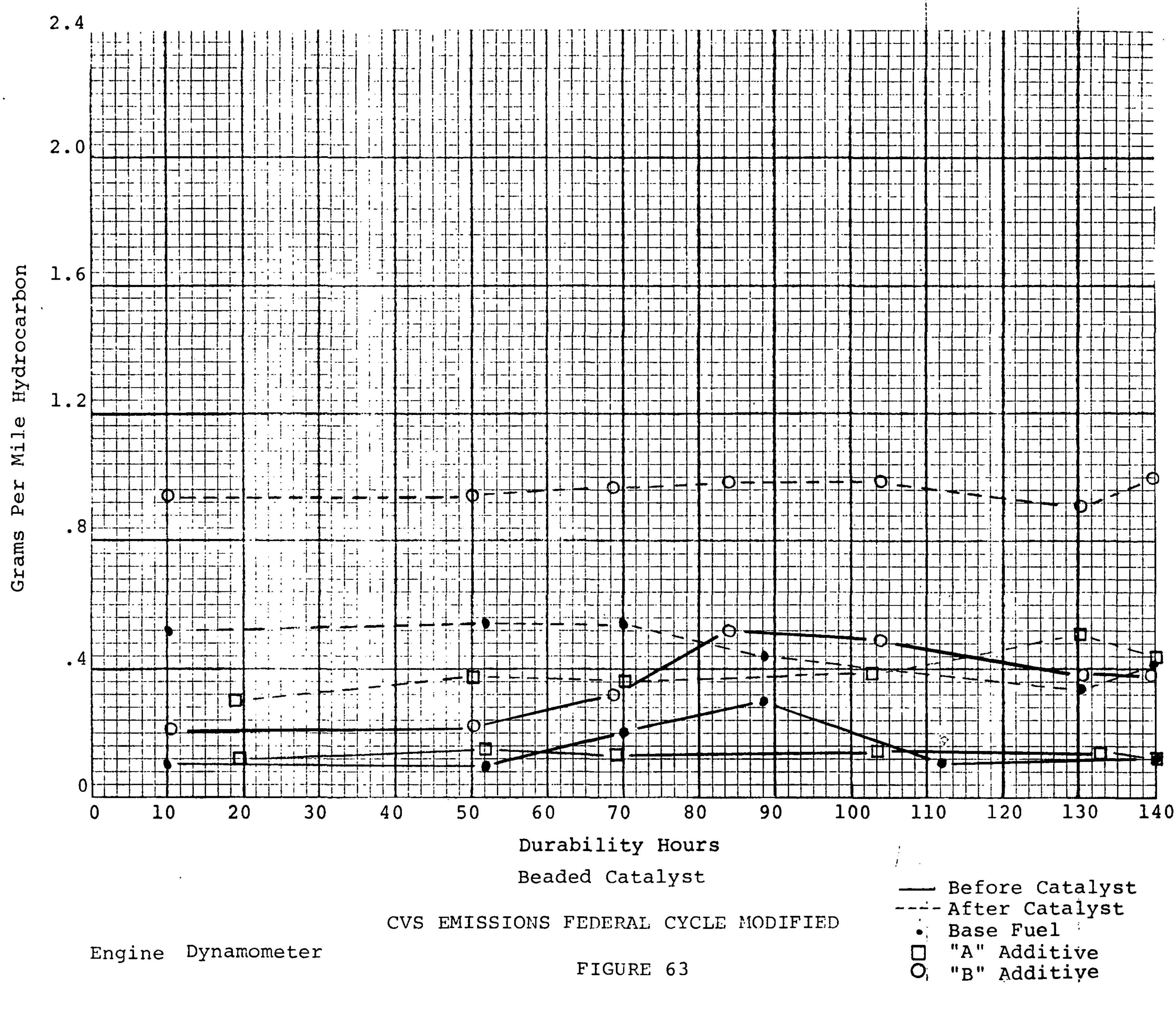
Beaded Catalyst

Engine Dynamometer

CVS EMISSIONS FEDERAL CYCLE

FIGURE 62

• Base Fuel
□ "A" Additive
○ "B" Additive

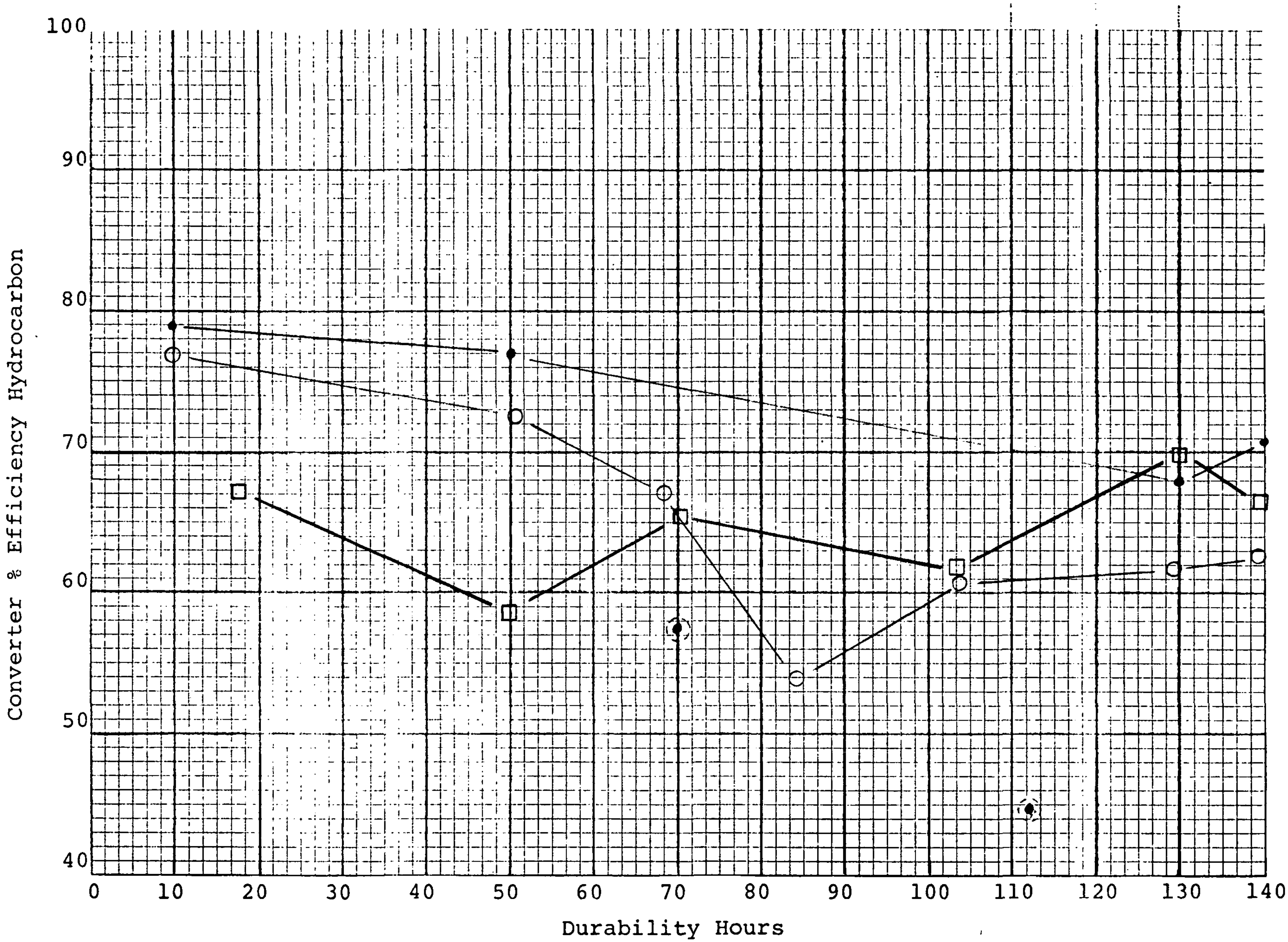


Beaded Catalyst

CVS EMISSIONS FEDERAL CYCLE MODIFIED

Engine Dynamometer

FIGURE 63



Beaded Catalyst

CVS EMISSIONS FEDERAL CYCLE MODIFIED

Engine Dynamometer

FIGURE 64

• Base Fuel
□ "A" Additive
○ "B" Additive

E. Comparison of Beaded and Monolithic Catalysts, Engine Stand, Three Fuels

The following set of graphs are a comparison of the monolithic type catalysts versus the beaded type catalysts, using the base fuel and the two additive fuels. This data compares hydrocarbon and carbon monoxide emission levels under Federal Cycle and the Federal Cycle Modified test condition, measured on an engine dynamometer.

COMMENTS: Base Line Fuel

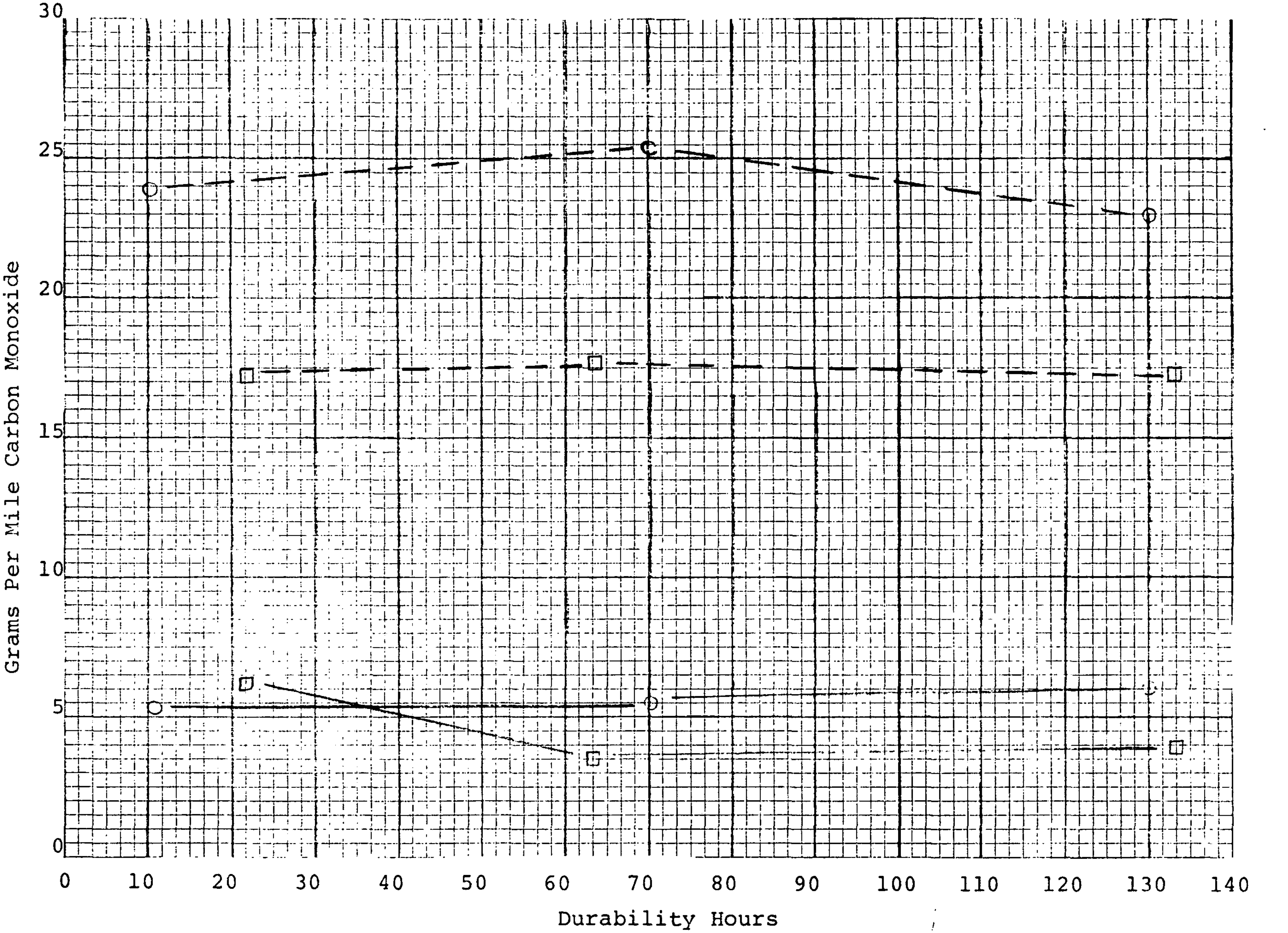
1. Carbon monoxide emission levels were lower using the beaded catalysts for both the Federal Cycle and the Federal Cycle Modified.

2. Hydrocarbon emissions measured during the Federal Cycle conditions showed little difference between the two catalysts as far as efficiency. Under Federal Cycle Modified conditions, the beaded type catalysts appeared to be slightly more efficient.

3. There was no significant degradation of either catalyst over the durability hours study using base line fuel.

4. The beaded catalysts were slightly more efficient than the monolithic catalysts at the end of the durability test.

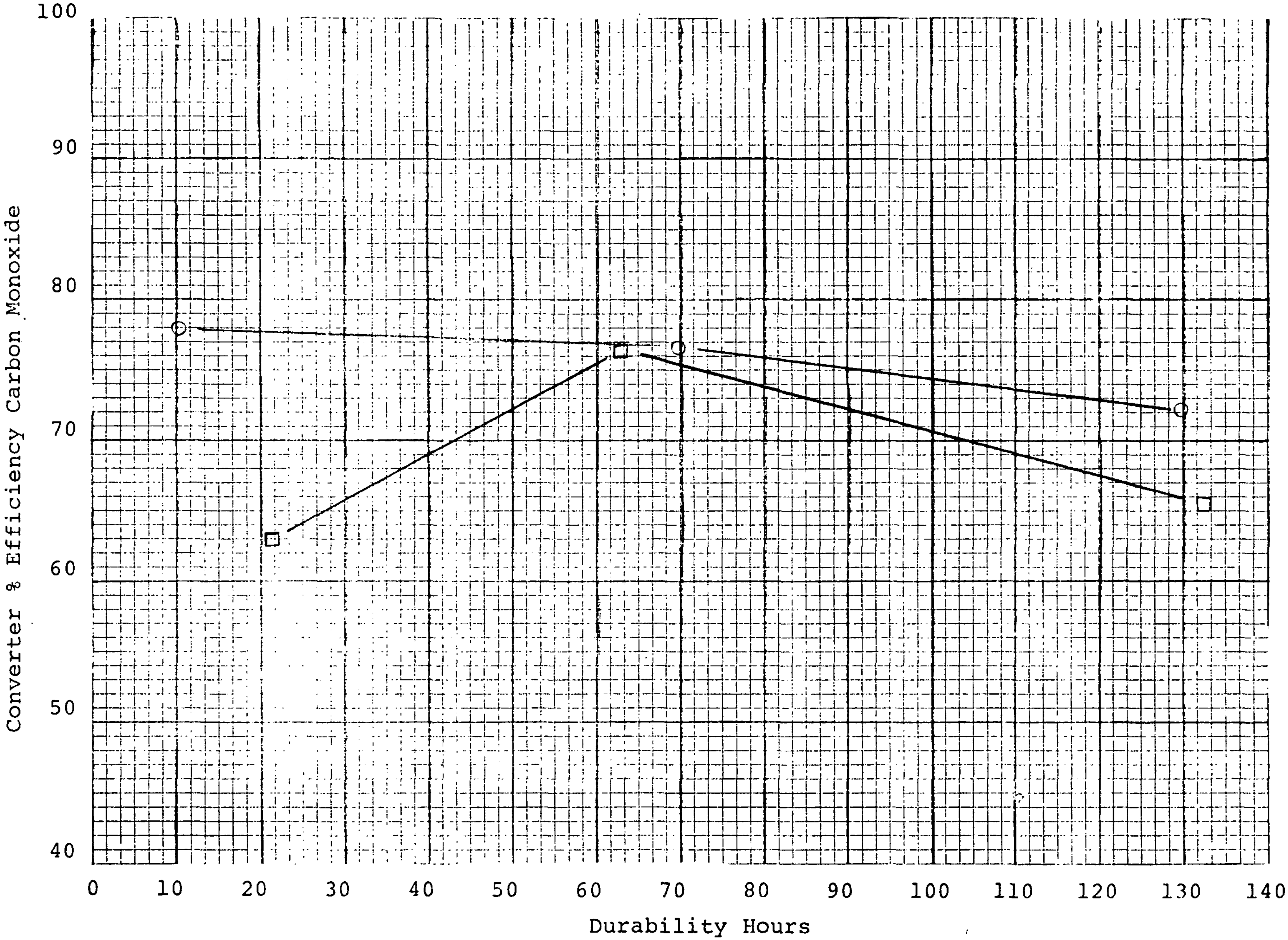
5. Both the monolithic catalysts and beaded catalysts were more effective in reducing the levels of carbon monoxide than they were in reducing hydrocarbons. This is especially true in the case of the Federal Cycle Modified.



CVS EMISSIONS FEDERAL CYCLE

Engine Dynamometer
Base Fuel

FIGURE 65

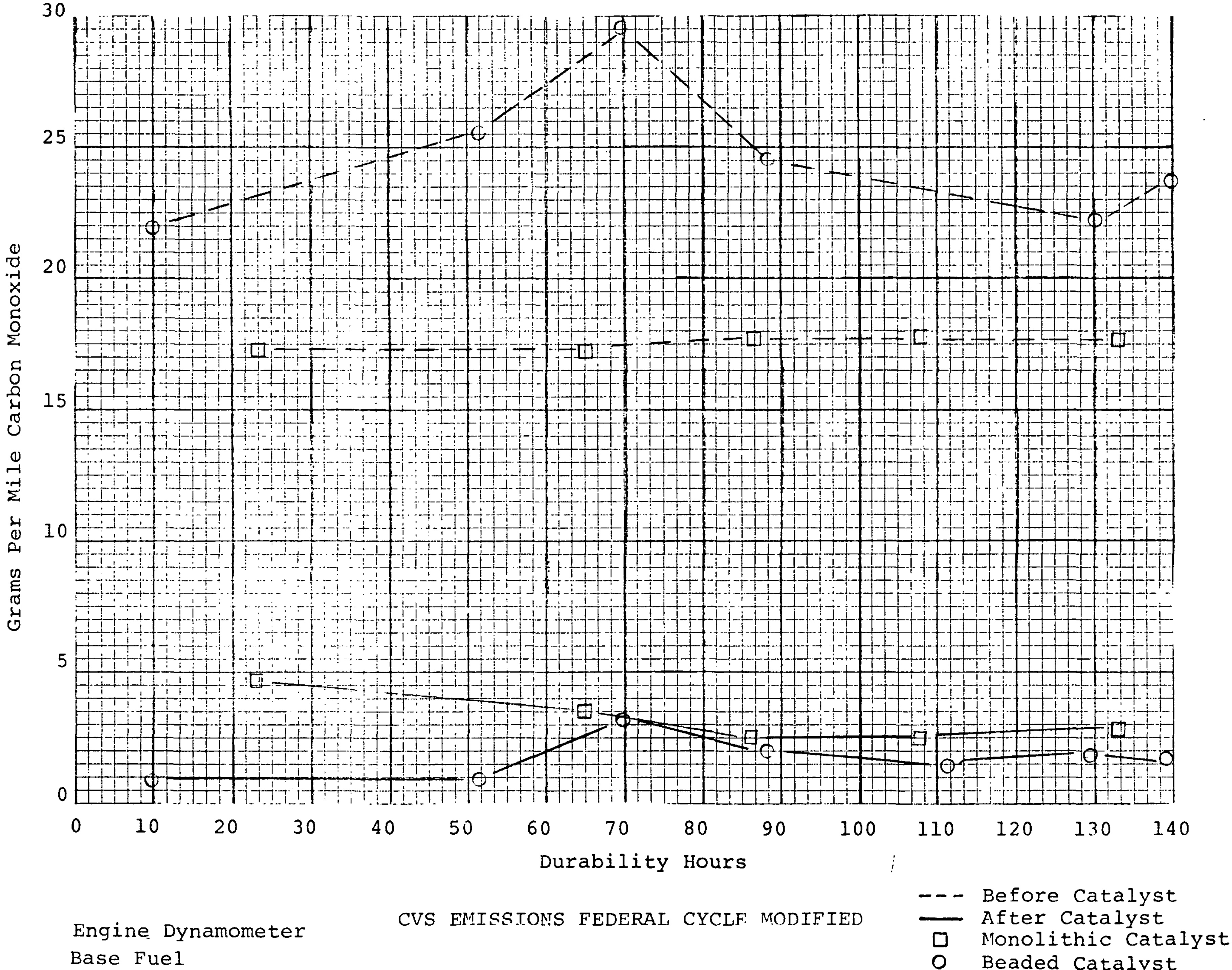


Engine Dynamometer
Base Fuel

CVS EMISSIONS FEDERAL CYCLE

FIGURE 66

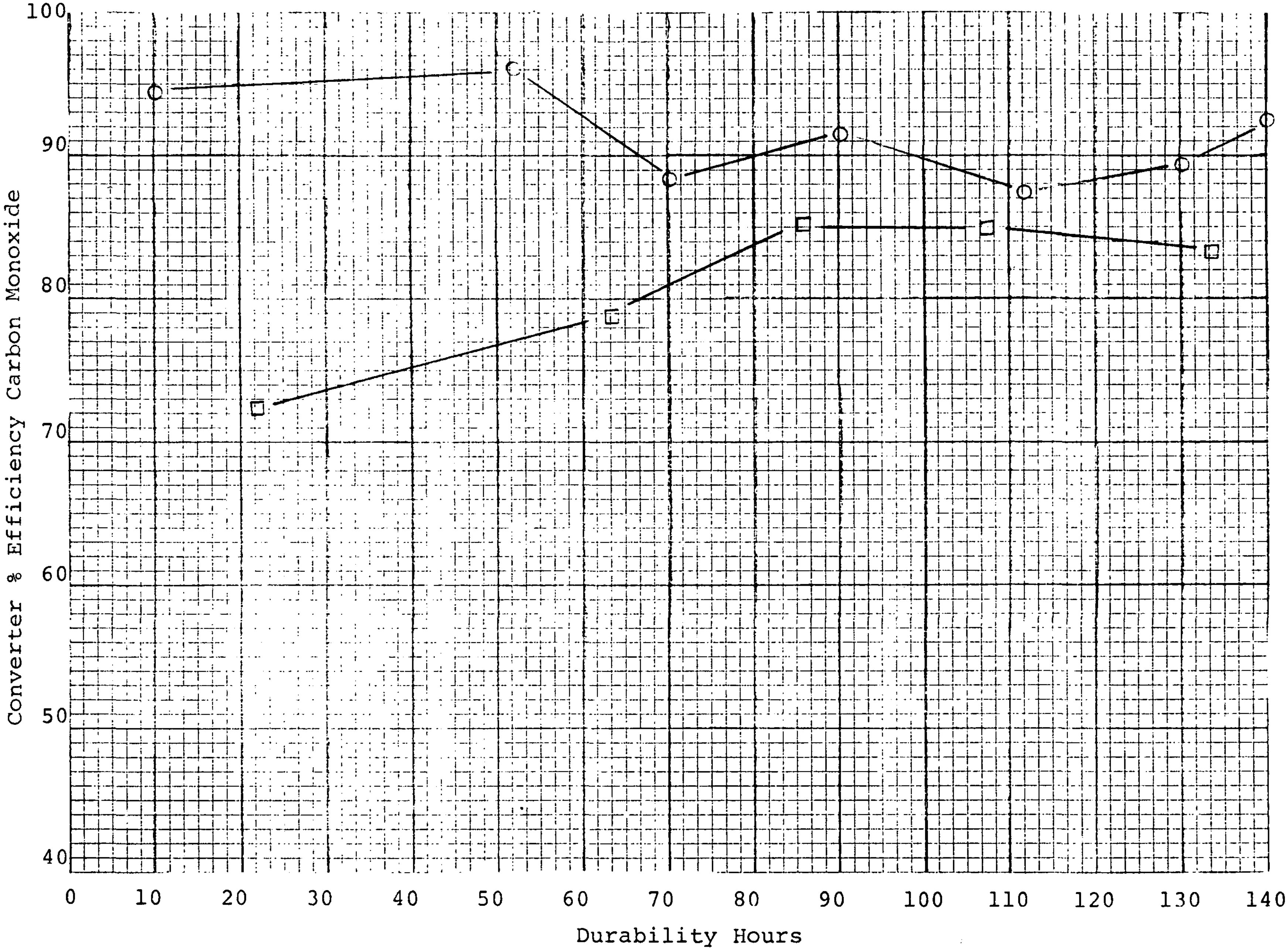
□ Monolithic Catalyst
○ Beaded Catalyst



Engine Dynamometer
Base Fuel

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 67

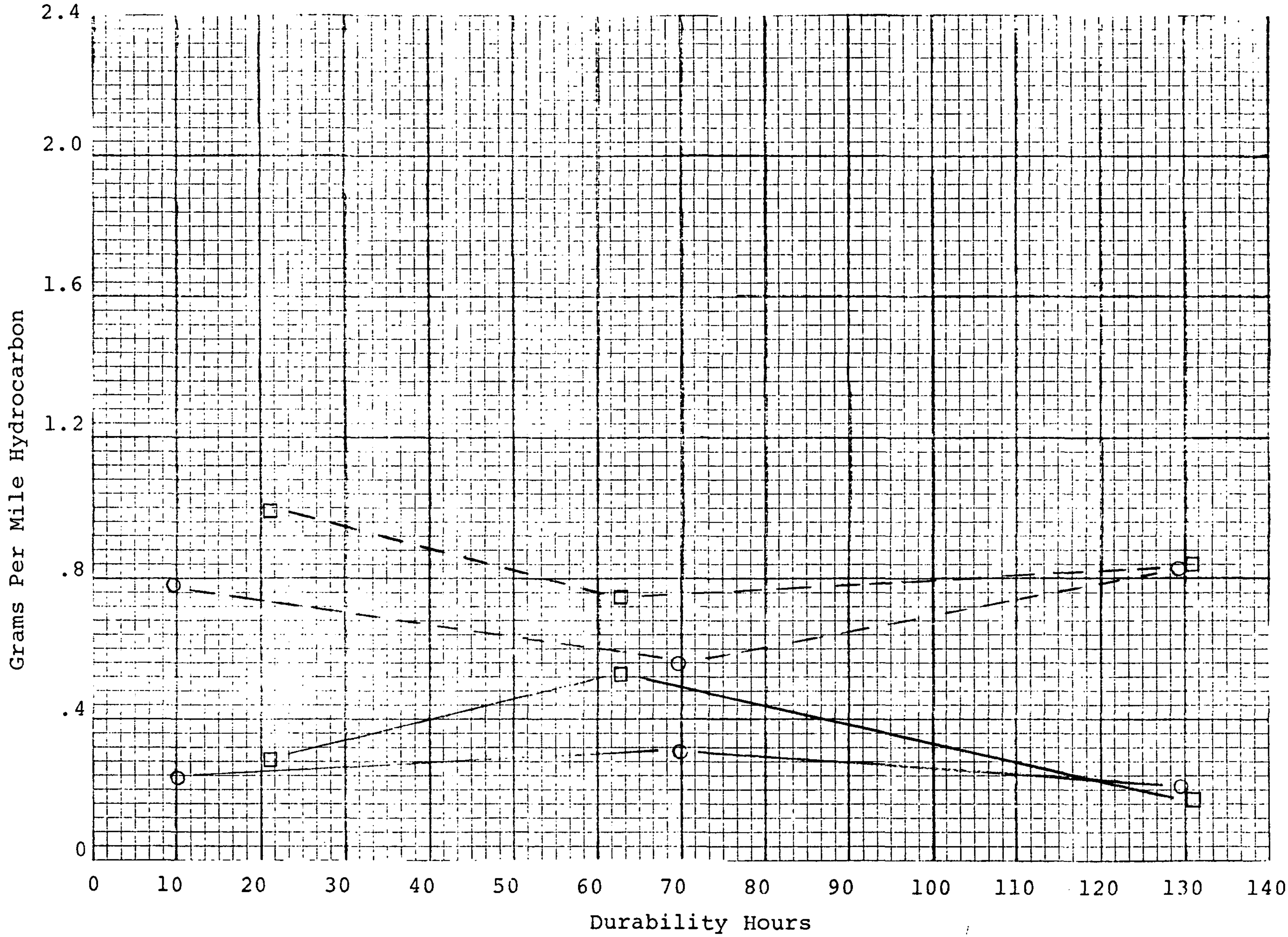


Engine Dynamometer
Base Fuel

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 68

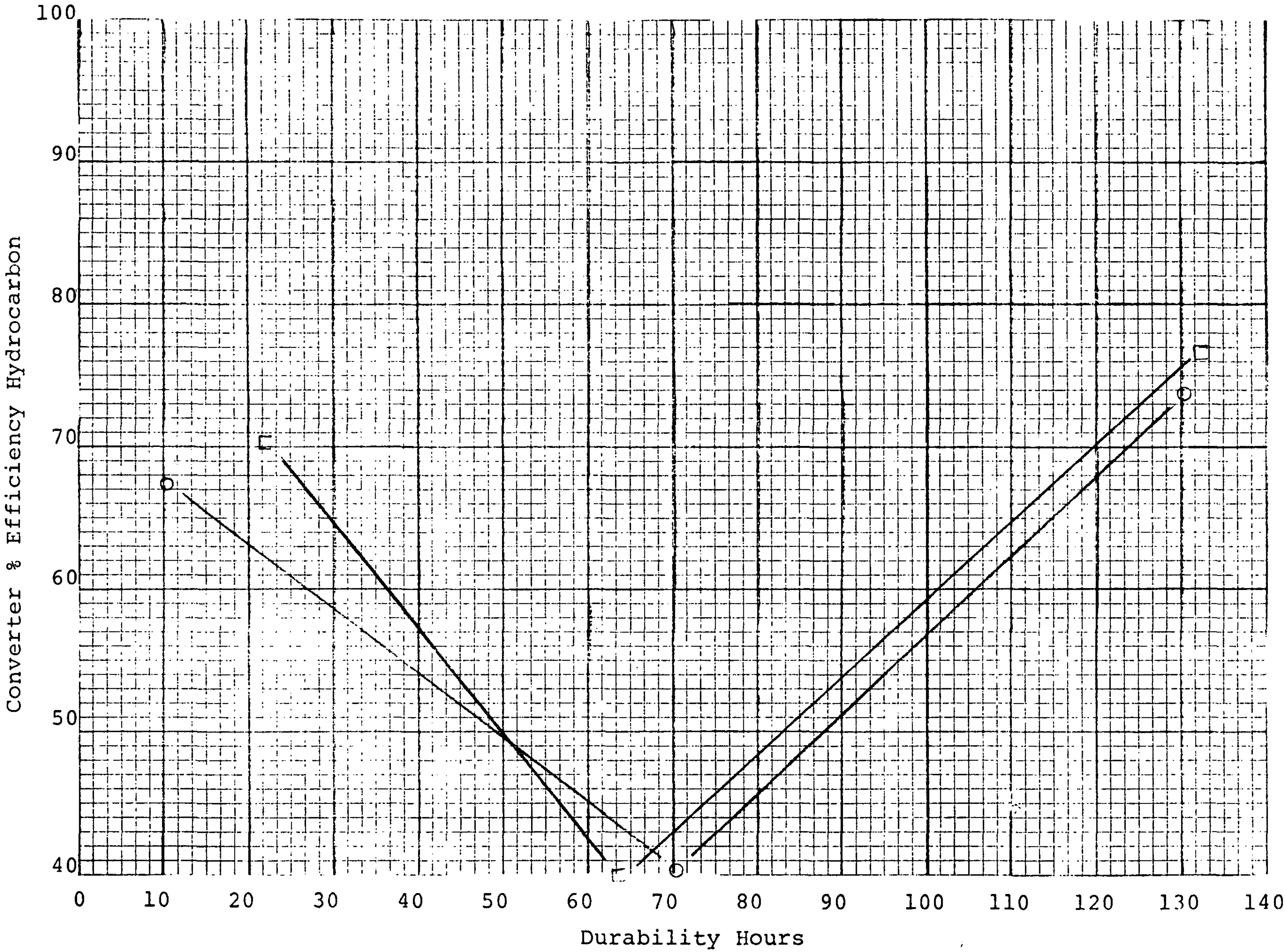
□ Monolithic Catalyst
O Beaded Catalyst



Engine Dynamometer
Base Fuel

CVS EMISSIONS FEDERAL CYCLE

FIGURE 69

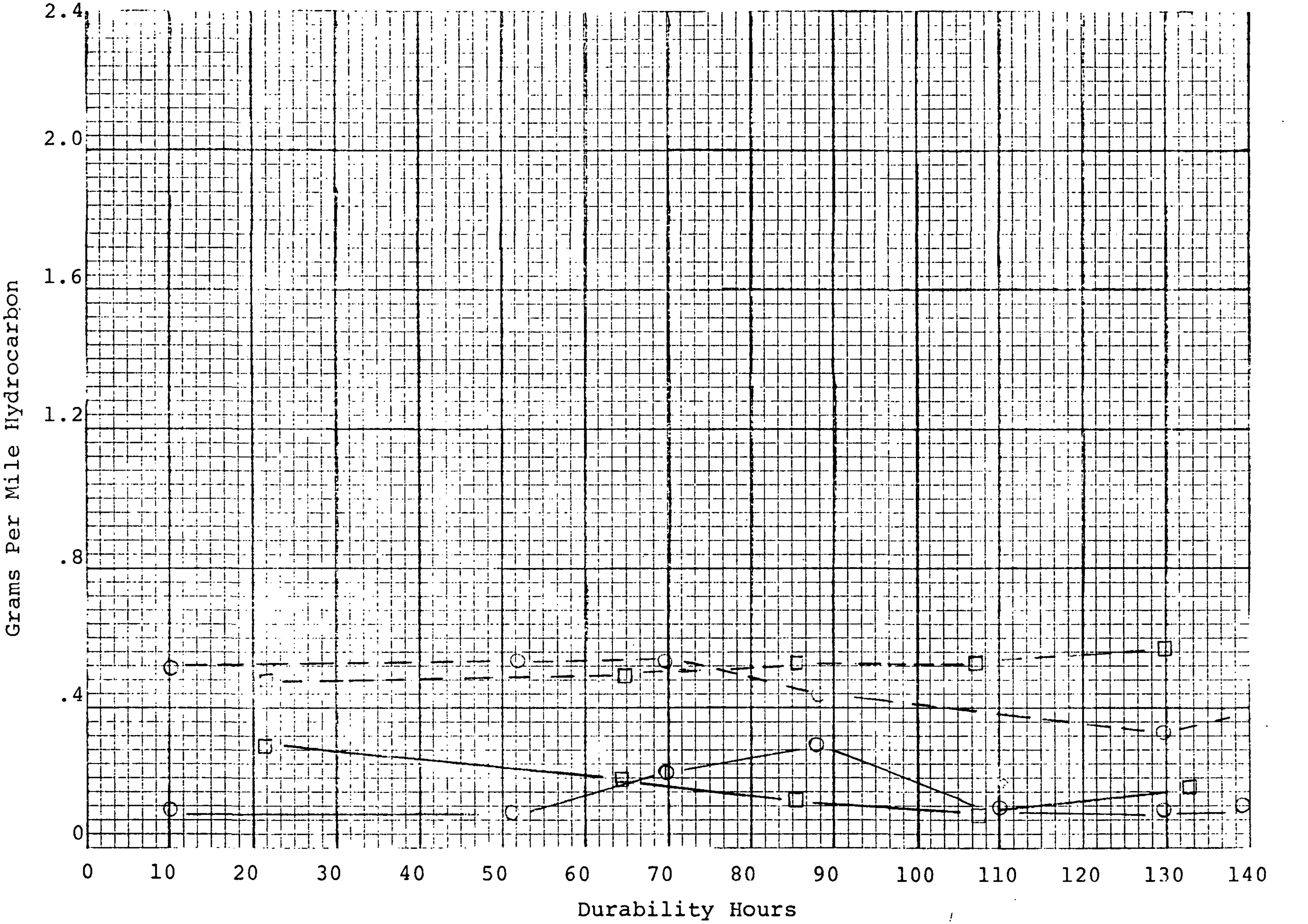


Engine Dynamometer
Base Fuel

CVS EMISSIONS FEDEPAL CYCLE

FIGURE 70

□ Monolithic Catalyst
○ Beaded Catalyst



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Engine Dynamometer

Base Fuel

FIGURE 71

<u>COMMENTS</u>: Additive "A" Fuel

1. Hydrocarbon emission levels measured during the Federal Cycle were definitely oxidized more efficiently by the beaded catalyst. The beaded catalyst was slightly more efficient than the monolith at oxidizing hydrocarbons as measured during the Federal Cycle Modified.

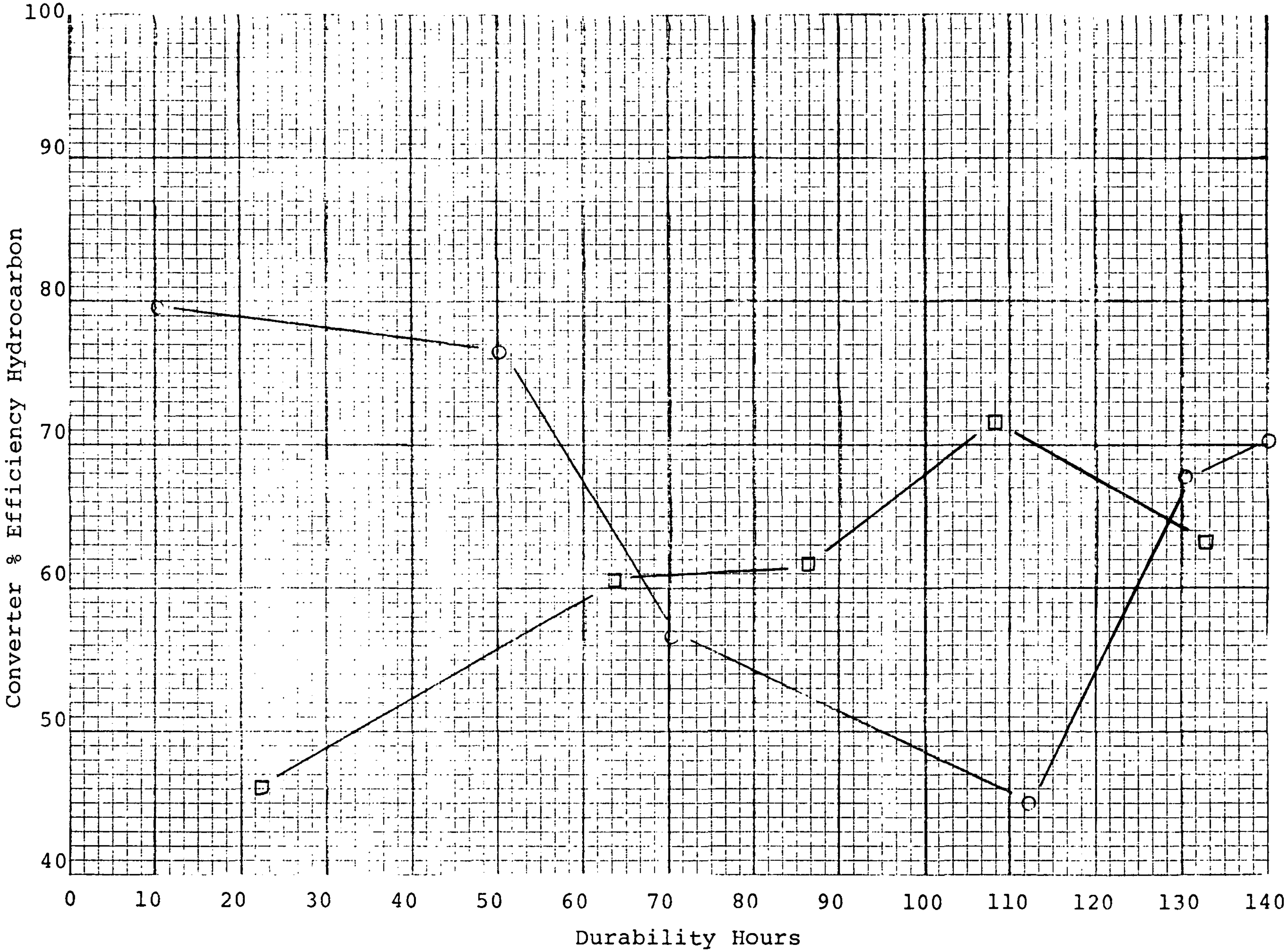
2. At the start of the test, the monolithic catalyst efficiency is higher, for both carbon monoxide and hydrocarbons, than the beaded catalysts; but the beaded catalyst is more efficient at the conclusion of the durability test.

3. The conversion efficiency of carbon monoxide is greater than that of hydrocarbons for both catalysts using Additive "A" fuel.

4. There was not a significant degradation of conversion efficiency using Additive "A" for both the duration of the tests with respect to carbon monoxide.

5. Using the monolithic catalysts under Federal Cycle conditions there appeared to be a large drop in conversion efficiency for hydrocarbons. The same drop in conversion efficiency for carbon monoxide did not materialize.

6. Fuel Additive "A" appears to have a more detrimental effect on monolithic catalyst conversion efficiency than the beaded catalysts.

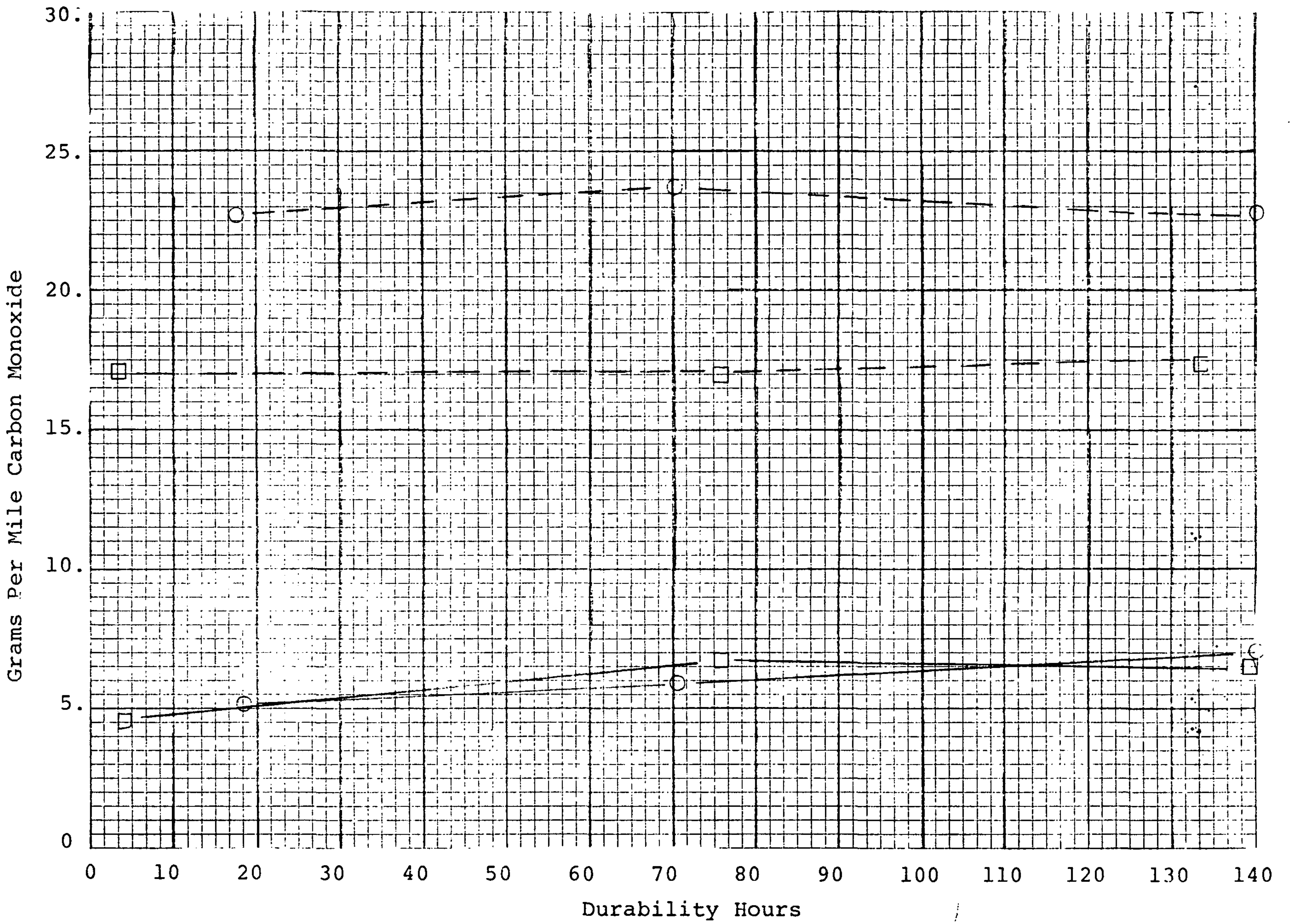


Engine Dynamometer
Base Fuel

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 72

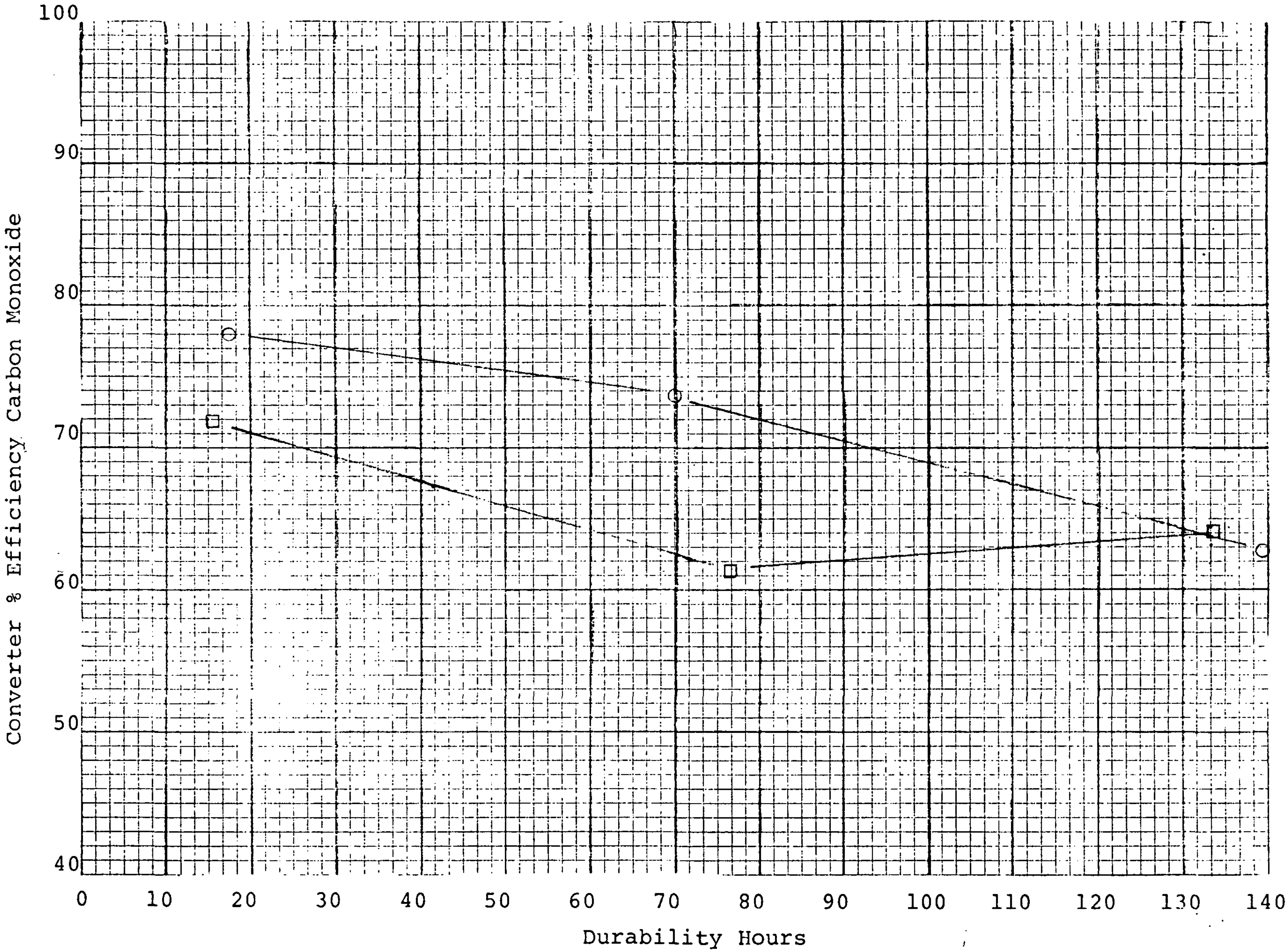
□ Monolithic Catalyst
O Beaded Catalyst



Engine Dynamometer
"A" Additive

CVS EMISSIONS FEDERAL CYCLE

FIGURE 73

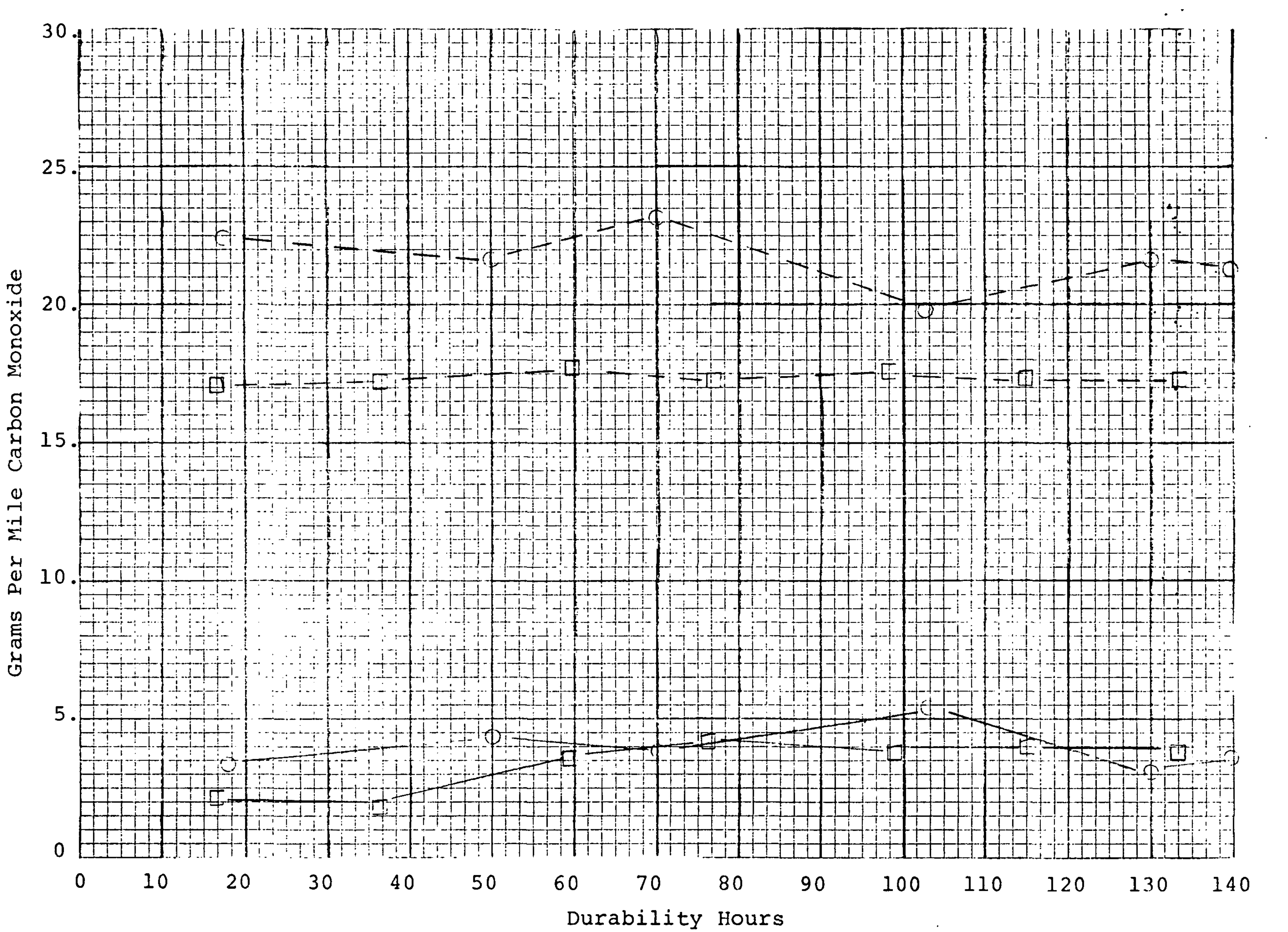


CVS EMISSIONS FEDERAL CYCLE

Engine Dynamometer
"A" Additive

□ Monolithic Catalyst
○ Beaded Catalyst

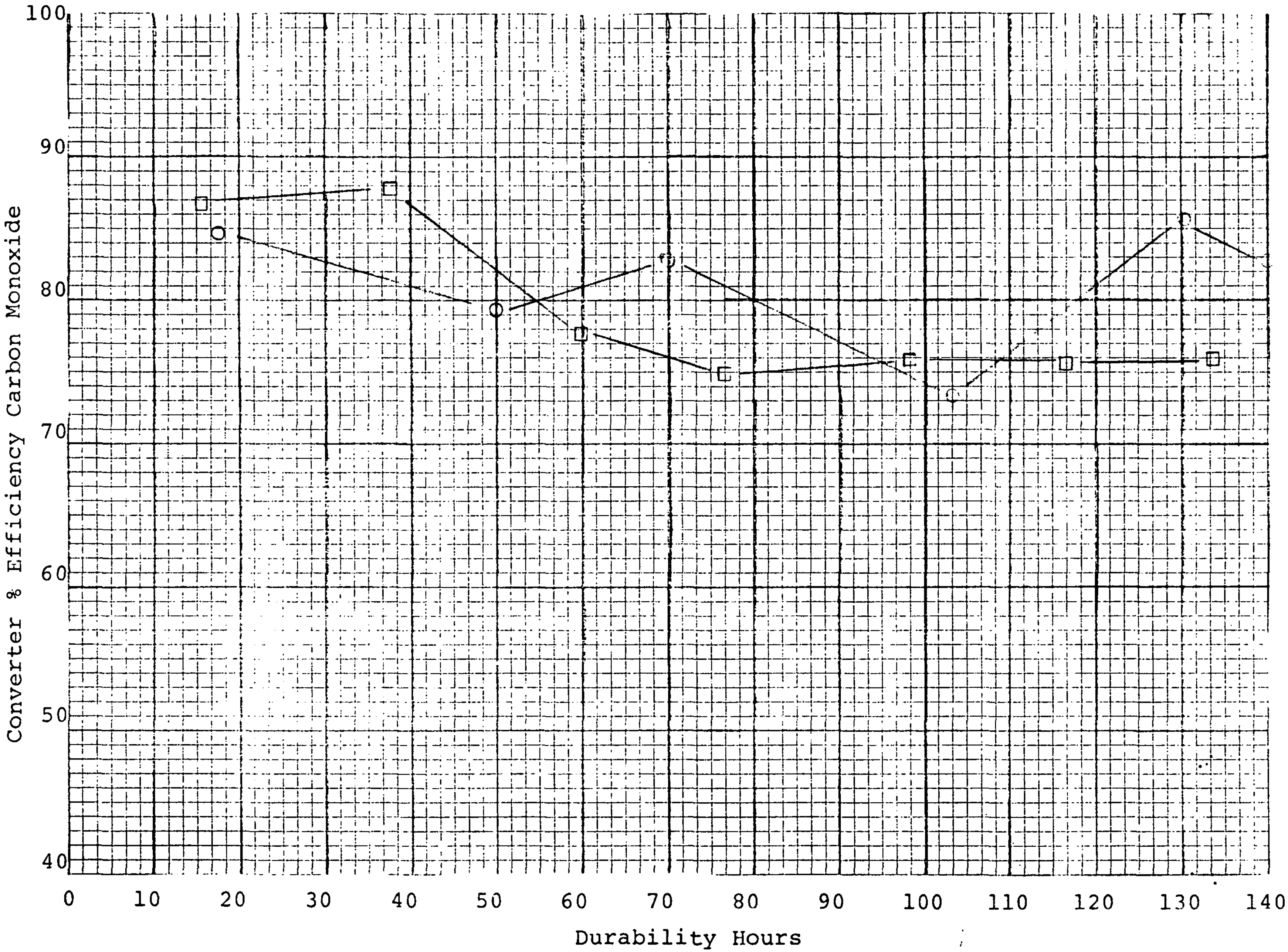
FIGURE 74



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Engine Dynamometer
"A" Additive

