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Measurement of Vehicle Contamination by Exhaust Gases

Transportation Systems Center

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MEASUREMENT OF VEHICLE CONTAMINATION BY EXHAUST GASES

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FINAL REPORT

Prepared for
DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
WASHINGTON, D. C. 20590

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ERRATA

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16. Abstract

An investigation of the concentration of carbon monoxide (CO) within the passenger compartment of motor vehicles has been made. A sample handling system has been developed to measure the concentrations of CO at as many as six locations inside and outside of a motor vehicle. To use this system effectively, a test procedure was developed with sixteen possible configurations of window, vent, and trunk lid openings. The sample system and test procedures were used on six different vehicles which represented several aerodynamic shapes and utilized different design features and auxiliary equipment. Data obtained in situations of low traffic density are presented.

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INTRODUCTION

The major objective of this program was to determine the level of CO in passenger compartments of motor vehicles. This report deals with work providing assistance in the proposed setting of new car compliance standards for self-contamination of passenger compartments by CO. Thus this work deals with one facet of the problem with others being contamination due to exhaust gases from other vehicles and exhaust system leaks.

There are at present no regulations in this country on the Federal level pertinent to limiting or eliminating completely the amount of CO entering the passenger compartments of motor vehicles. The Society of Automotive Engineers (SAE) has published a Recommended Practice entitled "Carbon Monoxide Concentration Test Procedure-SAE J989"[1]* which outlines a sequence of tests, with vehicle both stationary and moving, for measuring CO contamination of the vehicle. The complete text of this report appears in Appendix A. All U.S. manufacturers presently use SAE J989, or a modification of it, voluntarily to test all models before design release.

The Swedish government has developed regulations relating to self-contamination. One aspect of their testing procedure, not included in J989, is a test sequence performed with the trunk lid open 12 inches to simulate oversized cargo being carried in the trunk.

The need for the study of passenger compartment contamination by CO is demonstrated by the well established fact that hemoglobin (Hb) in the red blood cells of humans and animals has an especially high affinity for CO. This affinity is 200 to 240 times that of Hb for O_2. Twenty percent O_2 in air will fully saturate Hb while only one percent CO by volume in air will fully saturate Hb within minutes.[2]

The procedures that were developed during this program to make the required measurements are contained in this report. Included in these procedures are certain appropriate features of both J989 and the Swedish test procedures. The data and results of a testing program for six different vehicles are also presented.

*Numbers refer to references at the end of this report.

TEST VEHICLES

The vehicles used for measurement purposes were obtained from both government sources (GSA) and commercial leasing companies. They represented some of the various shapes and sizes of vehicles currently in wide use in this country. Since they were to represent vehicles in new car condition, the exhaust systems were checked for leaks and/or broken parts. If any such defects were found, they were corrected before measurements were made. Checks included broken tail-light covers and other exterior defects which could provide possible access for exhaust gases.

The six test vehicles, in order of test were (1) a 1968 Chevelle four door sedan, (2) a 1971 Plymouth station wagon, (3) a 1971 Ford Pinto two door sedan, (4) a 1970 Ford Econoline P.C. Van, (5) a 1969 Mercury station wagon, and (6) a 1969 Volkswagen "Beetle" two door sedan. In addition ot these six vehicles, an enclosed van trailer was towed by the fifth car for some of its tests and a roof rack with covered box was carried by the sixth car. Both these tests were made to determine the effect, if any, of the change of air flow on exhaust contamination. (See Appendix B for a more detailed description of each vehicle.)

TEST DESCRIPTION

INTRODUCTION

Each vehicle was individually instrumented in such a way that the ambient CO level outside the vehicle could be sampled simultaneously with the CO levels at various points inside the passenger compartment (and trunk, if applicable). The instrumentation consisting of a CO analyzer, sample-handling system, and electric power sources is described in greater detail in Appendix C.

The testing program was divided into three basic areas: (1) tests while driving at 30 and 60 mph with different configurations of passenger compartment openings, (2) tests at idle with all passenger compartment openings closed, and (3) road and dynamometer tests to determine exhaust CO concentrations at typical road loads and speeds.