FIGURE 75

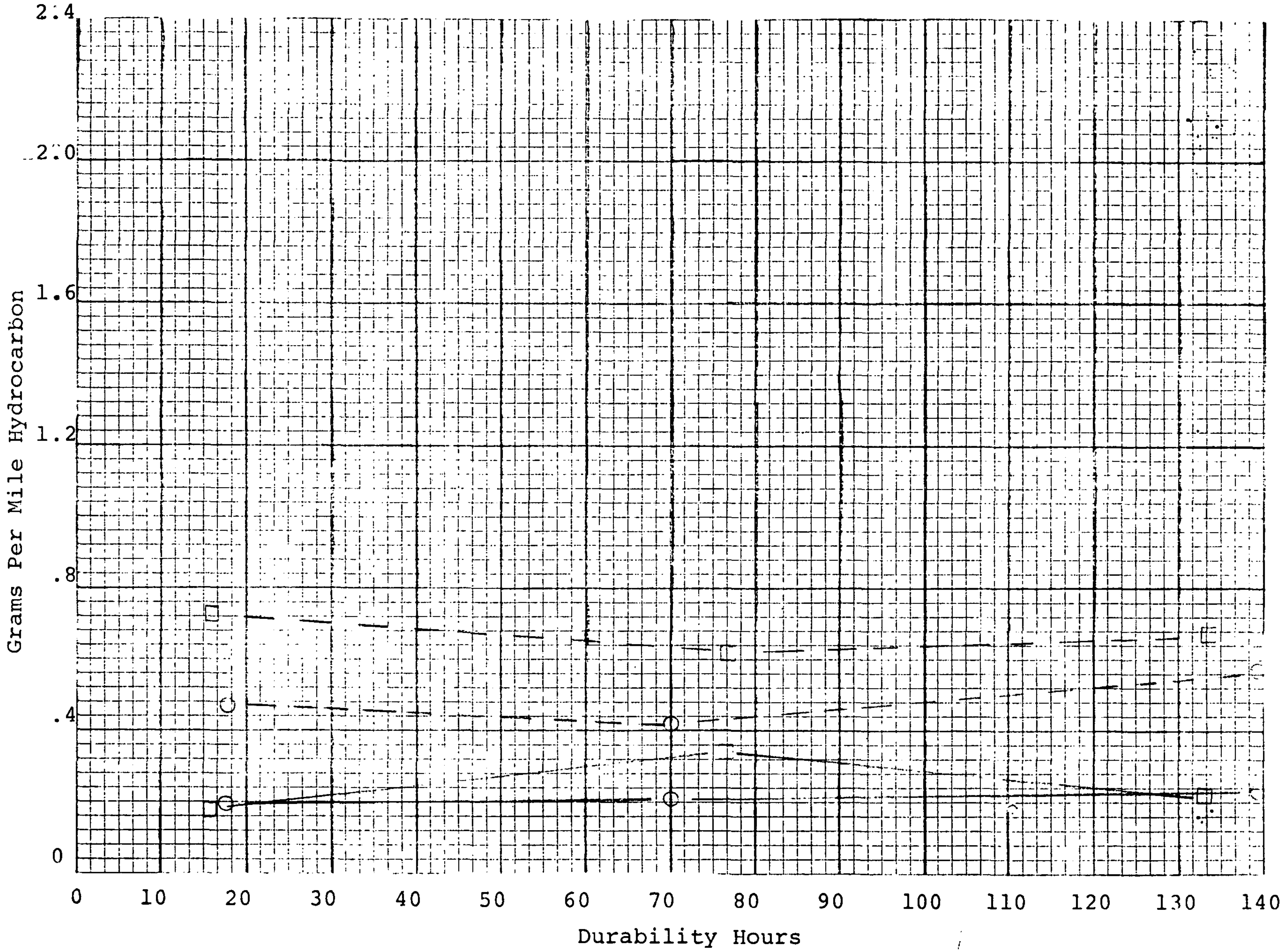


Engine Dynamometer
"A" Additive

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 76

□ Monolithic Catalyst
O Beaded Catalyst

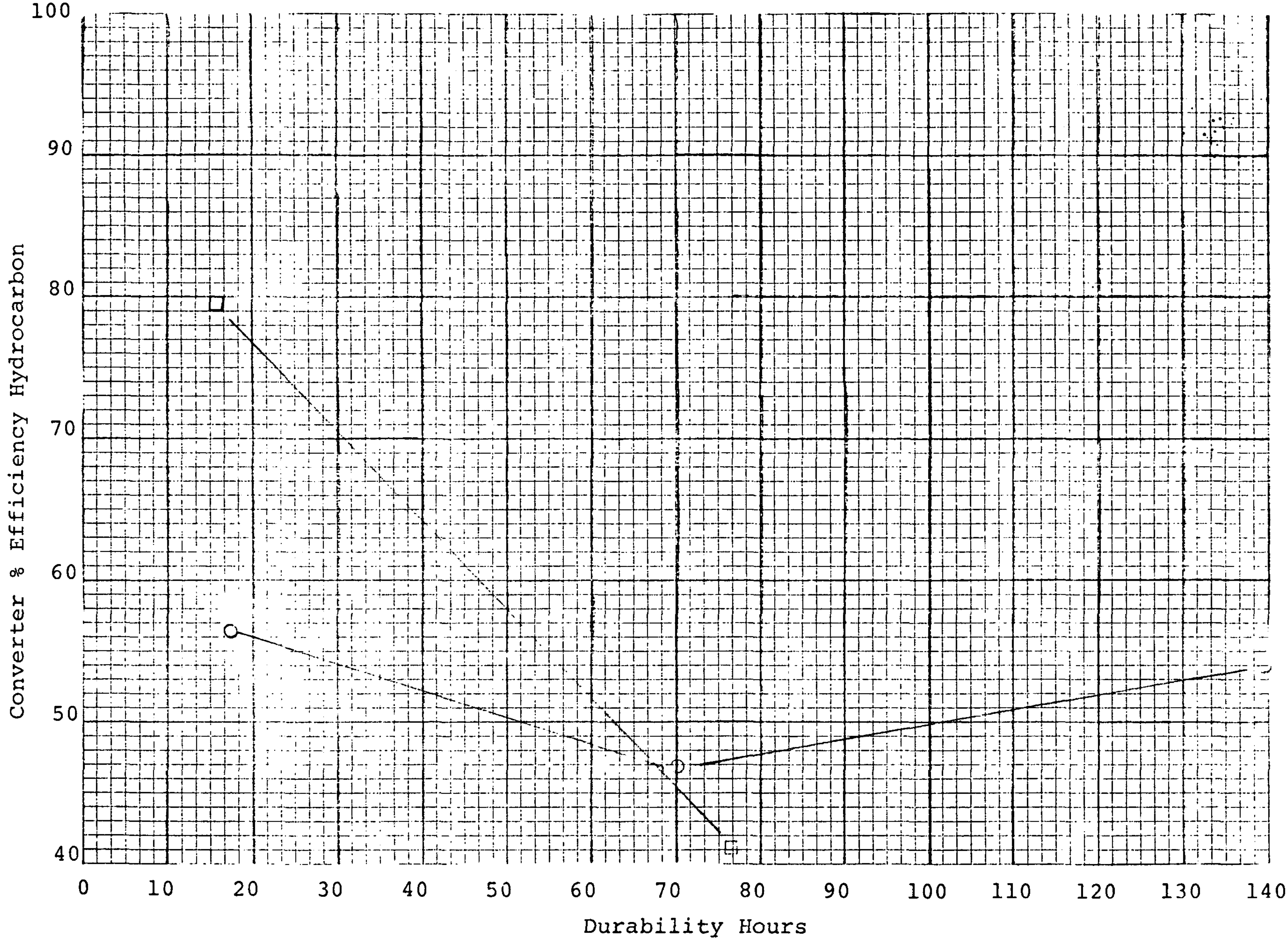


--- Before Catalyst
— After Catalyst
□ Monolithic Catalyst
O Beaded Catalyst

Engine Dynamometer
"A" Additive

CVS EMISSIONS FEDERAL CYCLE

FIGURE 77

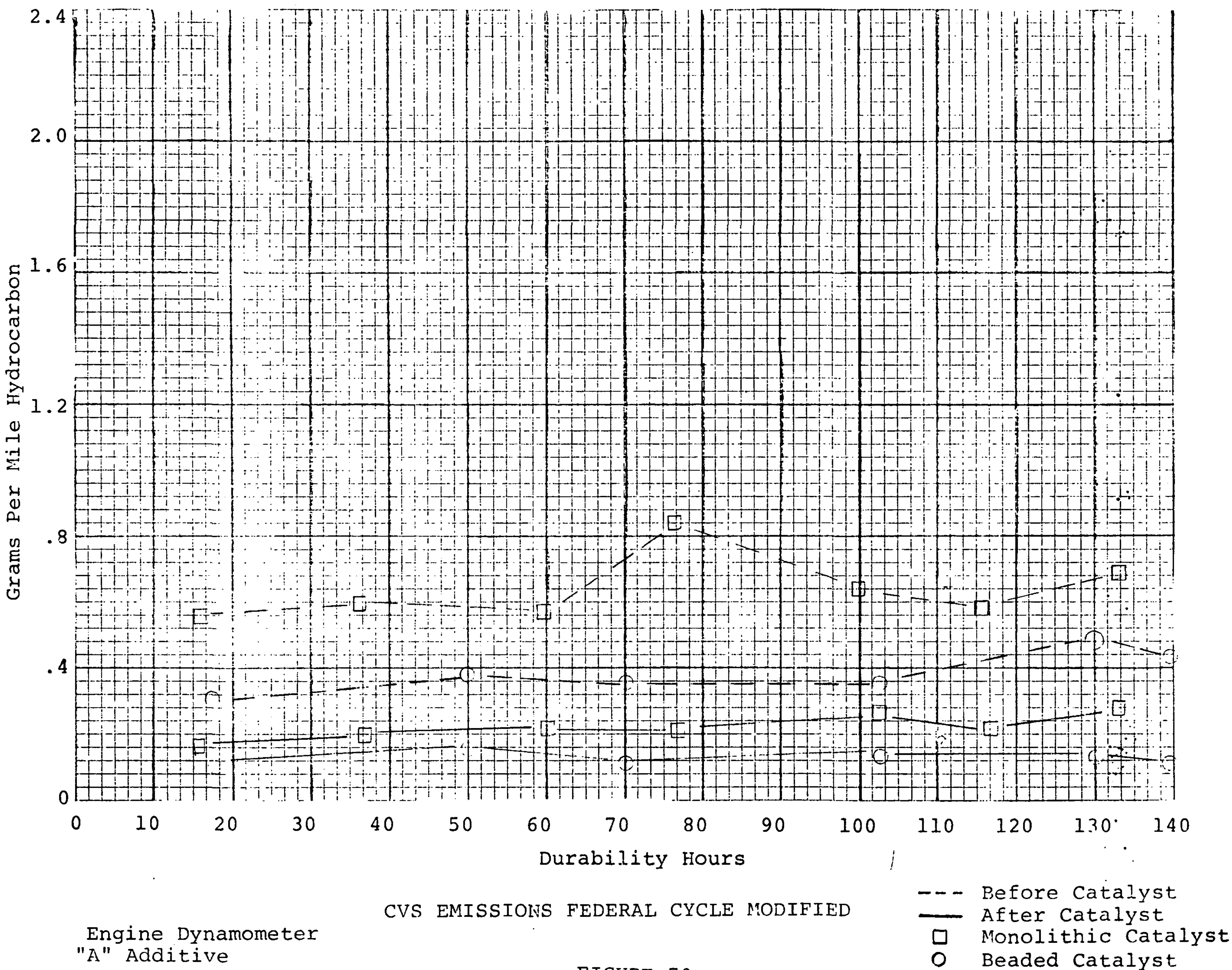


CVS EMISSIONS FEDERAL CYCLE

Engine Dynamometer
"A" Additive

□ Monolithic Catalyst
○ Beaded Catalyst

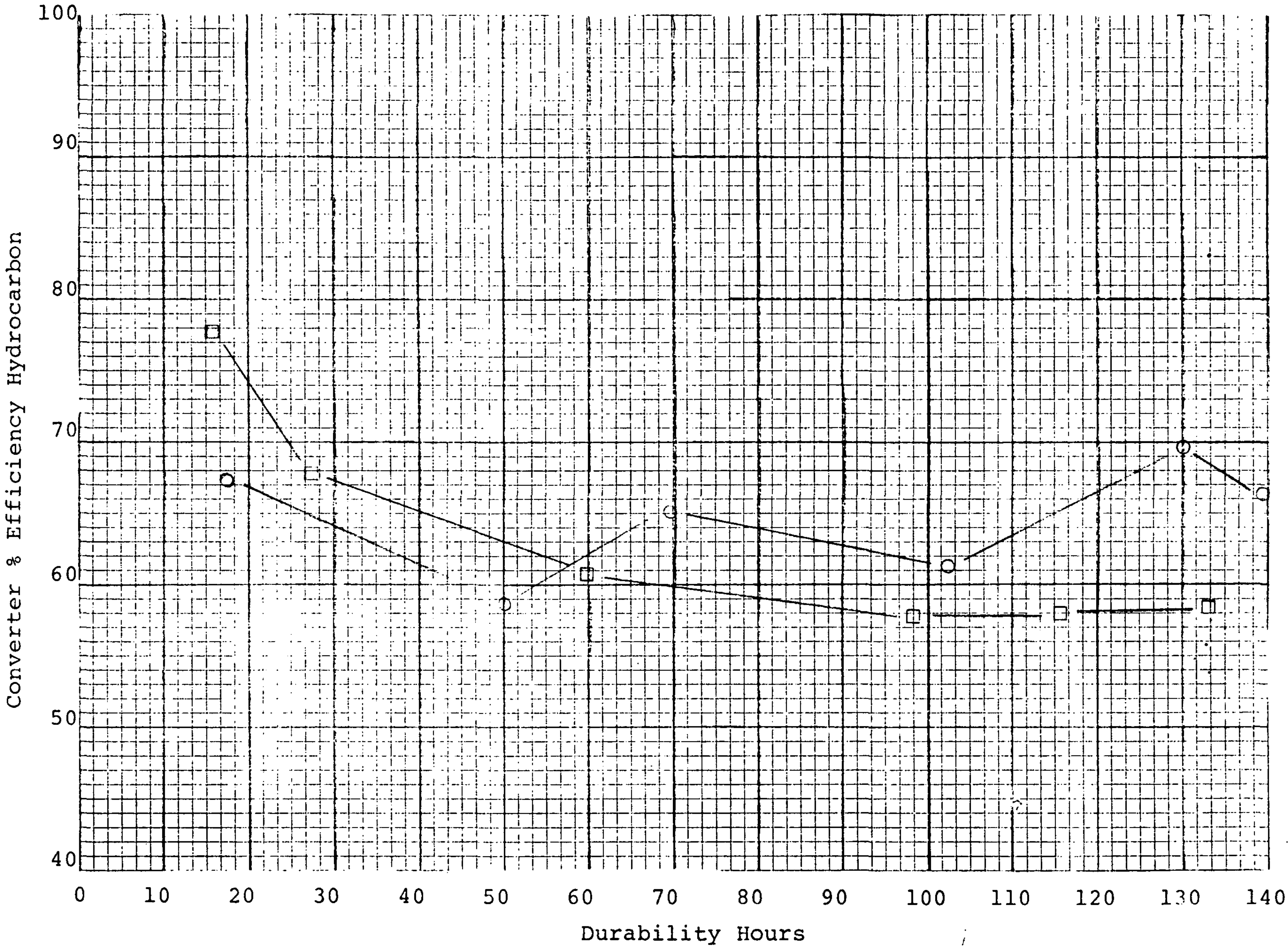
FIGURE 78



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Engine Dynamometer
"A" Additive

FIGURE 79



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Engine Dynamometer
"A" Additive

□ Monolithic Catalyst
○ Beaded Catalyst

FIGURE 80

COMMENTS: Additive "B" Fuel

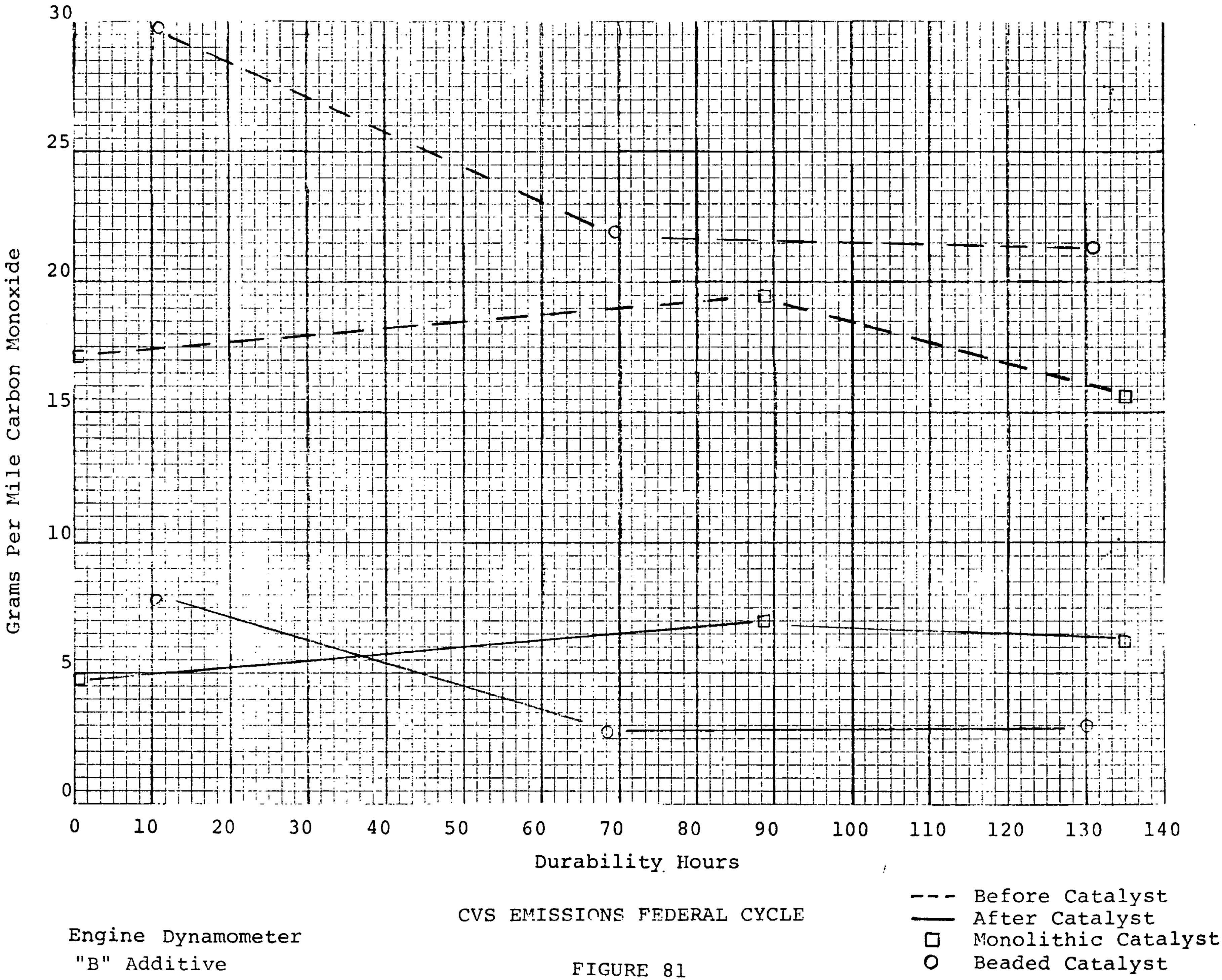
1. Both types of catalyst show some deterioration in efficiency over the time period studied using Additive "B".

2. Carbon monoxide emission levels were reduced more efficiently using the beaded catalysts for the Federal Cycle, compared to the monolith catalyst, but were not significantly more efficient measured under the Federal Cycle Modified conditions.

3. Hydrocarbon emission levels were significantly reduced using the beaded catalysts compared to the monolithic catalysts on cold start conditions, but the monolithic catalysts were more efficient on the Federal Cycle Modified tests.

4. The conversion efficiency of carbon monoxide versus hydrocarbons was not different with Additive "B", but with the base fuel and "A" additive we did observe a greater conversion efficiency of the carbon monoxide than we did for the hydrocarbons.

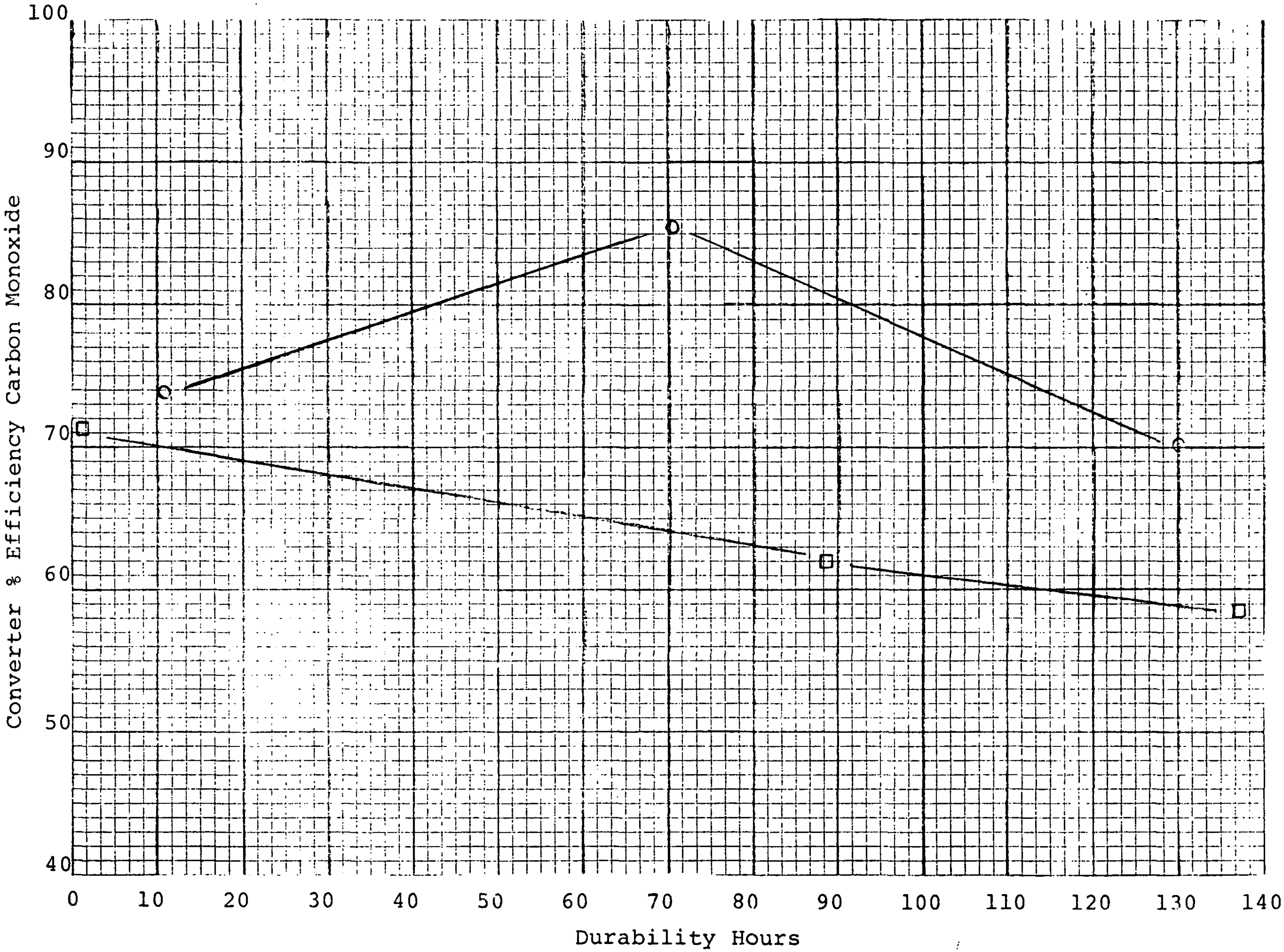
5. Carbon monoxide conversion efficiency with the beaded catalysts was more efficient for both Federal Cycle and Federal Cycle Modified using Additive "B", but the monolithic catalyst was more efficient in the hydrocarbon conversion for both Federal Cycle and Federal Cycle Modified.



Engine Dynamometer
"B" Additive

CVS EMISSIONS FEDERAL CYCLE

FIGURE 81



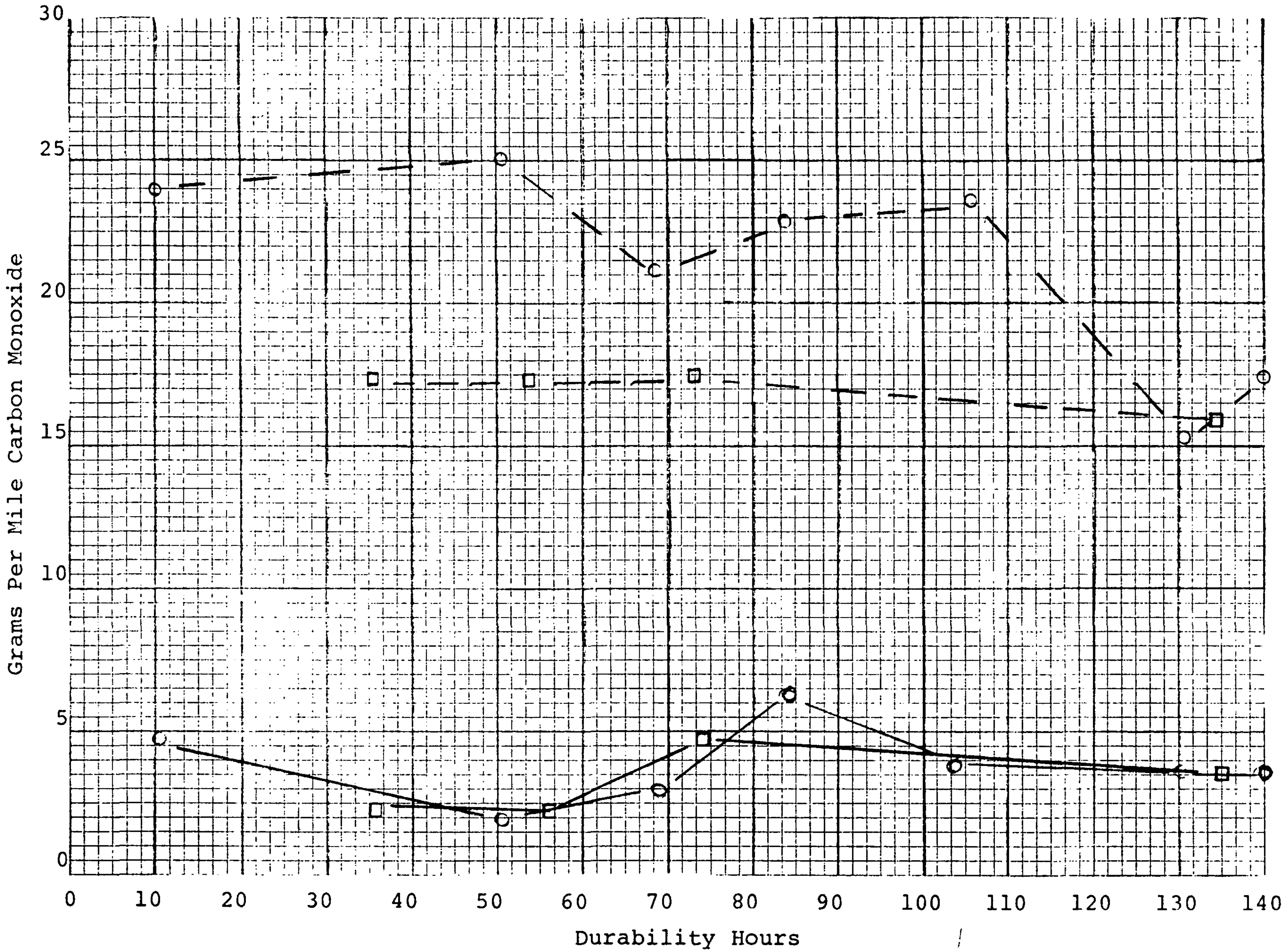
CVS EMISSIONS FEDERAL CYCLE

Engine Dynamometer

"B" Additive

FIGURE 82

□ Monolithic Catalyst
O Beaded Catalyst



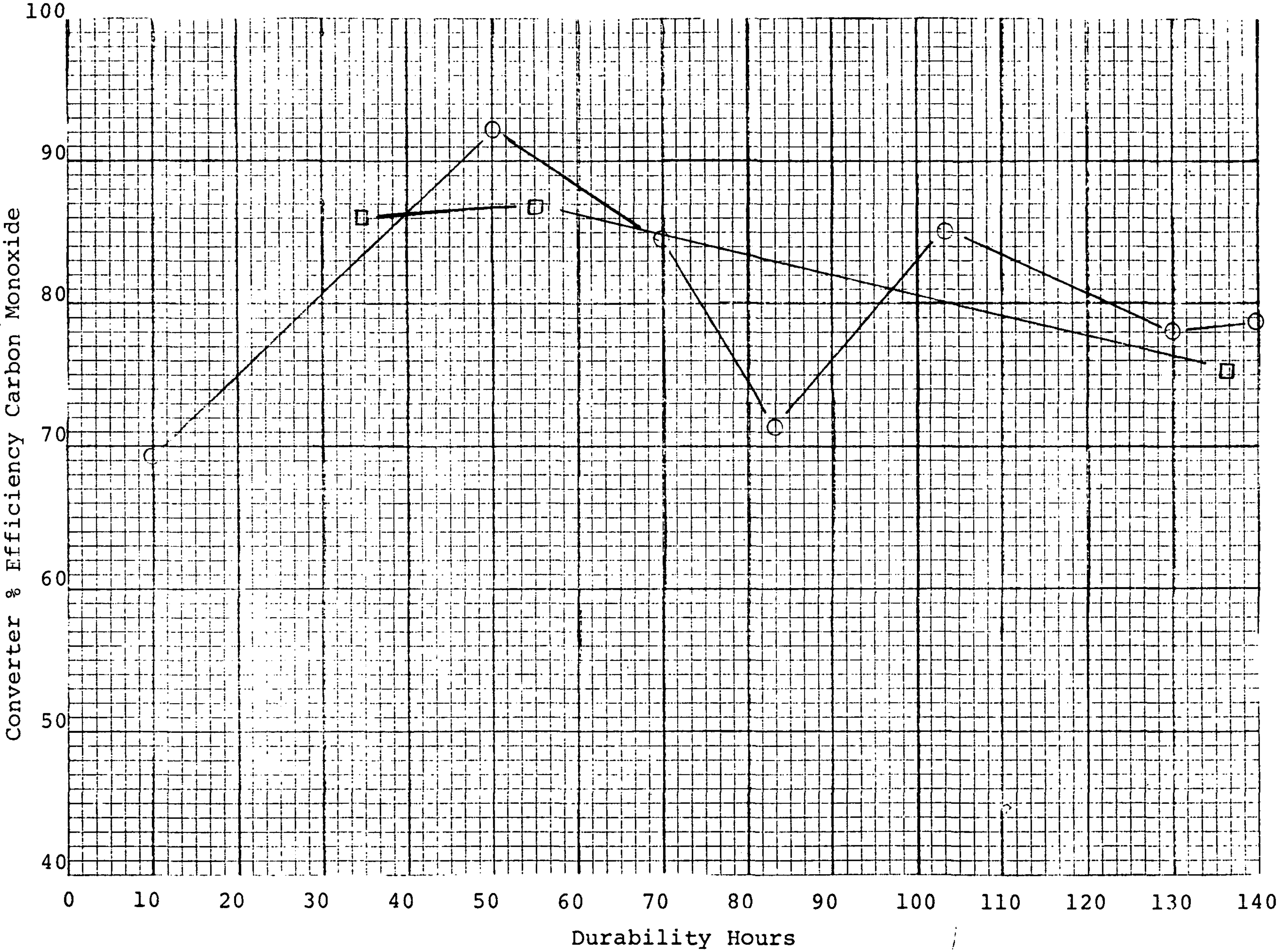
--- Before Catalyst
— After Catalyst
□ Monolithic Catalyst
○ Beaded Catalyst

Engine Dynamometer

"B" Additive

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 83

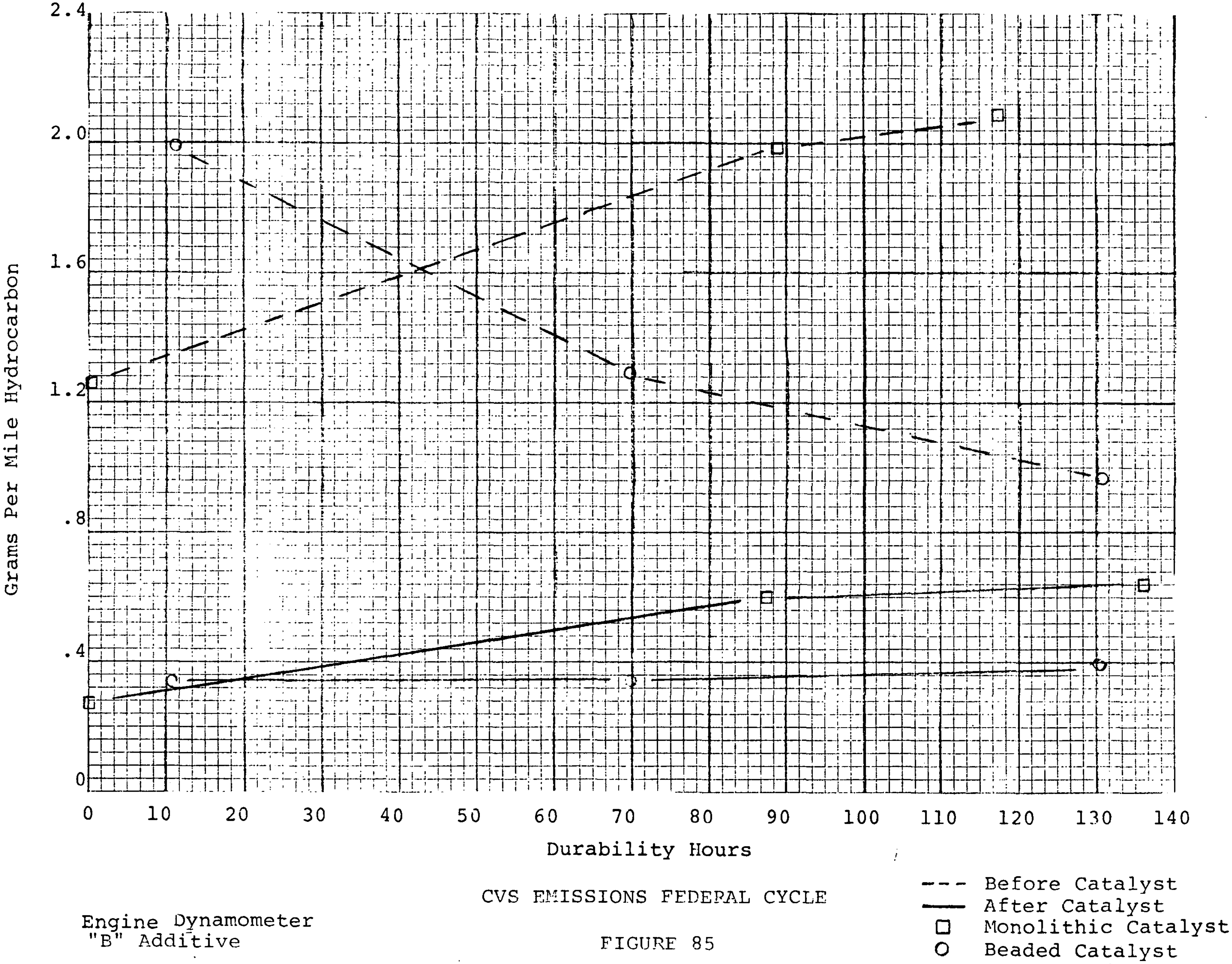


CVS EMISSIONS FEDERAL CYCLE MODIFIED

Engine Dynamometer
"B" Additive

FIGURE 84

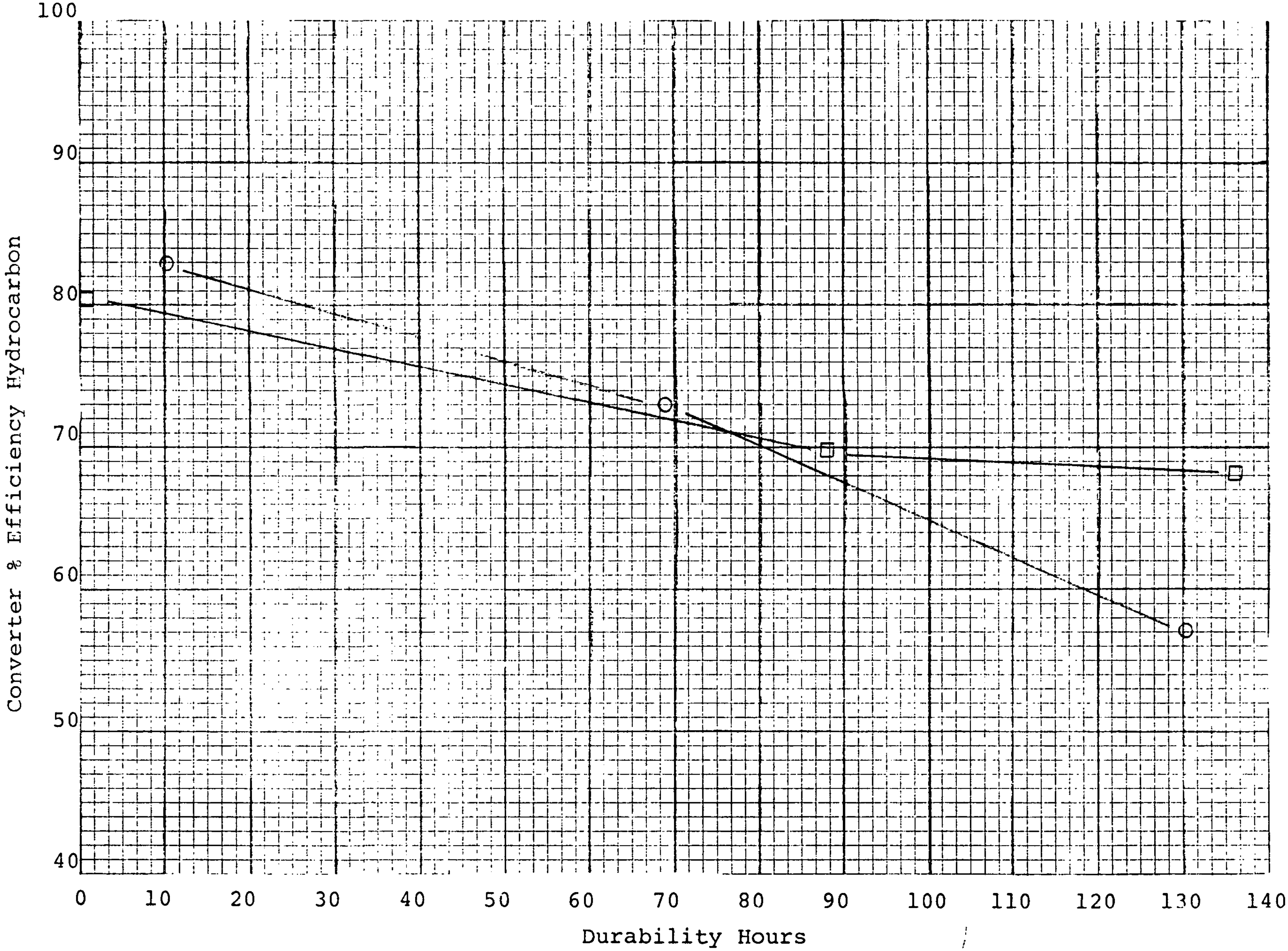
□ Monolithic Catalyst
O Beaded Catalyst



Engine Dynamometer
"B" Additive

CVS EMISSIONS FEDERAL CYCLE

FIGURE 85



CVS EMISSIONS FEDERAL CYCLE

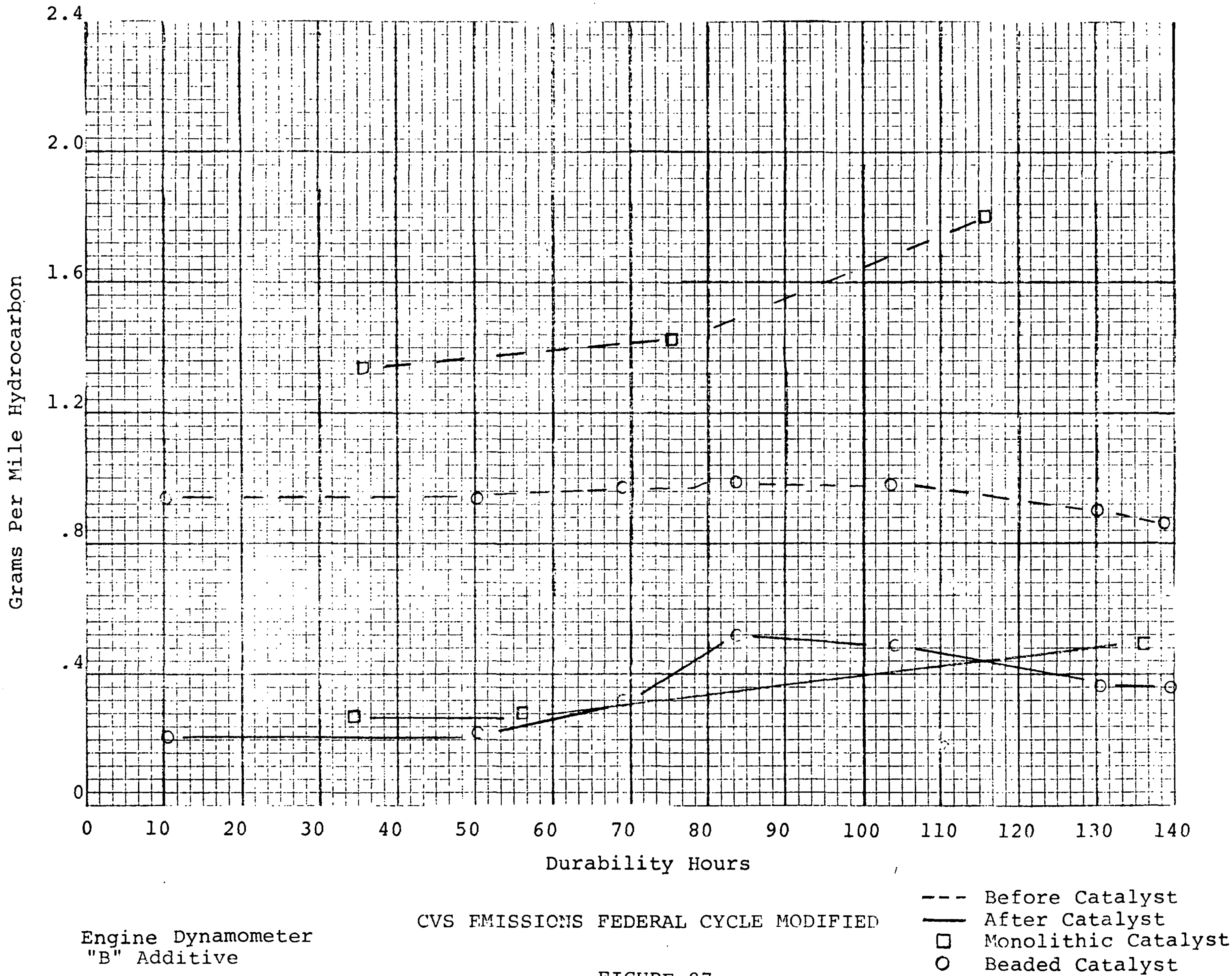
Engine Dynamometer

"B" Additive

FIGURE 86

□ Monolithic Catalyst

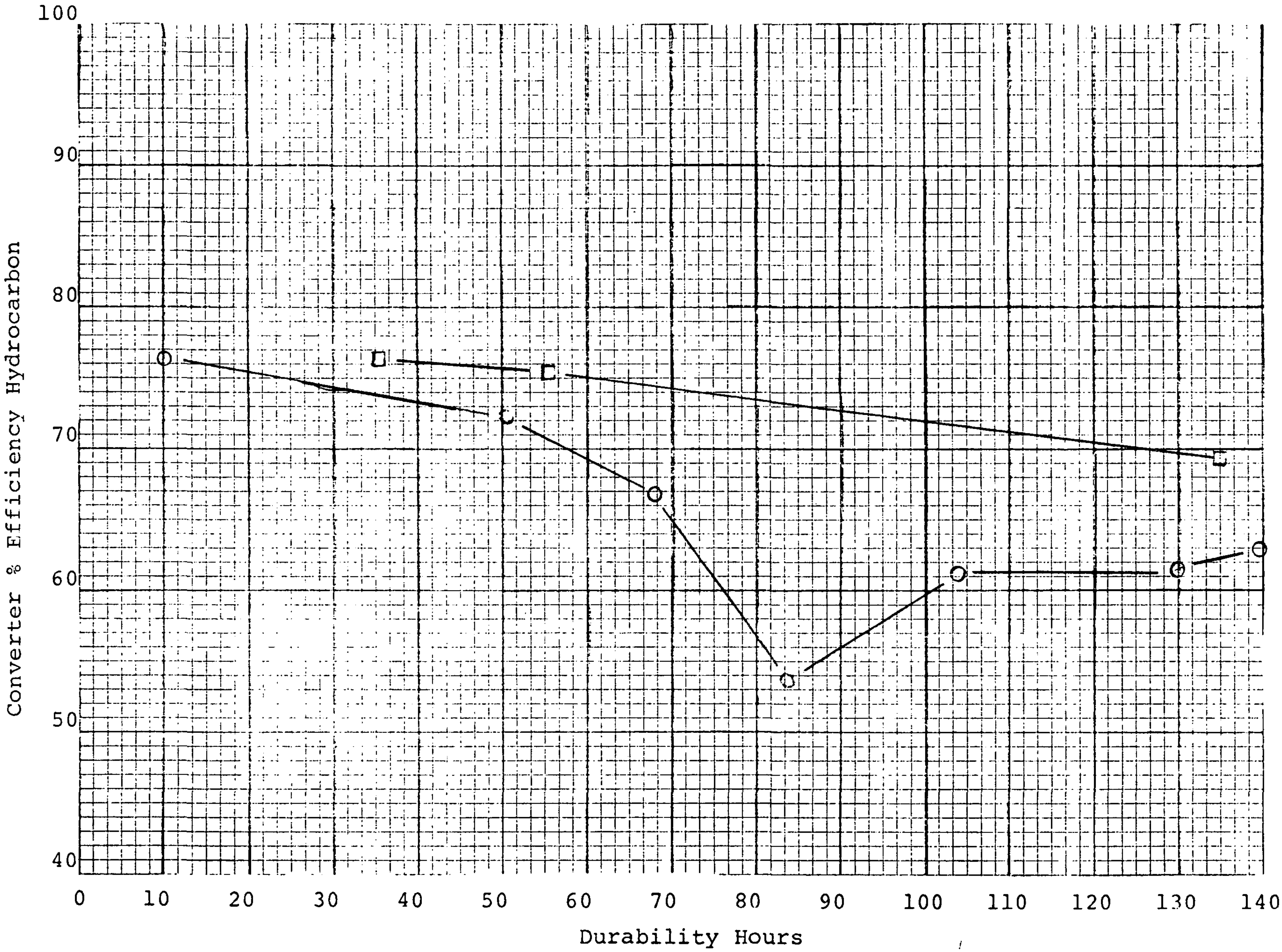
O Beaded Catalyst



Engine Dynamometer
"B" Additive

CVS EMISSIONS FEDERAL CYCLE MODIFIED

FIGURE 87



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Engine Dynamometer
"B" Additive

□ Monolithic Catalyst
○ Beaded Catalyst

FIGURE 88

F. Raw Data, Chassis Dynamometer, Beaded Catalyst, Three Fuels

The data on the following set of graphs is the raw data for the segments of the Federal Cycle, as determined from tests on the three vehicles, each equipped with bead type catalytic converters running on the three different fuels previously described. Exhaust gases were collected using a Heath International CVS (constant volume sampler) System. The gases were analyzed using the following analytical instruments.

A. Unburned hydrocarbons by Beckman Flame Ionization.

B. NO_x by Chemilumeuescence (EPA built instrument)

C. Argon, Hydrogen, Oxygen, Carbon Monoxide, Carbon Dioxide — Fisher Gas Partitioner coupled to a Hewlett Packard 3370A Integrator

D. Carbon Monoxide 0-280 and 0-3000 ppm range, Beckman Infrared Analyzer Model 1R315.

The results from the above analytical instruments were fed into a computer, which returned all values as grams/mile.

TABLE 21. DURABILITY MILES ON CATALYST, BEADED CATALYST, CHASSIS DYNAMOMETER, GRAMS/MILE. *

Zero Catalyst Miles

	Hot HC	Hot CO	Hot NO_x	Cold HC	Cold CO	Cold NO_x
Base Fuel						
Cold Transient	.35	3.99	2.46	.66	6.16	2.29
Stabilized	.08	.125	1.19	.10	.15	1.25
Hot Transient	.10	.44	2.44	.10	.41	2.31
Weighted	.14	.98	1.78	.21	1.42	1.75
"A" Additive						
Cold Transient	.07	.70	3.37	.72	6.05	2.85
Stabilized	.06	.04	1.78	.08	0	1.60
Hot Transient	.06	.64	3.37	.17	1.53	3.16
Weighted	.06	.33	2.52	.23	1.62	2.26
"B" Additive						
Cold Transient	.13	.97	2.53	.55	6.64	2.53
Stabilized	.03	.04	1.63	.04	.11	1.63
Hot Transient	.06	1.20	2.91	.07	1.36	2.22
Weighted	.06	.54	2.15	.15	1.75	1.97

2,000 Catalyst Miles

	Hot HC	Hot CO	Hot NO_x	Cold HC	Cold CO	Cold NO_x
Base Fuel						
Cold Transient	.09	.84	3.44	.51	6.72	3.46
Stabilized	.11	.13	1.81	.12	.24	1.89
Hot Transient	.12	.21	.49	.17	3.98	3.51
Weighted	.11	.29	1.79	.21	2.53	2.63
"A" Additive						
Cold Transient	.06	.23	.43	.46	8.20	4.24
Stabilized	.04	.06	2.32	.16	.08	2.32
Hot Transient	.08	.53	3.95	.07	.53	4.34
Weighted	.06	.22	2.37	.20	1.83	3.24
"B" Additive						
Cold Transient	.16	5.06	2.29	.47	6.69	1.92
Stabilized	.12	.40	1.61	.16	.47	1.66
Hot Transient	.13	2.62	2.72	.16	6.67	2.58
Weighted	.13	1.93	1.91	.22	3.37	1.96

4,000 Catalyst Miles

	Hot HC	Hot CO	Hot NO_x	Cold HC	Cold CO	Cold NO_x
Base Fuel						
Cold Transient	.16	2.41	5.23	.64	6.85	5.10
Stabilized	.09	.15	2.69	.10	.29	2.75
Hot Transient	.12	2.36	5.26	.14	2.34	4.56
Weighted	.11	1.19	3.89	.22	2.15	3.70
"A" Additive						
Cold Transient	.18	5.83	3.34	.12	6.72	2.76
Stabilized	.07	.60	1.88	.07	.55	1.77
Hot Transient	.11	3.96	6.29	.15	3.11	3.14
Weighted	.10	2.55	3.35	.10	2.47	2.33
"B" Additive						
Cold Transient	.21	3.82	2.31	.57	19.08	2.65
Stabilized	.16	.77	1.39	.16	.99	1.39
Hot Transient	.24	4.86	2.68	.21	4.08	2.14
Weighted	.19	2.47	1.92	.26	5.18	1.84

6,000 Catalyst Miles

	Hot HC	Hot CO	Hot NO_x	Cold HC	Cold CO	Cold NO_x
Base Fuel						
Cold Transient	.15	2.38	3.24	.64	23.6*	2.87
Stabilized	.12	.22	1.59	.09	.38	1.74
Hot Transient	.18	2.38	3.01	.11	1.82	3.28
Weighted	.14	1.23	2.30	.21	5.43*	2.38
"A" Additive						
Cold Transient	.16	3.93	3.09	1.14	6.77	2.78
Stabilized	.11	1.06	2.05	.07	1.15	1.89
Hot Transient	.15	5.37	2.81	.21	6.78	2.85
Weighted	.13	2.78	2.46	.32	3.78	2.32
"B" Additive						
Cold Transient						
Stabilized						
Hot Transient						
Weighted						

TABLE 21. DURABILITY MILES ON CATALYST, BEADED CATALYST, CHASSIS DYNAMOMETER, GRAMS/MILE (Cont'd)

Hot			Cold			Hot			Cold			Hot			Cold			Hot			Cold			
HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	
8,000 Catalyst Miles						9,500 Catalyst Miles						9,500 Catalyst Miles						9,500 Catalyst Miles						
Base Fuel																								
.14	1.59	2.44	.99	25.1	2.9	.16	1.57	3.92	.33	15.0	3.06	.12	5.17	3.43	.36	24.6	2.1	.14	3.37	3.67	.35	19.8	2.08	Cold Transient
.10	.24	2.09	.09	.42	2.19	.14	.23	2.09	.04	.28	1.92	.06	.72	1.27	.06	.32	2.14	.10	.47	1.68	.05	.30	2.03	Stabilized
.11	2.19	3.60	.18	3.58	4.28	.09	.20	3.17	.13	1.94	3.48	.13	5.20	3.63	.05	4.03	2.33	.11	2.7	3.4	.09	2.98	2.90	Hot Transient
.11	1.03	2.56	.29	6.22	2.89	.13	.49	2.75	.13	3.69	2.57	.09	2.81	2.37	.12	6.19	2.18	.11	1.65	2.53	.125	4.94	2.37	Weighted
"A" Additive																								
.17	4.38	3.28	1.15*	24.8	3.49	.17	6.12	2.90	.72	24.5	3.22	.13	24.8	2.31	.56	24.71	1.68	.15	15.5	2.6	.64	24.6	2.45	Cold Transient
.12	1.76	2.08	.14	1.85	2.24	.08	1.71	1.76	.12	.92	1.76	.12	1.75	1.93	.12	2.12	1.12	.10	1.73	1.84	.12	1.52	1.4	Stabilized
.17	5.10	3.24	.17	4.13	4.09	.16	4.69	2.90	.12	4.92	2.80	.37	7.40	2.68	.10	4.95	1.91	.26	6.0	2.79	.11	4.93	2.35	Hot Transient
.14	3.18	2.63	.35	7.07	2.98	.12	2.29	2.29	.24	6.72	2.33	.19	7.88	2.21	.20	7.41	1.44	.15	5.63	2.25	.22	7.06	1.88	Weighted
"B" Additive																								
.19	6.07	1.58	1.25	23.9	2.6	.22	6.21	1.4	.69	24.8	1.59							.20	6.14	1.5	.97	24.4	2.09	Cold Transient
.16	.98	.86	.29	1.81	1.29	.14	1.09	.92	.21	1.41	.86							.15	1.03	.89	.25	1.61	1.07	Stabilized
.18	6.09	1.62	.25	7.67	2.15	.16	3.97	1.36	.19	3.48	1.58							.17	5.10	1.49	.22	5.57	1.86	Hot Transient
.17	3.36	1.21	.47	7.81	1.78	.16	2.88	1.13	.31	6.66	1.20							.165	3.12	1.2	.39	7.23	1.49	Weighted

*Corrected for ambient conditions.

TABLE 22. AMBIENT CONDITIONS, VEHICLE TESTS.

Modified Federal Cycle	X	X	X	X	X	X	X
Federal Cycle	X	X	X	X	X	X	X
Catalyst Miles	ZERO	2000.	4000.	6000.	8000.	9500.	9500.*
BASE FUEL							
Barometer	29.25	29.48	29.61	29.53	29.40	29.82	29.26
Corrected Barometer	-----	29.33	29.46	29.40	20.26	29.56	29.00
Ambient Air °F	82.	84.	84.	77.	82.	72.	72.
Wet Bulb °F	-----	71.	54.	53.	57.	57.	59.
Dry Bulb °F	-----	86.	83.	79.	81.	74.	74.
Humidity %	58.44	47.84	8.99	11.97	19.27	33.04	40.14
"A" ADDITIVE							
Barometer	29.22	29.64	29.25	29.38	29.45	29.22	29.15
Corrected Barometer	29.08	29.51	29.12	29.26	29.31	28.95	29.00
Ambient Air °F	82.	79.	79.	72.	80.	74.	74.
Wet Bulb °F	62.	63.5	61.5	54.	56.	61.	52.5
Dry Bulb °F	79.	79.	79.	71.	79.	77.	76.5
Humidity %	26.69	41.97	35.93	28.35	19.98	39.14	14.43
"B" ADDITIVE							
Barometer	29.31	28.98	29.68	28.82	29.29**		
Corrected Barometer	29.20	28.85	29.57	28.42	29.04		
Wet Bulb °F	54.	52.	48.	63.	58.		
Dry Bulb °F	61.	78.	68.	75.	73.		
Humidity %	63.67	13.01	16.88	51.51	39.34		

*Repeat of 9500.

**Repeat of 6000.

COMMENTS: Base Fuel

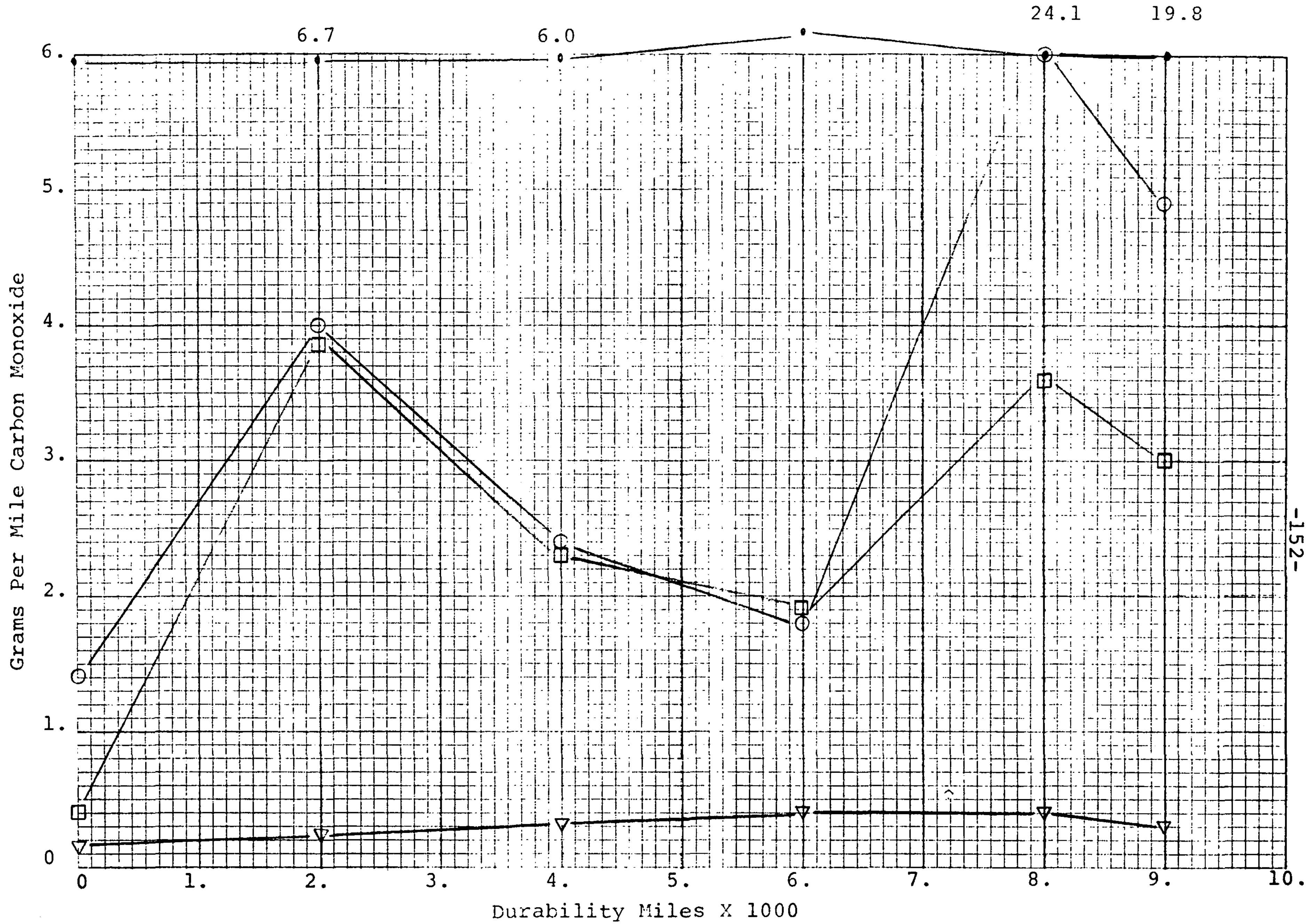
1. The CO, HC and NO_x emission levels, as analyzed from the CVS, appeared in this order: Cold Start $>$ Hot Start $>$ Weighted $>$ Stabilized.

2. NO_x emission levels were higher during the Modified Federal Cycle operation than during Federal Cycle testing.

3. Carbon monoxide emission levels were higher during the Federal Cycle operation than during Modified Federal Cycle testing.

4. Repeatability from run to run was better (less scatter of data points) during the Modified Federal Cycle than during the Federal Cycle tests for hydrocarbons.

5. The data shows that there was not significant deterioration of the catalyst for the duration of the test.



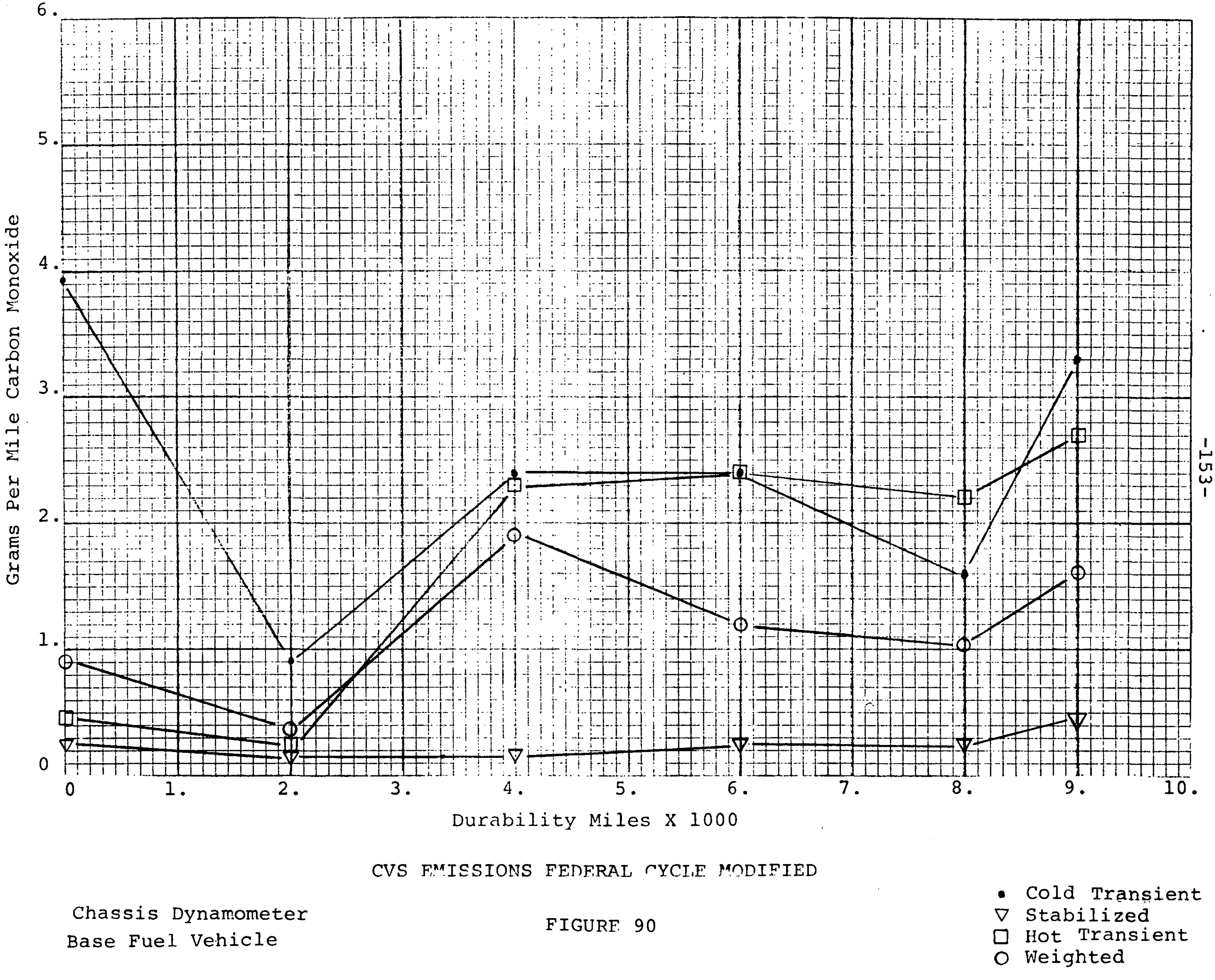
CVS EMISSIONS FEDERAL CYCLE

Chassis Dynamometer

Base Fuel Vehicle

FIGURE 89

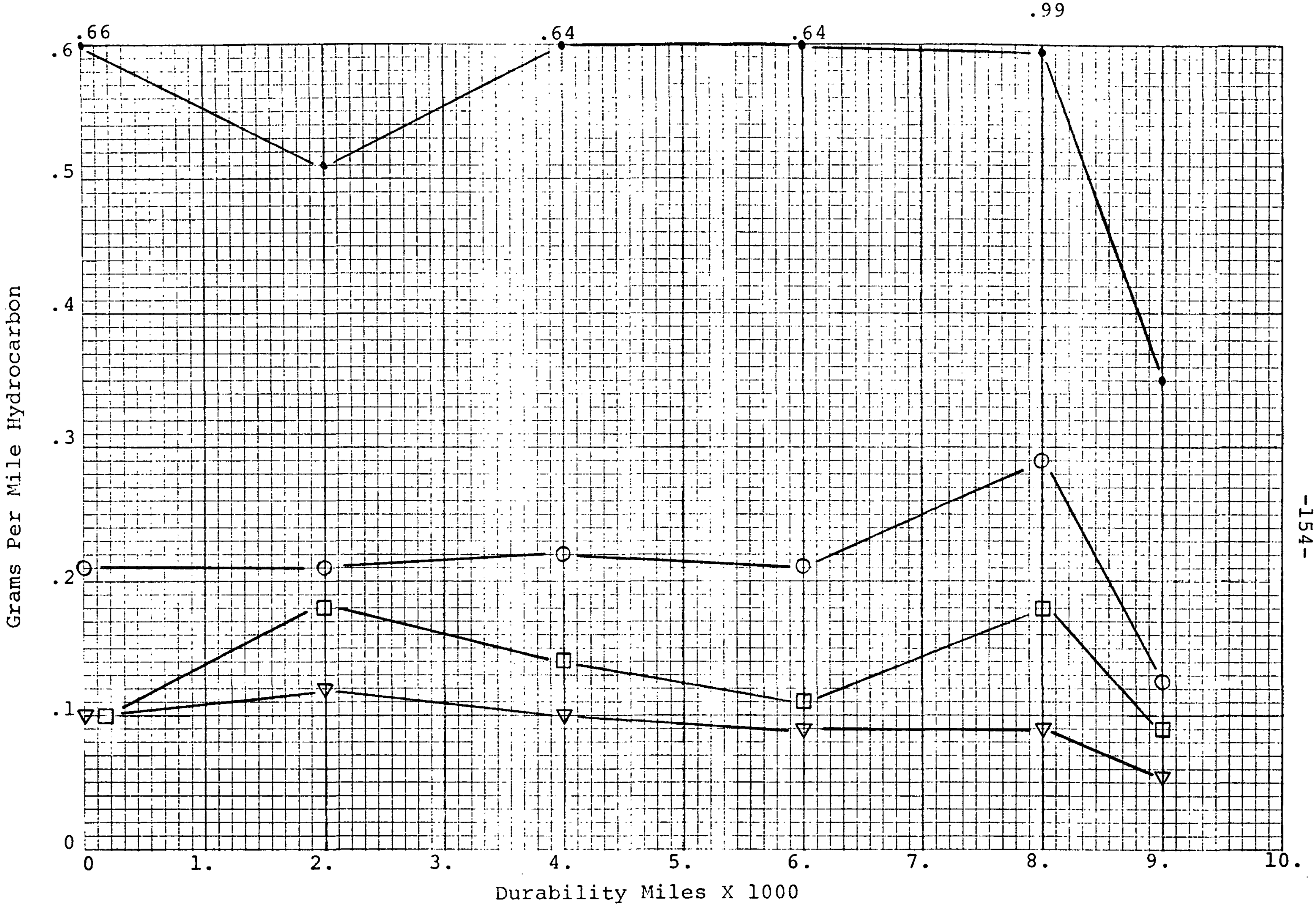
• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Chassis Dynamometer
Base Fuel Vehicle

FIGURE 90

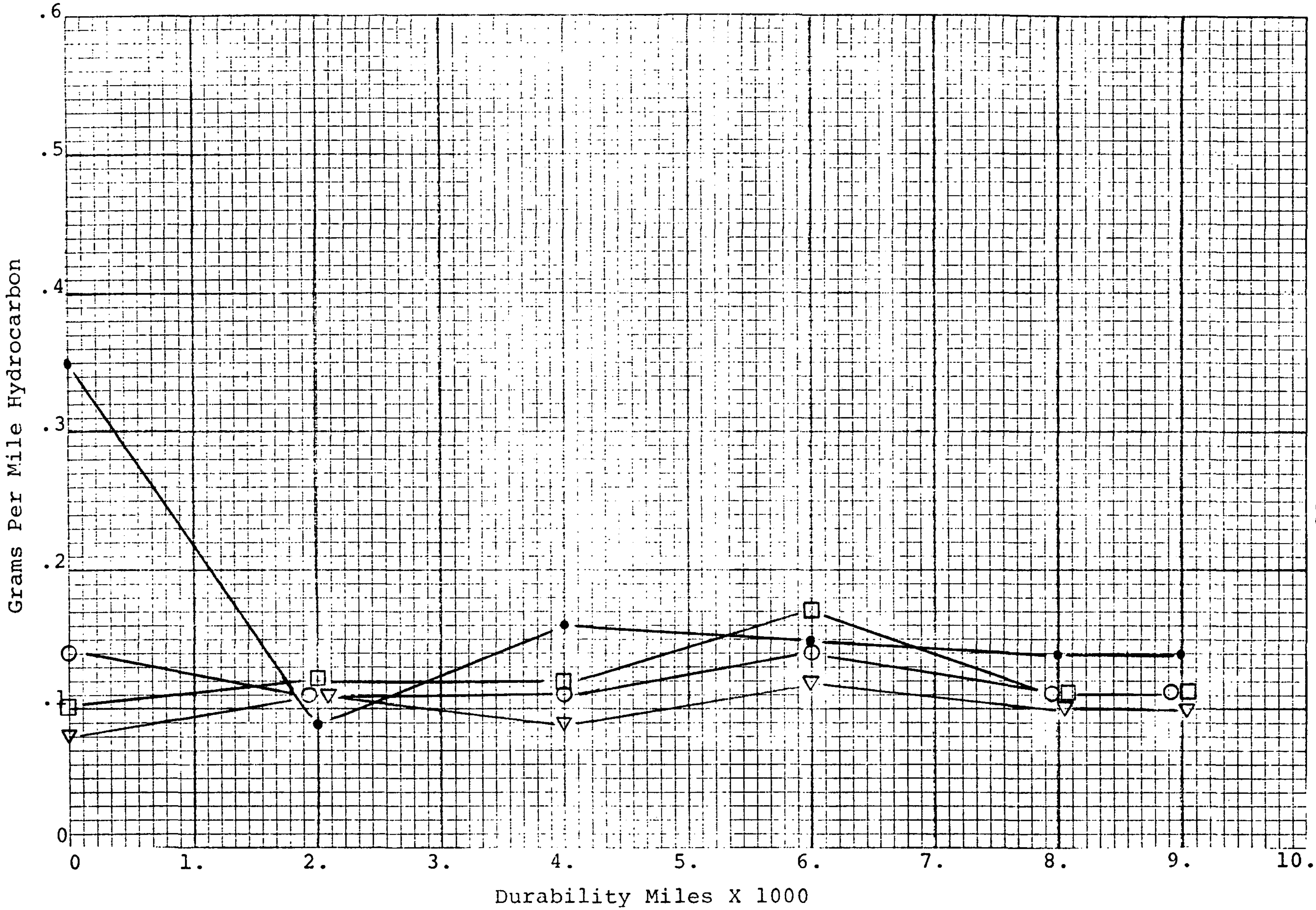


CVS EMISSIONS FEDERAL CYCLE

Chassis Dynamometer
Base Fuel Vehicle

FIGURE 91

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

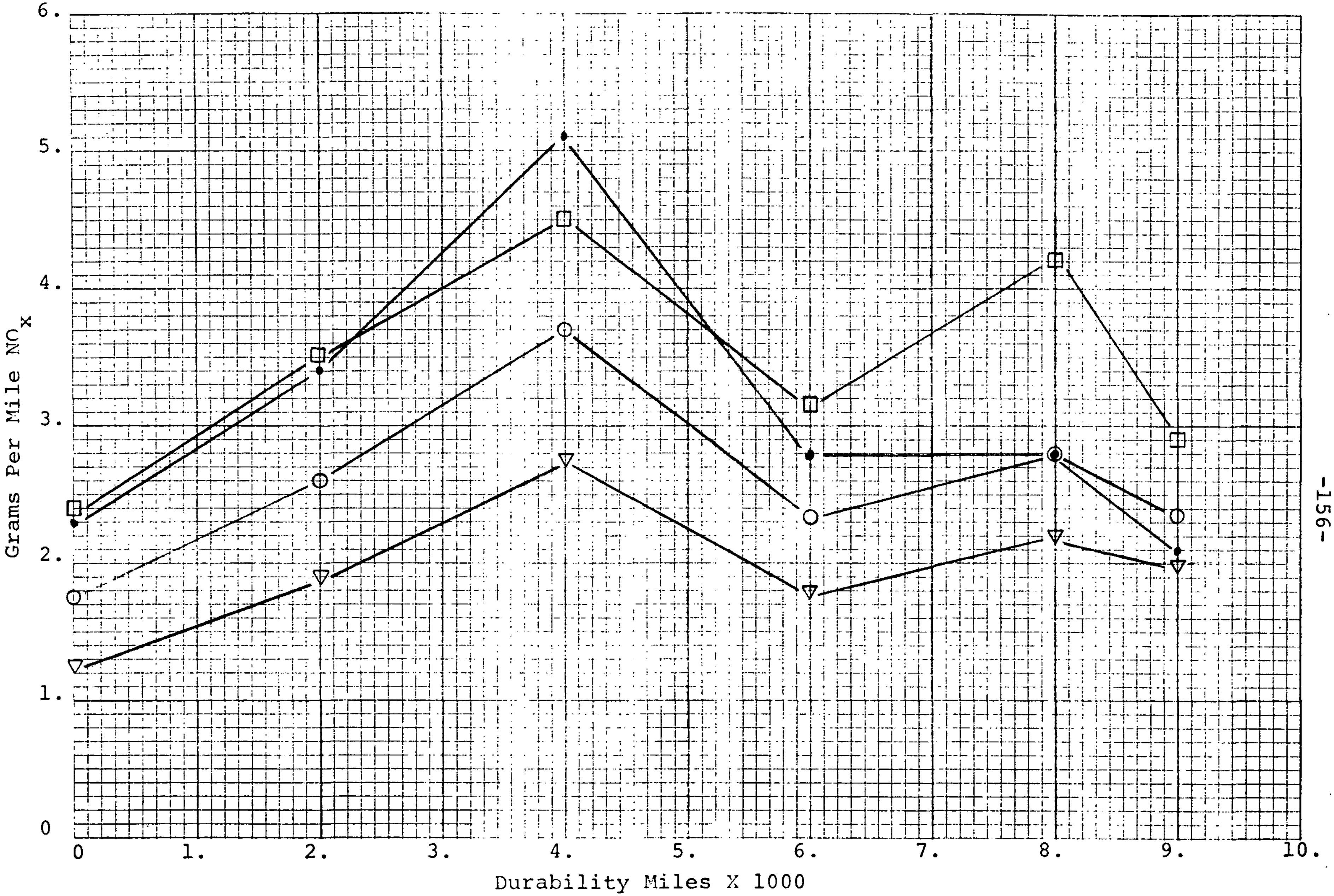


CVS EMISSIONS FEDERAL CYCLE MODIFIED

Chassis Dynamometer
Base Fuel Vehicle

FIGURE 92

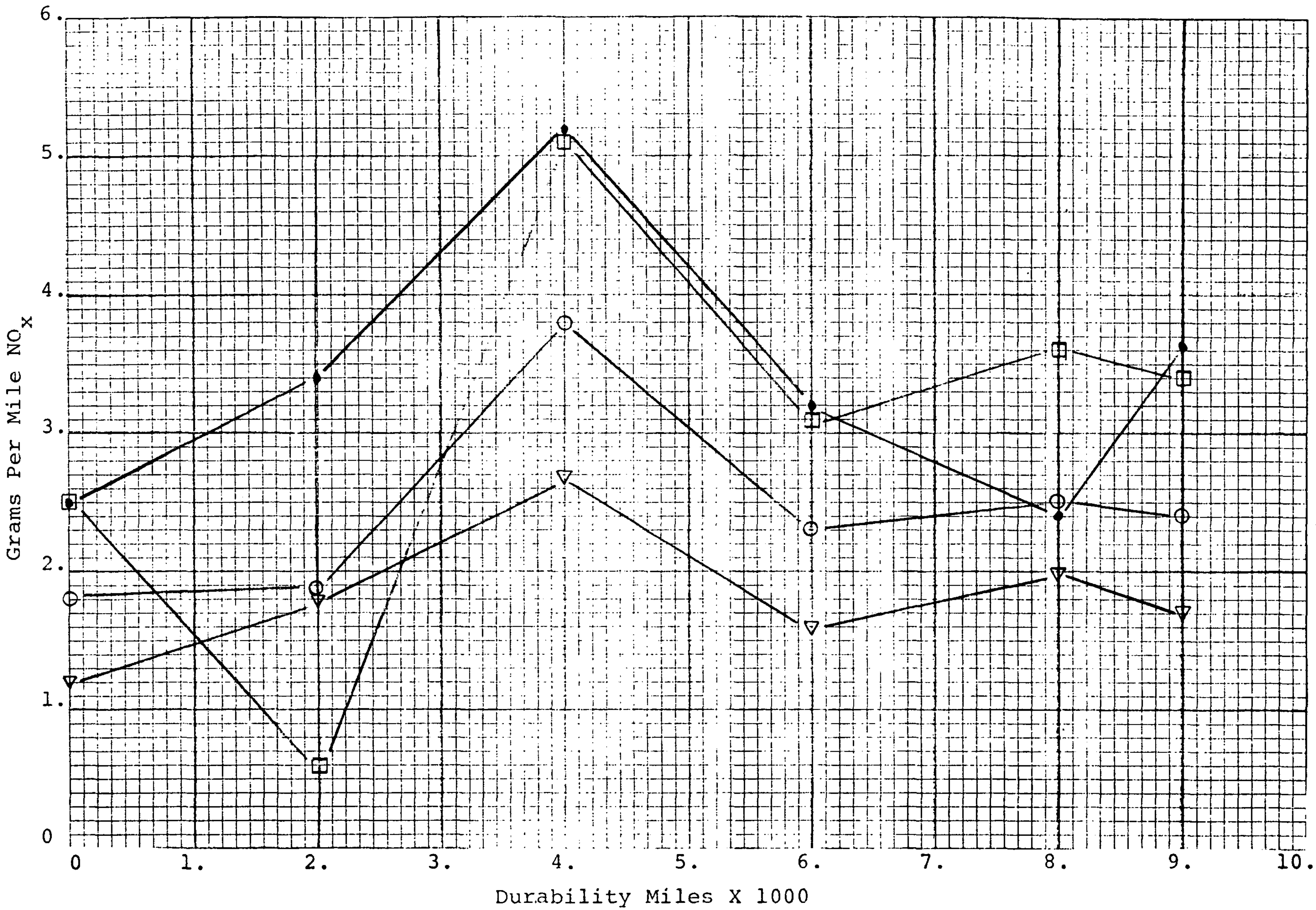
• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted



CVS EMISSIONS FEDERAL CYCLE

Chassis Dynamometer
Base Fuel Vehicle

FIGURE 93



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Chassis Dynamometer
Base Fuel Vehicle

FIGURE 94

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

<u>COMMENTS</u>: Additive "A" Fuel

1. Carbon monoxide levels measured during Federal Cycle tests are not significantly different from those measured during the Modified Federal Cycle. The carbon monoxide does increase, however, as mileage is accumulated, indicating some catalyst degradation.

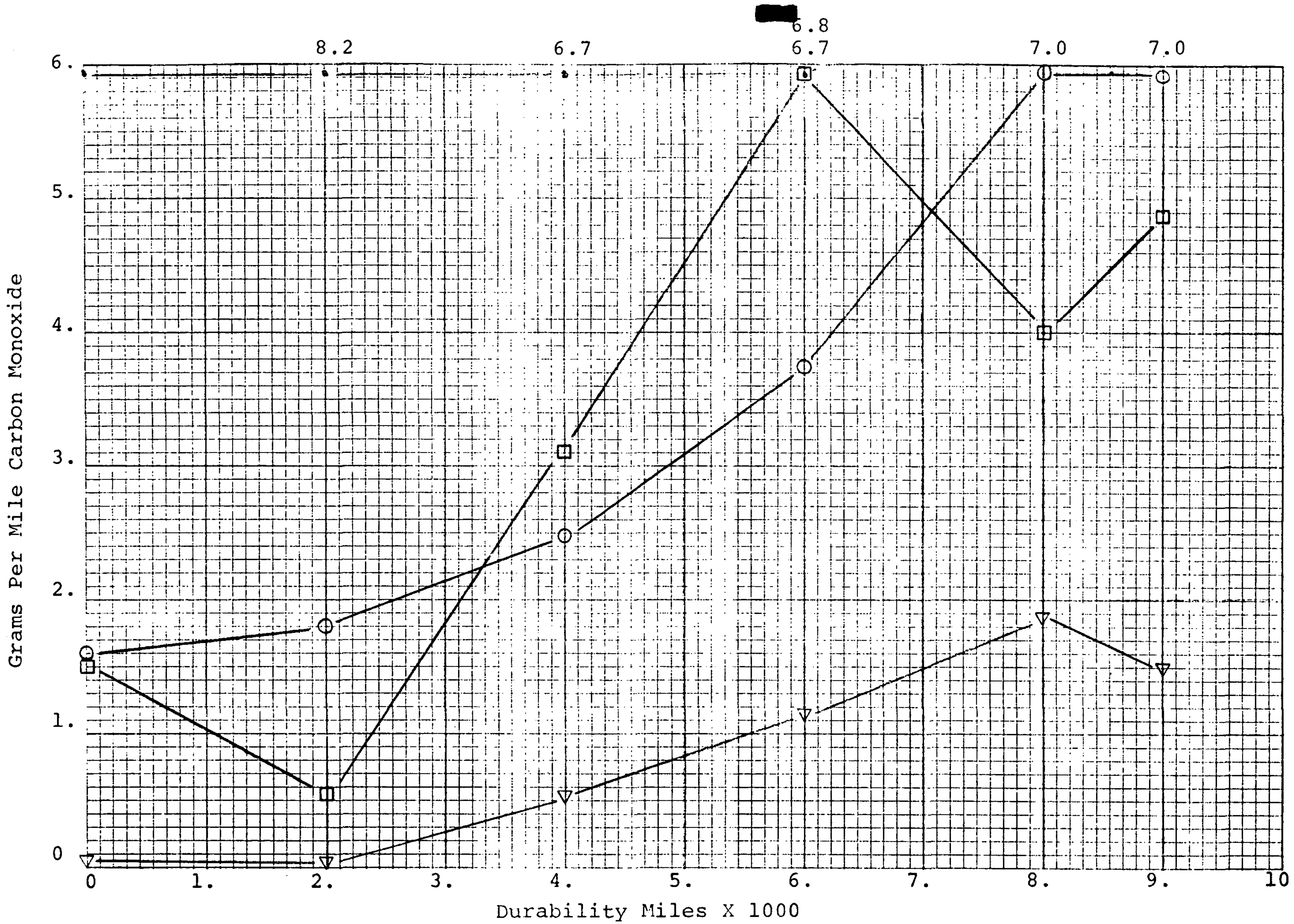
2. Hydrocarbon emission levels from the three CVS portions of the Modified Federal Cycle are consistent from test to test, forming a nearly flat curve with a slight upward slope with time.

3. Unlike the hydrocarbon emissions data mentioned above, the data points from the Federal Cycle CVS are quite scattered and it is difficult to form meaningful conclusions.

4. The NO_x emission level did not increase with durability miles for either the Federal Cycle or Modified Federal Cycle tests.

5. NO_x emission data points, from the three CVS portions of the Federal Cycle, are quite close and form a nearly flat curve; whereas, the Modified Federal Cycle data points showed considerable scatter. This is not unexpected, since the higher temperatures of the Federal Cycle Modified would tend to generate higher NO_x levels.

6. The NO_x emissions, as analyzed from the CVS, appeared in the following order: Hot Start $<$ Cold Start $<$ Weighted $<$ Stabilized.