EXHAUST EVALUATION

Prior to the road and dynamometer tests, the vehicles were equipped with a tachometer and intake manifold vacuum gauge. Engine speed and vacuum were recorded at 30, 40, 50, and 60 mph while traveling on a relatively flat highway. The data thus obtained were used in subsequent chassis dynamometer tests of each vehicle to simulate road loads as closely as feasible. CO concentrations in the exhaust at each simulated road condition, and at idle, were measured.

VEHICLE-IN-MOTION-TESTS

These tests were performed on relatively level portions of public highways under wind conditions of less than 10 mph. The passenger compartment configurations used for these tests are described in Table 1. These configurations represent worst-case conditions of potential hazard. In addition, certain configurations considered commonly in use by many drivers were investigated. It must be noted that the applicability of any of these 16 different configurations depended on the specific vehicle and its design.

After choosing an applicable test configuration, the vehicle was driven at either 30 or 60 mph to collect samples. Immediately upon attaining the appropriate test speed, the air samples were collected for a period of about two minutes. These were then analyzed while stationary, before taking the next set of samples.

Table 1
Passenger Compartment Self-Contamination Test Configurations

Configuration No.	Non-Exh.-Side Front Window Vent	Non-Exh.-Side Front Window	Exh.-Side Rear Window	Center Rear or Tailgate Window	Rear door, Trunk Lid, or Tailgate	Fresh Air Inlet	Heater & Defroster	Expected Hazard Potential (1=Worst)
1	C	C	C	C	C	C	C	2
2	O/2	C	C	C	C	C	C	2
3	O/2	C	O/2	C	C	C	C	2
4	C	O/2	C	C	C	C	C	2
5	C	O/2	O/2	C	C	C	C	2
6	O/2	C	C	O/2	C	C	C	1
7	O/2	C	C	O/2	C	O	C	2
8	O/2	C	C	O/F	C	C	C	1
9	O/2	C	C	C	O/F	C	C	1
10	C	C	C	O/2	C	O	C	4*
11	C	C	O/2	C	C	O	C	3
12	C	O/2	C	C	C	O	C	4**
13	All windows open full			C	C	C	C	3
14	All windows open full			O/F	C	C	C	2-3
15	C	C	C	C	C	C	O	2
16	O/2	C	C	C	C	C	O	1

C = Closed or off.

O/X = Open X in.

O/F = Open fully, windows, or tailgate; open 12 inches trunk lid; open 1 in., rear door.

O = inlet open full; On full, heater & defroster

* (Typ. winter station wagon driving)
** (Typ. winter sedan driving)

TESTS AT IDLE

The self-contamination tests at idle were performed with all passenger compartment openings closed. The vehicle was tested inside a large open building where open air conditions could be simulated without the effects of climatic variables. The ambient CO level in the building was measured and compared with the concentration measured in the front seat of the vehicle. One such test was made every five minutes for up to ninety minutes, until CO concentrations stopped increasing. Detailed discussions of the test procedures and test route are in Appendices D and E respectively.

RESULTS AND DISCUSSION

INTRODUCTION

In general, t e measurements made revealed low concentrations of CO within the passenger compartment of all the vehicles tested. This was true whether the tests were made while moving or at idle. Indeed, most of the samples collected for all six cars exhibited concentrations under 10 ppm.

TWO MINUTE DRIVING TEST

Figure 1 shows the distribution by frequency of occurrence versus ppm of all two-minute test readings below 35 ppm for all the vehicles tested (there being only five measurements above 35 ppm inside any car during the two-minute driving tests). The figure represents data from 665 samples. About 63 percent of the readings were under 5 ppm and 90 percent under 10 ppm.

CONCENTRATIONS AT IDLE

Figure 2 is a combined plot of the CO concentration versus time histories at idle for all six test vehicles. These plots define an envelope with a lower boundary at 3 ppm and an upper boundary at 20 ppm. It can be noted that in most cases the level of contamination did not stabilize until between 30 and 45 minutes of operation.

1971 PINTO

The one exception to the otherwise consistently low readings was the 1971 Ford Pinto when driven with the trunk lid open. Under this condition, readings in excess of 100 ppm were at times recorded. This vehicle, under open trunk conditions, accounted for the only two measurements over 60 ppm obtained while collecting the two minute samples. Due to these higher than usual readings, a special test was performed with this car.