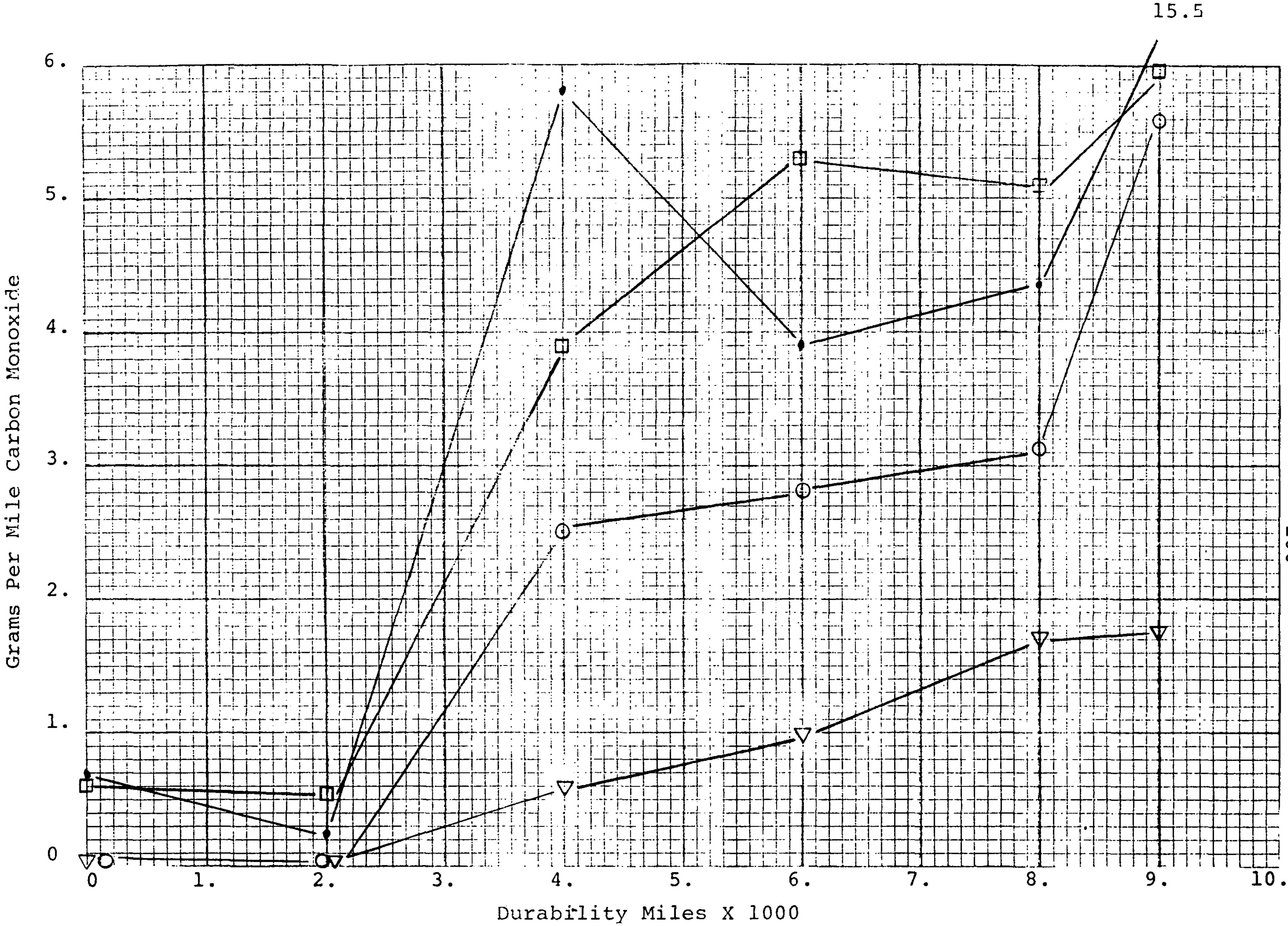
CVS EMISSIONS FEDERAL CYCLE

Chassis Dynamometer

"A" Additive Vehicle

FIGURE 95

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted



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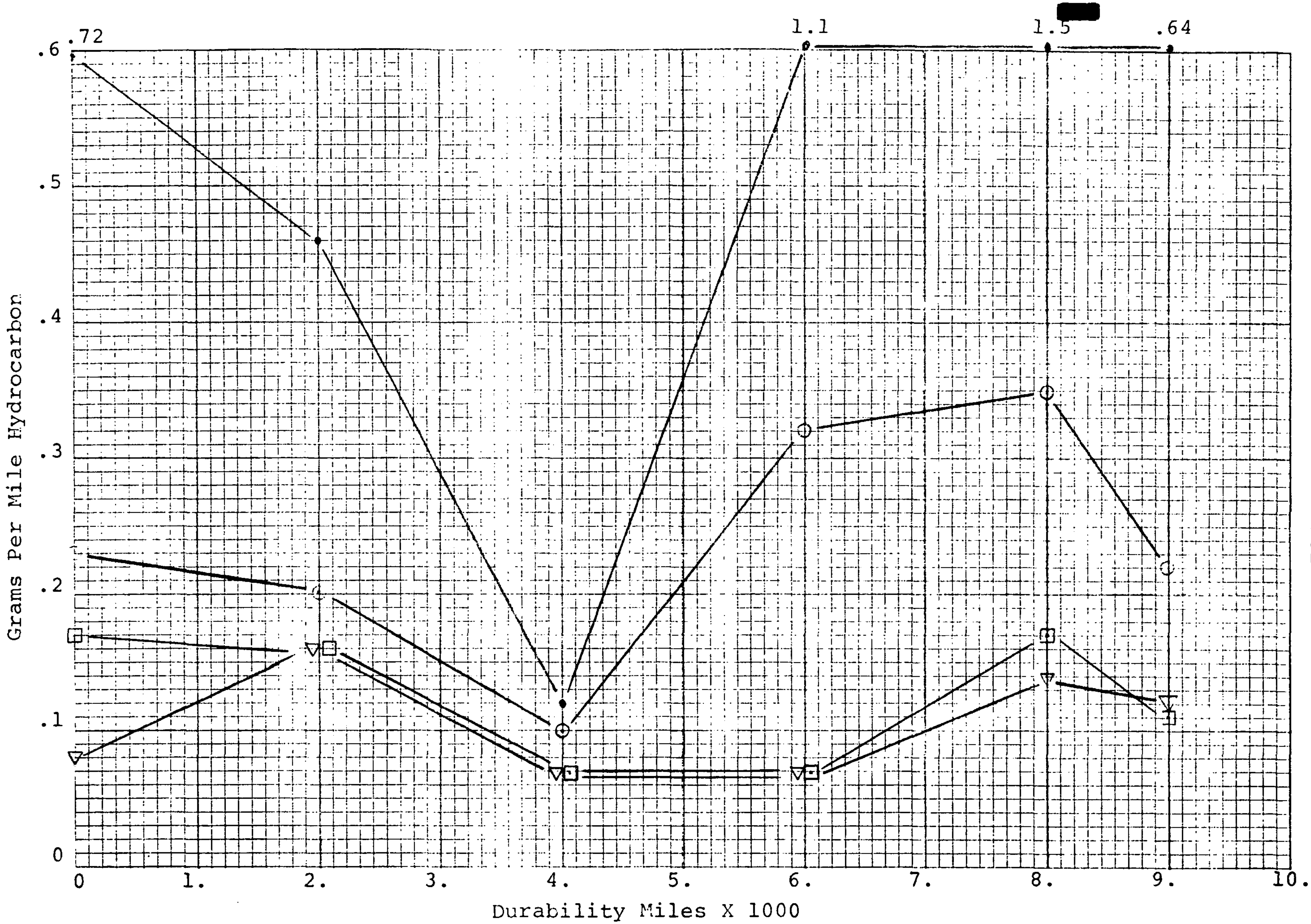
CVS EMISSIONS FEDERAL CYCLE MODIFIED

Chassis Dynamometer
"A" Additive Vehicle

FIGURE 96

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

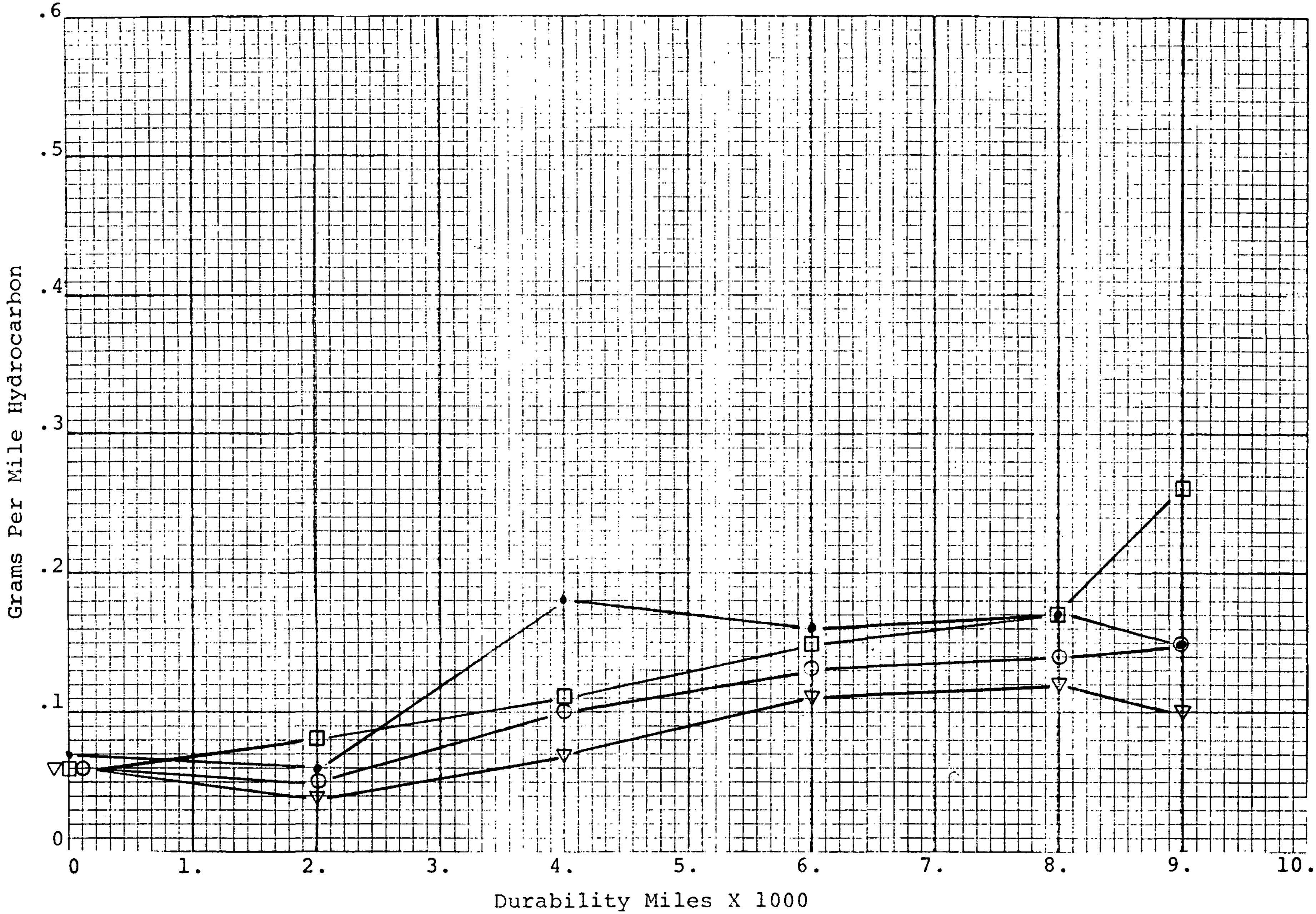


CVS EMISSIONS FEDERAL CYCLE

Chassis Dynamometer
"A" Additive Vehicle

FIGURE 97

- Cold Transient
- ▽ Stabilized
- □ Hot Transient
- ○ Weighted

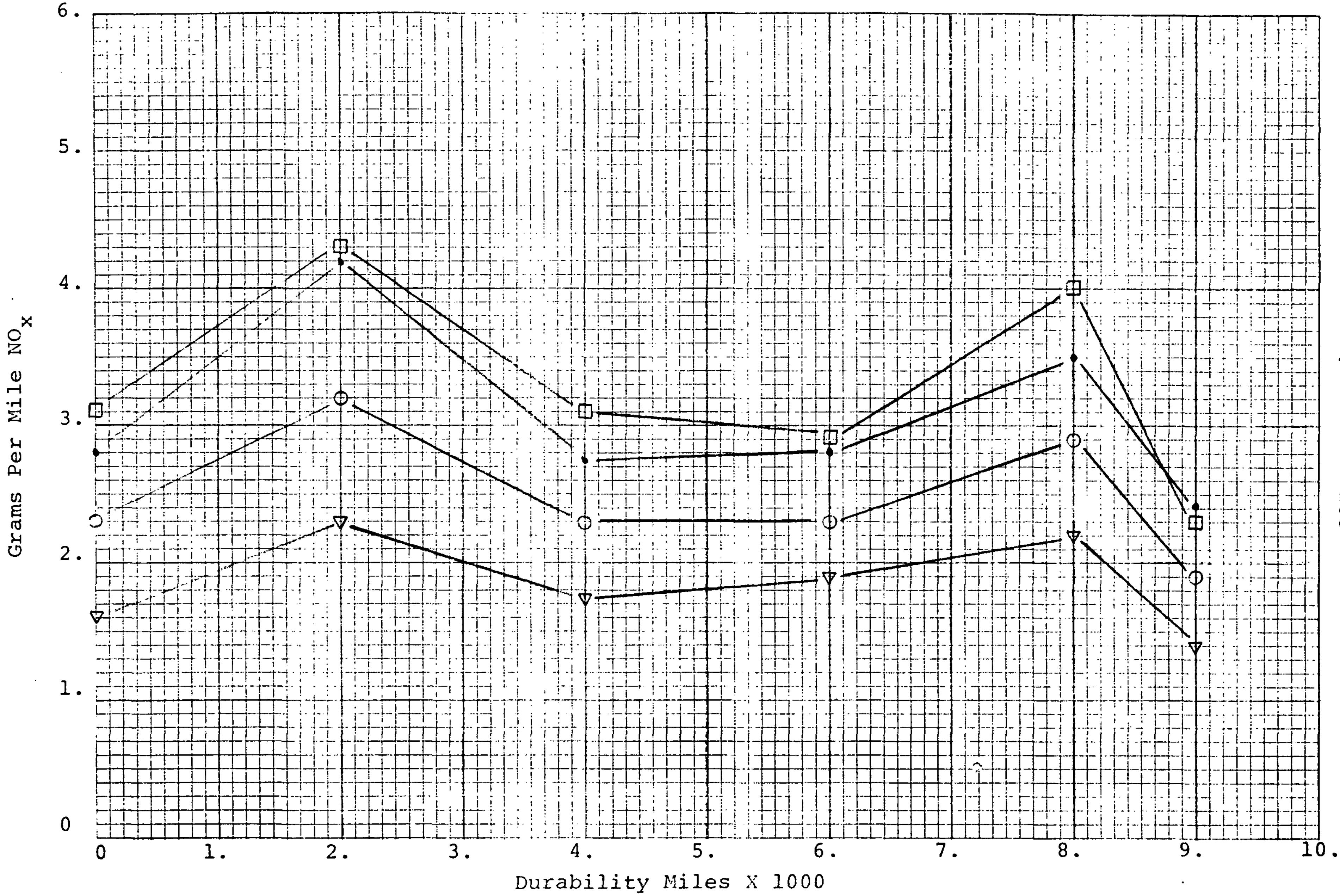


CVS EMISSIONS FEDERAL CYCLE MODIFIED

● Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

Chassis Dynamometer
"A" Additive Vehicle

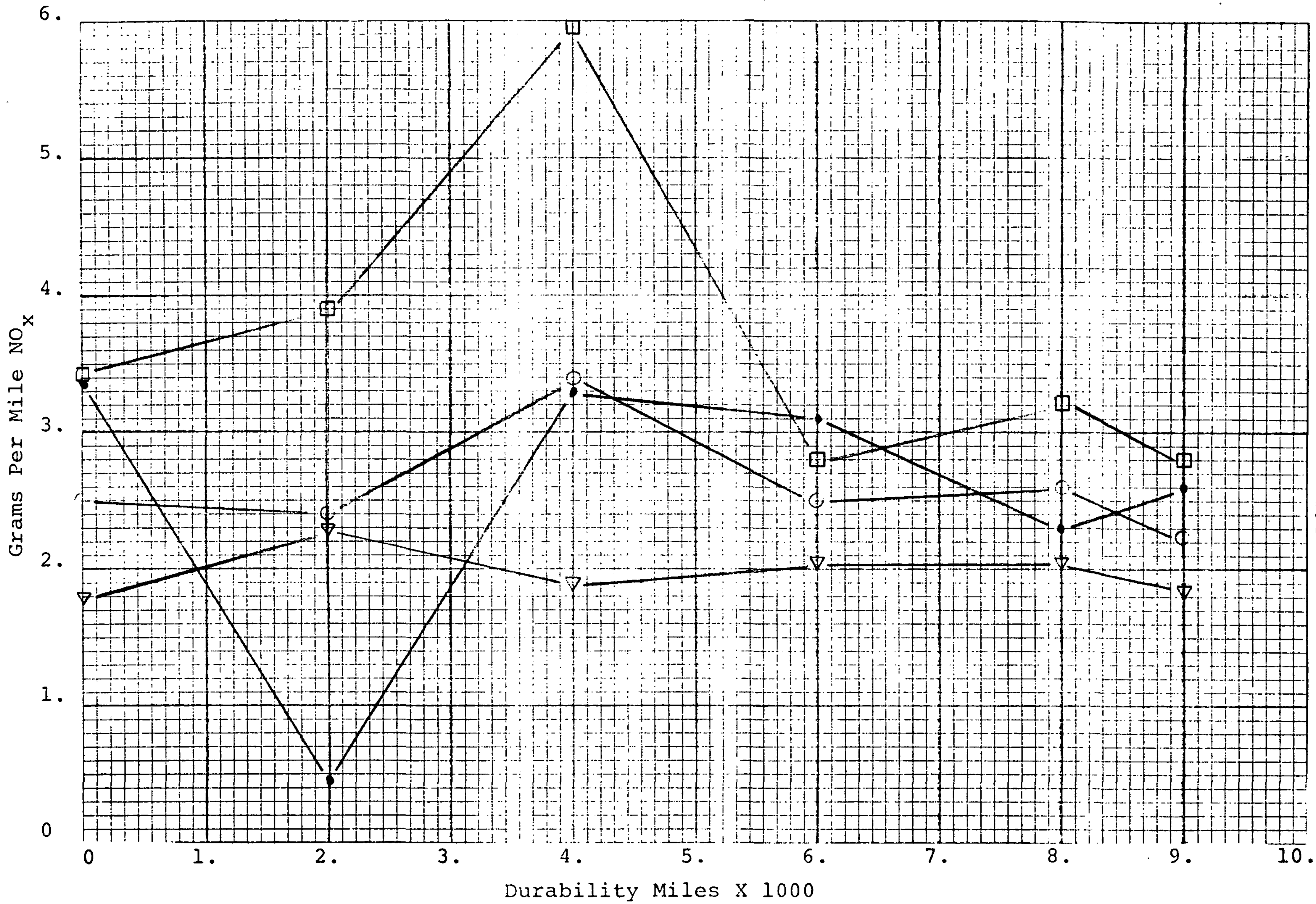
FIGURE 98



CVS EMISSIONS FEDERAL CYCLE

Chassis Dynamometer
"A" Additive Vehicle

FIGURE 99



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Chassis Dynamometer
"A" Additive Vehicle

FIGURE 100

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

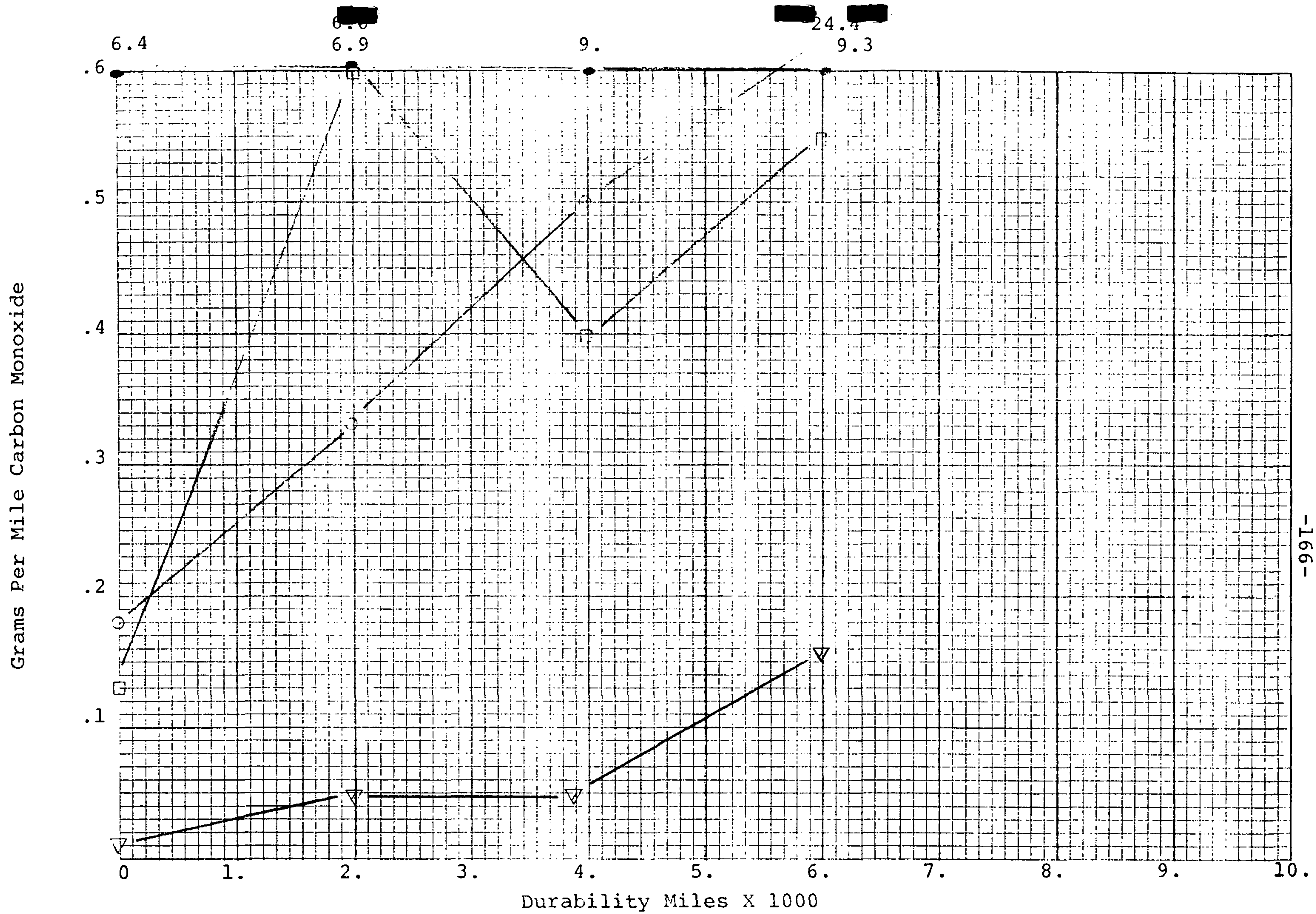
COMMENTS: Additive "B"

1. Carbon monoxide emission level data points from both the Federal Cycle and the Modified Federal Cycle test procedures showed considerable scatter which had an overall upward trend with time, indicative of a loss of converter efficiency.

2. Hydrocarbon emissions from both the Federal Cycle and the Modified Federal Cycle tests show much less scatter than does carbon monoxide, however, both test cycles show an upward trend with time for hydrocarbons as well as carbon monoxide.

3. NO_x emissions from both the Federal Cycle and the Modified Federal Cycle tests show a downward trend with test miles.

4. The NO_x emissions, as analyzed from the CVS, appeared in the following order: Hot Start $<$ Cold Start $<$ Weighted $<$ Stabilized.

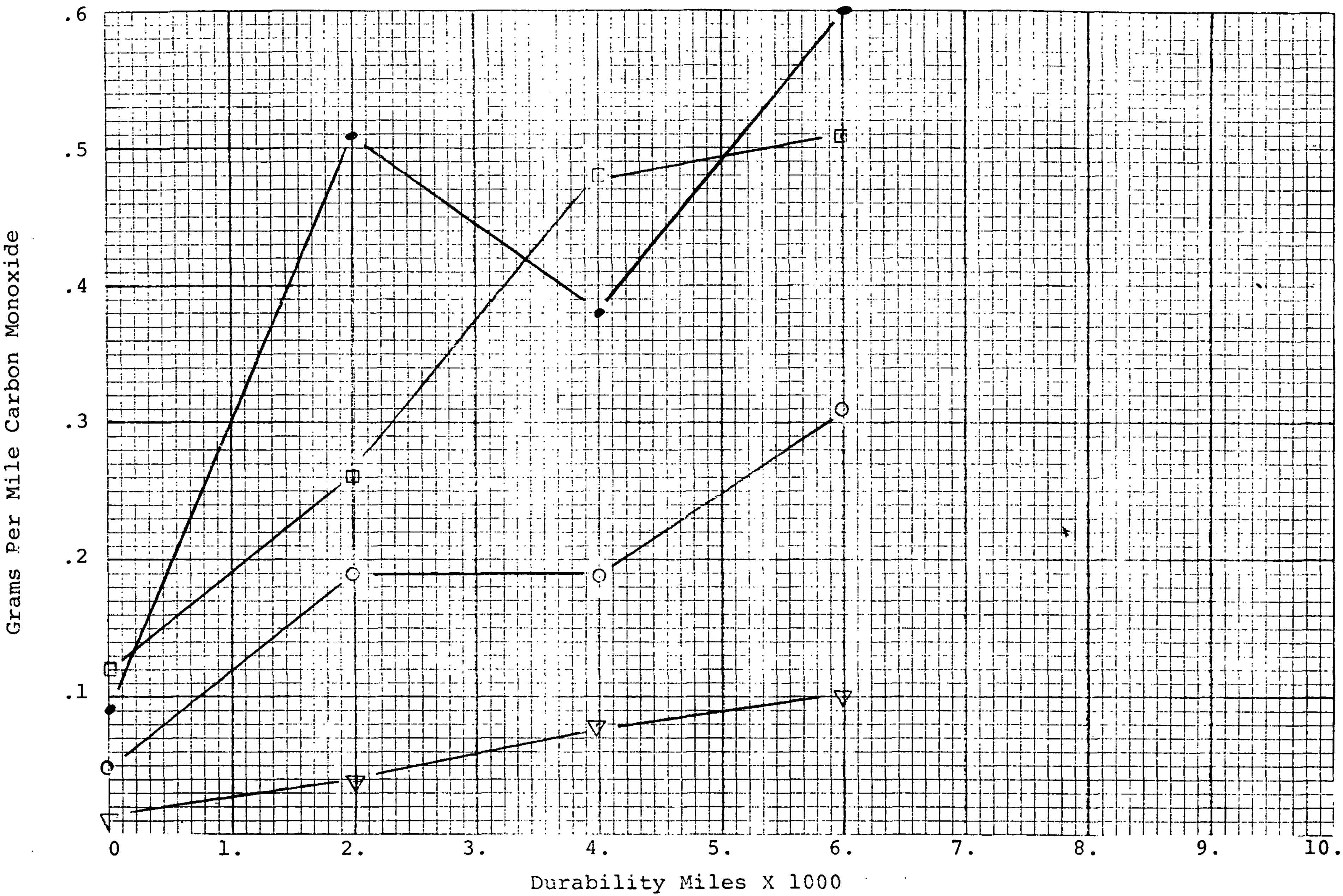


CVS EMISSIONS FEDERAL CYCLE

Chassis Dynamometer
"B" Additive Vehicle

FIGURE 101

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

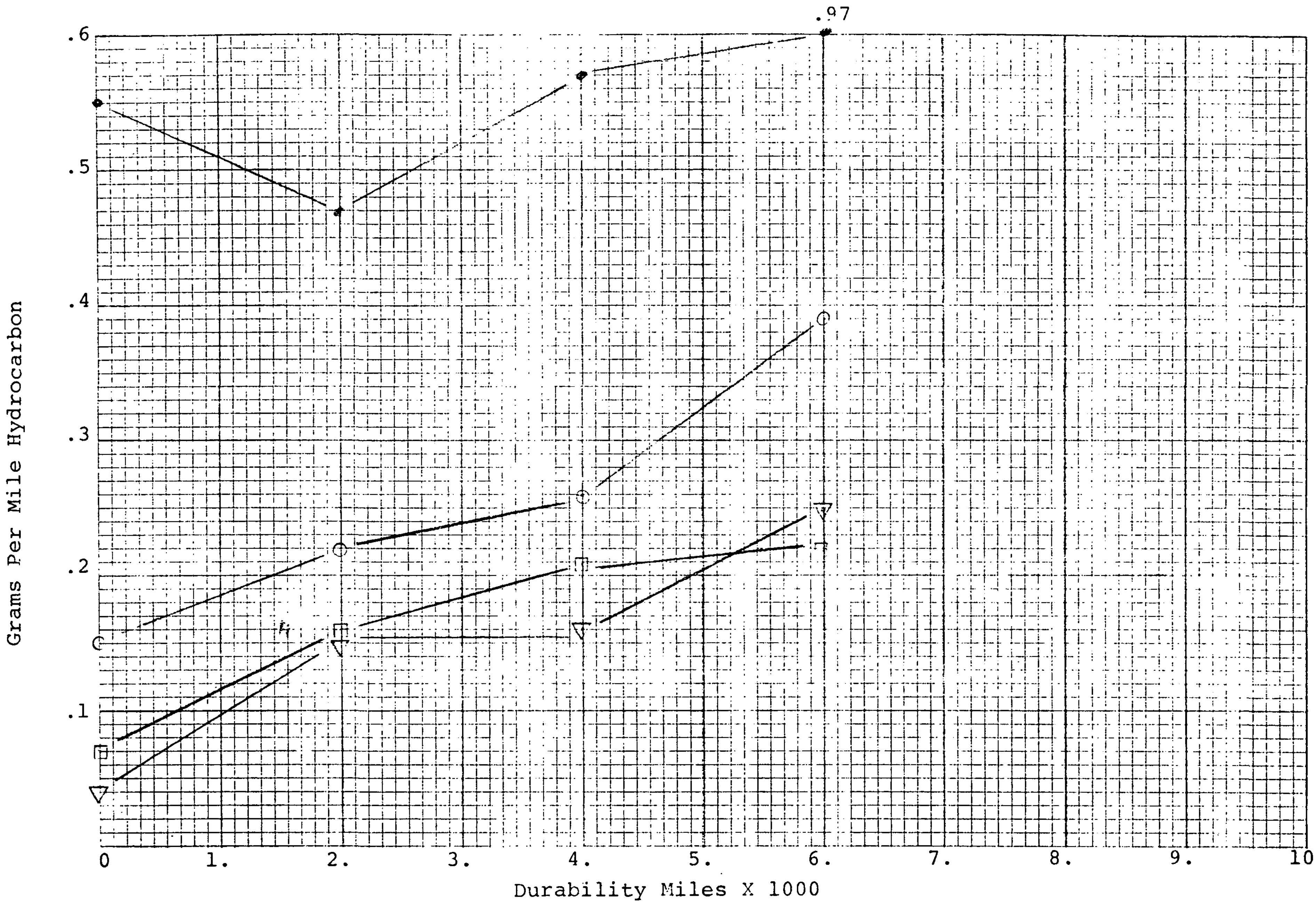


CVS EMISSIONS FEDERAL CYCLE MODIFIED

Chassis Dynamometer
"B" Additive Vehicle

FIGURE 102

● Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted



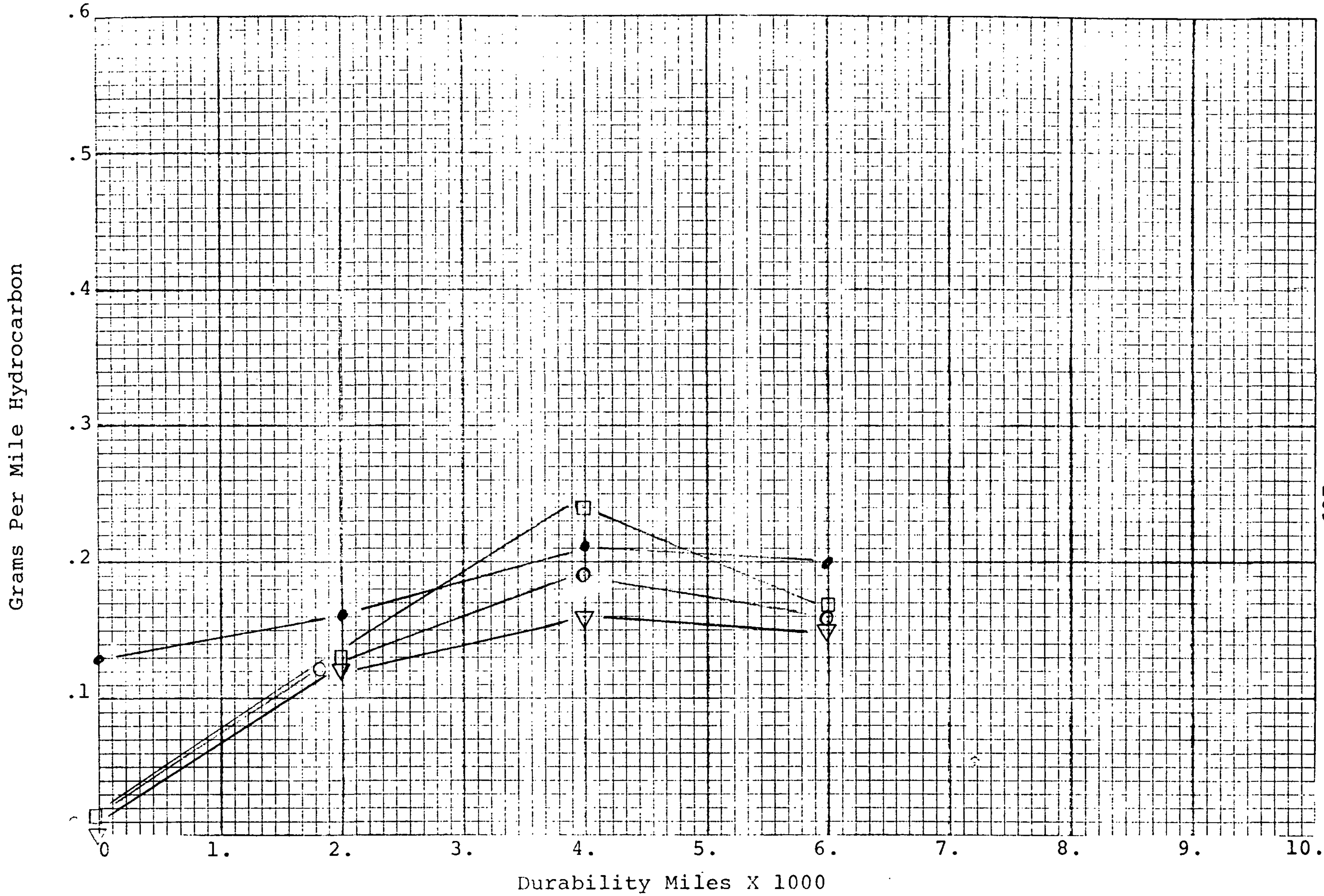
CVS EMISSIONS FEDERAL CYCLE

Chassis Dynamometer

"B" Additive Vehicle

FIGURE 103

- Cold Transient
- ▽ Stabilized
- □ Hot Transient
- ○ Weighted

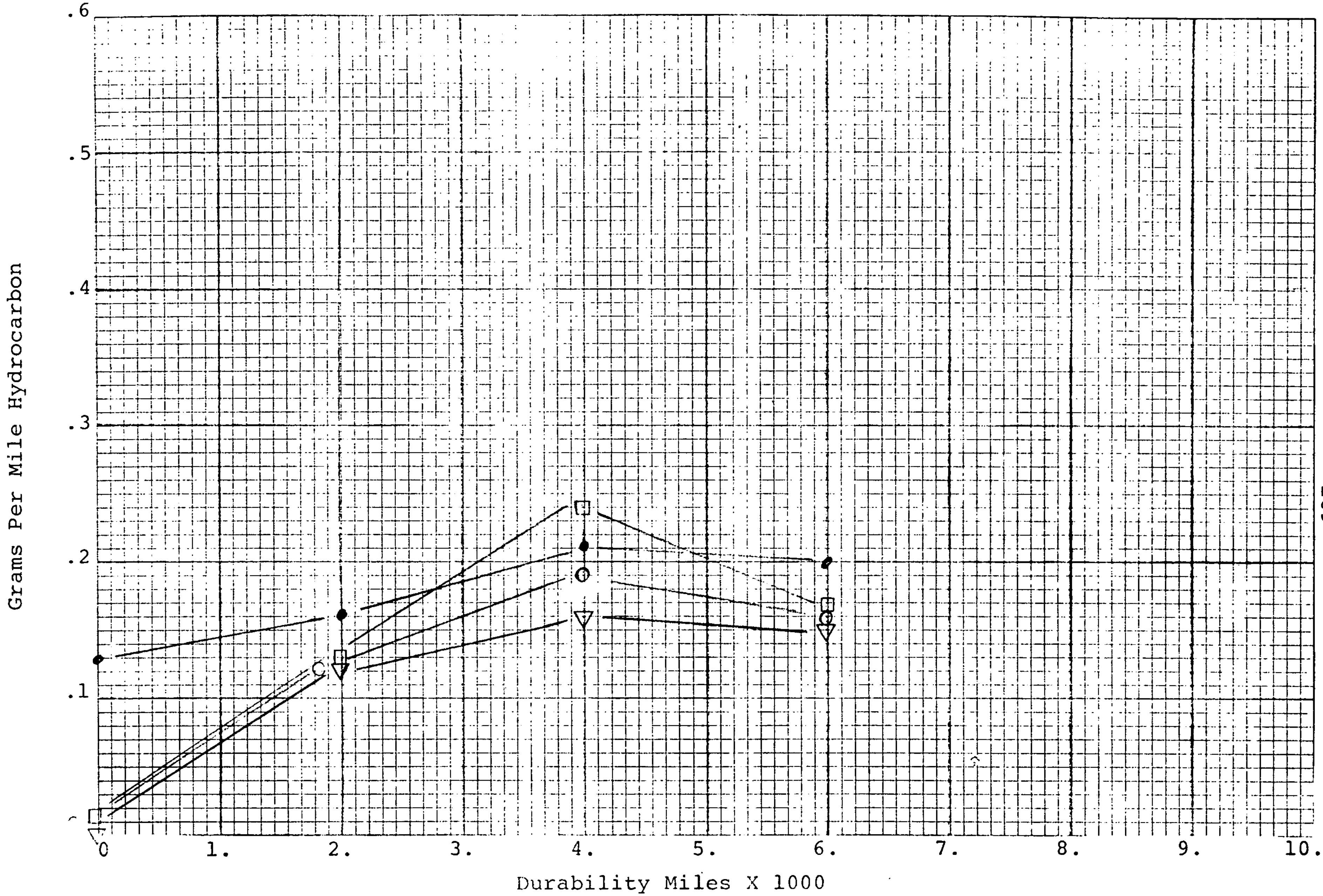


CVS EMISSIONS FEDERAL CYCLE MODIFIED

Chassis Dynamometer
"B" Additive Vehicle

FIGURE 104

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

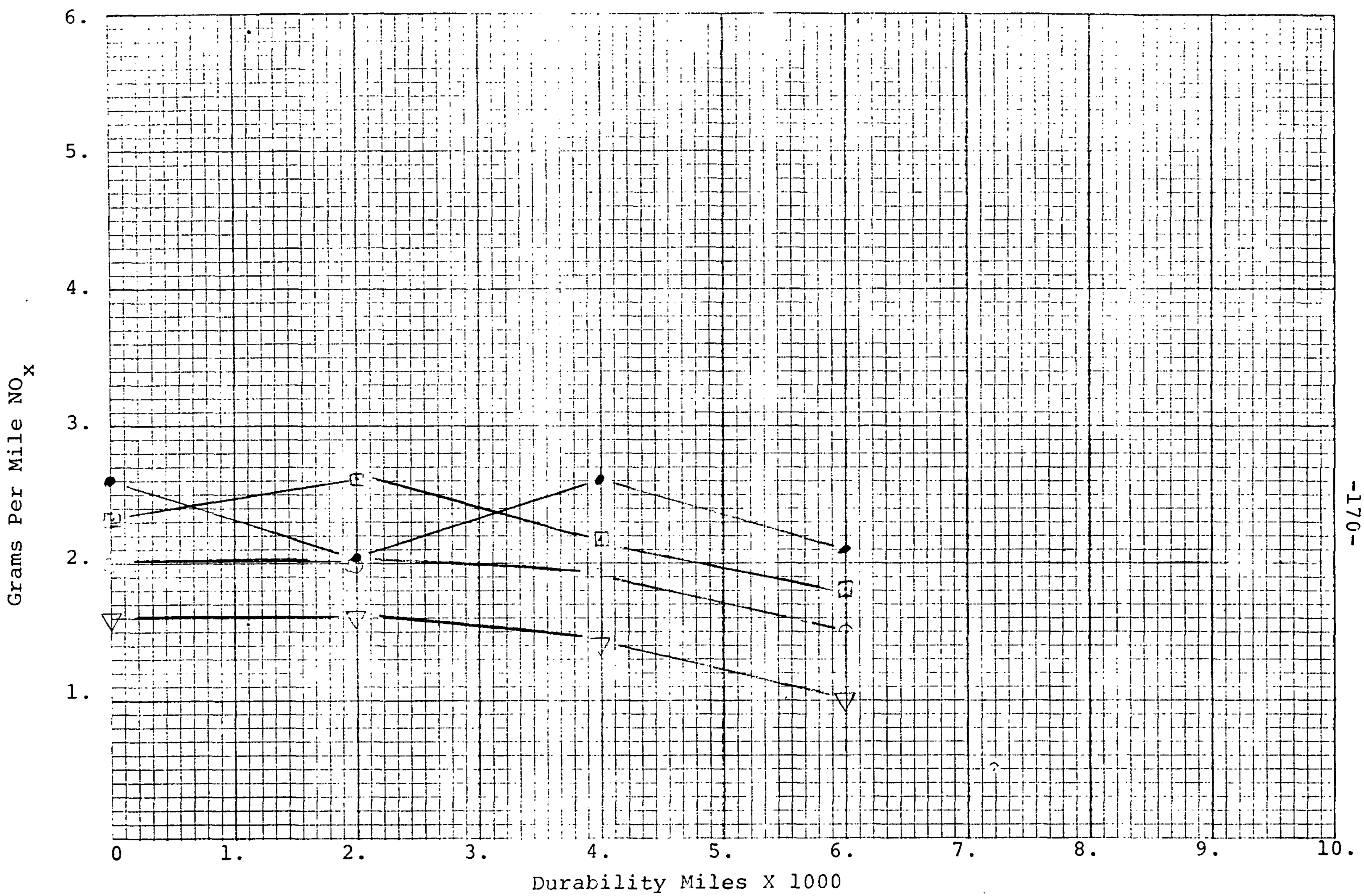


CVS EMISSIONS FEDERAL CYCLE MODIFIED

Chassis Dynamometer
"B" Additive Vehicle

FIGURE 104

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted

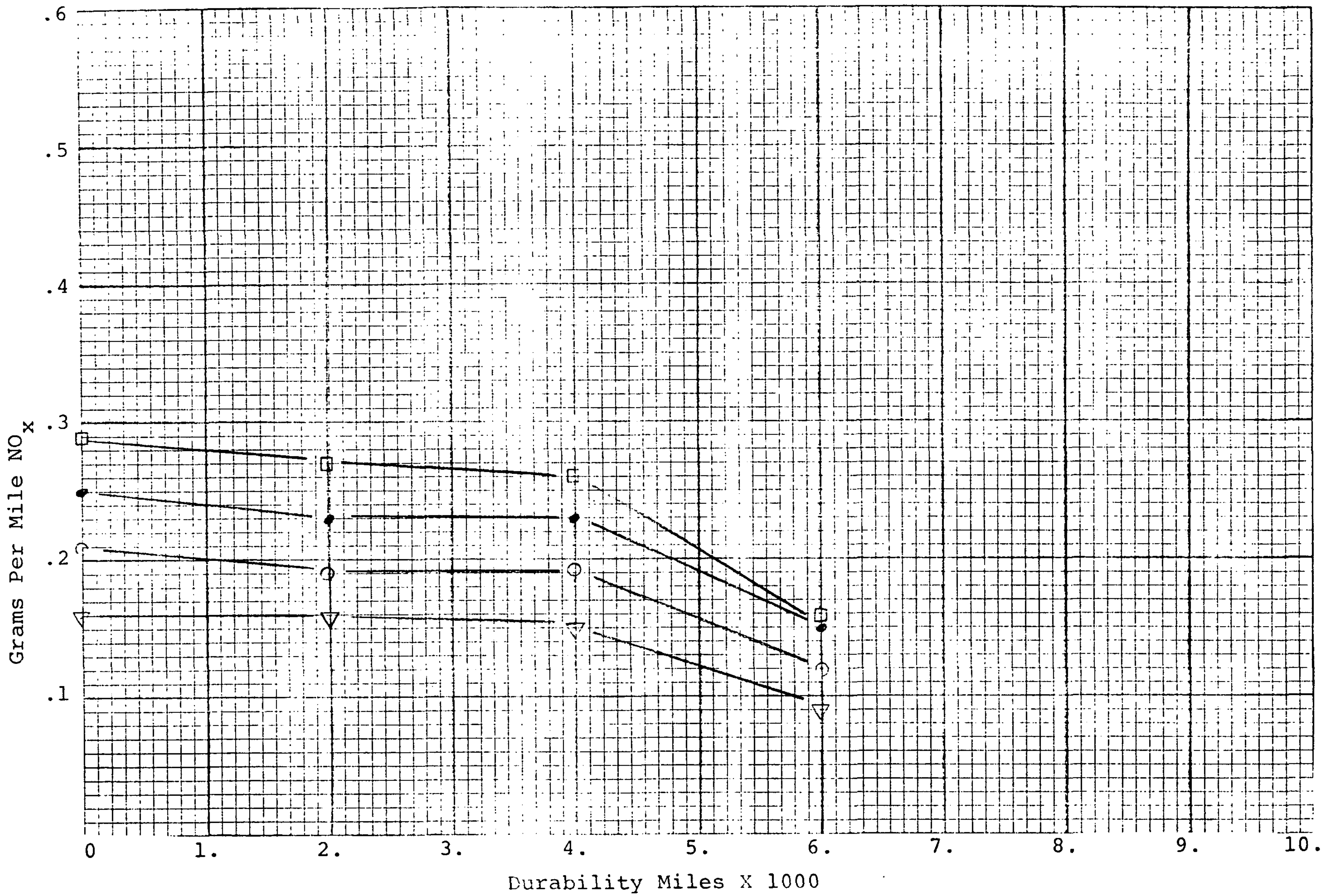


CVS EMISSIONS FEDERAL CYCLE

Chassis Dynamometer
"B" Additive Vehicle

FIGURE 105

• Cold Transient
▽ Stabilized
□ Hot Transient
○ Weighted



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Chassis Dynamometer

"B" Additive Vehicle

FIGURE 106

G. Comparison of Three Fuels, Chassis Dynamometer, Beaded Catalyst

COMMENTS:

1. The NO_x values did not vary during the durability test for any of the fuels, whether tested via Federal Cycle or Federal Cycle Modified.

2. The carbon monoxide emissions increased during the durability test for all three fuels. This was true for Federal Cycle and Federal Cycle Modified tests.

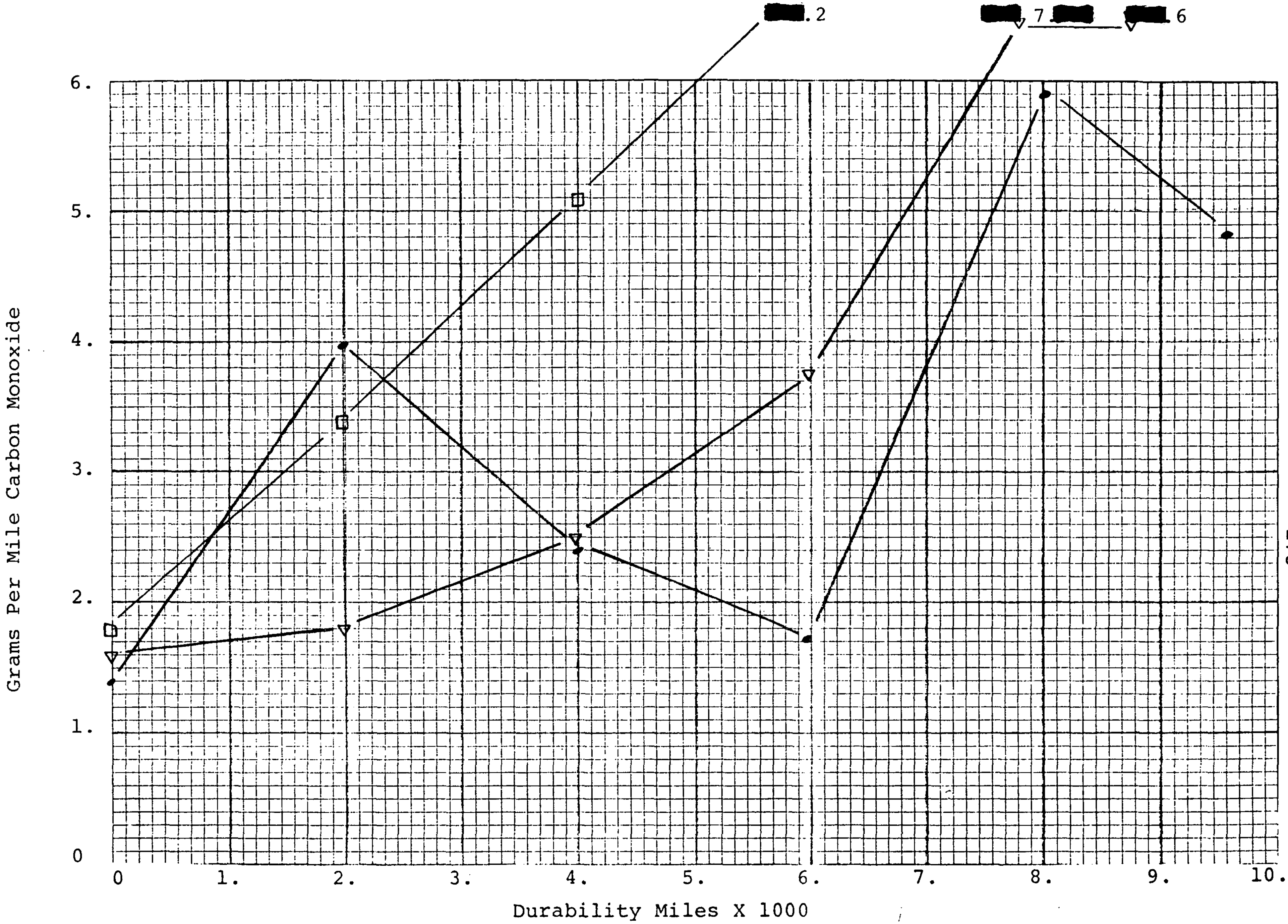
3. Carbon monoxide emissions, tested during the Federal Cycle, increased more rapidly during durability tests than when measured during the Federal Cycle Modified. This could be a result of a high light off temperature for the converter.

4. Carbon monoxide emission levels during the durability test increased the least with the base fuel car. The Additive "A" car increased slightly more, while the Additive "B" car had the greatest amount of carbon monoxide increase during the durability test.

5. The carbon monoxide emission levels were lower during the Federal Cycle than they were during the Federal Cycle Modified.

6. Hydrocarbon emission levels were lower when tested under the Federal Cycle Modified test than under the Federal Cycle.

7. Hydrocarbon emission levels did not increase during durability testing for the base fuel car or for the Additive "A" fuel car, but the Additive "B" car did show a slight increase during the durability test.