A long term driving test (90 minutes) was made with the trunk open 12 inches and continuous monitoring of the CO concentration inside the passenger compartment at the top center of the rear seat back rest. A sample of the data collected is included in Figure 3. The route included connecting sections of routes 93, 128 and 3. In addition, a fourth portion of the route included travel in residential

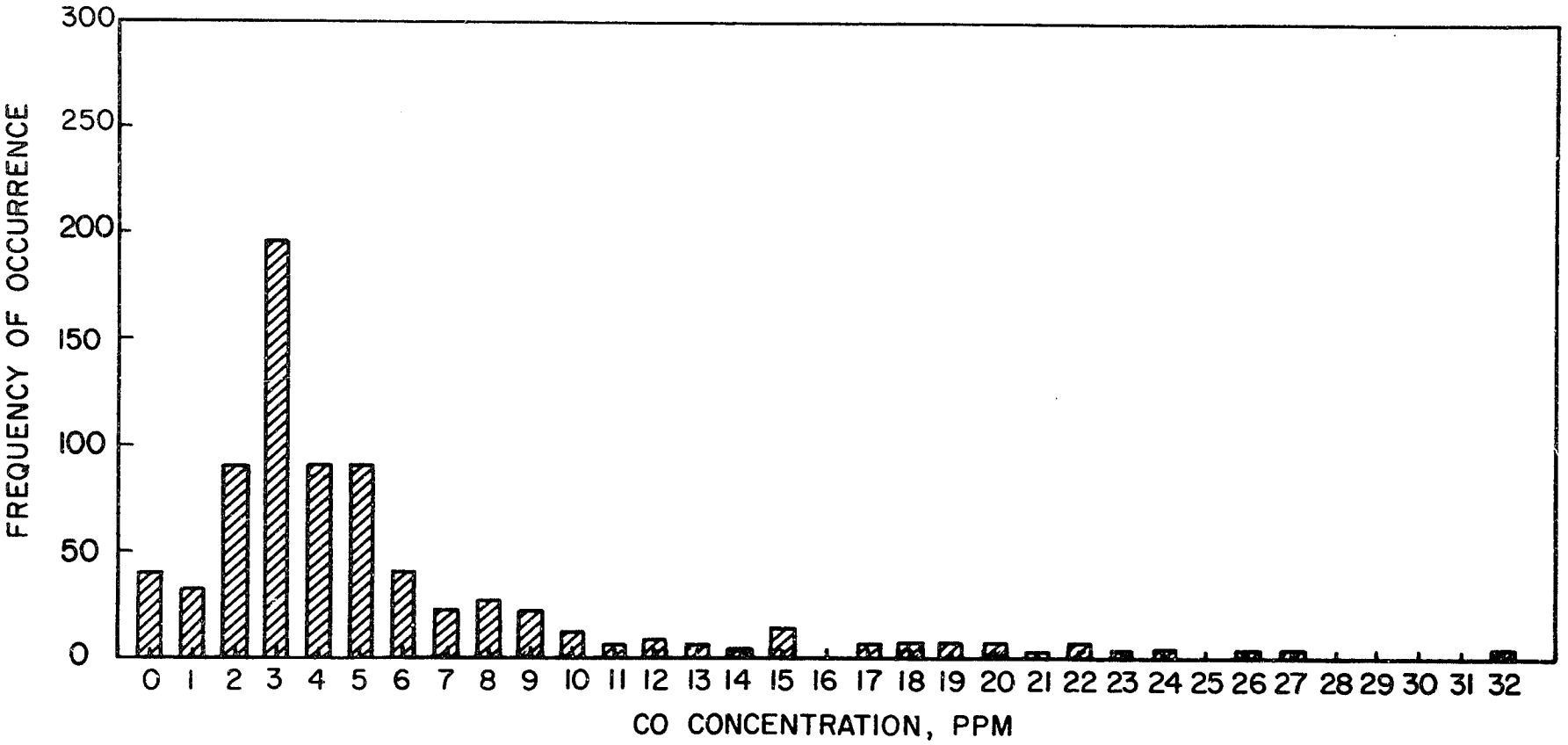

Figure 1. Composite Distribution of Readings Less Than 35 ppm Inside of All Six Test Vehicles.