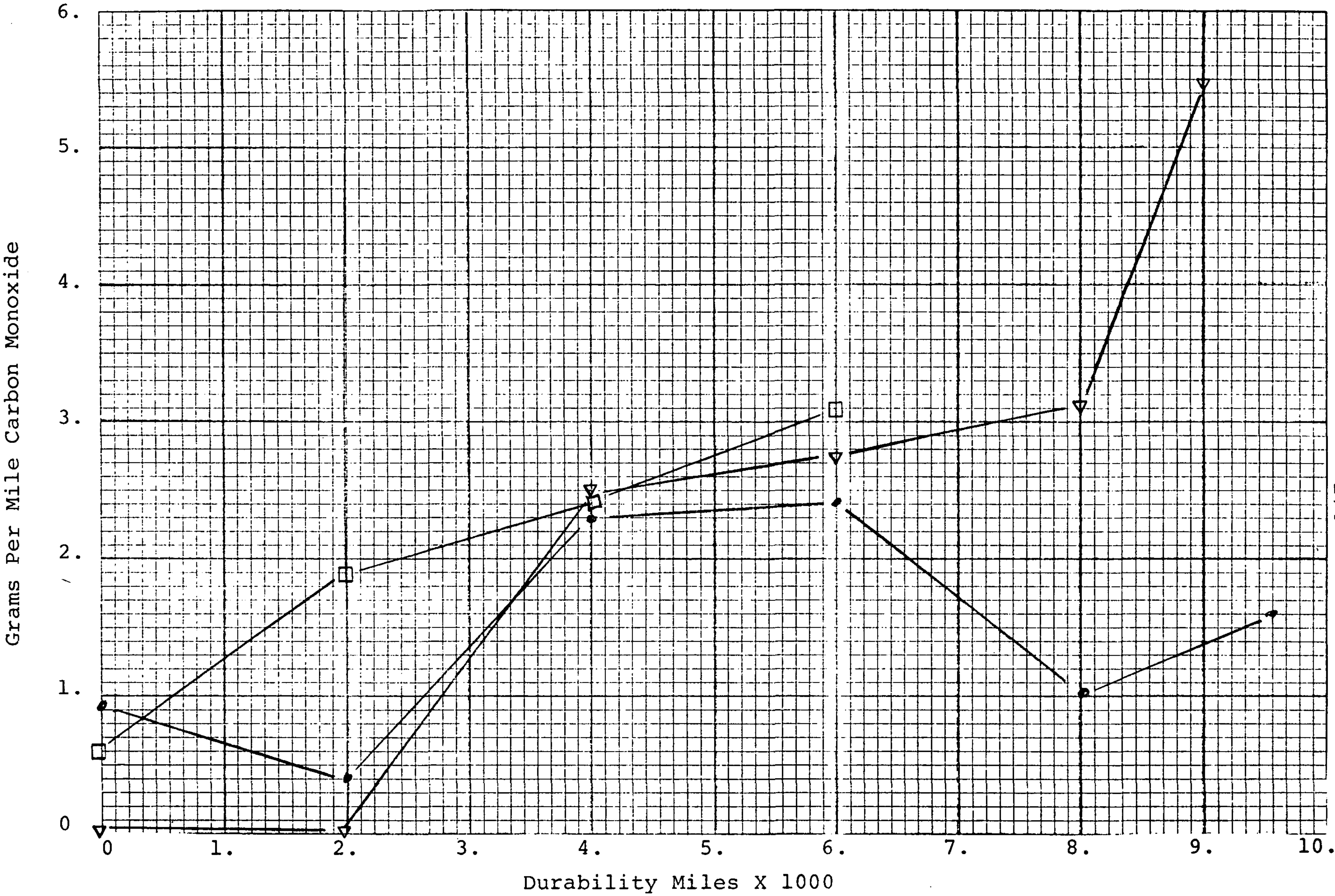


CVS EMISSIONS FEDERAL CYCLE

Chassis Dynamometer

FIGURE 107

• Baseline
▽ "A" Additive
□ "B" Additive

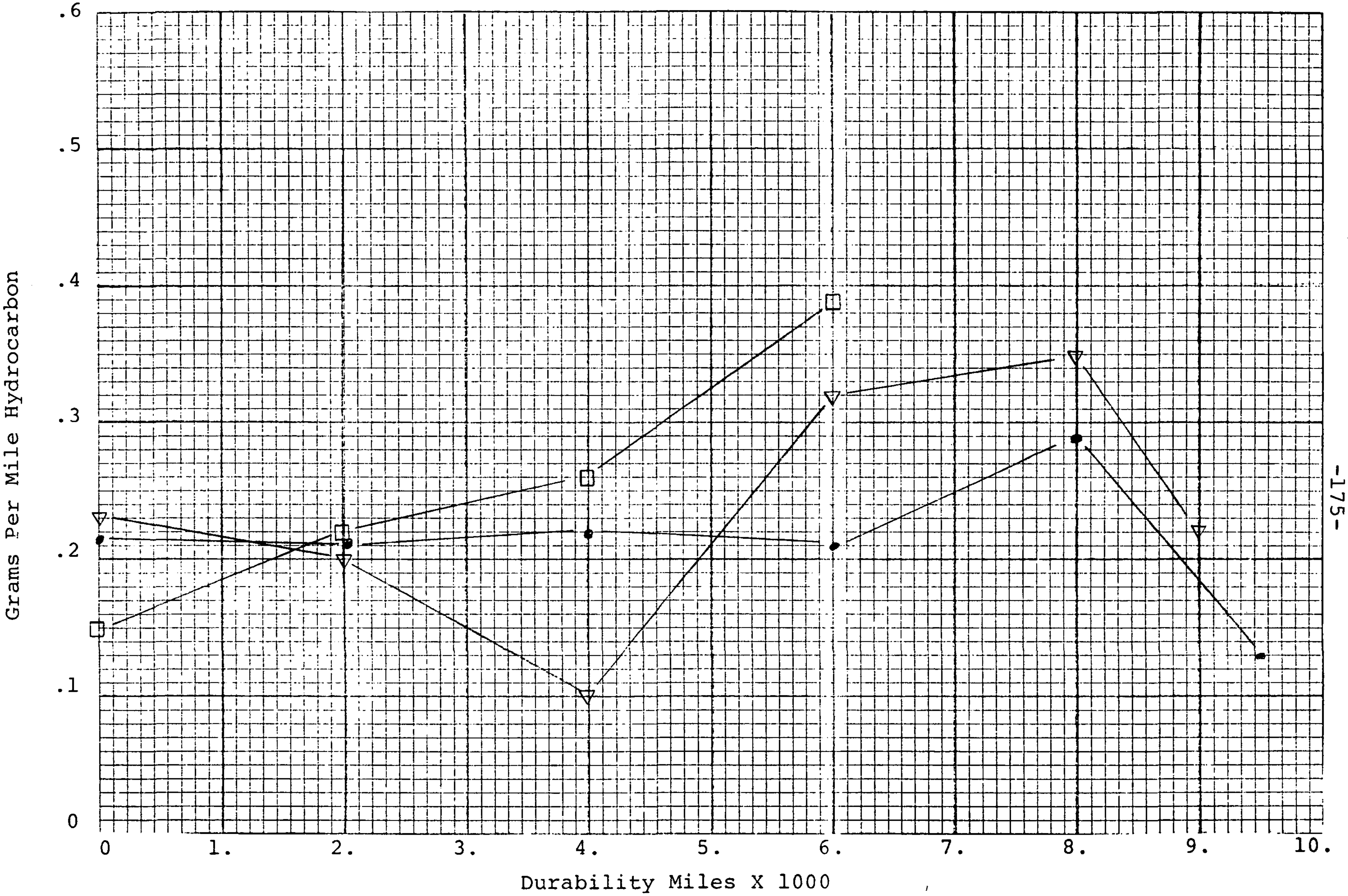


CVS EMISSIONS FEDERAL CYCLE MODIFIED

• Baseline
▽ "A" Additive
□ "B" Additive

Chassis Dynamometer

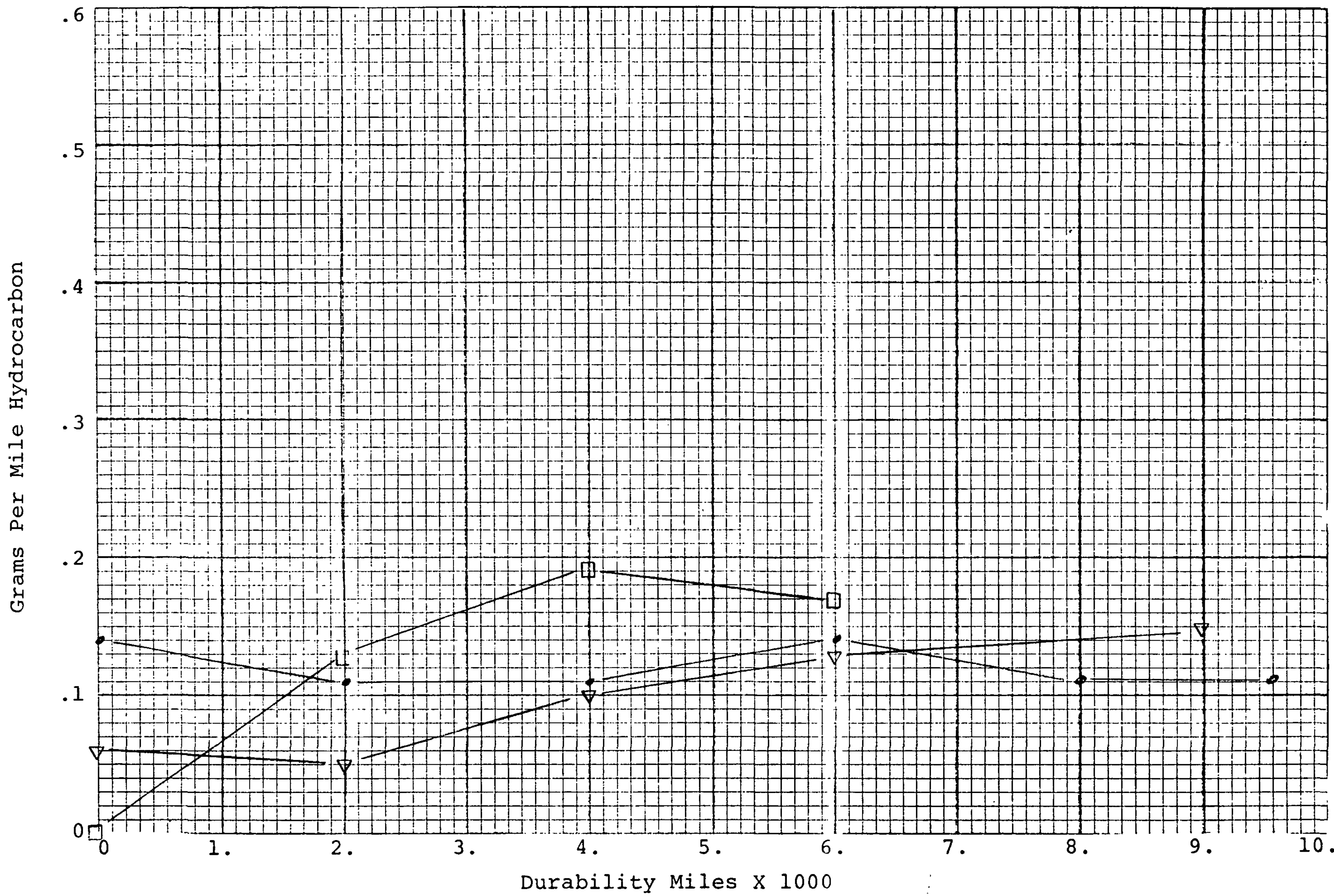
FIGURE 108



CVS EMISSIONS FEDERAL CYCLE

Chassis Dynamometer

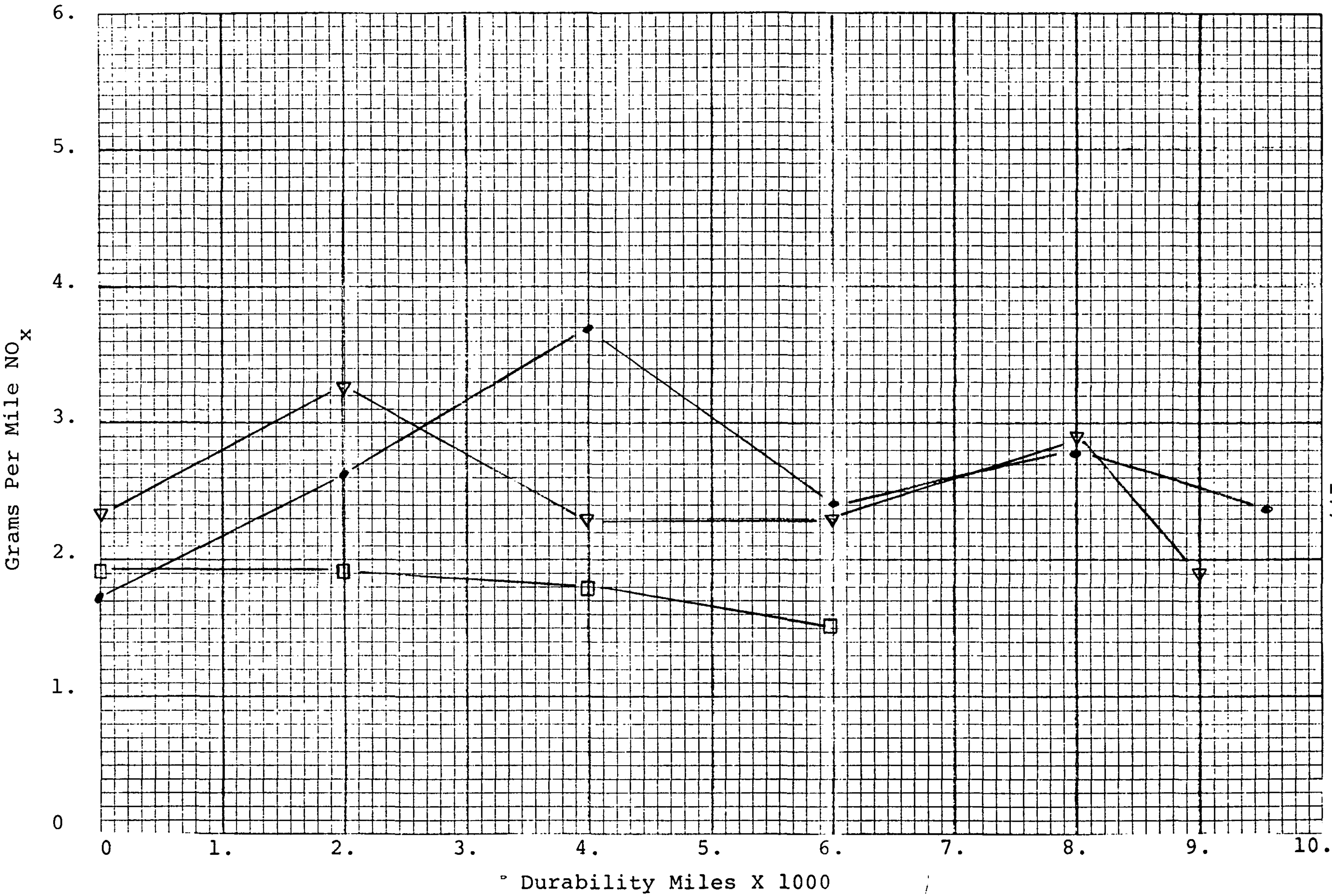
FIGURE 109



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Chassis Dynamometer

FIGURE 110

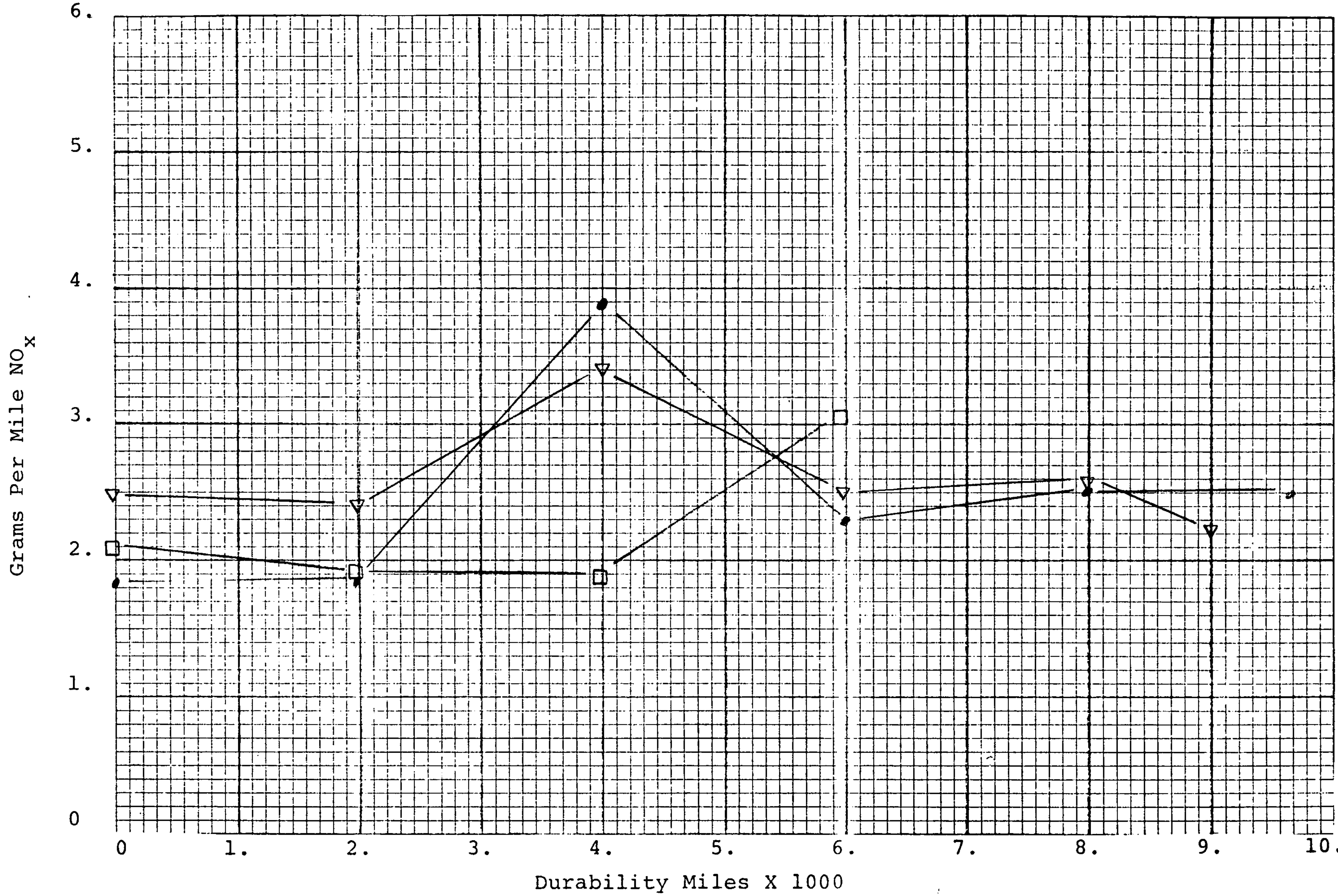


CVS EMISSIONS FEDERAL CYCLE

• Baseline
▽ "A" Additive
□ "B" Additive

Chassis Dynamometer

FIGURE 111



CVS EMISSIONS FEDERAL CYCLE MODIFIED

Chassis Dynamometer

FIGURE 112

• Baseline
▽ "A" Additive
□ "B" Additive

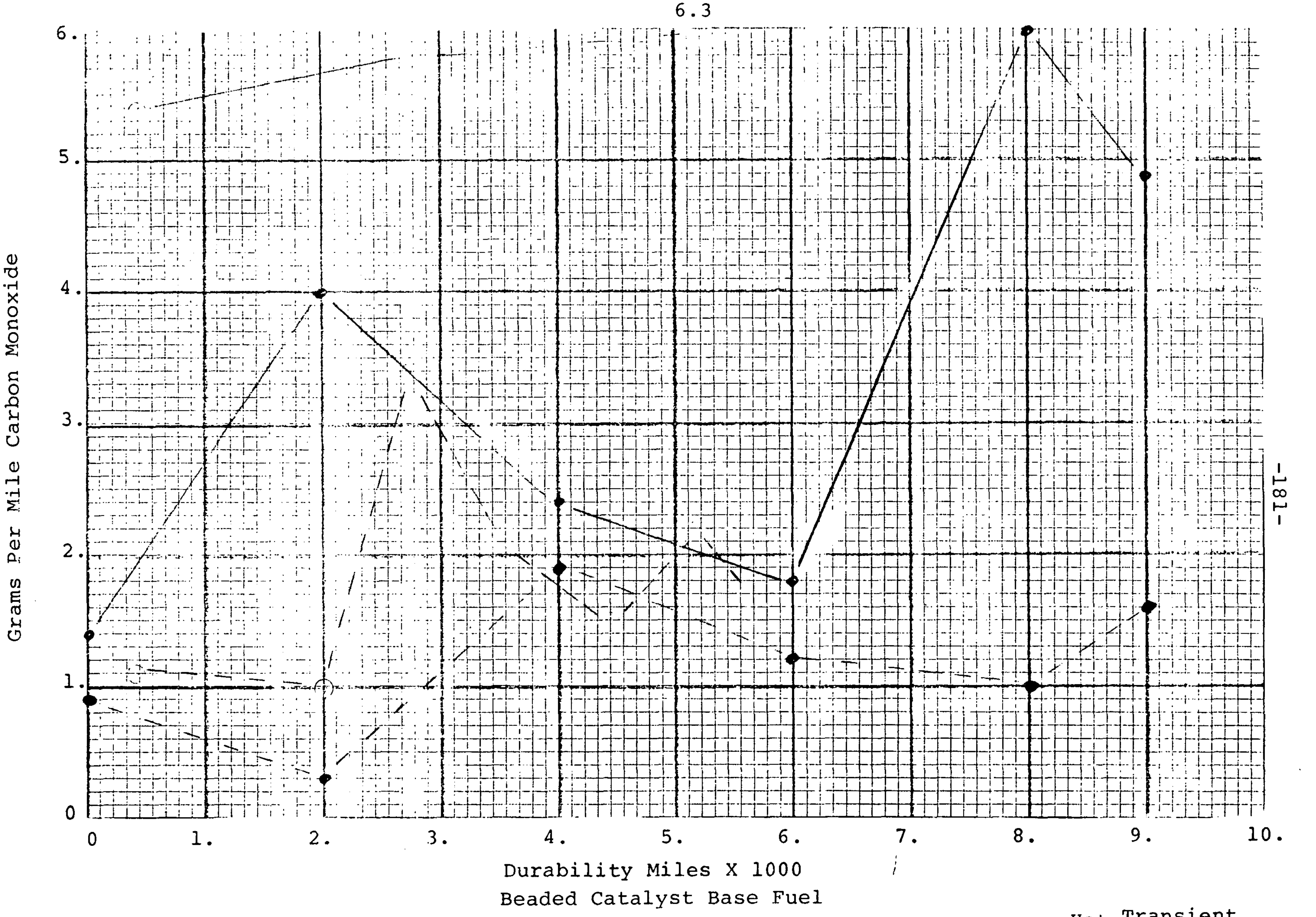
H. Comparison of Chassis Vs. Engine Dynamometer, Beaded Catalyst, Three Fuels

The following set of graphs is a comparison of the data collected from the engine dynamometer and vehicle chassis dynamometer studies running on the three different fuels. Both engines and vehicles were equipped with identical beaded type catalytic converters. The data obtained from the constant volume sample (CVS) system was plotted as grams per mile vs. durability miles. The following conclusions were made from these graphs.

<u>COMMENTS</u>: Baseline Fuel

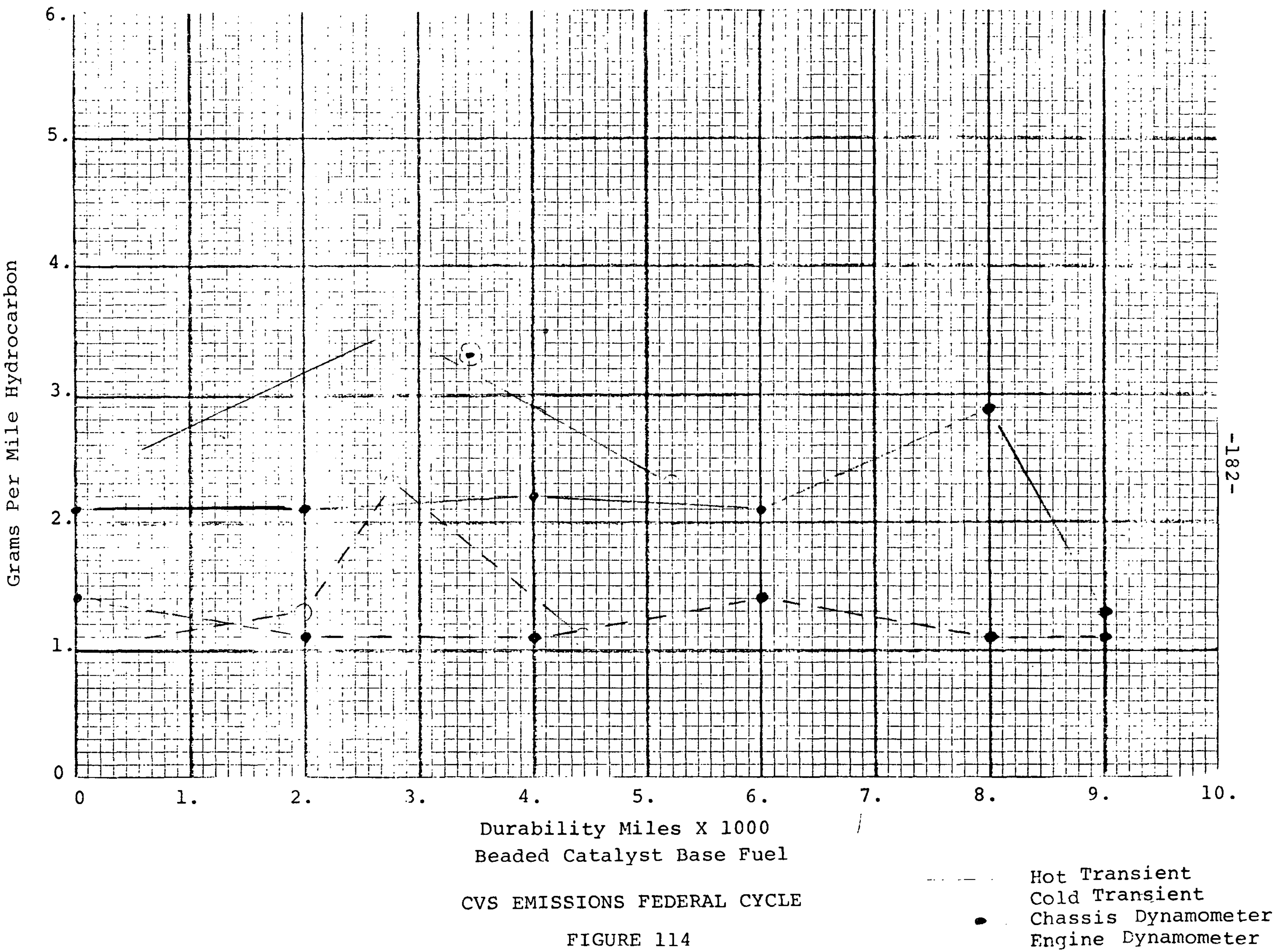
1. Carbon monoxide levels during the cold start testing were much higher for the engine dynamometer runs than those made on the chassis dynamometer. Very little difference was noted during the hot start test procedure.

2. Unburned hydrocarbons, as expected, were higher during cold start testing than during hot start tests, with not much difference between engine dynamometer and chassis dynamometer runs.



CVS EMISSIONS FEDERAL CYCLE

FIGURE 113



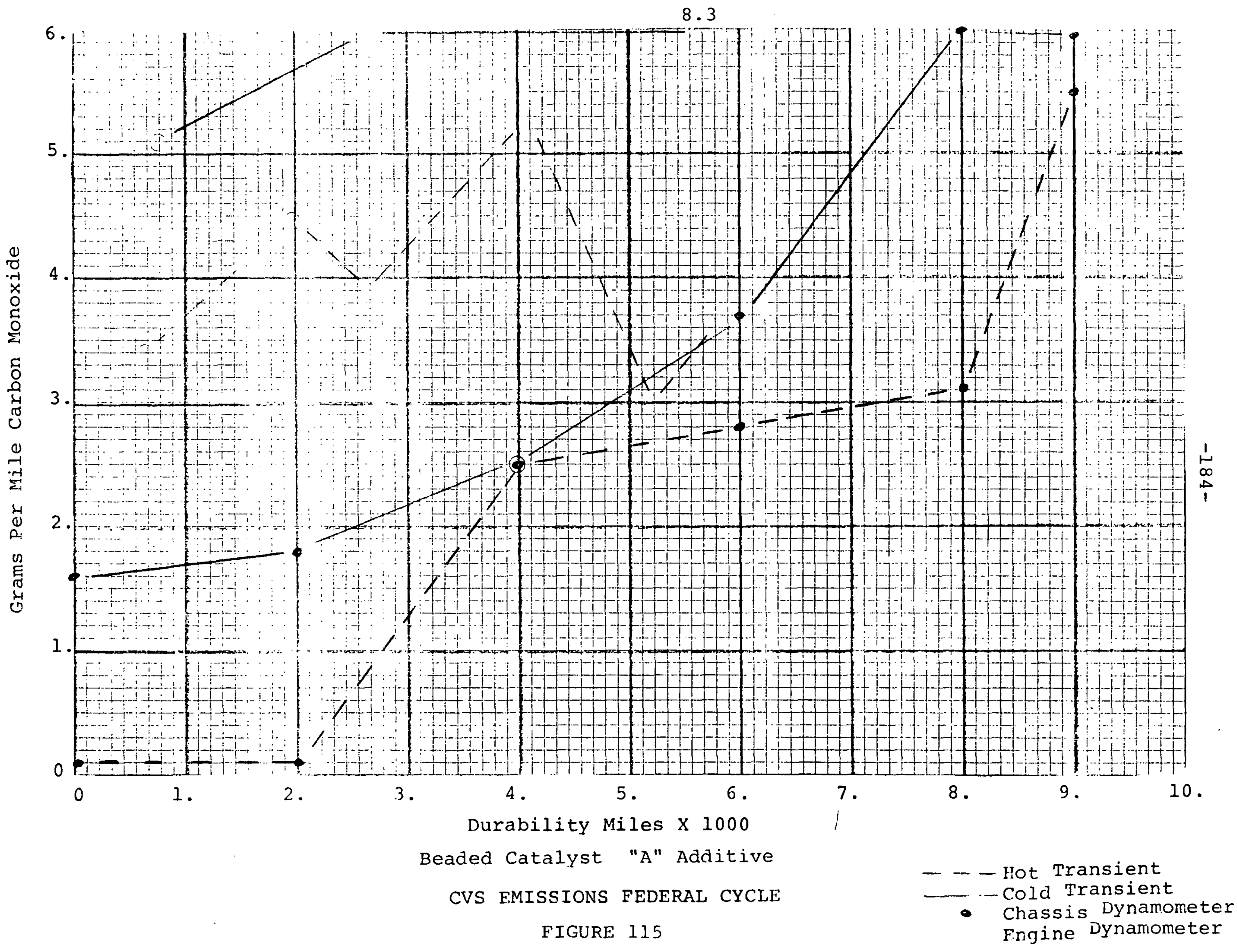
CVS EMISSIONS FEDERAL CYCLE

FIGURE 114

COMMENTS: Additive "A"

1. Carbon monoxide emission levels were higher for the engine dynamometer than for the chassis dynamometer runs for both the cold and hot start tests.

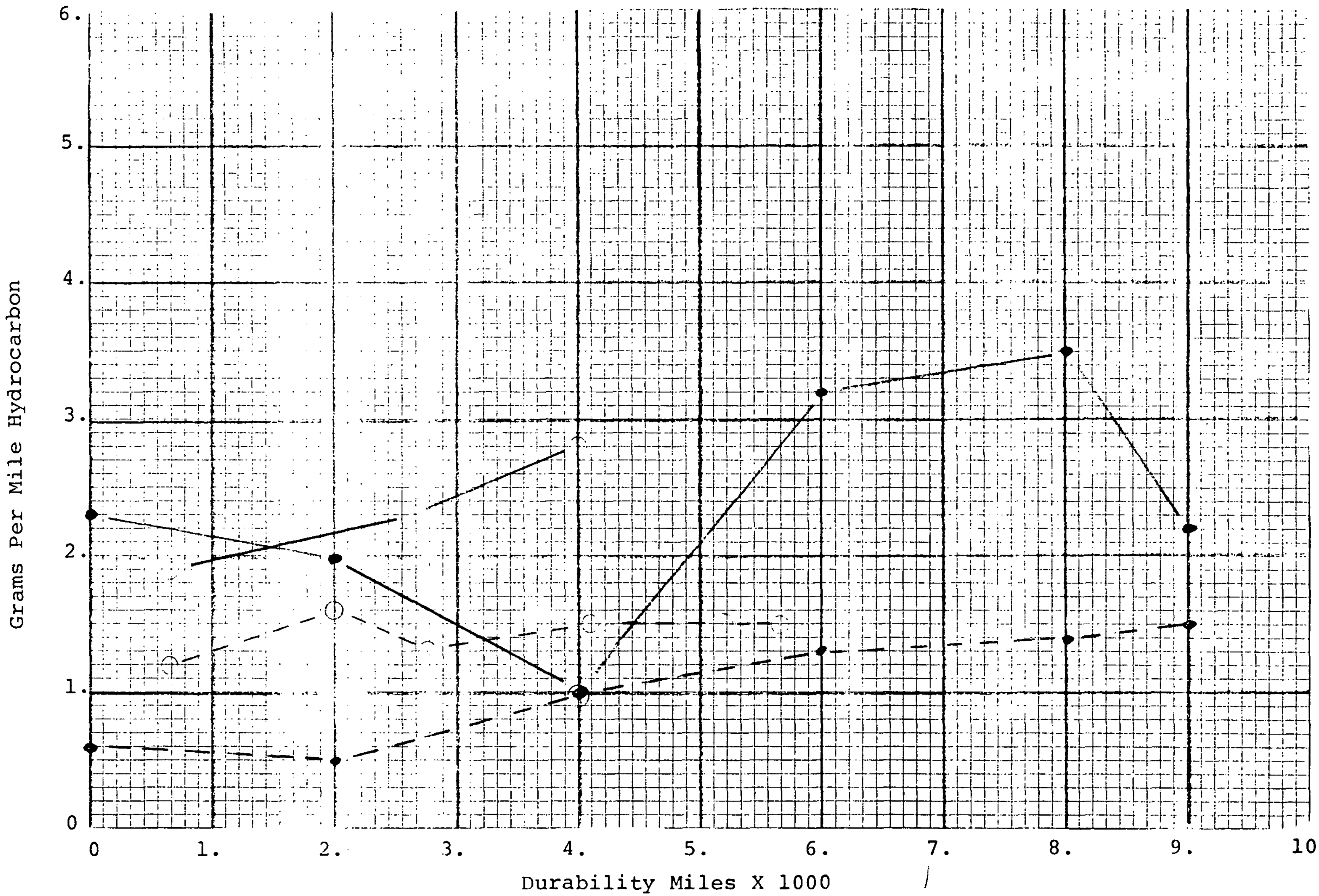
2. Hydrocarbon emission levels are higher for the engine dynamometer tests than for the chassis dynamometer tests for both cold and hot start operations; however, the differences were much smaller than in the case of carbon monoxide.



Beaded Catalyst "A" Additive

CVS EMISSIONS FEDERAL CYCLE

FIGURE 115



Beaded Catalyst "A" Additive

CVS EMISSIONS FEDERAL CYCLE

FIGURE 116

— — — Hot Transient
Cold Transient
Chassis Dynamometer
Engine Dynamometer

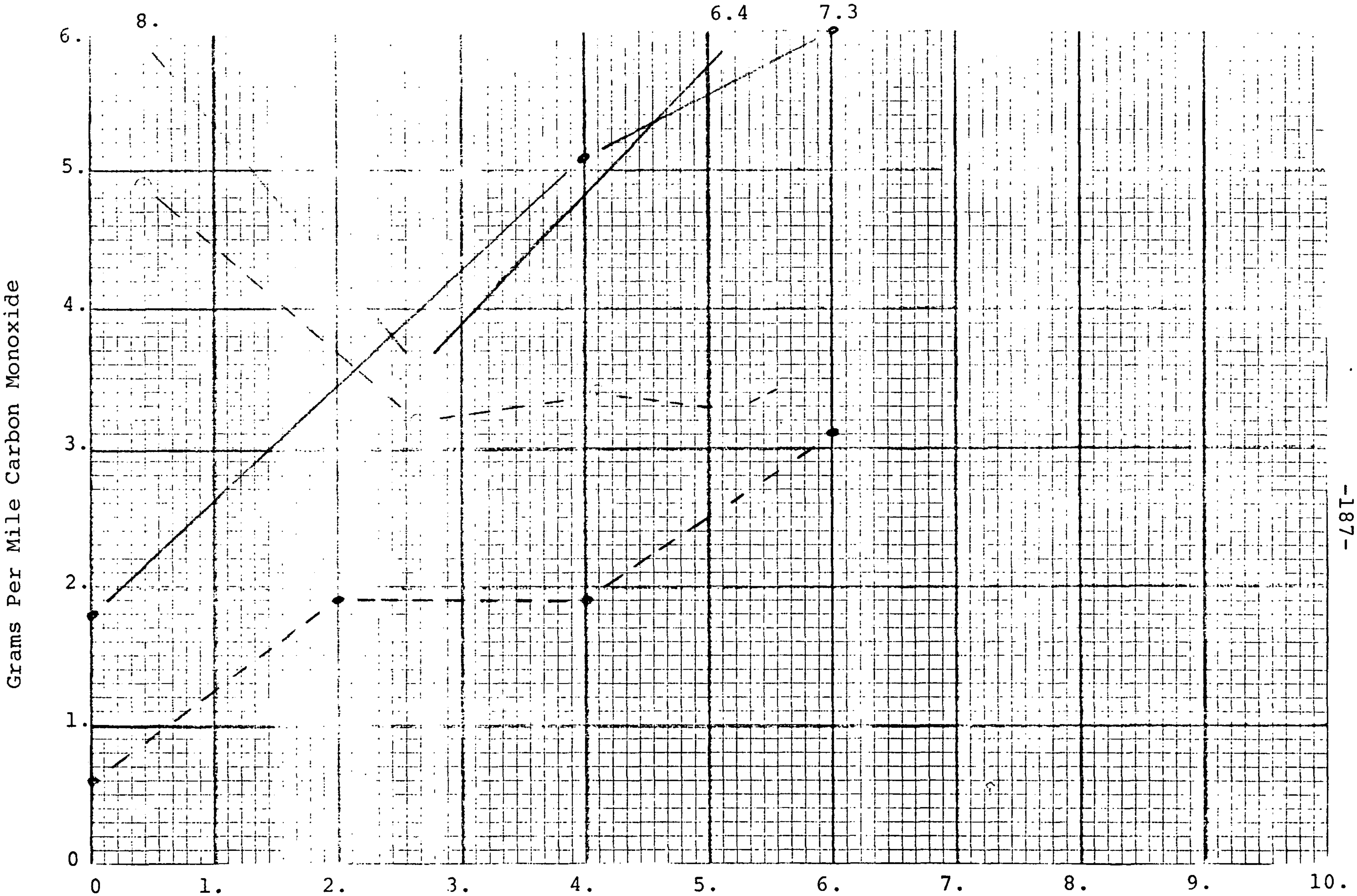
COMMENTS: Additive "B"

1. Carbon monoxide emission levels were higher initially for the engine dynamometer runs, but stabilized to levels not significantly different from the chassis dynamometer tests. This appeared to be true for both hot and cold start tests.

2. Carbon monoxide emissions increased as a function of miles in the chassis dynamometer study, indicating some catalyst deterioration. The data from the engine dynamometer is somewhat inconclusive, although a slight decrease in carbon monoxide as a function of time is noted.

3. Hydrocarbon engine dynamometer runs show higher levels of unburned hydrocarbon in hot start studies, while the final cold start measurements are quite close for both engine and chassis.

4. Both engine dynamometer and chassis dynamometer studies show an increase in hydrocarbons with time.

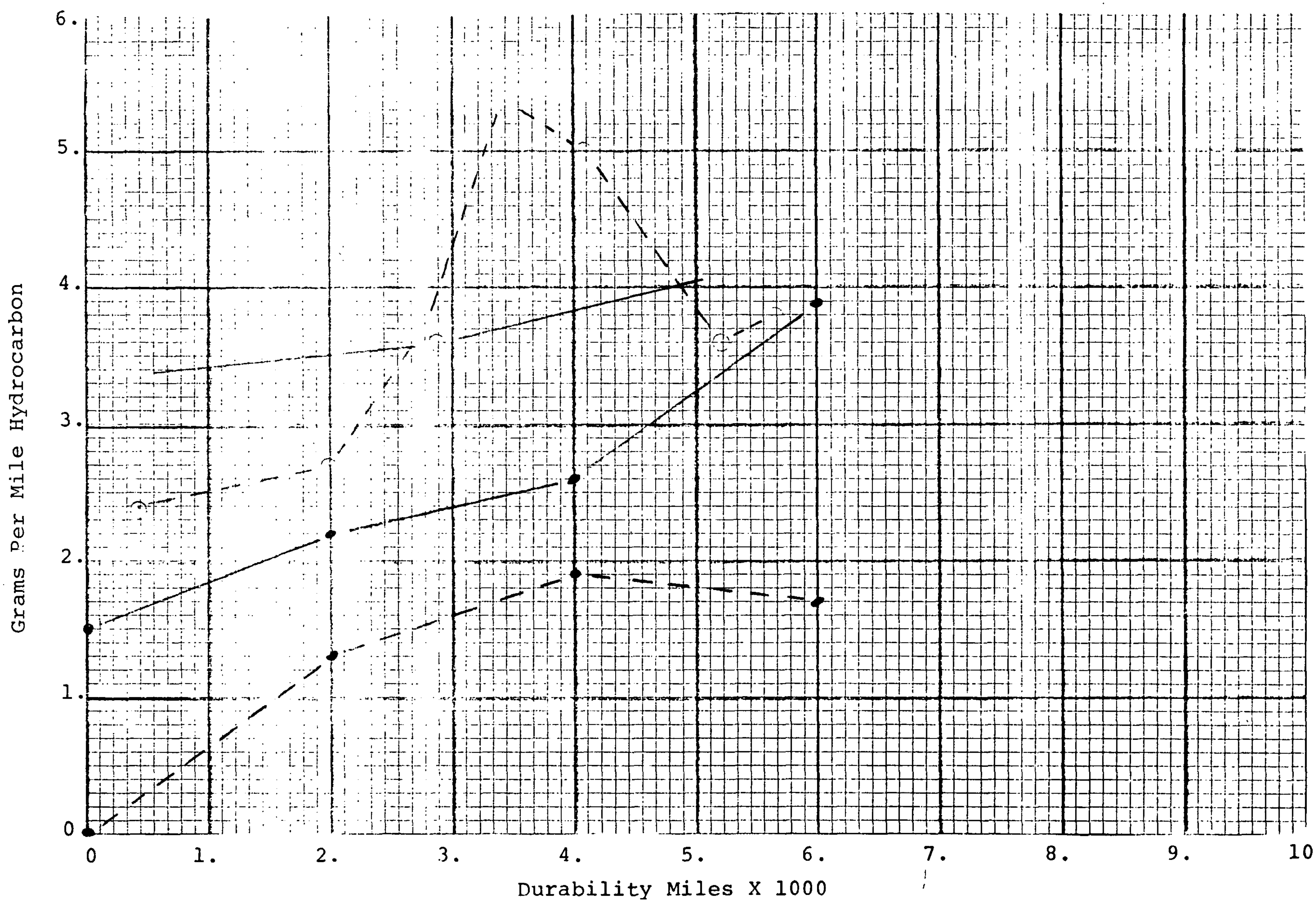


Durability Miles X 1000
Beaded Catalyst "B" Additive

CVS EMISSIONS FEDERAL CYCLE

FIGURE 117

— Hot Transient
- - Cold Transient
• Chassis Dynamometer
Engine Dynamometer



Beaded Catalyst "B" Additive

CVS EMISSIONS FEDERAL CYCLE

FIGURE 118

— — — Hot Transient
Cold Transient
• Chassis Dynamometer
· Engine Dynamometer

IV. EXPERIMENTAL DATA, PARTICULATE EMISSIONS

The major emphasis of this contract was to evaluate the effect of fuel additives on catalysts and the subsequent effect on gaseous emissions. Since the facilities used for the gaseous studies were the same as those used in prior particulate studies (Reports APID-1567: "Characterization of Particulates and Other Non-regulated Emissions from Mobile Sources and the Effects of Exhaust Emissions Control Devices on These Emissions"; EPA-R2-72-066: "Effect of Fuel Additives on the Chemical and Physical Characteristics of Particulate Emissions in Automotive Exhaust"; EHS70-101: "Development of Particulate Emission Control Techniques for Spark-Ignition Engines"; EPA-650/2-74-061: "Determination of Effect on Particulate Exhaust Emissions of Additives and Impurities in Gasoline"), several evaluations of the particulate emissions were made. The details of the procedures and equipment for particulate measurement is included in the reports mentioned above. A summary of the particulate collection is as follows:

The exhaust was diluted in a 26' x 18" dilution chamber, at approximately 12 to 1 air/exhaust ratio, and 550 cfm diluted exhaust was sampled at a constant 100°F, 1 cfm rate. The particulate was collected in four locations. An Anderson cascade impactor, backed up with a 142 mm fiberglass filter was used for mass/size distribution studies. Two additional 142 mm fiberglass filters were used to collect particulate for grams/mile determinations and for carbon, hydrogen, nitrogen and benzo(a) pyrene analyses. A fourth 142 mm millipore filter was used to collect particulate samples for trace metal determinations.

A separate 47 mm filter with a millipore membrane was used to collect samples for sulfate analysis. These filters were sent to EPA for their analyses and the data is not included in this report. On several occasions, after the vehicles had accumulated several thousand miles, an attempt was made to find platinum or palladium in the collected particulate. These analyses were made using x-ray fluoresence, and in none of the analyses could either of the noble metals be detected. The sensitivity of the x-ray fluorescence was 1.0 u/g per cm^2 of filter area. This translates into a grams/mile sensitivity of around .01 grams/mile, depending on the sample size.

The particulate samples were collected from both the engine runs and the vehicle runs. In the case of the engine runs, the samples were collected only from the Federal Cycle Modified (starting with a fully warmed-up engine) and 60 mph steady state. It was felt to be more appropriate to do the gaseous analyses on the cold start and, because of the timing of the runs, the only way to do the particulate was on a warm engine. (See Table 3 for details on engine test sequence.) Particulate samples were collected for both Federal Cycle and Federal Cycle Modified, as well as 60 mph steady state, for both vehicles.

In the case of the engine runs, the same engine was used for all tests. At the conclusion of a run on a given additive and catalyst, the engine was disassembled. Any deposits were removed from the head, valves, and pistions. The valves were reseated and a blowby and compression check was made. The tests were set up such that the baseline was bracketed by the additive runs, with Additive A being run first and Additive B being run after the baseline. The tests for particulate were run at approximately 25 and 140 hours on the engine stand, with the exception of the Additive B on the monolith catalyst, which was run at 0 and 88 hours. In the case of the vehicles the tests were run at about 3,000 and 9,000 miles.

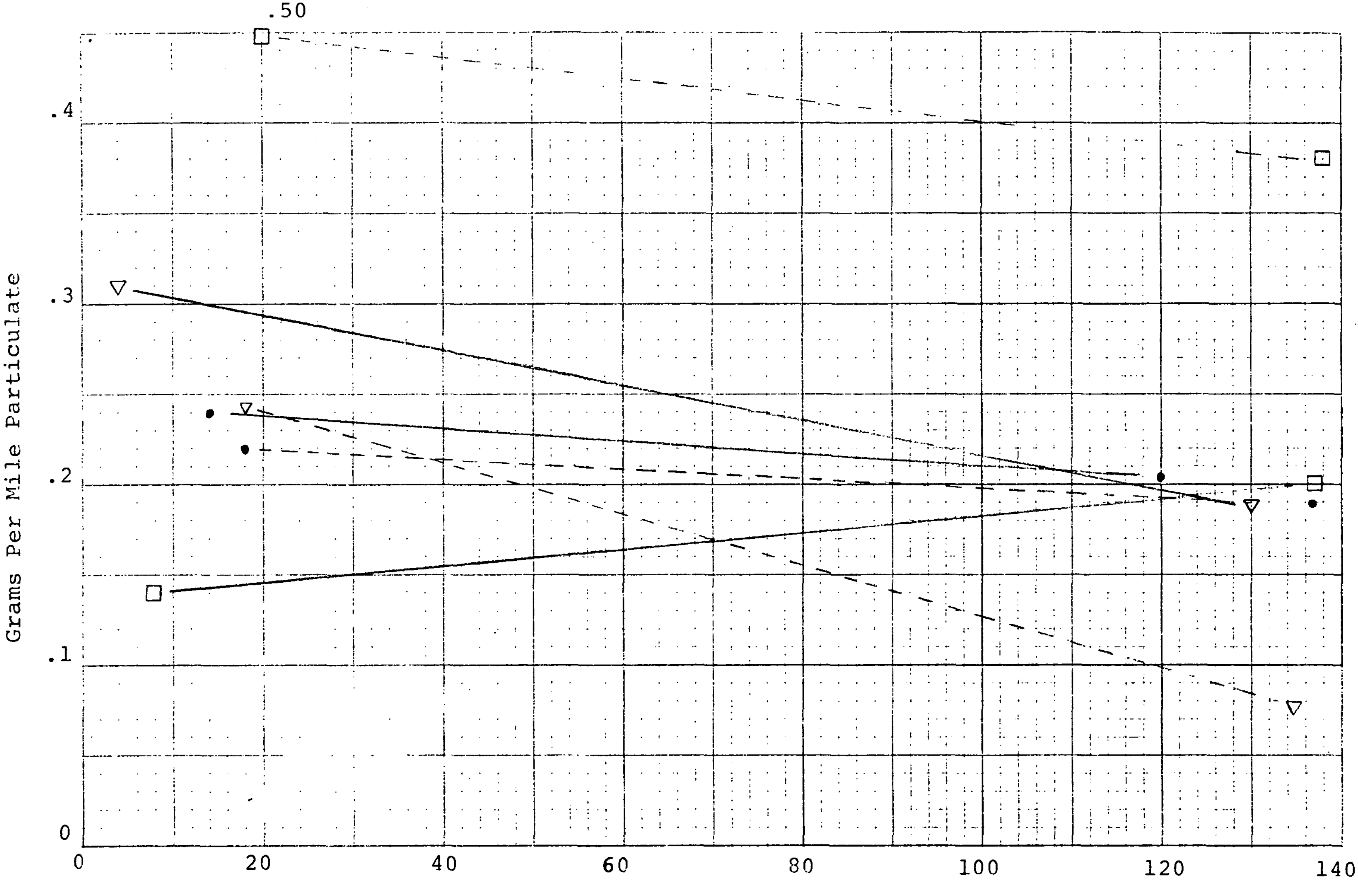
In general, it is felt that the duration of both engine and vehicle tests was too short to allow any definitive prediction as to particulate mass emission trends. Particulate tests under contract 68-02-0332 (see report EPA-650/2-74-061) on methodology for determining effects of fuel additives on particulate emissions showed that some plateau seemed to be reached at about 17,000 vehicle miles. It is also likely that with a catalyst in the system, particulate buildup in the catalyst would cause particulate stabilization to take longer.

Since only two tests were run on each combination of additive and catalyst, the statistical significance of any trend is quite low. However, based on past experience with the particulate collection techniques used in this study, it is felt that large increases (2X or greater) in emitted particulate are at least indicative of a reliable trend. With this in mind, following are several general conclusions from the particulate data. The data is plotted in Figures 119 and 120 for the engine runs and Figure 121 for the vehicle tests.

1. The engine stand data shows the monolithic catalyst producing higher amounts of particulate than the beaded catalyst. This is true for both the steady state and Modified Federal Cycle at both the beginning and end of the durability test. The base fuel and both Additives A and B show the same trend. The analytical data does not account for the increase. Since $SO_4^=$ was not specifically analyzed, the increase could possibly be due to collection of the H_2SO_4. Another possible explanation is that the beaded catalyst, with its longer surface area and its different geometry, could be holding up more of the particulate, although after 140 hours it is expected that the particulate would have stabilized.

2. In general, the engines equipped with monolith catalysts showed lower particulate after the durability run, while the beaded catalyst engines remained essentially constant.

3. The particulate emissions from the 60 mph steady state runs are higher than the Federal Cycle Modified when measured on the vehicles, while the engine stand data shows a reversal in this tend with the Federal Cycle Modified being higher than the steady state.

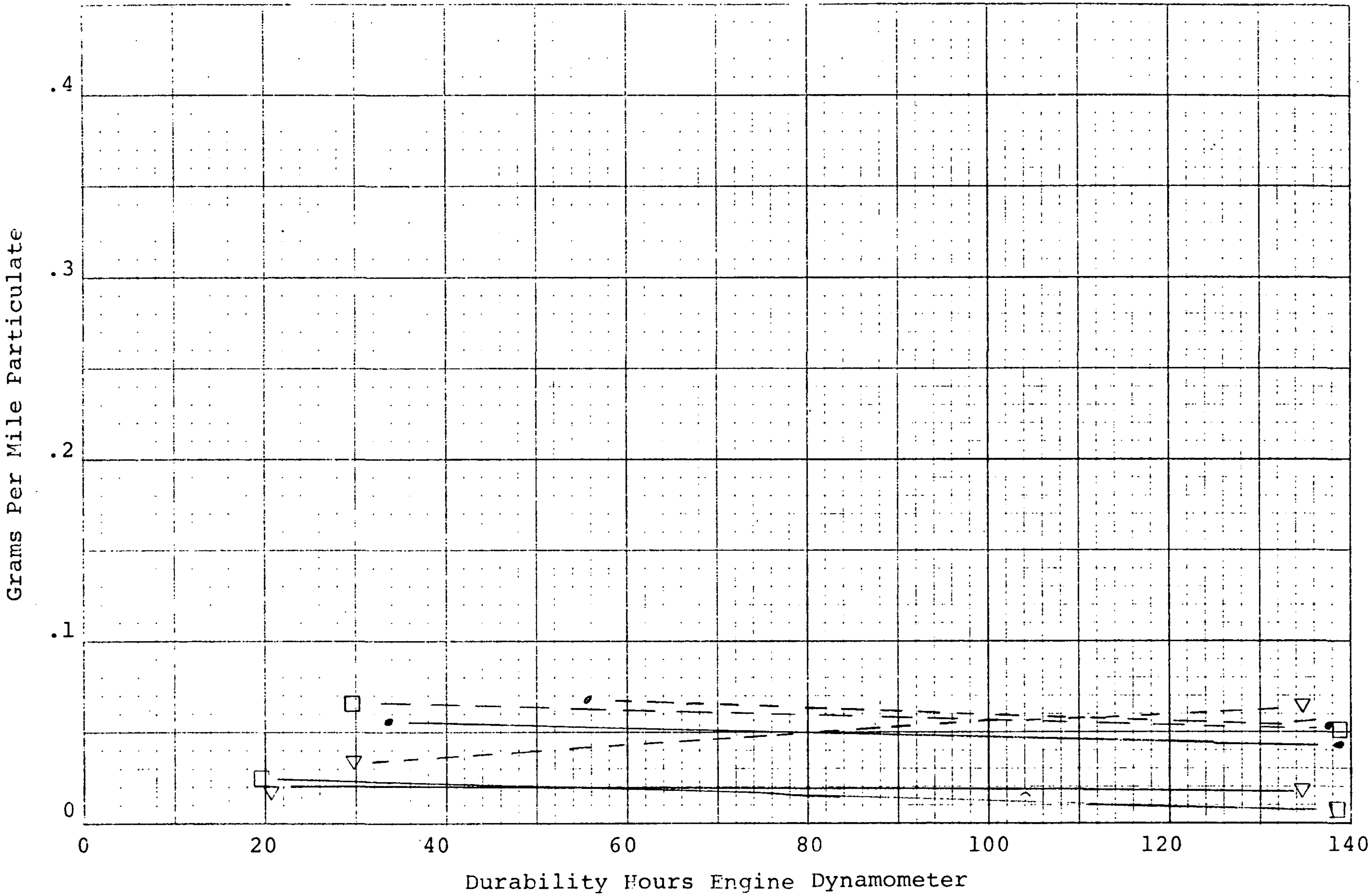


PARTICULATE EMISSION VS DURABILITY HOURS

Monolithic Catalyst
142 mm Glass Filter

FIGURE 119

——— 60 MPH Steady State
- - - - Federal Cycle Hot
• Base Fuel
▽ "A" Additive
□ "B" Additive

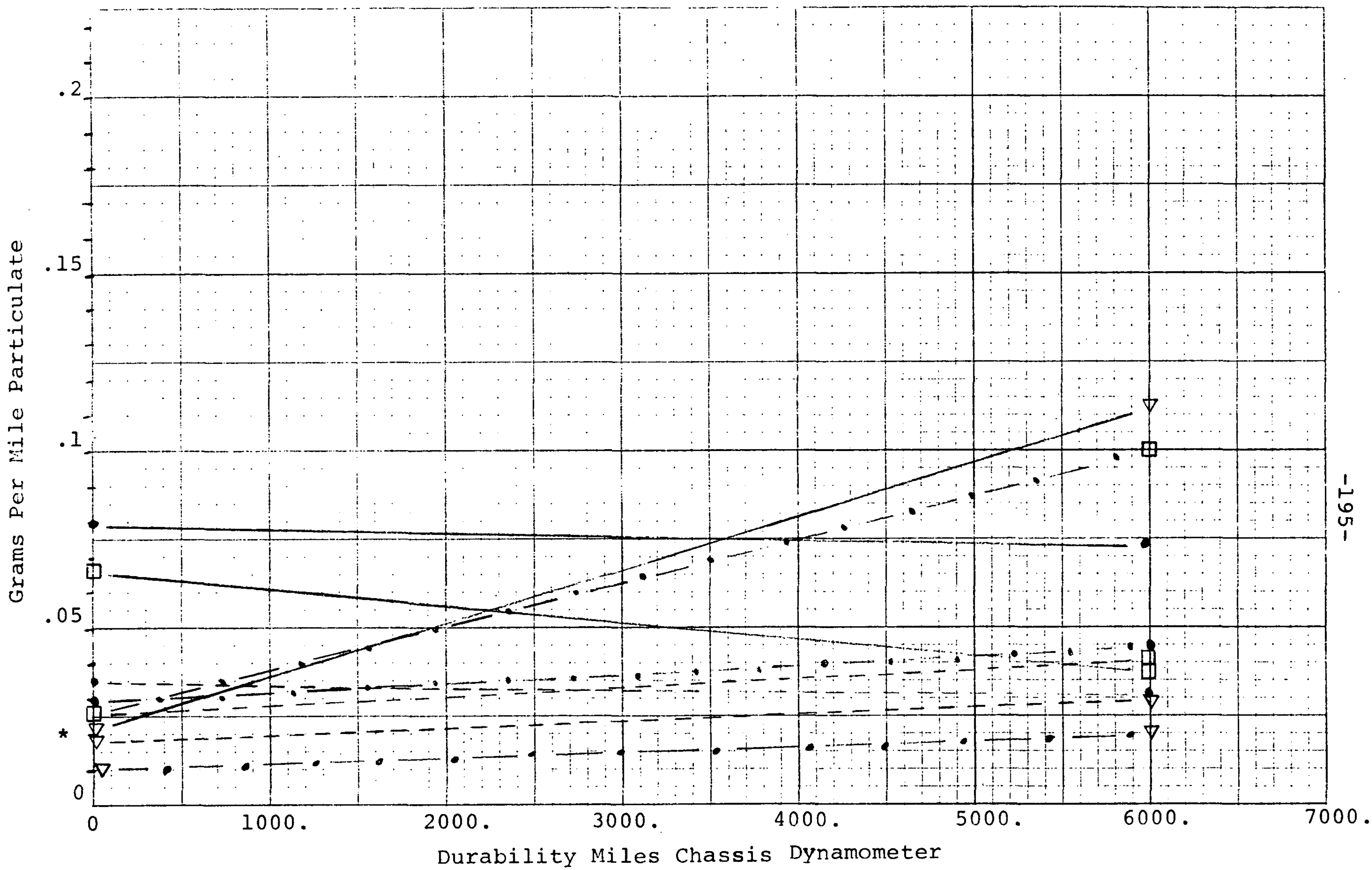


PARTICULATE EMISSION VS DURABILITY HOURS

Beaded Catalyst
142 mm Glass Filter

FIGURE 120

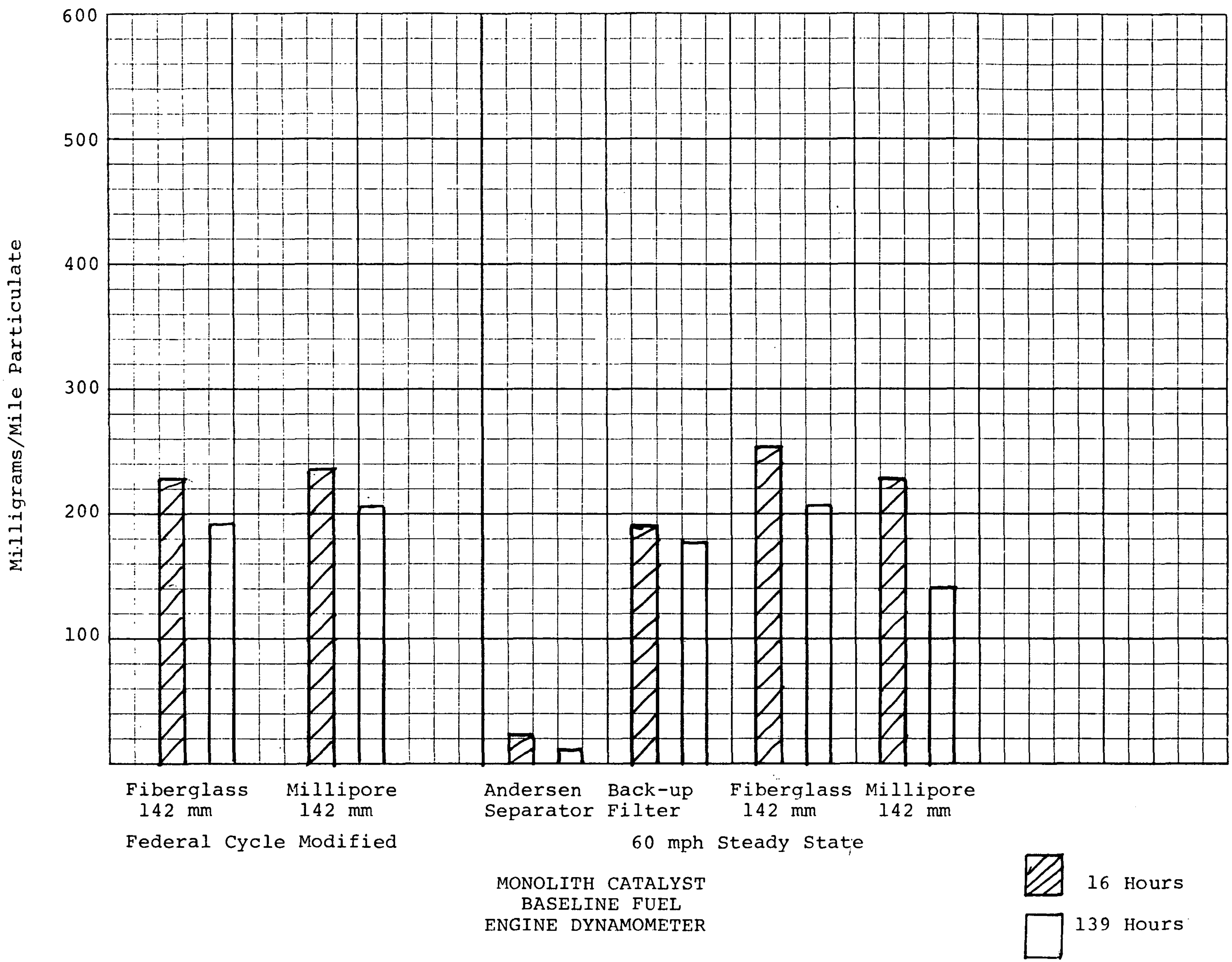
60 MPH Steady State
Federal Cycle Hot
• Base Fuel
▽ "A" Additive
□ "B" Additive



PARTICULATE EMISSION VS DURABILITY MILES

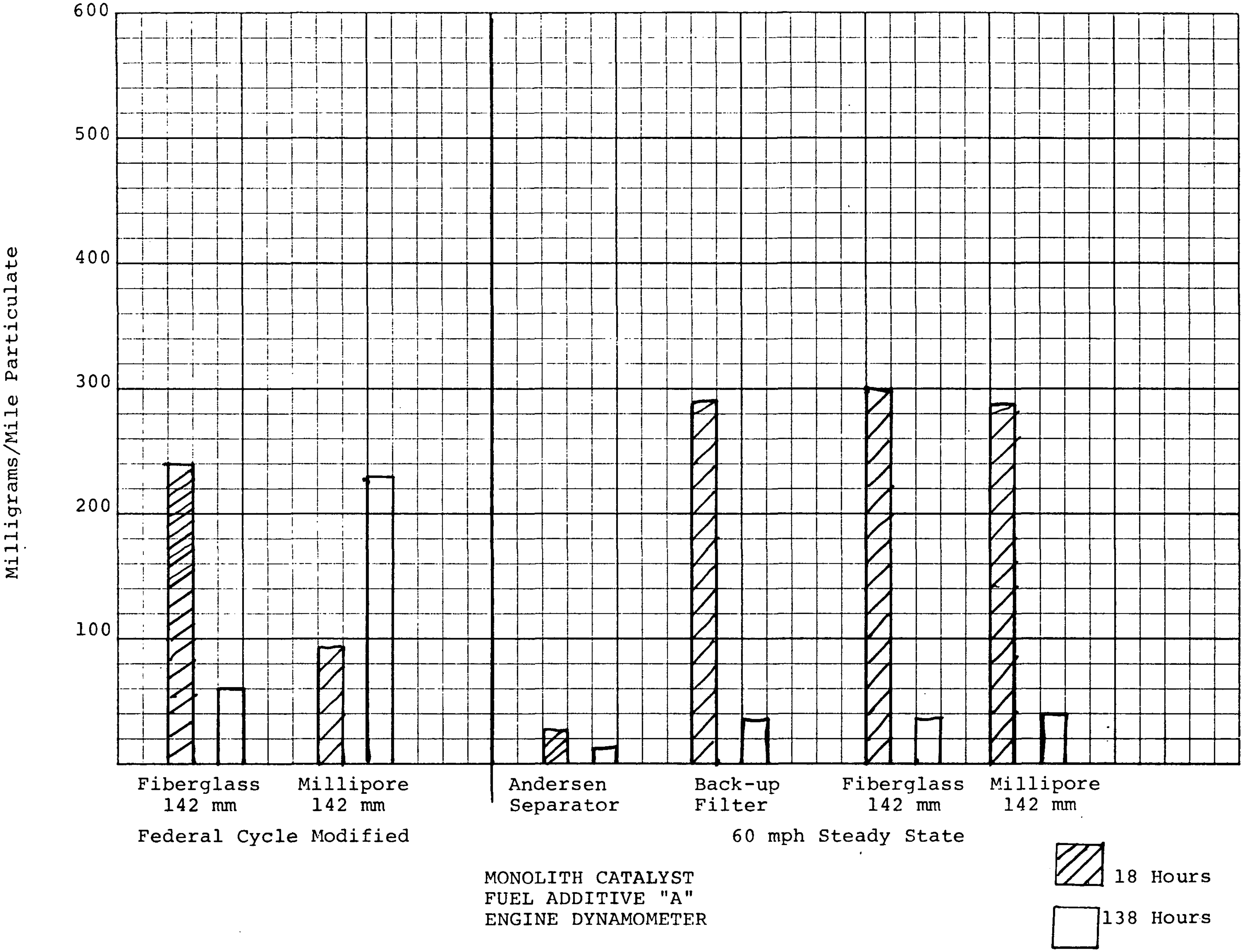
Beaded Catalyst
142 mm Glass Filter

FIGURE 121



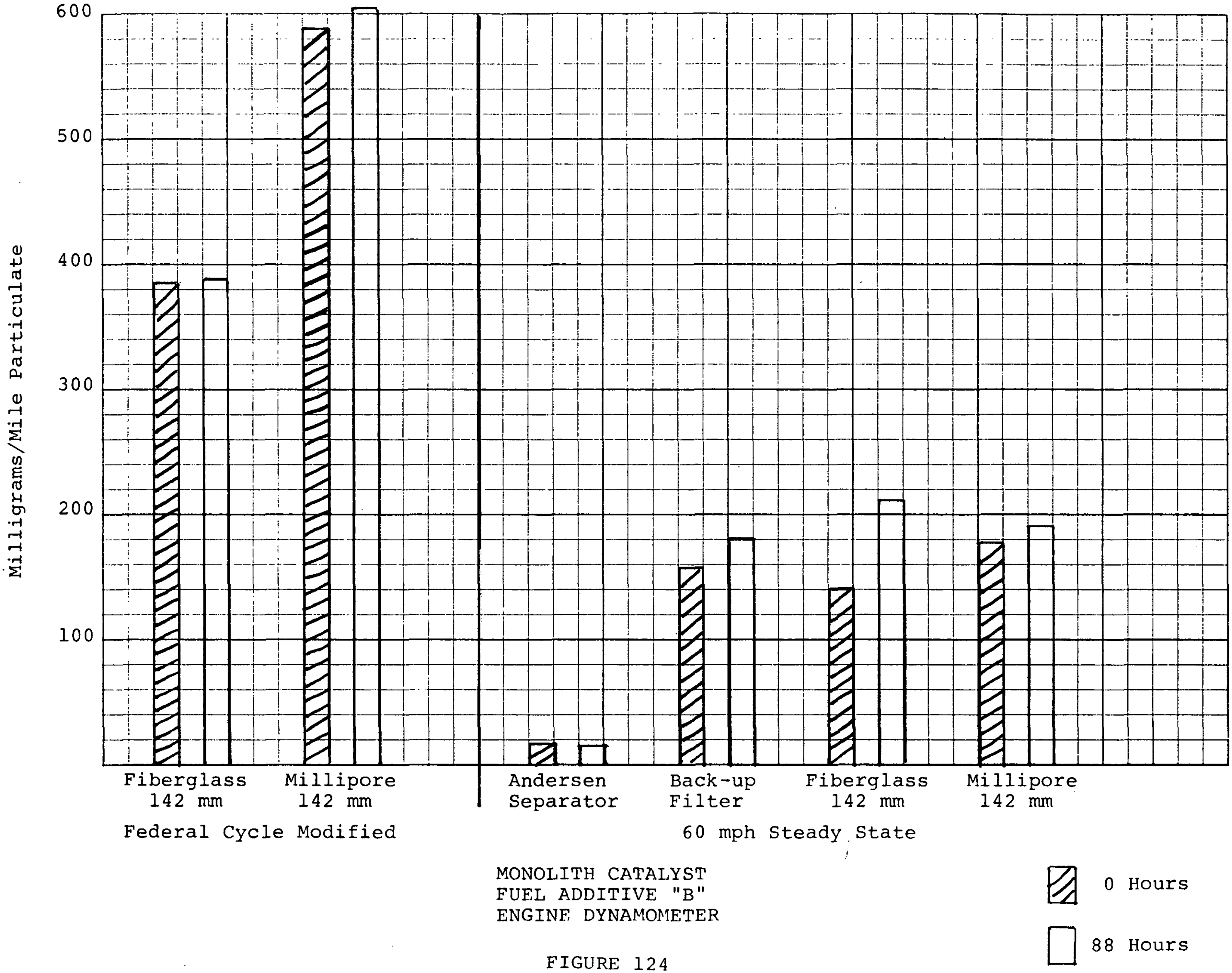
MONOLITH CATALYST
BASELINE FUEL
ENGINE DYNAMOMETER

FIGURE 122



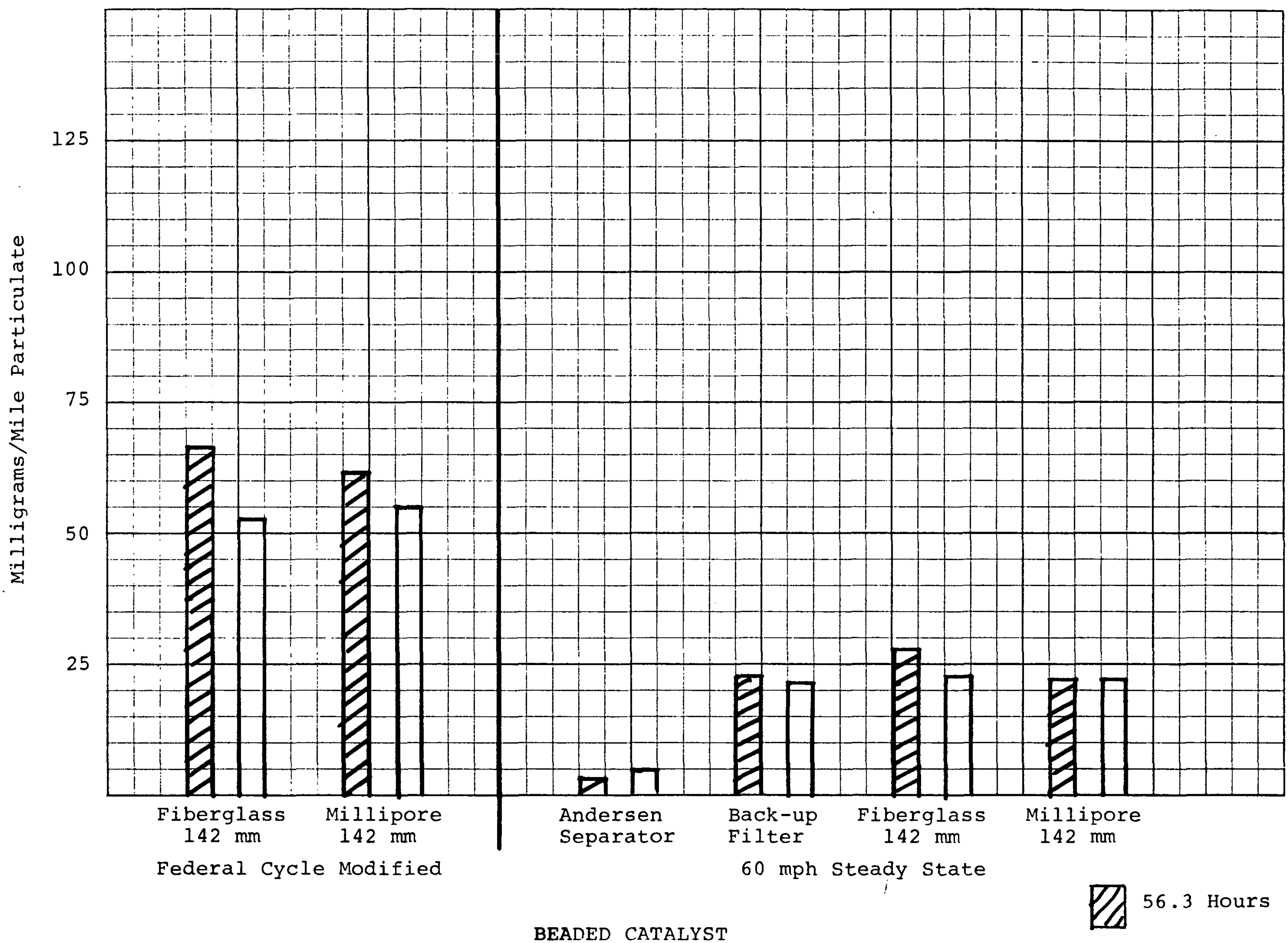
MONOLITH CATALYST
FUEL ADDITIVE "A"
ENGINE DYNAMOMETER

FIGURE 123



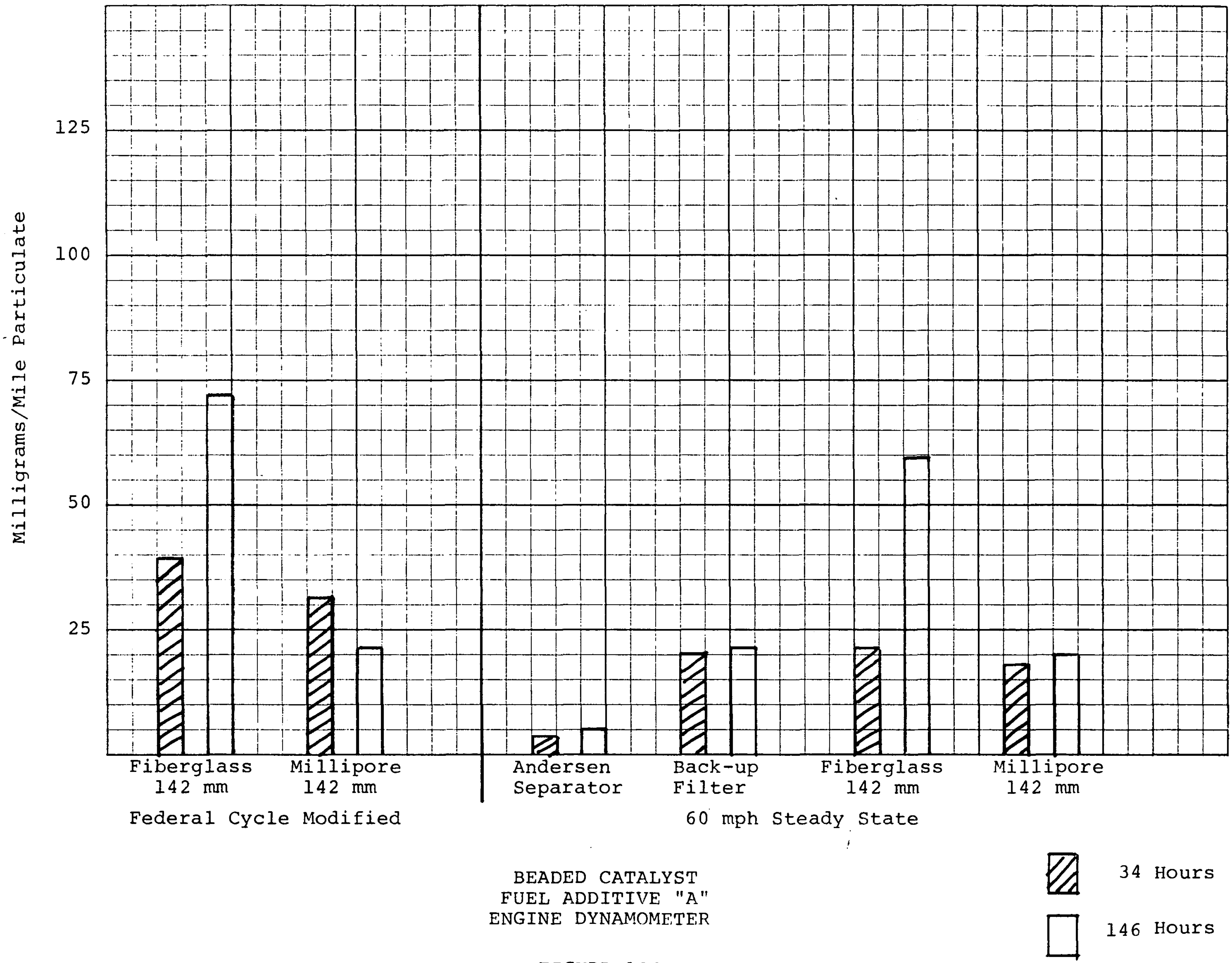
MONOLITH CATALYST
FUEL ADDITIVE "B"
ENGINE DYNAMOMETER

FIGURE 124



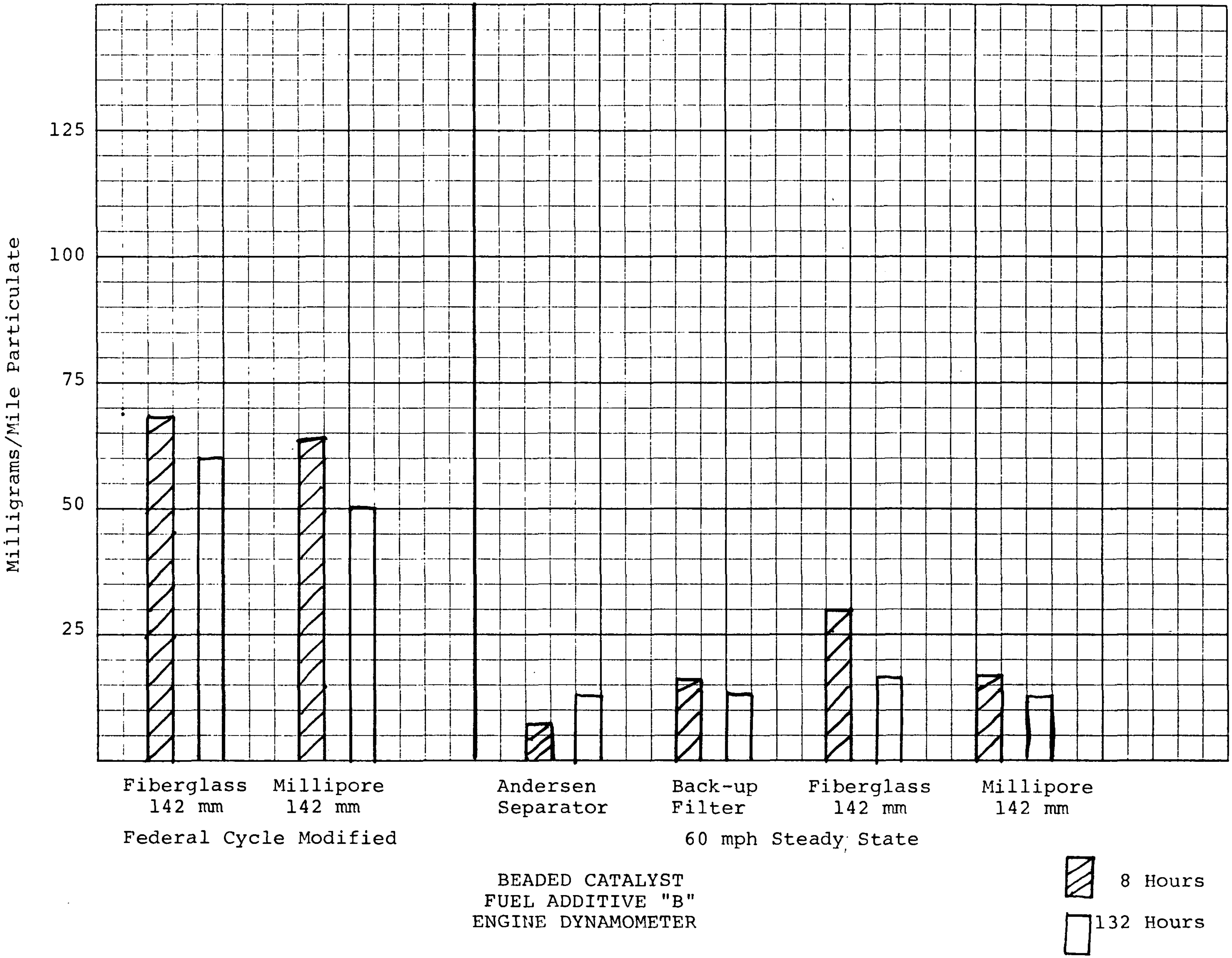
BEADED CATALYST
BASELINE FUEL
ENGINE DYNAMOMETER

FIGURE 125



BEADED CATALYST
FUEL ADDITIVE "A"
ENGINE DYNAMOMETER

FIGURE 126



BEADED CATALYST
FUEL ADDITIVE "B"
ENGINE DYNAMOMETER

FIGURE 127

DYNAMOMETER TEST

TABLE 23

Engine Stand

VEHICLE TYPE: 1972 Chevrolet

FUEL: Baseline

CONVERTER: Monolith

Vehicle Test No.	Test Hours	Test Miles	Test Mode	Grams per 1.61 km (1 mile): Andersen Sampler	Follow-up glass Filter	Andersen + Filter	Glass Filter 142 mm (Avg. of two)	Millipore 142 mm
276A	13.5		60 MPH SS	.0153	.1960	.2113	.2448	.2171
276B	16.0		FCHS	--	--	--	.2639	.2347
276C	17.0		FCHS	--	--	--	.1906	.2199
276T	135.8		60 MPH	.0107	.1915	.2023	.2048	.1376
276U	138.0		FCHS	--	--	--	.1613	.1906
276V	139.0		FCHS	--	--	--	.2297	.2199

TABLE 23 (Cont'd)
EXHAUST GAS ANALYSIS

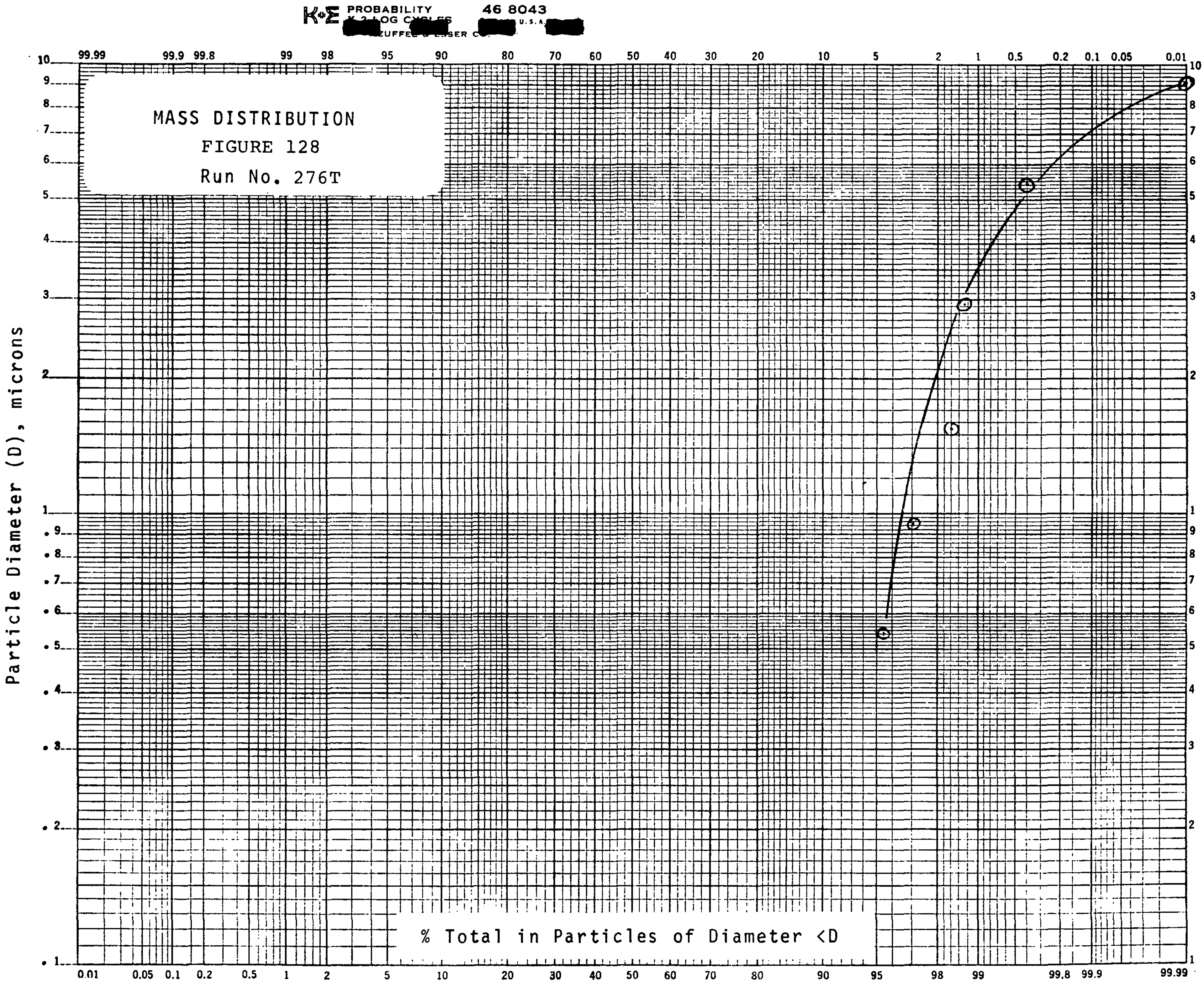
Vehicle Test No.	% by Volume CO_2	O_2	N_2	Parts Per Million CO	C_6 H.C.	NO_2	NO	NO_x - N_x	
276A	10.45	6.2	82.45	24.2	5.0		483	665	Start
	10.50	6.2	81.40	26.6	4.0		532	728	Final
276B	10.50	6.1	82.5	>250	21.0		540	957	
276C	10.70	5.9	82.55	>250	12.0		660	1121	
276T	10.50	6.05	82.55	65.4	15.0		742	983	Start
	9.35	7.75	82.0	53.3	9.0		790	975	Final
276U	10.20	6.25	82.65	>250	20.0		530	895	
276V	10.40	6.10	82.7	>250	24.0		581	968	

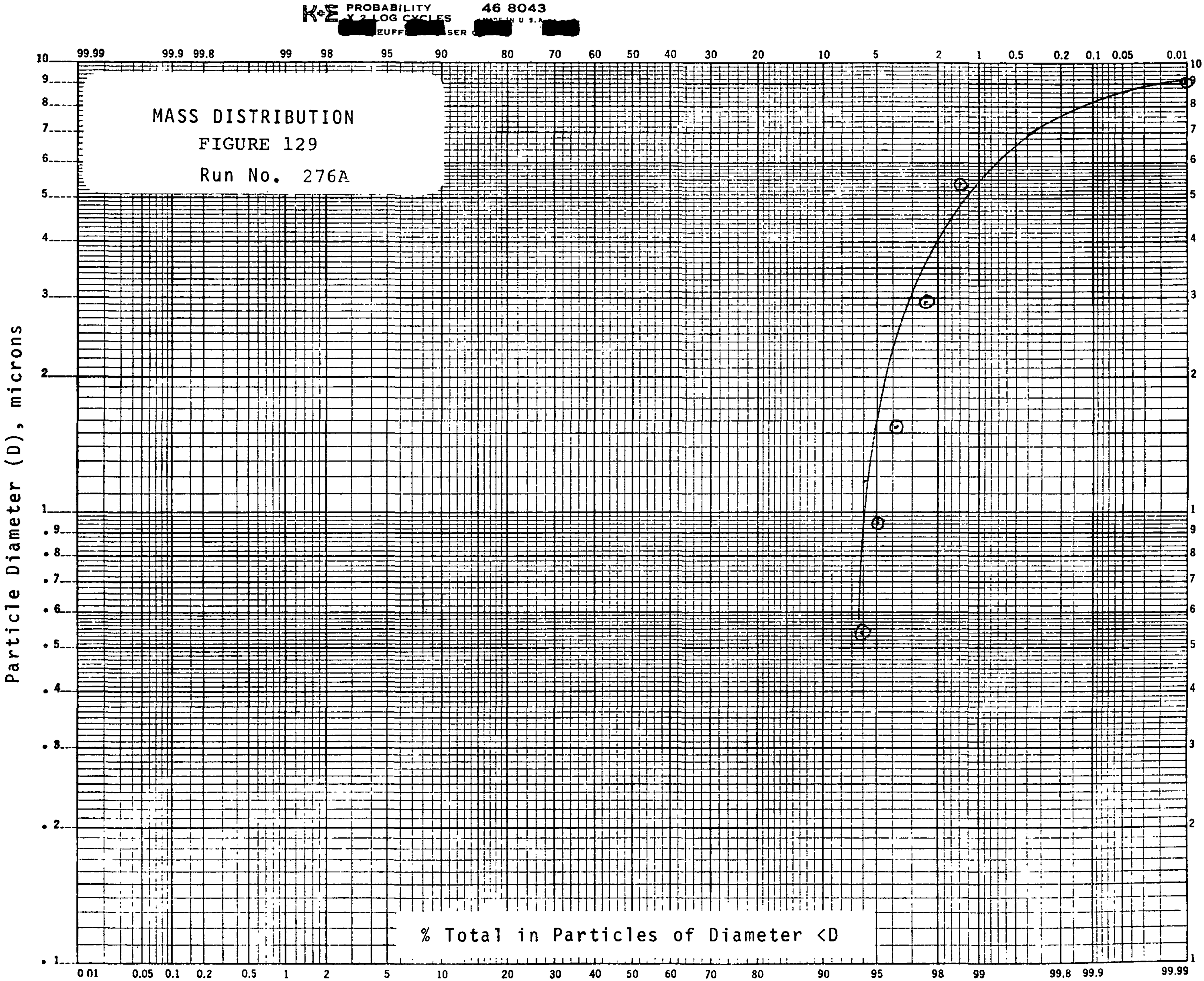
TABLF 23 (Cont'd)

ANALYSIS OF EXHAUST PARTICULATE

Trace Metals on Millipore Filter (%)

Vehicle Test No.	Fe	Ni	Cu	Al	Ca	Mg	Mn	Cr	Sn	Zn	Ti	Pb	$\%SO_4$	Glass Fiber Filters			
														%C	%H	%N	PPM BAP
276 A	.02	<.01	.02	<.01	.2	.03	.009	<.01	<.01	<.03	<.01	.07		0.1	1.42	2.77	1
276 B&C	.5	<.05	.2	.1	3.5	.6	.16	.06	<.05	.3	<.05	<.2		<0.1	<0.1	<0.1	20
276 T	.04	<.01	.04	.04	.3	.05	<.005	.01	<.01	.07	<.01	.06		1.0	2.15	2.60	60
276 U&V	1.7	<.02	.29	.17	2.8	.55	.02	.06	<.02	.23	.03	.04		<0.1	<0.1	<0.1	10


K+E PROBABILITY X 2 LOG CYCLES [redacted] KEUFFEL & ESSER CO. [redacted]
46 8043 [redacted] U.S.A. [redacted]
MASS DISTRIBUTION
FIGURE 128
Run No. 276T
Particle Diameter (D), microns
% Total in Particles of Diameter <D
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
10 9 8 7 6 5 4 3 2 1 .9 .8 .7 .6 .5 .4 .3 .2 .1


K+E PROBABILITY X 2 LOG CYCLES
46 8043
[redacted]
MASS DISTRIBUTION
FIGURE 129
Run No. 276A
Particle Diameter (D), microns
% Total in Particles of Diameter <D

DYNAMOMETER TEST

TABLE 24

Engine Stand

VEHICLE TYPE: 1972 Chevrolet

FUEL: Baseline + Fuel Additive A

CONVERTER: Monolith

Vehicle Test No.	Test Hours	Test Miles	Test Mode	Grams per 1.61 km (1 mile): Andersen Sampler	Follow-up glass Filter	Andersen + Filter	Glass Filter 142 mm (Avg. of two)	Millipore 142 mm
279C	3.7		SS - 60 MPH	.0147	.2900	.3047	.3117	.2867
279F	18.0		FCHS	--	--	--	.2053	.0879
279G	18.6		FCHS	--	--	--	.2835	.1026
279X	135.7		SS - 60 MPH	.0116	.1792	.1808	.1974	.2074
279Y	138.0		FCHS	--	--	--	.0733	.1907
279Z	138.6		FCHS	--	--	--	.0812	.2347

TABLE 24 (Cont'd)

EXHAUST GAS ANALYSIS

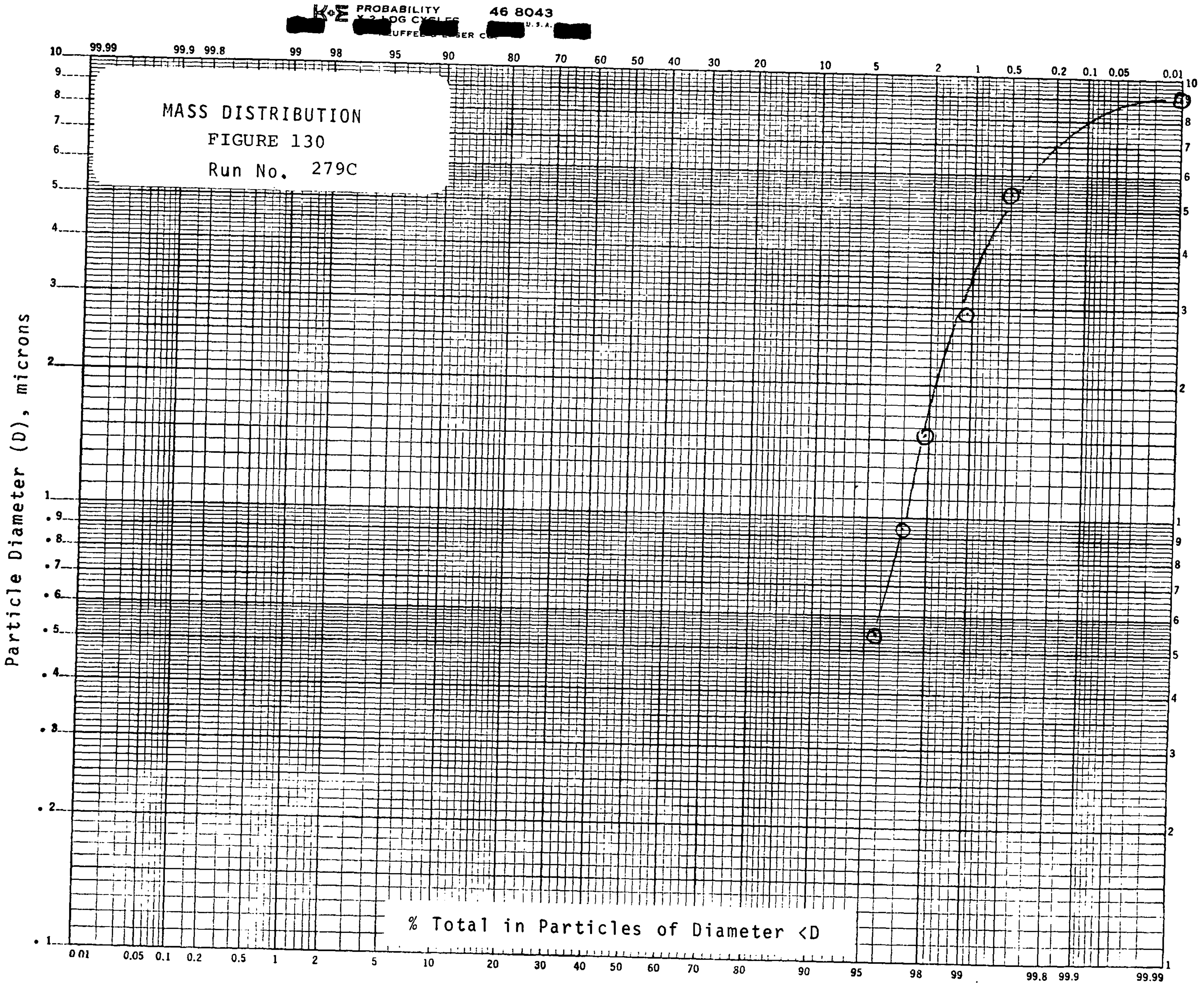
Vehicle Test No.	% by Volume CO_2	O_2	N_2	Parts Per Million CO	C_6 H.C.	NO_2	NO	$NO_x - N_x$
279C	6.5	11.40	81.0	36.3	4		718	978
	9.0	8.15	82.0	38.7	5		969	1036
279F	6.0	10.5	82.6	>250	26.0		640	1170
279G	6.4	10.2	82.45	>250	28.0		676	1162
279X	10.2	6.4	82.55	123.4	22.0		1034	1235
	10.25	6.25	82.6	130.3	20.0		1019	1375
279Y	9.5	7.5	82.2	239.6	35.0		540	1009
279Z	9.5	7.4	82.2	>250.0	40.0		604	1048

TABLE 24 (Cont'd)

ANALYSIS OF EXHAUST PARTICULATE

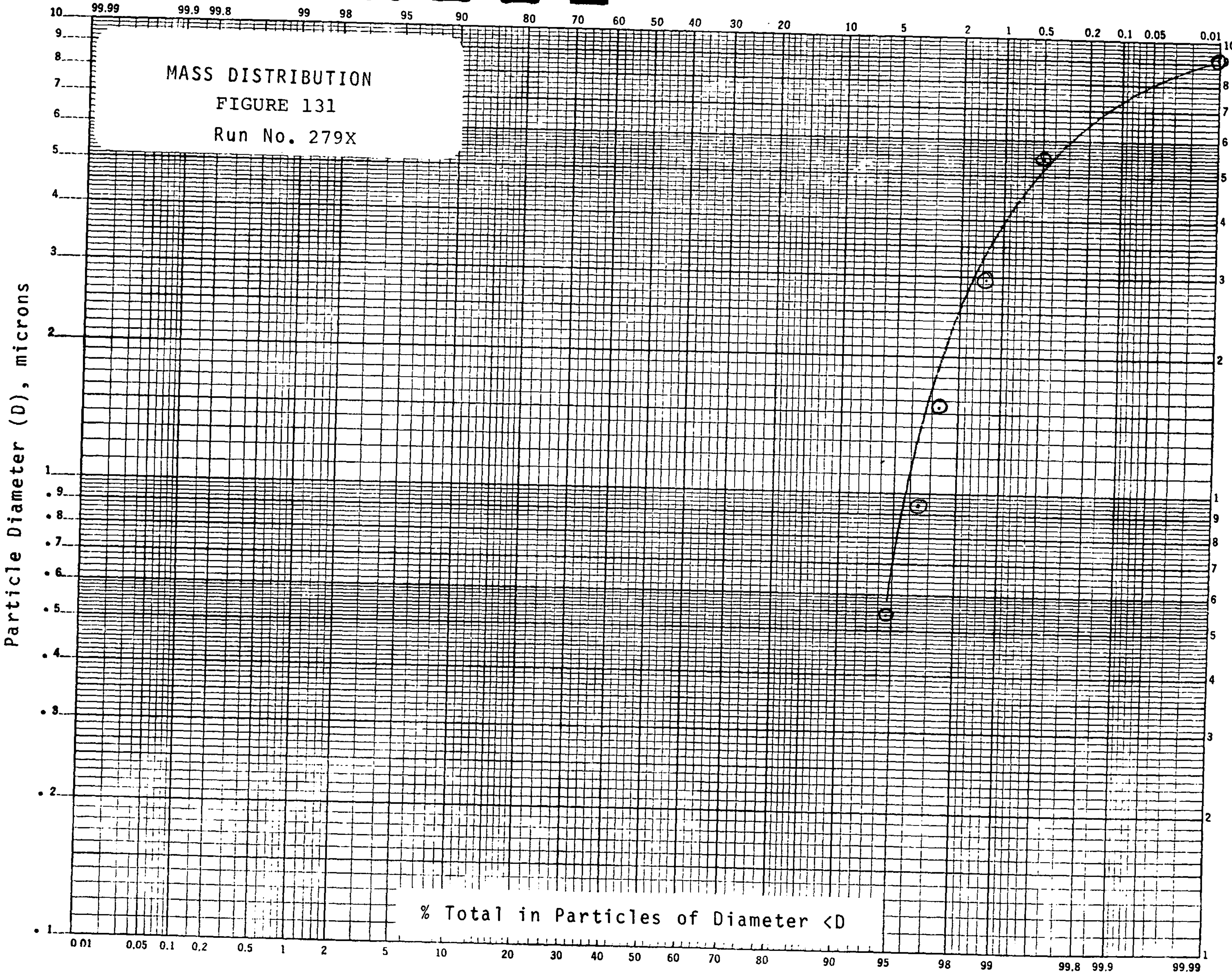
Trace Metals on Millipore Filter (%)

Vehicle Test No.	Fe	Ni	Cu	Al	Ca	Mg	Mn	Cr	Sn	Zn	Ti	Pb	%SO_4	Glass Fiber Filters %C	%H	%N	PPM BAP
279 C	.07	<.01	.02	.02	.14	.03	<.005	<.01	<.01	<.03	<.01	.2		1.05	2.06	1.19	1
279 F&G	1.9	<.05	.7	.5	7.4	1.4	.09	.1	<.05	.5	.09	.4		6.05	1.01	4.19	20
279 X	.03	<.01	.02	.03	.17	.04	<.005	<.01	<.01	<.03	<.01	.1		1.49	2.41	1.25	15
279 Y&Z	.4	<.05	.3	.2	3.6	.6	.01	.1	<.05	.2	.02	.1		28.18	8.92	3.05	55



K&E PROBABILITY [redacted] 46 8043 [redacted]
MASS DISTRIBUTION
FIGURE 130
Run No. 279C
Particle Diameter (D), microns
% Total in Particles of Diameter <D

K+E PROBABILITY X 2 LOG CYCLES 46 8043
[redacted] [redacted]UFFE[redacted]ER C[redacted] MADE IN U.S.A. [redacted]



MASS DISTRIBUTION
FIGURE 131
Run No. 279X

DYNAMOMETER TEST

TABLE 25

Engine Stand

VEHICLE TYPE: 1972 Chevrolet

FUEL: Baseline + Fuel Additive B

CONVERTER: Monolith

Vehicle Test No.	Car Miles	Test Hrs.	Test Mode	Grams per 1.61 km (1 mile): Andersen Sampler	Follow-up glass Filter	Andersen + Filter	Glass Filter 142 mm (Avg. of two)	Millipore 142 mm
272B		0	60 MPH SS	.0185	.1551	.1734	.1402	.1781
272D		0	FCHS	--	--	--	.3666	.5280
272E		0	FCHS	--	--	--	.4008	.6453
272M		88	60 MPH SS	.0179	.1795	.1974	.2072	.1876
272O		88	FCHS	--	--	--	.3960	.5570
272P		88	FCHS	--	--	--	.3764	.6453

TABLE 25 (Cont'd)

EXHAUST GAS ANALYSIS

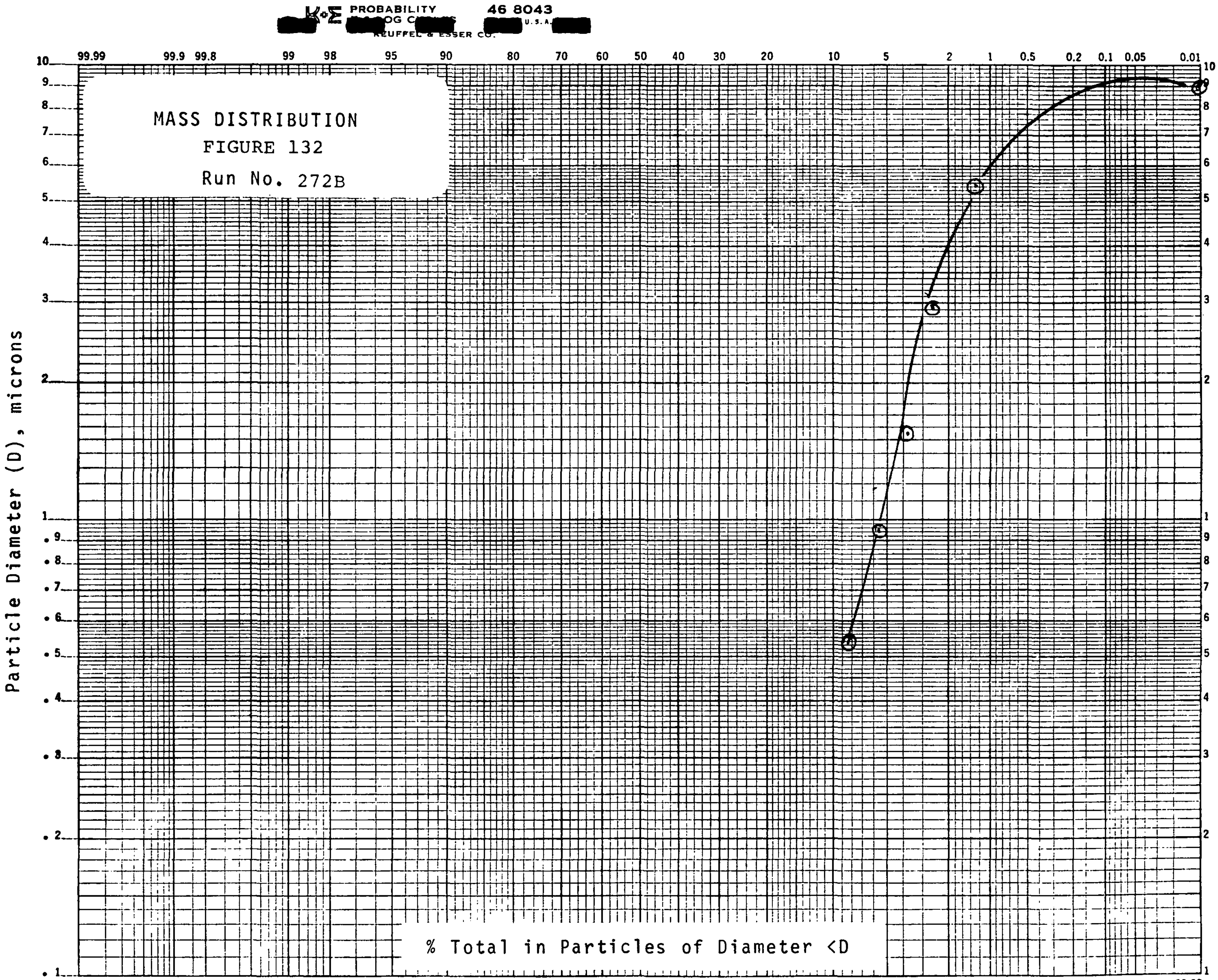
Vehicle Test No.	% by Volume			Parts Per Million					
	CO_2	O_2	N_2	CO	C_6 H.C.	NO_2	NO	NO_x - N_x	
272B	10.35	6.3	82.45	38.7	15		875	1209	Start
	10.45	6.2	82.45	36.3	12		942	1398	Finish
272M	9.7	7.2	82.3	144.7	35		792	1214	Start
	10.2	6.4	82.5	53.2	30		646	897	Finish

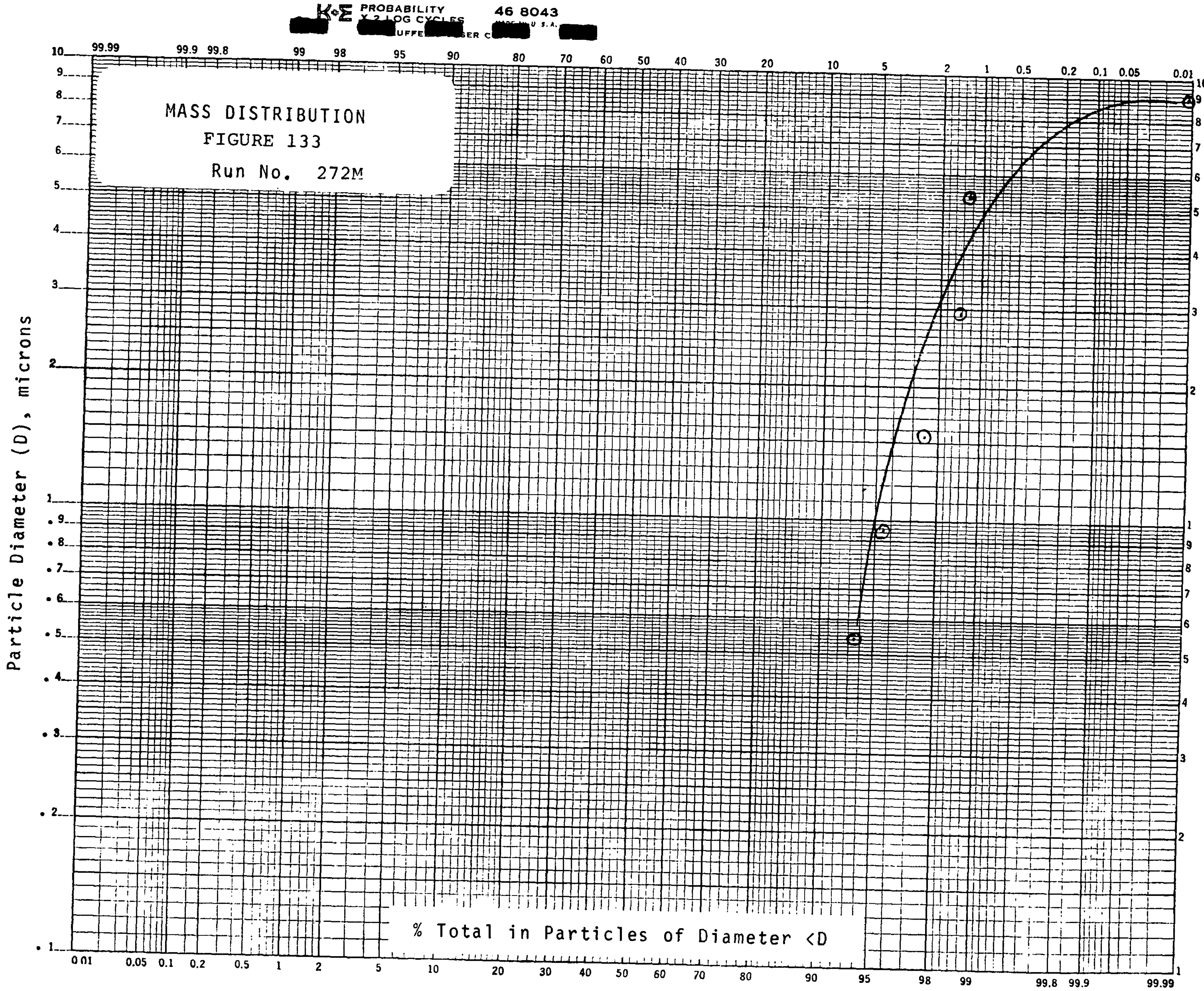
TABLE 25 (Cont'd)

ANALYSIS OF EXHAUST PARTICULATE

Trace Metals on Millipore Filter (%)

Vehicle Test No.	Fe	Ni	Cu	Al	Ca	Mg	Mn	Cr	Sn	Zn	Ti	Pb	$\%SO_4$	Glass Fiber Filters			
														%C	%H	%N	PPM BAP
272 B	.03	<.01	.03	<.01	.2	.07	2.7	<.01	<.01	.03	<.01	1.3		1.67	3.34	4.77	4
272 D	.13	<.01	.16	.04	1.4	.27	2.8	.02	<.01	.11	.01	.3		3.46	3.17	4.11	90
272 M	.02	<.01	.02	<.01	.16	.05	2.1	<.01	<.01	.03	<.01	1.2		0.83	2.40	2.12	3
272 P	.12	<.01	.13	.04	.87	.22	2.7	.04	<.01	.13	.02	.58		18.45	5.15	0.94	40


[redacted] K+E PROBABILITY [redacted] 46 8043 [redacted]
KEUFFEL & ESSER CO.
MASS DISTRIBUTION
FIGURE 132
Run No. 272B
Particle Diameter (D), microns
% Total in Particles of Diameter <D
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99


MASS DISTRIBUTION
FIGURE 133
Run No. 272M
Particle Diameter (D), microns
% Total in Particles of Diameter <D

DYNAMOMETER TEST

TABLE 26

Engine Stand

VEHICLE TYPE: 1972 Chevrolet

FUEL: Baseline

CONVERTER: Beaded

Vehicle Test No.	Test Hours	Test Miles	Test Mode	Grams per 1.61 km (1 mile): Andersen Sampler	Follow-up glass Filter	Andersen + Filter	Glass Filter 142 mm (Avg. of two)	Millipore 142 mm
286E	38.4		2 HRS SS	.0030	.0459	.0489	.0574	.0447
286H	56.3		FCHS	--	--	--	.0611	.0440
286I	56.9		FCHS	--	--	--	.0708	.0806
286X	145.1		2 HRS SS	.0048	.0432	.0481	.0462	.0447
286Y	146.0		FCHS	--	--	--	.0562	.0513
286Z	146.7		FCHS	--	--	--	.0513	.0586

TABLE 26 (Cont'd)

EXHAUST GAS ANALYSIS

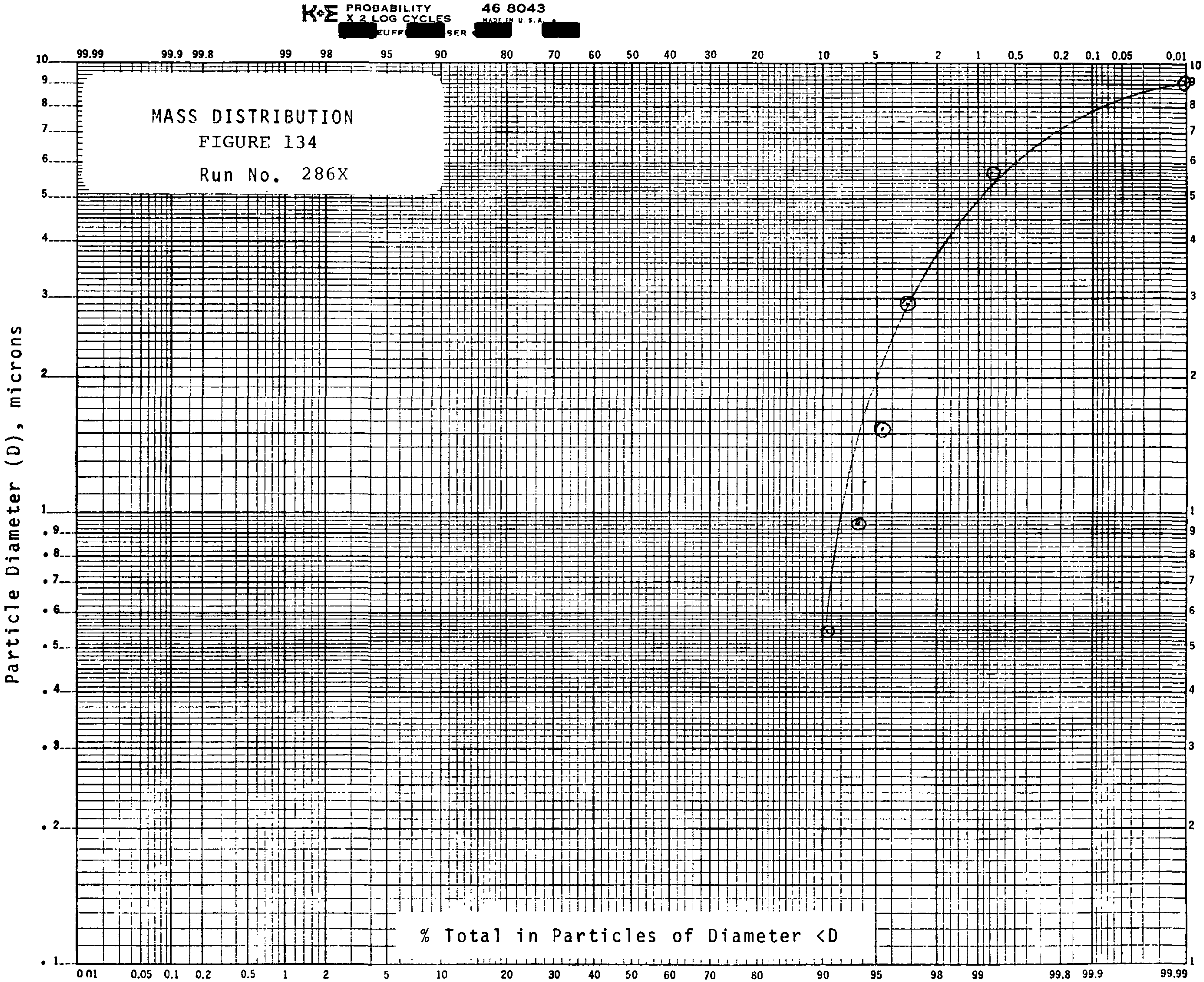
Vehicle Test No.	% by Volume CO_2	O_2	N_2	Parts Per Million CO	C_6 H.C.	NO_2	NO	$NO_x - N_x$	
286E	10.4	6.7	82.0	33.9	9		1506	1975	Start
	10.1	6.3	82.65	33.9	8		983	1520	Finish
286H	9.8	6.5	82.8	133.1	22		557	1141	
286I	10.7	5.25	83.1	208.1	23		1025	1597	
286X	10.3	6.4	82.4	48.4	7		732	1054	Start
	9.95	7.1	82.2	36.3	6		845	1168	Finish
286Y	10.3	5.65	83.1	186.4	20		475	864	
286Z	9.85	6.25	83.0	850.0	67		462	904	

TABLE 26 (Cont'd)

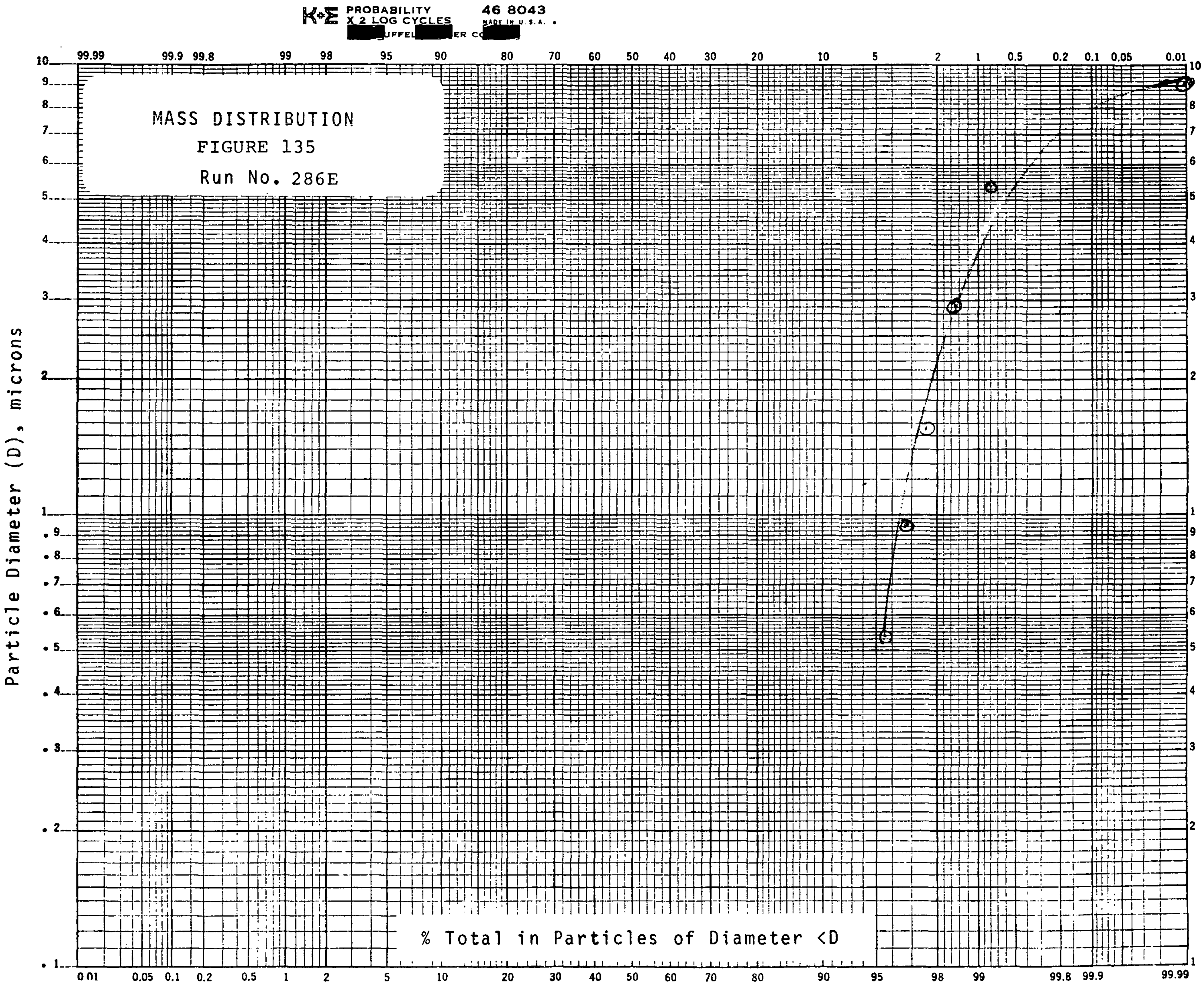
ANALYSIS OF EXHAUST PARTICULATE

Trace Metals on Millipore Filter (%)

Vehicle Test No.	Fe	Ni	Cu	Al	Ca	Mg	Mn	Cr	Sn	Zn	Ti	Pb	$\%SO_4$	%C	%H	%N	PPM BAP
														Glass Fiber Filters			
286 E	.04	<.01	.05	.04	.45	.10	<.005	.01	<.01	<.03	.01	<.03		2.42	3.37	5.09	15
286 I	.53	<0.1	.38	.25	3.9	.78	<.05	<0.1	<0.1	<0.3	<0.1	<0.3		11.56	3.07	3.31	<20
286 X	.06	<.01	.04	.02	.40	.09	.005	.01	<.01	<.03	<.01	.03		2.59	3.69	7.01	5
286 Y	.67	<.05	.53	.37	6.1	1.4	.03	.17	<.05	.38	.07	<.2		46.97	3.41	7.46	75



K&E PROBABILITY X 2 LOG CYCLES
46 8043
MADE IN U.S.A.
[redacted] EUFF [redacted] SER C [redacted] [redacted]
MASS DISTRIBUTION
FIGURE 134
Run No. 286X
Particle Diameter (D), microns
% Total in Particles of Diameter <D
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99


K&E PROBABILITY X 2 LOG CYCLES 46 8043
MADE IN U.S.A.
[redacted]UFFEL[redacted]ER C[redacted]
MASS DISTRIBUTION
FIGURE 135
Run No. 286E
Particle Diameter (D), microns
% Total in Particles of Diameter <D

DYNAMOMETER TEST

TABLE 27

Engine Stand

VEHICLE TYPE: 1972 Chevrolet

FUEL: Baseline + Fuel Additive A

CONVERTER: Beaded

Vehicle Test No.	Test Hours	Test Miles	Test Mode	Grams per 1.61 km (1 mile): Andersen Sampler	Follow-up glass Filter	Andersen + Filter	Glass Filter 142 mm (Avg. of two)	Millipore 142 mm
289C	20.0	120	2HRS 60 MPH	.0027	.0197	.0224	.0217	.0170
289F	33.7	7.5	FCHS	--	--	--	.0440	.0366
289G	34.3	7.5	FCHS	--	--	--	.0342	.0293
289X	142.9	120	2HRS 60 MPH	.0042	.0207	.0249	.0219	.0192
289Y	145.0	7.5	FCHS	--	--	--	.0875	.0220
289Z	145.6	7.5	FCHS	--	--	--	.0586	.0220

TABLE 27 (Cont'd)

EXHAUST GAS ANALYSIS

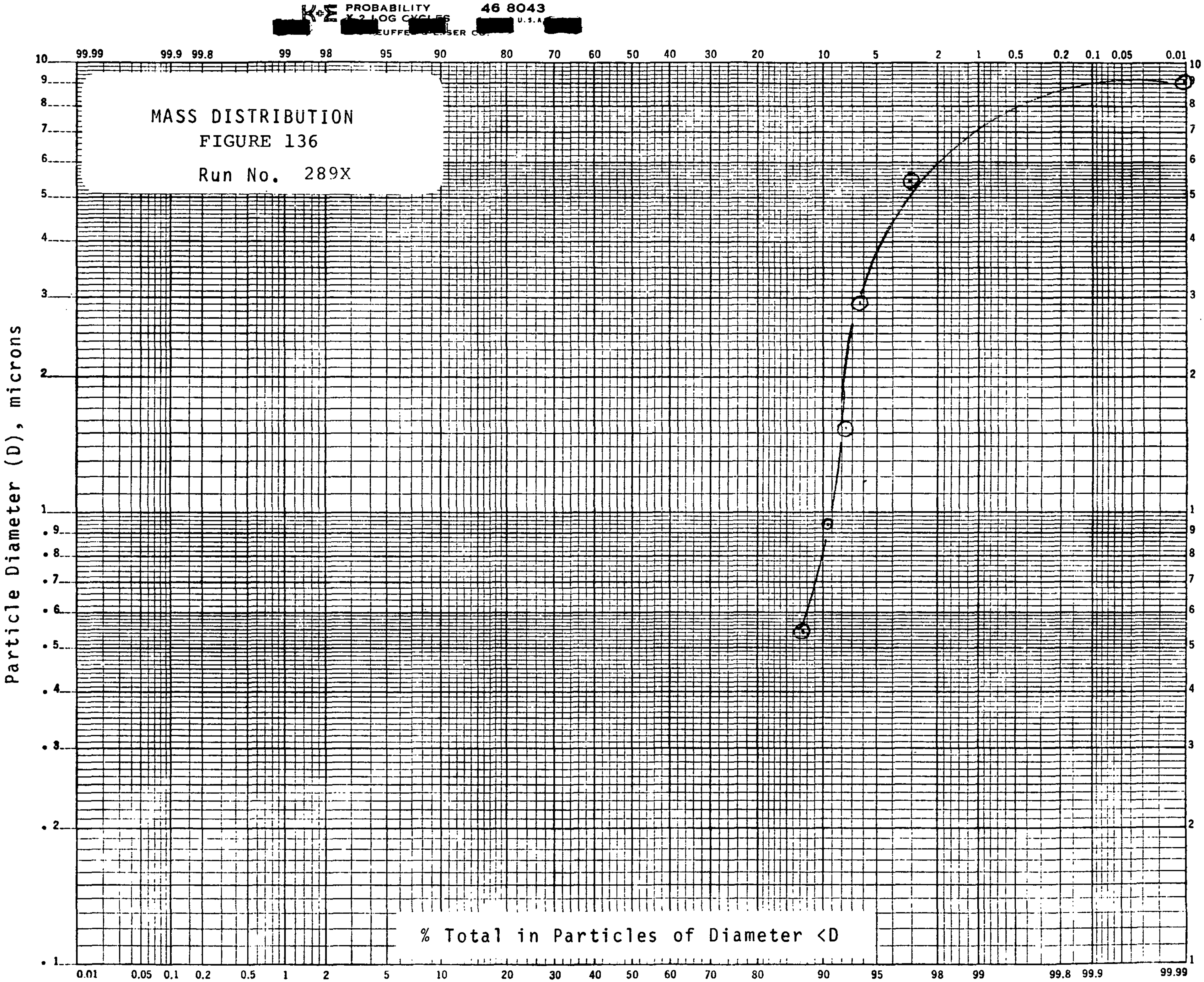
Vehicle Test No.	% by Volume			Parts Per Million					
	CO_2	O_2	N_2	CO	C_6 H.C.	NO_2	NO	$NO_x - N_x$	
289C	11.1	5.65	82.35	18.0	9		1167	1387	Start
	11.0	5.70	82.40	18.0	9		1387	1696	Final
289F	10.4	4.3	84.40	260	23		345	580	
289G	10.0	4.7	84.40	460	23		347	583	
289X	11.0	5.15	83.05	550	12		990	1321	Start
	10.9	5.35	82.9	300	12		1089	1546	Final
289Y	10.15	5.10	83.6	2270	79		475	952	
289Z	10.40	4.90	83.7	780	38		588	1004	

TABLE 27 (Cont'd)

ANALYSIS OF EXHAUST PARTICULATE

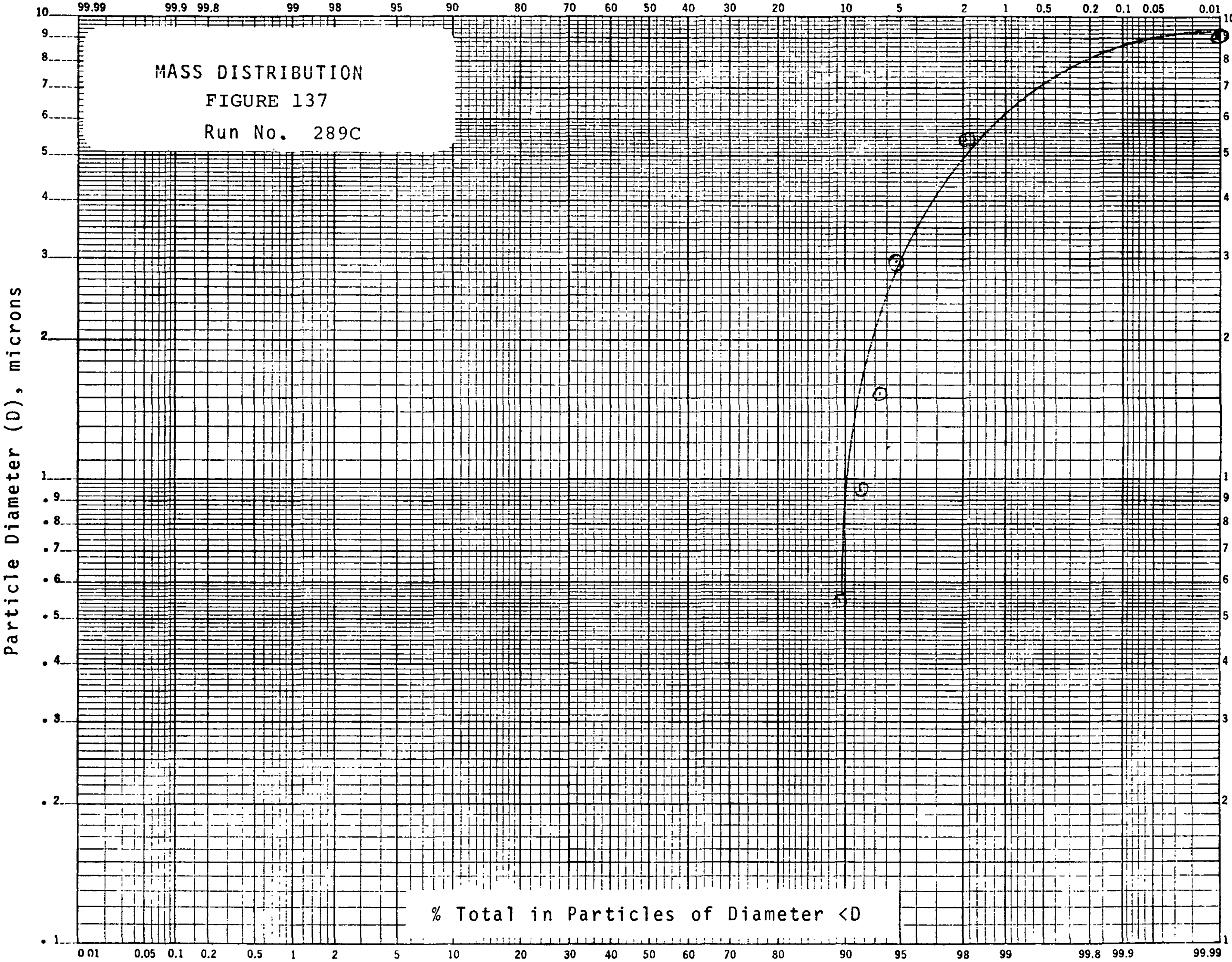
Trace Metals on Millipore Filter (%)

Vehicle Test No.	Fe	Ni	Cu	Al	Ca	Mg	Mn	Cr	Sn	Zn	Ti	Pb	%SO_4	Glass Fiber Filters %C	%H	%N	PPM BAP
289 C	.15	.02	.11	.06	1.1	.23	.014	.03	<.01	.07	<.01	.28		3.63	3.33	7.58	37
289 F	1.50	<.1	.86	.73	8.6	1.7	.12	.26	<.1	.62	<.1	.98		TRACE	5.23	20.91	430
289 X	.16	.01	.11	.05	0.9	.17	.009	.03	<.01	.07	<.01	.33		1.39	2.72	9.43	<7
289 Y	5.9	.14	1.9	1.3	17.6	3.2	.70	.53	0.1	1.4	.17	27.1		1.80	TRACE	9.86	75



K+E PROBABILITY 46 8043
[redacted] X 2 LOG CYCLES [redacted] U.S.A. [redacted]
MASS DISTRIBUTION
FIGURE 136
Run No. 289X
Particle Diameter (D), microns
% Total in Particles of Diameter <D

K+E PROBABILITY 46 8043 [redacted]



DYNAMOMETER TEST

TABLE 28

Engine Stand

VEHICLE TYPE: 1972 Chevrolet

FUEL: Baseline + Fuel Additive B

CONVERTER: Beaded

Vehicle Test No.	Test Hours	Test Miles	Test Mode	Grams per 1.61 km (1 mile): Andersen Sampler	Follow-up glass Filter	Andersen + Filter	Glass Filter 142 mm (Avg. of two)	Millipore 142 mm
282C	5.5		60 MPH SS	.0039	.0206	.0245	.0245	.0129
282F	8		FCHS	--	--	--	.0733	.0733
282G	8		FCHS	--	--	--	.0660	.0611
282U	131.3		FCHS	--	--	--	.0582	.0513
282V	132.0		FCHS	--	--	--	.0586	.0513
282W	132.3		60 MPH SS	.0065	.0119	.0185	.0133	.0096

*Polycarbonate Filter.

TABLE 28 (Cont'd)

ANALYSIS OF EXHAUST PARTICULATE

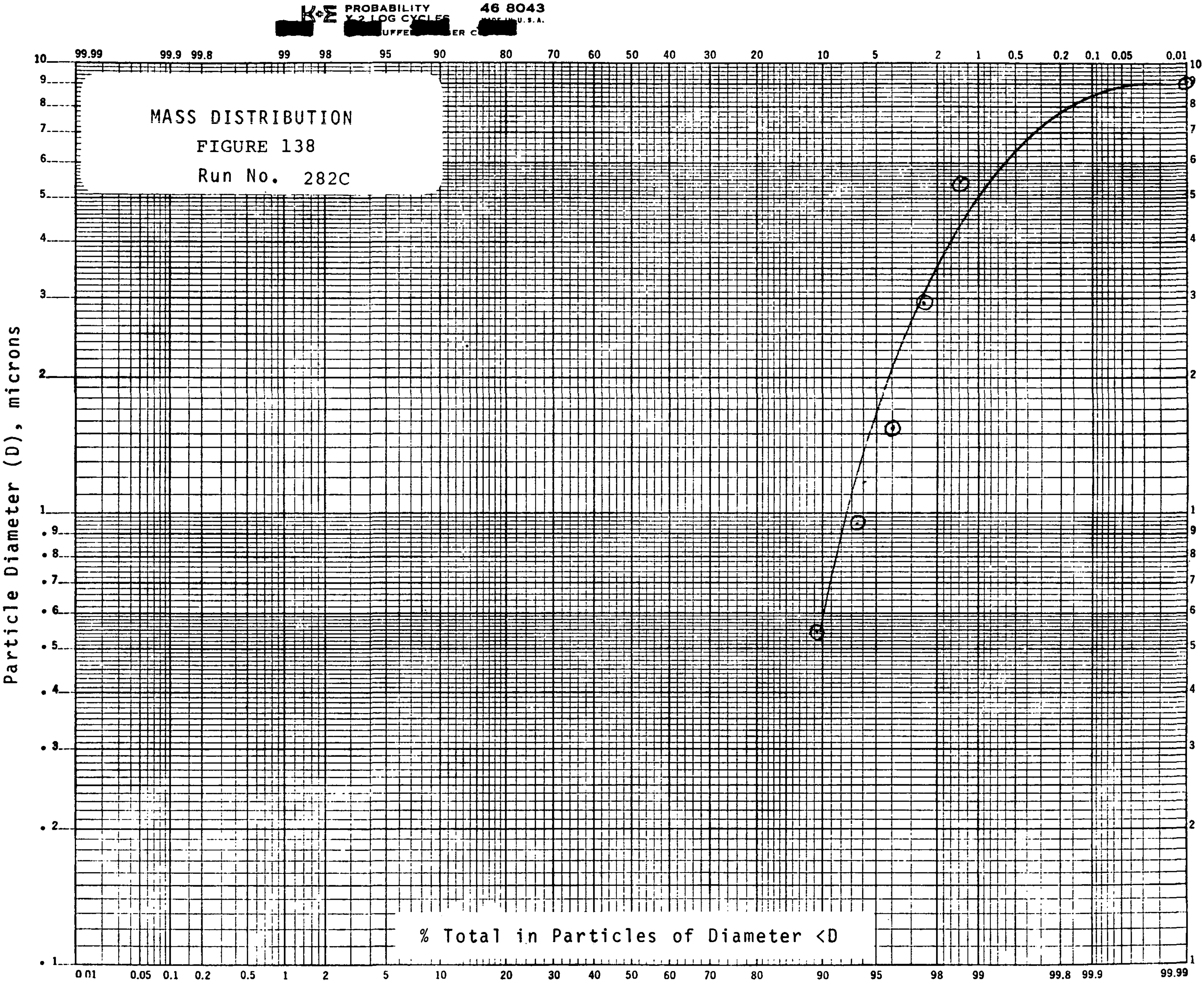
Trace Metals on Millipore Filter (%)

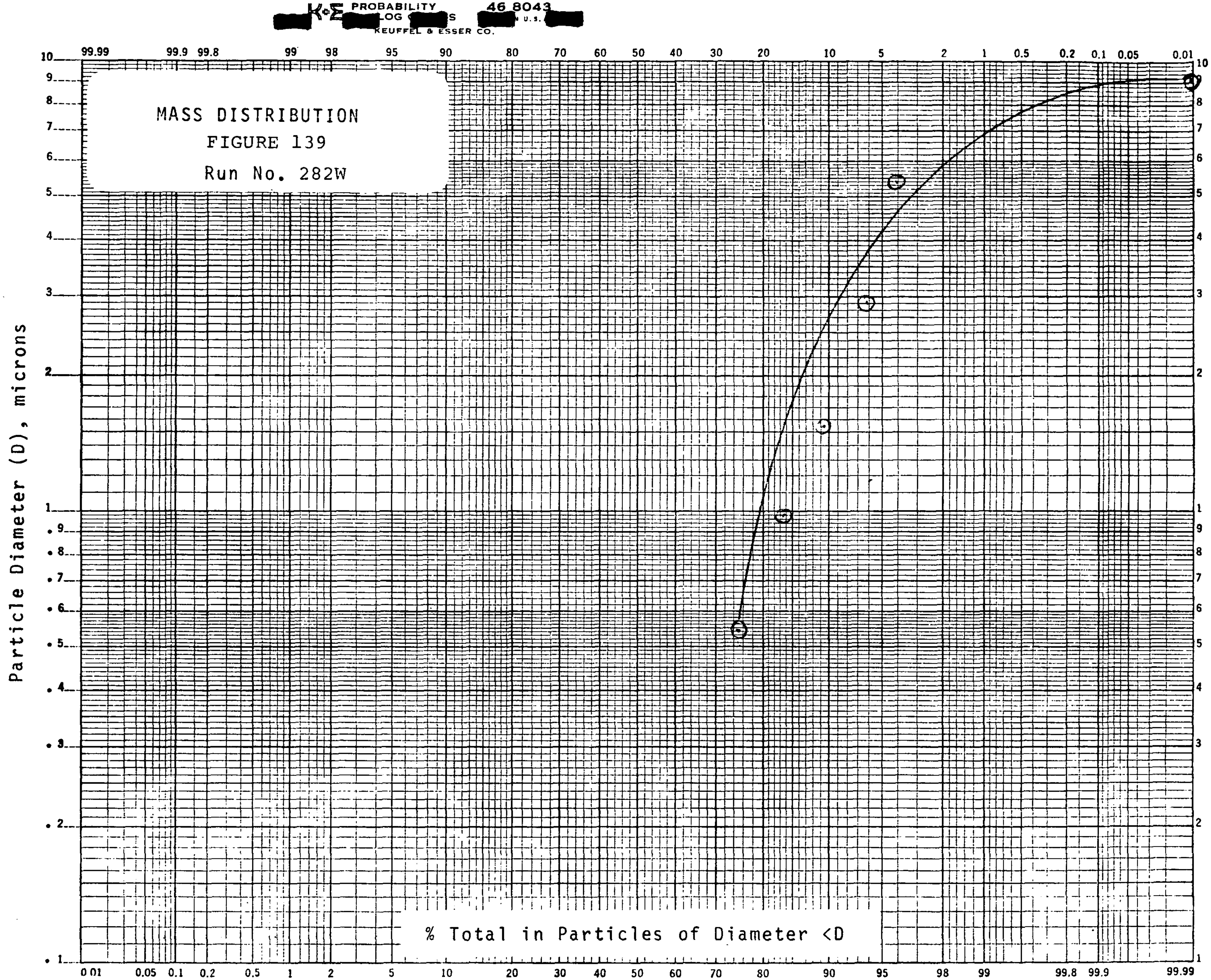
Vehicle Test No.	Fe	Ni	Cu	Al	Ca	Mg	Mn	Cr	Sn	Zn	Ti	Pb	%SO_4	Glass Fiber Filters %C	%H	%N	PPM BAP
282 C	.1	<.05	.1	.06	1.0	.3	14.0	<.05	<.05	.2	<.05	5.1		0.95	2.09	4.35	24
282 F&G	.7	<.05	.4	.28	3.4	.8	6.0	.09	<.05	.4	.05	2.0		2.84	1.45	0.95	160
282 U&V	.8	<.1	.7	.35	5.3	1.3	8.3	.15	<.1	.6	<.1	2.7		2.87	3.35	1.10	10
282 W	.2	<.05	.2	.13	1.7	.5	18.0	<.05	<.05	.3	<.05	9.1		3.33	2.47	1.37	60

TABLE 28 (Cont'd)

EXHAUST GAS ANALYSIS

Vehicle Test No.	% by Volume			Parts Per Million					
	CO_2	O_2	N_2	CO	C_6 H.C.	NO_2	NO	NO_x - N_x	
282C	11.10	4.9	83.0	204.0	16		946	1058	Start
	9.95	6.6	82.5	133.1	16		1128	1308	Finish
282F	10.4	6.15	82.55	1150	75		467	906	
282G	10.6	6.0	82.6	495	50		667	965	
282U	10.1	6.8	82.1	360	55		385	805	
282V	10.0	6.6	82.6	675	68		384	779	
282W	10.4	6.5	82.3	121.1	30		730	1272	Start
	9.2	8.1	81.8	111.3	30		782	1395	Finish


K&E PROBABILITY X 2 LOG CYCLES
46 8043
MADE IN U.S.A.
[redacted] [redacted]UFFE[redacted]ER C[redacted]
MASS DISTRIBUTION
FIGURE 138
Run No. 282C
Particle Diameter (D), microns
% Total in Particles of Diameter <D



MASS DISTRIBUTION
FIGURE 139
Run No. 282W

CHASSIS DYNAMOMETER TEST

TABLE 29

CAR NUMBER: D-0435

VEHICLE TYPE: 1972 Tan Chevrolet

FUEL: Baseline No Pb.

CONVERTER: Beaded

				Grams per 1.61 km (1 mile)				
Vehicle Test No.	Car Miles	Test Miles	Test Mode	Andersen Sampler	Follow-up glass Filter	Andersen + Filter	Glass Filter 142 mm (Avg. of two)	Millipore 142 mm
267A	2,871.0	11.5	MFCCS	.1004	.0095	.1100	.0286	.0813
267B	2,991.0	120.0	60 MPH SS	.0044	.0509	.0554	.0806	.0311
267C	2,998.5	7.5	FCHS	--	--	--	.0293	.0293
267D	3,006.0	7.5	FCHS	--	--	--	.0391	.1173
283A	8,755.0	11.5	MFCCS	.0526	.0143	.0669	.0454	.0286
283B		120.0	2 HRS SS	.0034	.0646	.0680	.0746	.0749
283C		7.5	FCHS	--	--	--	.0256	.0440
283D		7.5	FCHS	--	--	--	.0342	.0586

TABLE 29 (Cont'd)

ANALYSIS OF EXHAUST PARTICULATE

Trace Metals on Millipore Filter (%)

Vehicle Test No.	Fe	Ni	Cu	Al	Ca	Mg	Mn	Cr	Sn	Zn	Ti	Pb	$\%SO_4$	Glass Fiber Filters %C	%H	%N	PPM BAP
267 B	.06	<.01	.03	.02	.24	.05	<.005	<.01	<.01	.04	<.01	<.03		.45	2.71	4.26	<2
267 C	.45	<.01	.22	.2	2.7	.6	<.05	<.1	<.1	<0.3	<.1	<0.3		2.40	4.22	7.03	<40
267 D	.39	<.01	.22	.2	2.6	.6	<.05	<.1	<.1	<0.3	<.1	<0.3		-----	----	-------	
283 A																	
283 B	.03	<.01	.02	.02	.2	.04	<.005	<.01	<.01	.03	<.01	<.03		11.50	6.30	3.10	3
283 C																	
283 D	1.0	<.1	.5	.52	5.2	1.0	<.05	.15	<.1	.7	.08	1.8		23.77	3.73	0.28	<60

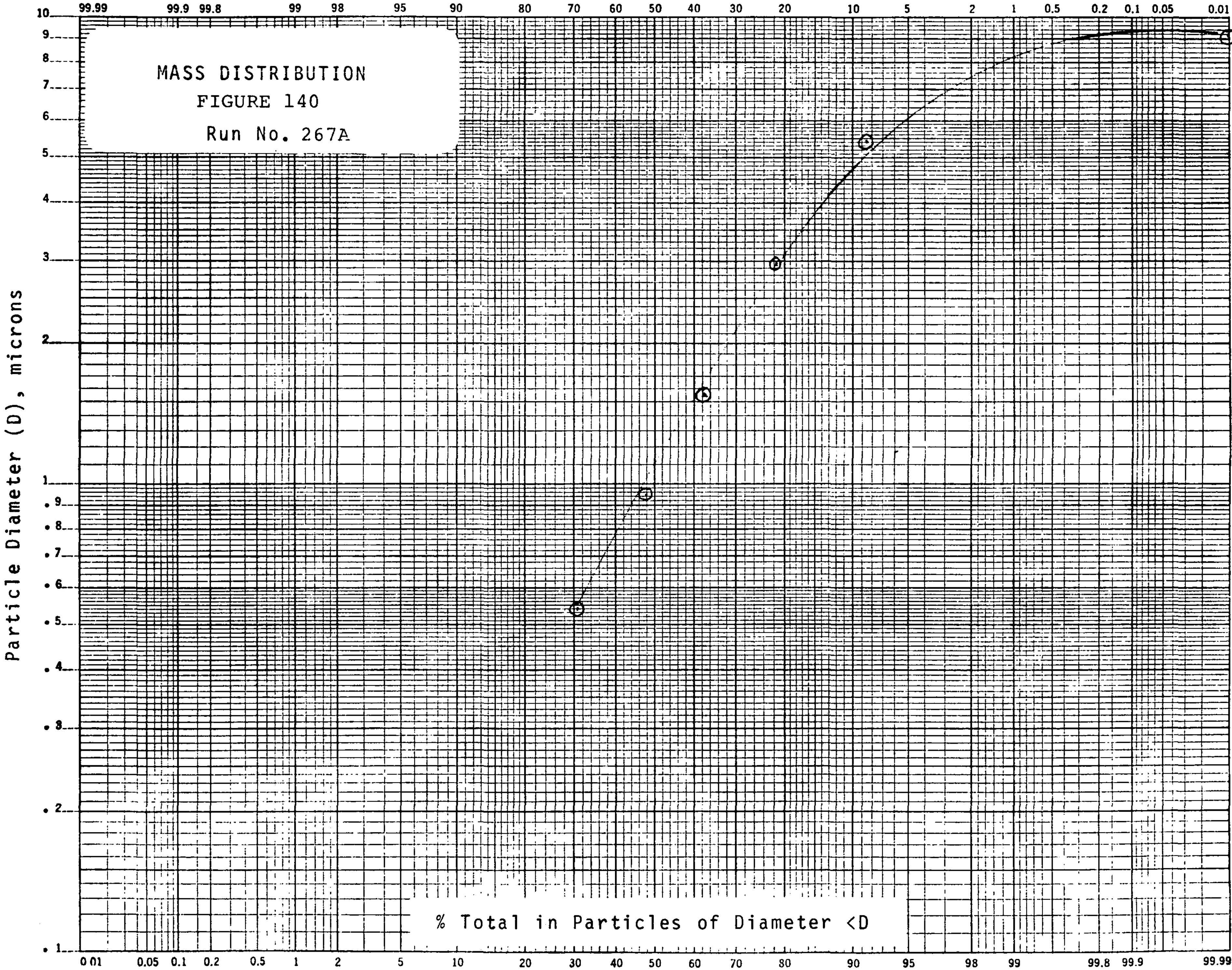
Only 283 B
283 D were analyzed

TABLE 29 (Cont'd)

EXHAUST GAS ANALYSIS

Vehicle Test No.	% by Volume CO_2	O_2	N_2	Parts Per Million CO	C_6 H.C.	NO_2	NO	NO_x - N_x	
267A	8.9	8.3	81.9	>250	55		152	209	23 Min.
	8.9	8.4	81.9	>250	35		260	298	41 Min.
267B	11.2	4.9	83.0	15.7	5		591	693	Start
	11.7	4.4	83.1	18.1	5		680	738	Finish
267C	9.1	7.8	82.1	215.3	10		188	277	
267D	8.9	8.3	82.0	123.4	20		181	257	
283A	9.3	7.65	82.15	880	35		188	280	1380 Sec.
	9.2	7:8	82.05	198.5	37		353	458	Last 505 Sec.
283B	11.4	4.7	83.0	70.2	3		1152	1295	Start
	12.15	3.6	83.35	50.8	2		1050	1204	Finish
283C	9.35	7.5	82.2	94.4	22		196	362	
283D	9.10	7.9	82.05	186.4	34		176	305	

[redacted] K+E PROBABILITY [redacted] KEUFFEL & ESSER CO. 46 8043 [redacted] U.S.A. [redacted]

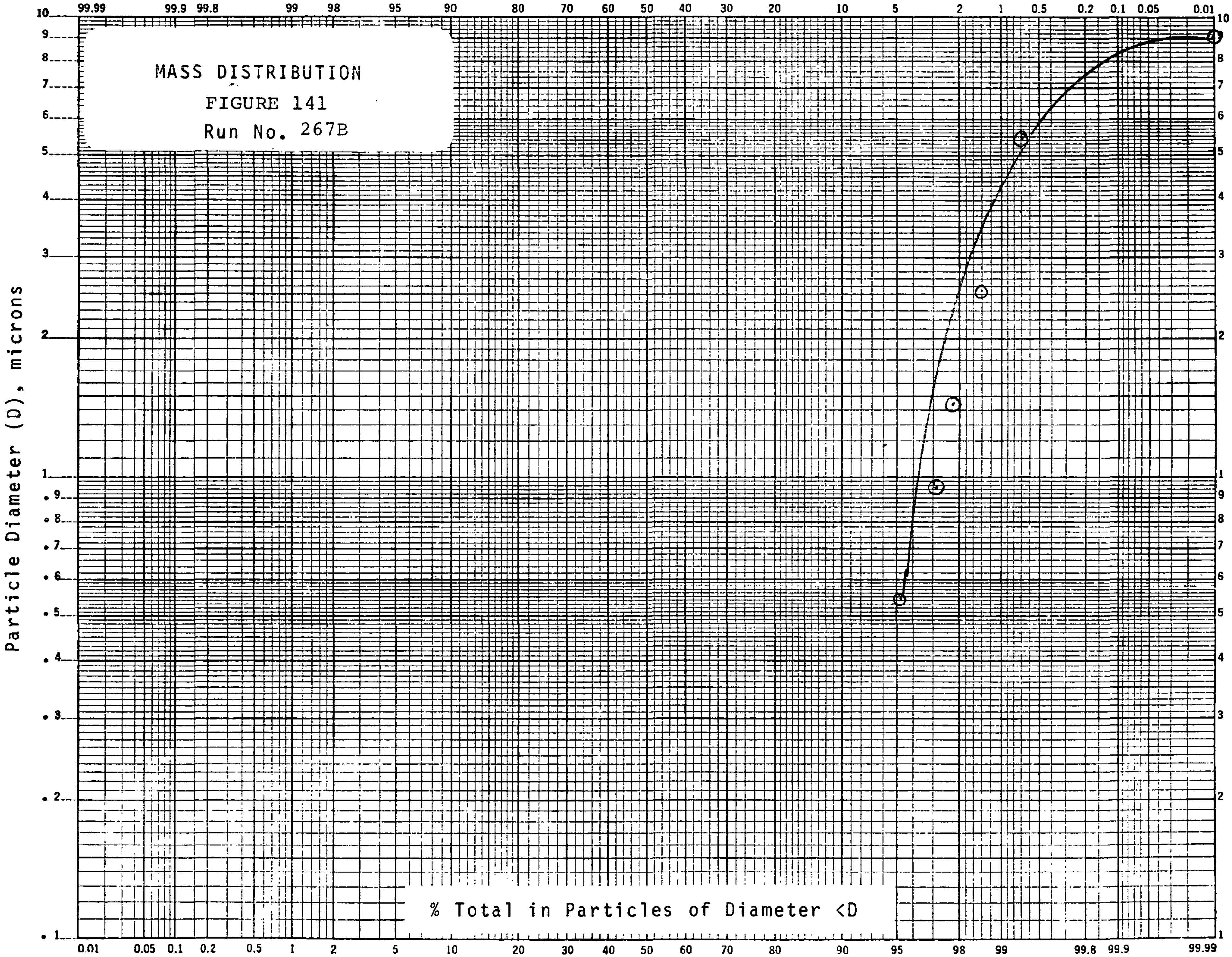


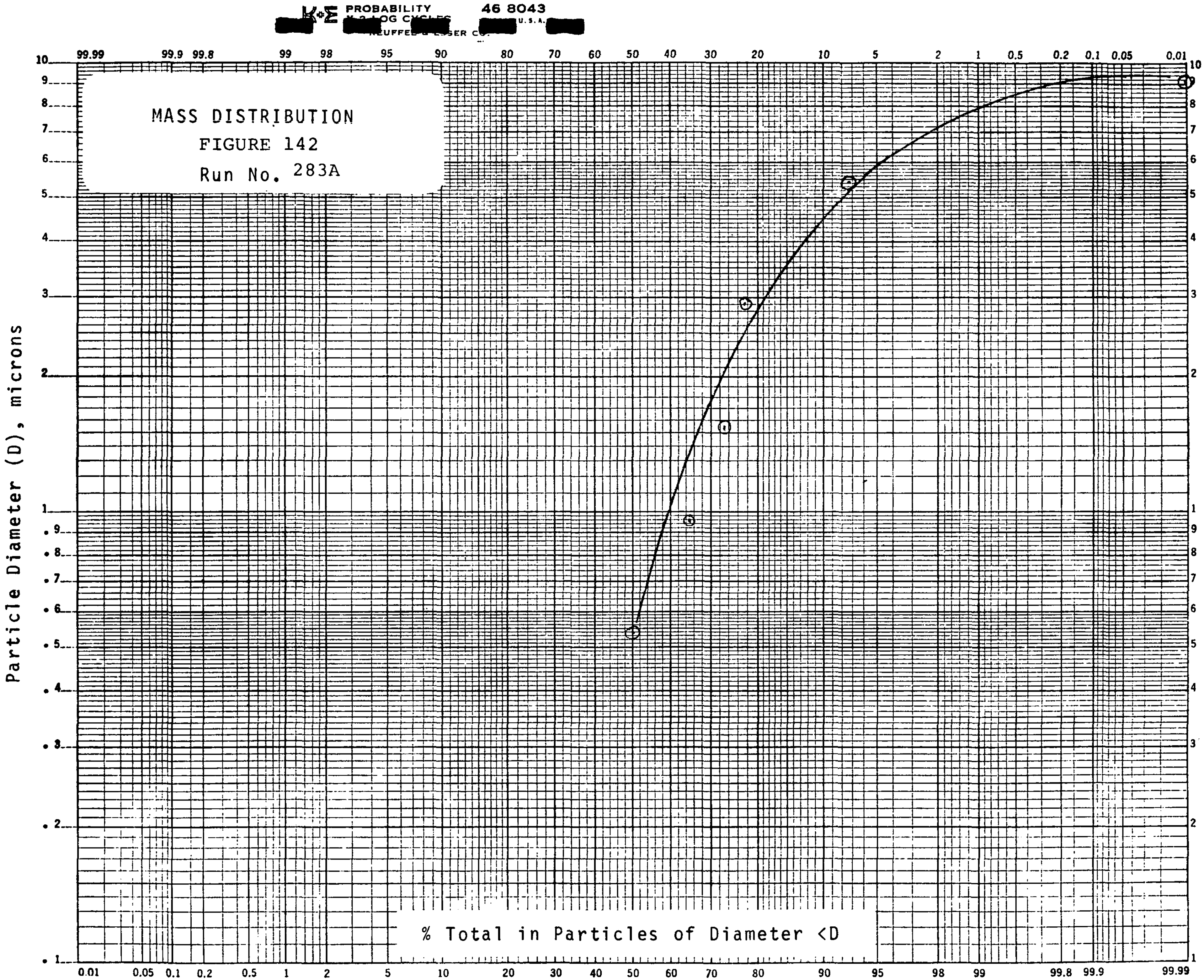
MASS DISTRIBUTION

FIGURE 140

Run No. 267A

[redacted] K+E PROBABILITY [redacted] 46 8043 [redacted] U.S.A. [redacted]
KEUFFEL & ESSER CO.





[redacted] K+E PROBABILITY [redacted]
46 8043
[redacted] U.S.A. [redacted]
MASS DISTRIBUTION
FIGURE 142
Run No. 283A
Particle Diameter (D), microns
% Total in Particles of Diameter <D
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
10 9 8 7 6 5 4 3 2 1 .9 .8 .7 .6 .5 .4 .3 .2 .1

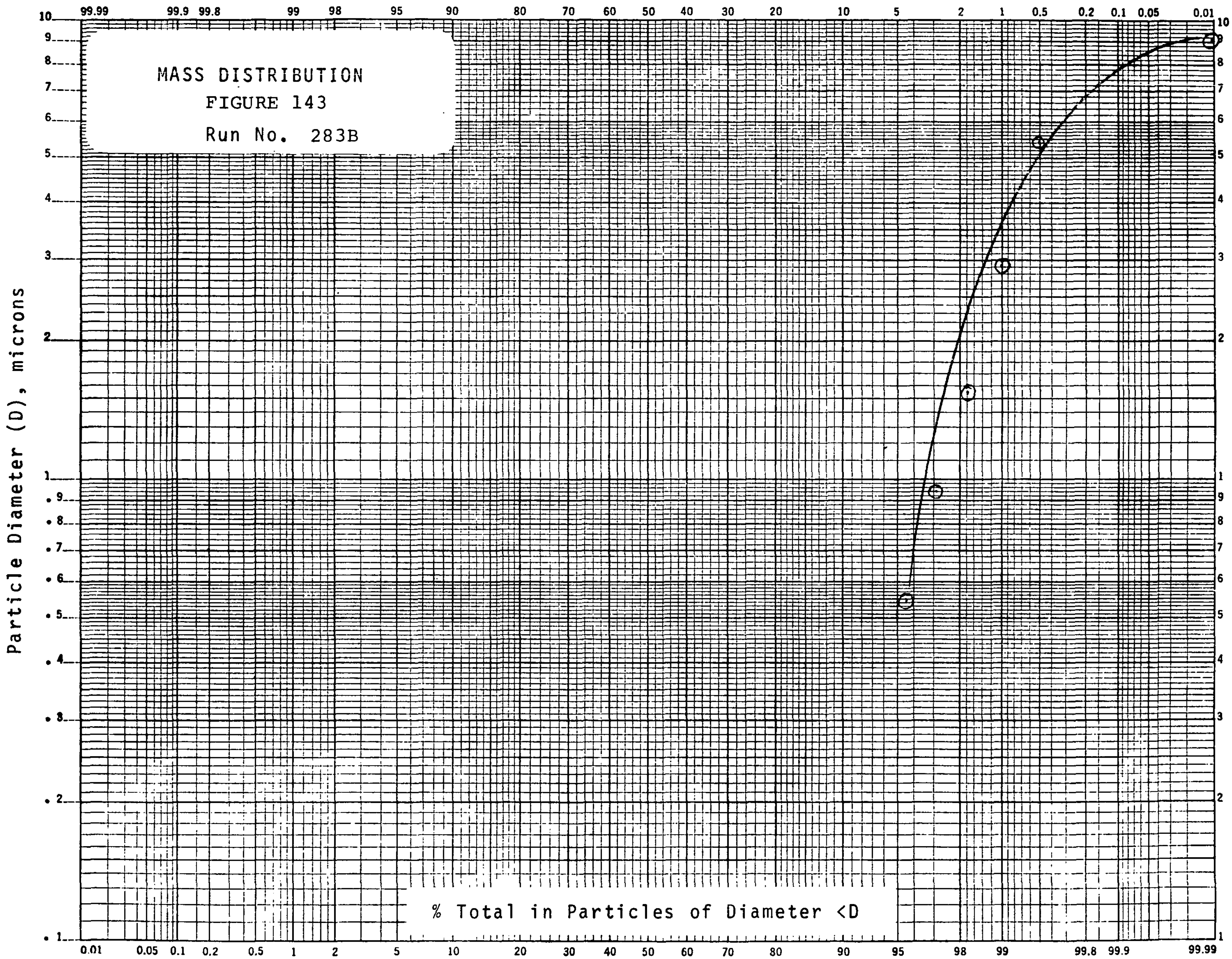
[redacted] K+E PROBABILITY [redacted] LOG [redacted] S [redacted] 46 8043 [redacted]

KEUFFEL & ESSER CO.

MASS DISTRIBUTION

FIGURE 143

Run No. 283B



CHASSIS DYNAMOMETER TEST

TABLE 30

CAR NUMBER: D-0436

VEHICLE TYPE: 1972 Chevrolet

FUEL: Baseline + Fuel Additive A

CONVERTER: Beaded

Vehicle Test No.	Car Miles	Test Miles	Test Mode	Grams per 1.61 km (1 mile): Andersen Sampler	Follow-up glass Filter	Andersen + Filter	Glass Filter 142 mm (Avg. of two)	Millipore 142 mm
268A	2,911.8	11.5	MFCCS	.0860	.0095	.0956	.0119	.0191
268B		120	SS 60 MPH	.0049	.0158	.0208	.0237	.0189
268C		7.5	FCHS	--	--	--	.0256	.0440
268D		7.5	FCHS	--	--	--	.0146	.0220
280C	9,063.0	11.5	MFCCS	.0547	.0383	.0930	.0191	.0047
280D		7.5	FCHS	--	--	--	.0317	.0293
280E		7.5	FCHS	--	--	--	.0317	.0440
280F		120	2 HRS SS	.0506	.1083	.1589	.1196	.1171

TABLE 30 (Cont'd)

EXHAUST GAS ANALYSIS

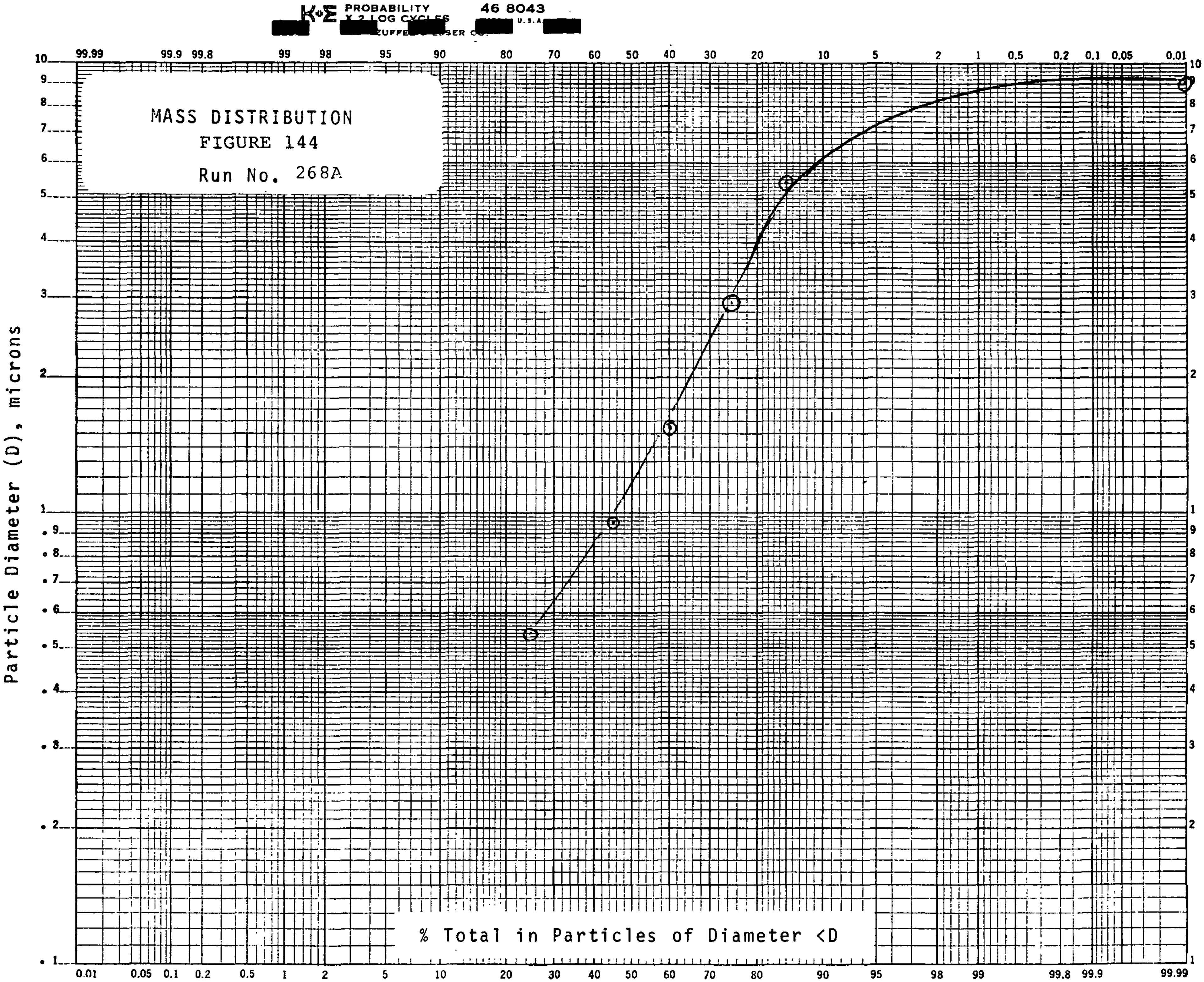
Vehicle Test No.	% by Volume CO_2	O_2	N_2	Parts Per Million CO	C_6 H.C.	NO_2	NO	NO_x - N_x	
268A	9.7	7.3	82.2	>250	35		178	253	Part #1
	9.5	7.3	82.4	210	25		328	406	Part #2
268B	13.0	2.55	83.65	193.6	2		990	143	Start
	14.85	0.3	84.2	>250	2		1075	147	Finish(Over temp)
268C	9.1	8.1	81.95	95.6	15		181	258	
268D	9.15	7.9	82.0	82.2	12		189	279	
280C	9.1	7.8	82.1	>250	50		173	244	1380 Sec.
	9.1	8.0	82.0	>250	140		305	352	505 Sec.
280D	9.1	8.0	82.0	>250	30		192	282	
280E	9.1	8.0	82.0	>250	55		179	274	
280F	12.0	3.8	83.3	96.8	2		550	731	Start
	11.8	4.1	83.2	84.7	2		620	747	Finish

TABLE 30 (Cont'd)

ANALYSIS OF EXHAUST PARTICULATE

Trace Metals on Millipore Filter (%)

Vehicle Test No.	Fe	Ni	Cu	Al	Ca	Mg	Mn	Cr	Sn	Zn	Ti	Pb	$\%SO_4$	Glass Fiber Filters %C	%H	%N	PPM BAP
268 B	.16	<0.1	.13	<.1	.8	.2	<.05	.2	<0.1	<0.3	<0.1	.5		0.48	4.36	14.43	55
268 C	1.6	<0.1	1.2	.5	11.2	2.2	.07	.2	<0.1	.7	.1	<0.3		1.32	1.93	4.93	750
280 F	.02	<.01	.02	.02	.14	.02	<.005	<.01	<.01	<.03	<.01	<.03		1.25	2.99	1.24	2
280 G&E	1.3	<.05	.9	.6	9.3	1.8	.05	.2	<.05	.9	.1	.3		5.68	3.60	0.0	50

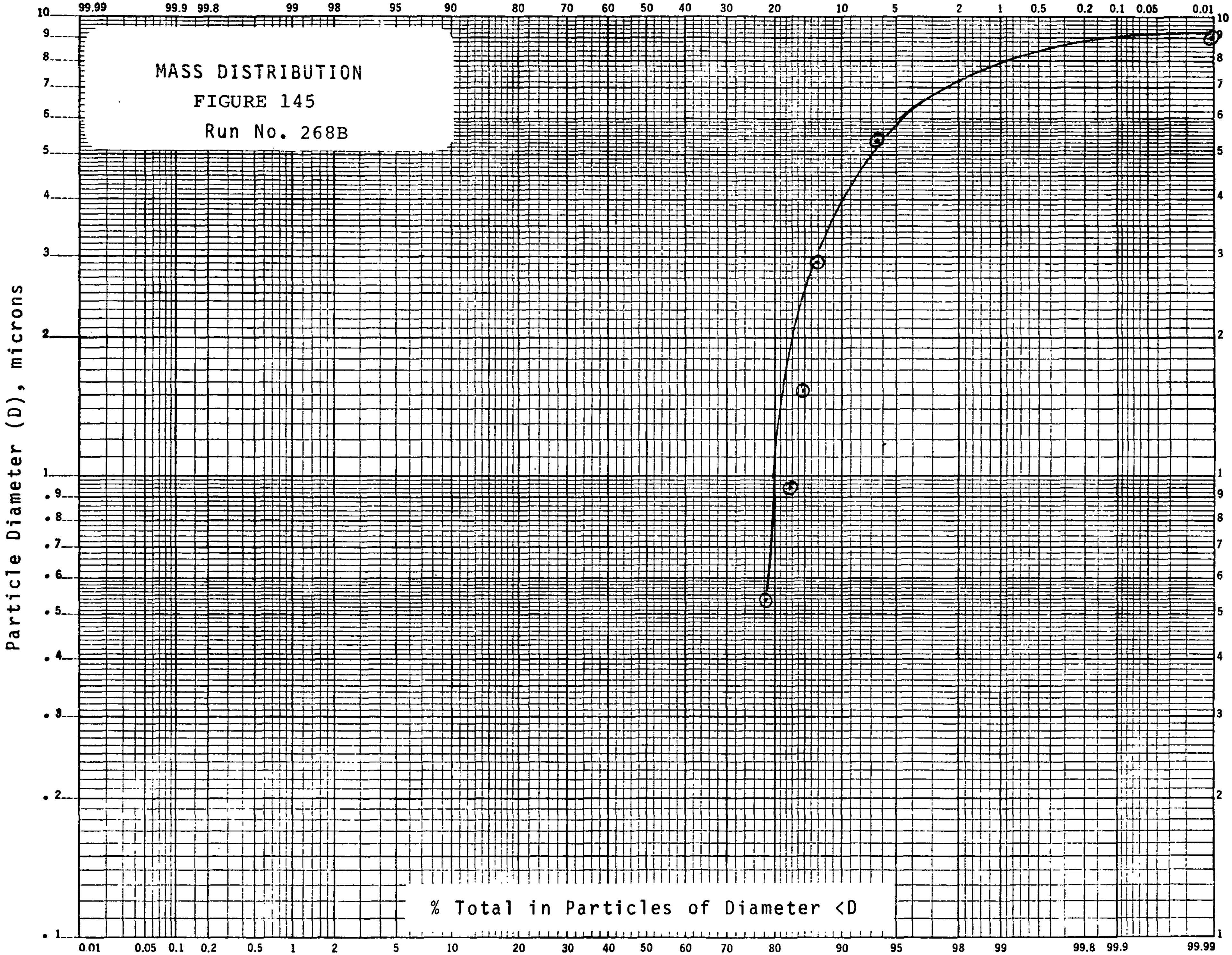

K+E PROBABILITY X 2 LOG CYCLES 46 8043
[redacted]
MASS DISTRIBUTION
FIGURE 144
Run No. 268A
Particle Diameter (D), microns
% Total in Particles of Diameter <D

K+E PROBABILITY [redacted] 46 8043 [redacted]

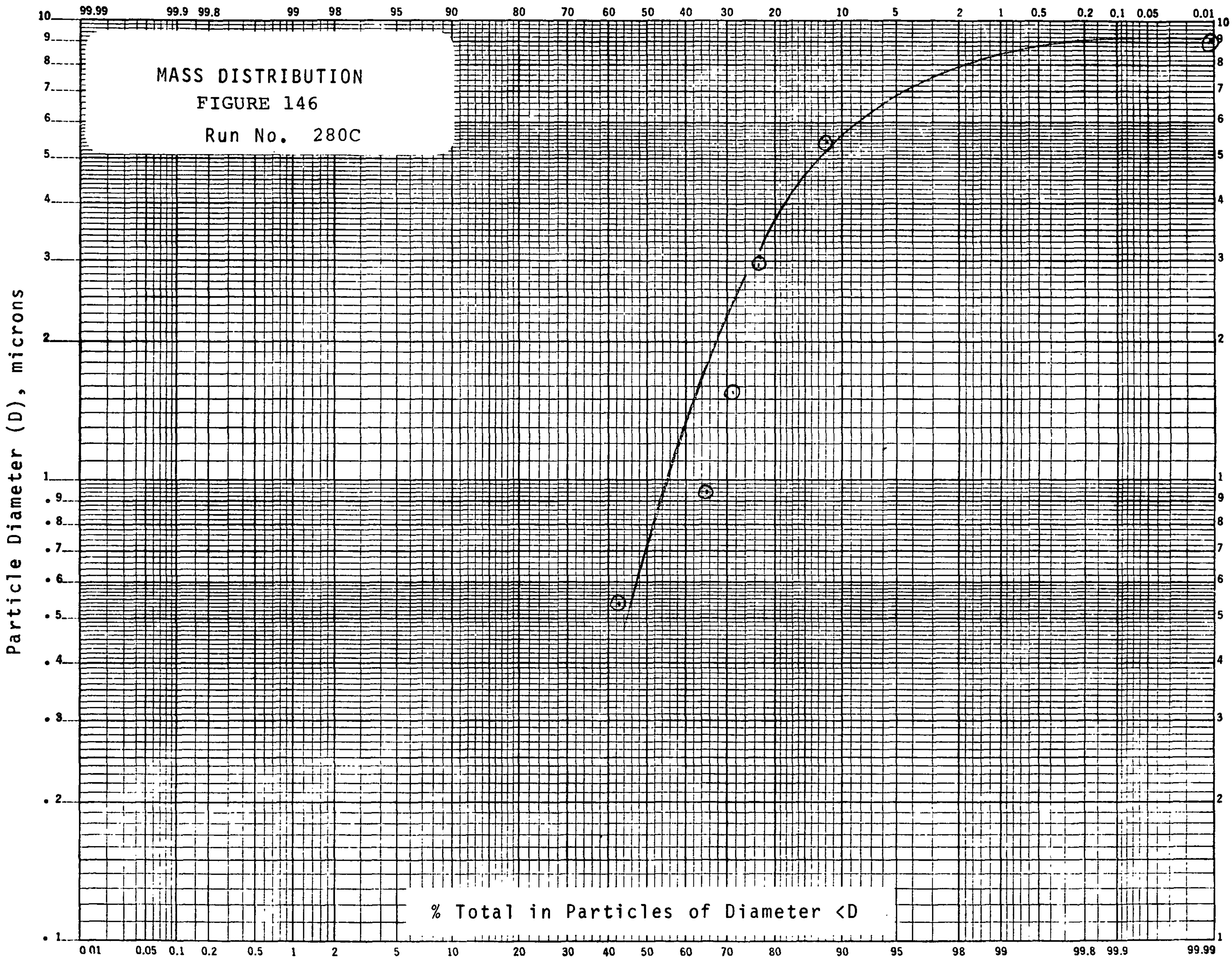
MASS DISTRIBUTION

FIGURE 145

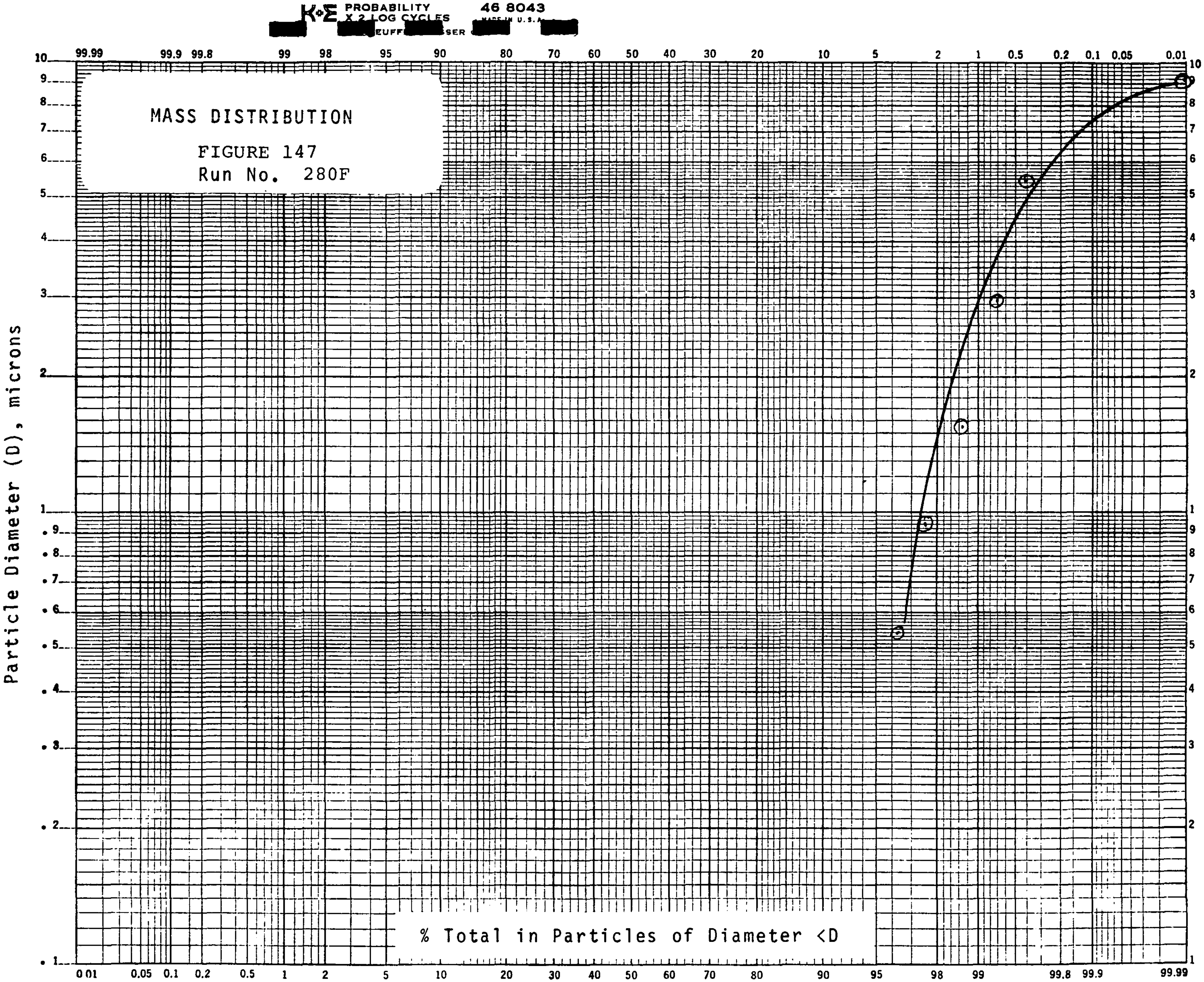
Run No. 268B



K&E PROBABILITY 46 8043
[redacted] X 2 LOG CYCLES [redacted] KEUFFEL & ESSER CO. [redacted]



MASS DISTRIBUTION
FIGURE 146
Run No. 280C



MASS DISTRIBUTION

FIGURE 147
Run No. 280F

CHASSIS DYNAMOMETER TEST

TABLE 31

CAR NUMBER: D-1585

VEHICLE TYPE: 1973 Chevrolet

FUEL: Baseline + Fuel Additive B

CONVERTER: Beaded

Vehicle Test No.	Car Miles	Test Miles	Test Mode	Grams per 1.61 km (1 mile): Andersen Sampler	Follow-up glass Filter	Andersen + Filter	Glass Filter 142 mm (Avg. of two)	Millipore 142 mm
275C	2,529.0	11.5	MFCCS	.1004	.0191	.1195	.0239	.0286
275D		120.0	60 MPH SS	.0054	.0373	.0428	.0669	.0580
275E		7.5	FCHS	--	--	--	.0244	.0439
275F		7.5	FCHS	--	--	--	.0219	.0439
296A	9,120	11.5	MFCCS	.0573	.0191	.0765	.0358	.0526
296B		7.5	FCHS	----	----	----	.0537	.0440
296C		7.5	FCHS	----	----	----	.0415	.0440
296D		120	60 MPH SS	.0065	.0714	.0779	.1004	.0935

TABLE 31 (Cont'd)

EXHAUST GAS ANALYSIS

Vehicle Test No.	% by Volume CO_2	O_2	N_2	Parts Per Million CO	C_6 H.C.	NO_2	NO	NO_x - N_x	
275C	9.55	7.15	82.4	>250	20.0		199	258	23 Min.
	9.30	7.50	82.3	>250	15.0		282	332	41 Min.
275D	11.20	4.9	83.05	16.9	2.0		665	805	Start
	11.35	4.85	82.95	14.5	1.0		516	626	Finish
275E	9.8	6.90	82.3	125.8	12.0		175	253	
275F	9.65	7.25	82.15	145.2	14.0		183	243	
	9.2	7.75	82.15	620	63		174	210	Part 1
296A	10.0	6.55	82.5	750	78		256	286	Part 2
296B	10.65	5.80	82.6	570	81		176	225	
296C	10.75	5.70	82.75	570	82		187	240	
296D	10.95	5.45	82.75	130.7	5		588	660	Start
	11.10	5.15	82.85	164.6	5		668	773	Finish

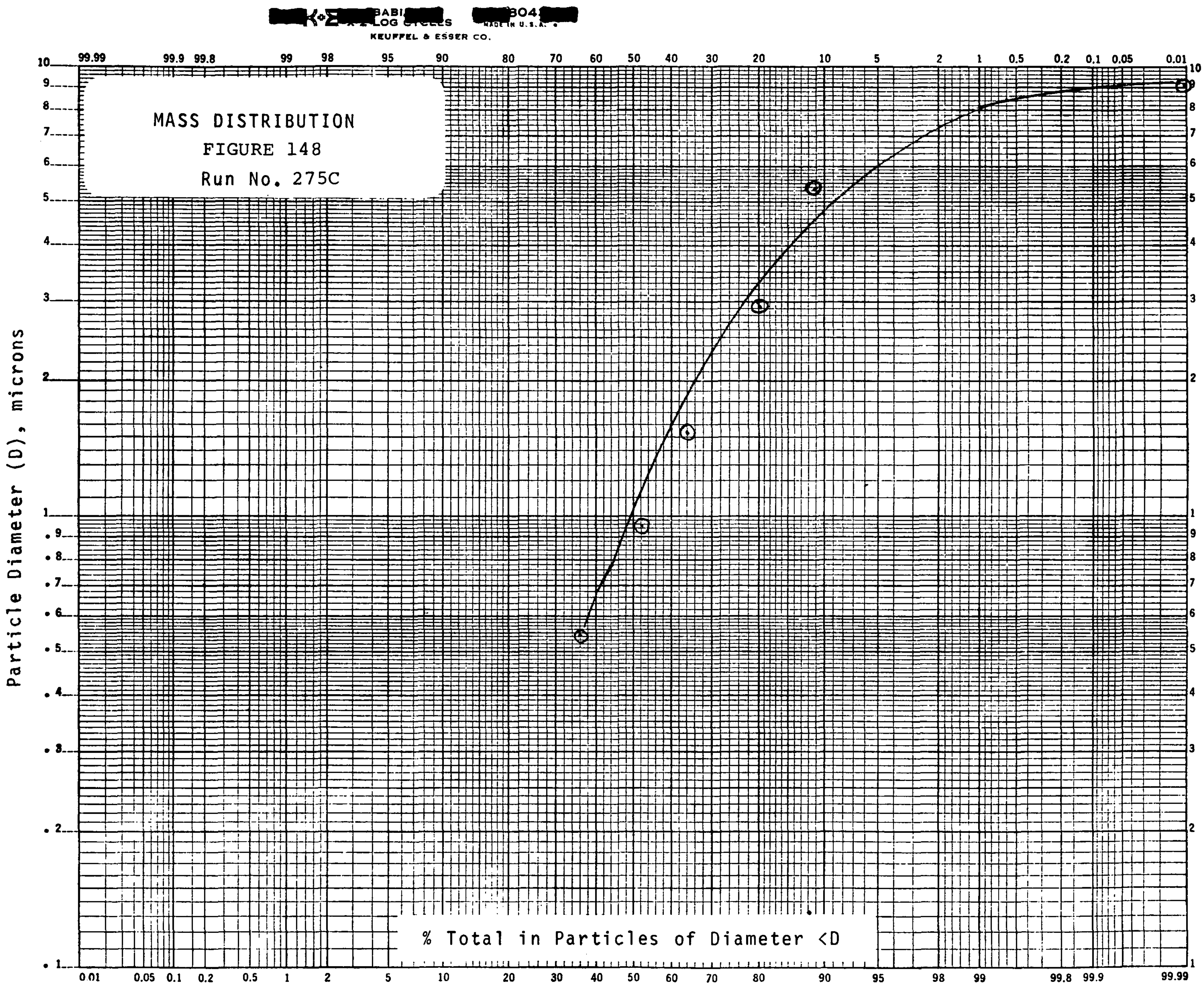
D1585 Copper Chev.

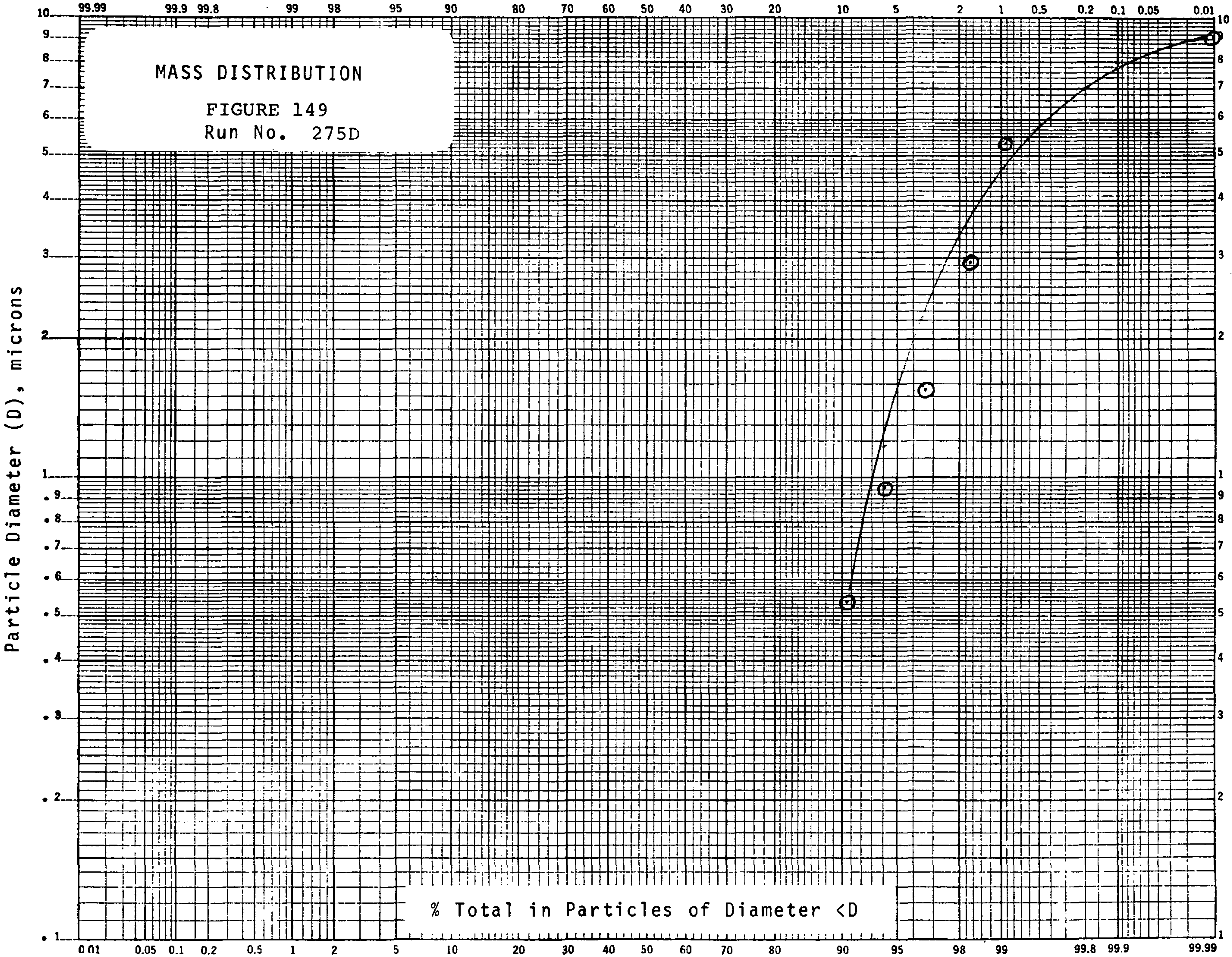
TABLE 31 (Cont'd)

ANALYSIS OF EXHAUST PARTICULATE

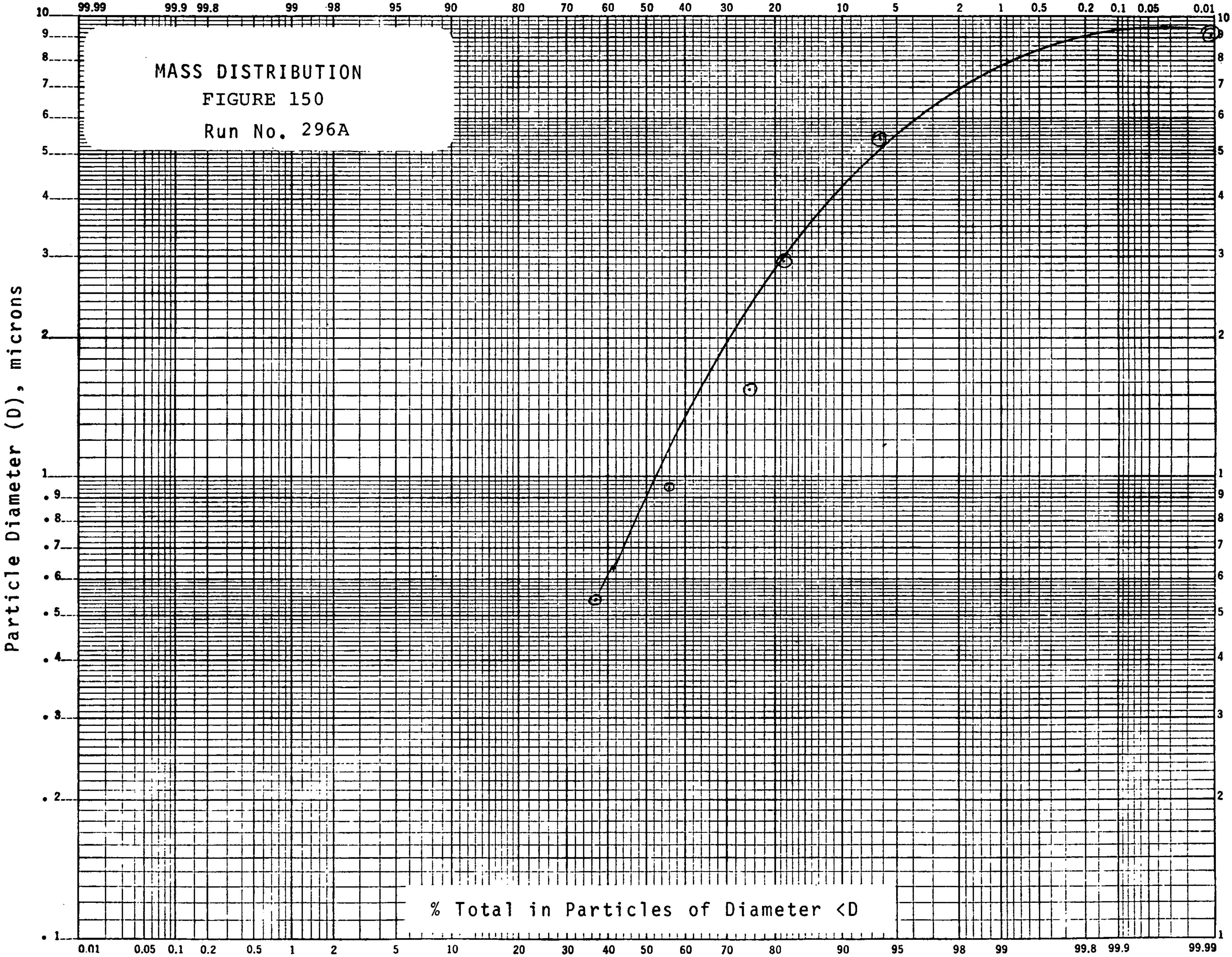
Trace Metals on Millipore Filter (%)

Vehicle Test No.	Fe	Ni	Cu	Al	Ca	Mg	Mn	Cr	Sn	Zn	Ti	Pb	$\%SO_4$	Glass Fiber Filters %C	%H	%N	PPM BAP
275 C	Not Analyzed																
275 D	.07	<.05	.04	<.05	.2	.09	<.03	<.05	<.05	<.15	<.05	<.15		1.78	3.79	5.12	60
275 E	.9	<.05	.6	.3	8.7	1.6	<.03	.2	<.05	.5	.06	<.15		6.60	3.20	0.0	480
275 F																	
296A	0.6	.06	.34	.17	3.8	1.2	2.8	.13	<.01	.2	.02	.4		12.8	0.60	0.0	<10
296C	1.0	<.01	.53	.29	8.6	1.5	4.0	.21	<.01	.4	.0	.7		41.9	>10.0	12.4	<70
296D	0.2	<.01	.01	.01	.02	.03	.08	<.01	<.01	<.03	<.01	.08		0.275	0.035	2.65	< 2

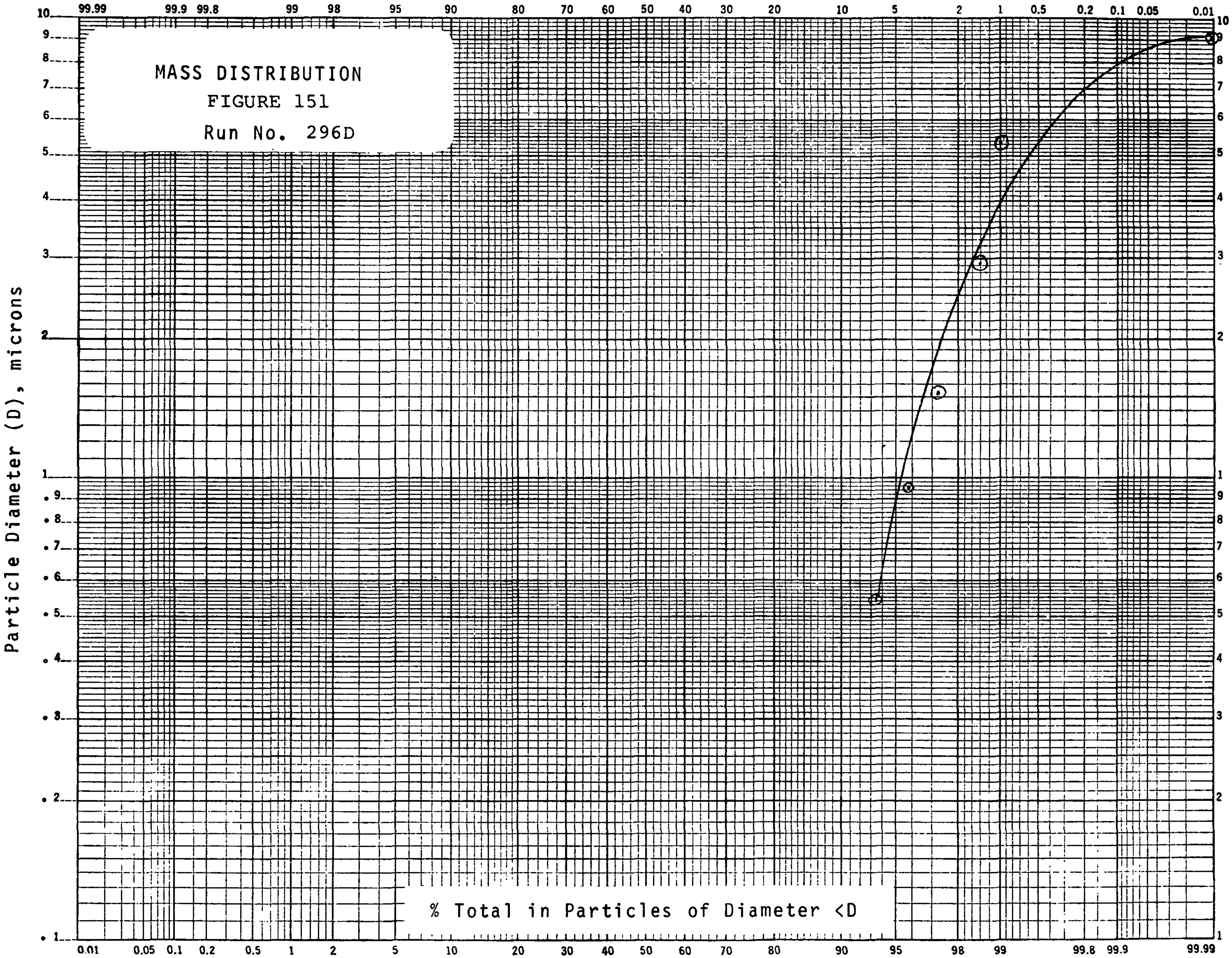

[redacted] LOG CYCLES [redacted] MADE IN U.S.A.
KEUFFEL & ESSER CO.
MASS DISTRIBUTION
FIGURE 148
Run No. 275C
Particle Diameter (D), microns
% Total in Particles of Diameter <D


MASS DISTRIBUTION
FIGURE 149
Run No. 275D
Particle Diameter (D), microns
% Total in Particles of Diameter <D

[redacted] K+E [redacted] X 2 LOG CYCLES [redacted] MADE IN U.S.A. KEUFFEL & ESSER CO.



[redacted] K·E [redacted] ABIL [redacted] [redacted] 043 [redacted]
X 2 LOG CYCLES
MADE IN U.S.A.
KEUFFEL & ESSER CO.



MASS DISTRIBUTION

FIGURE 151

Run No. 296D

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