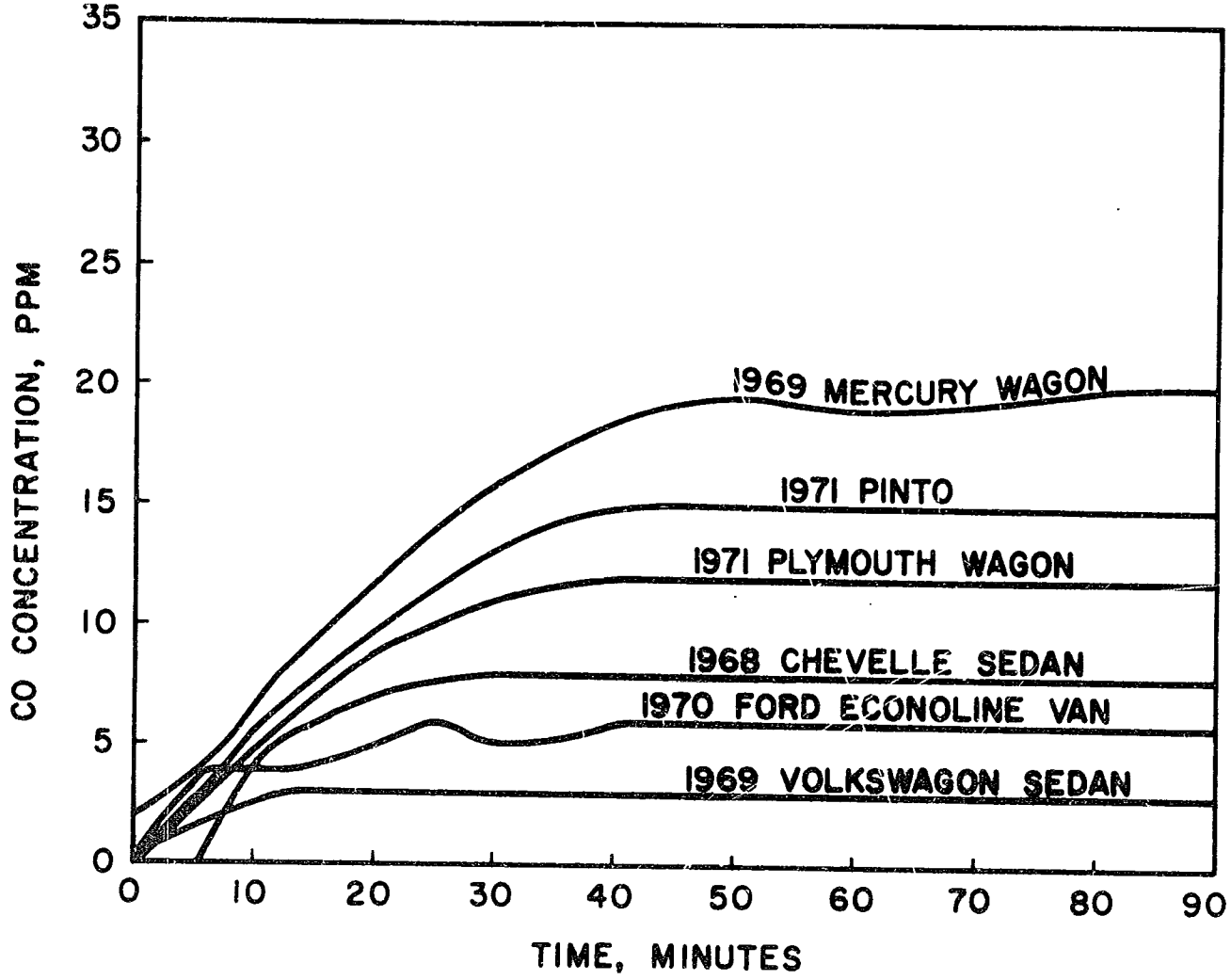

Figure 2. Composite Graph of All Idle Tests.

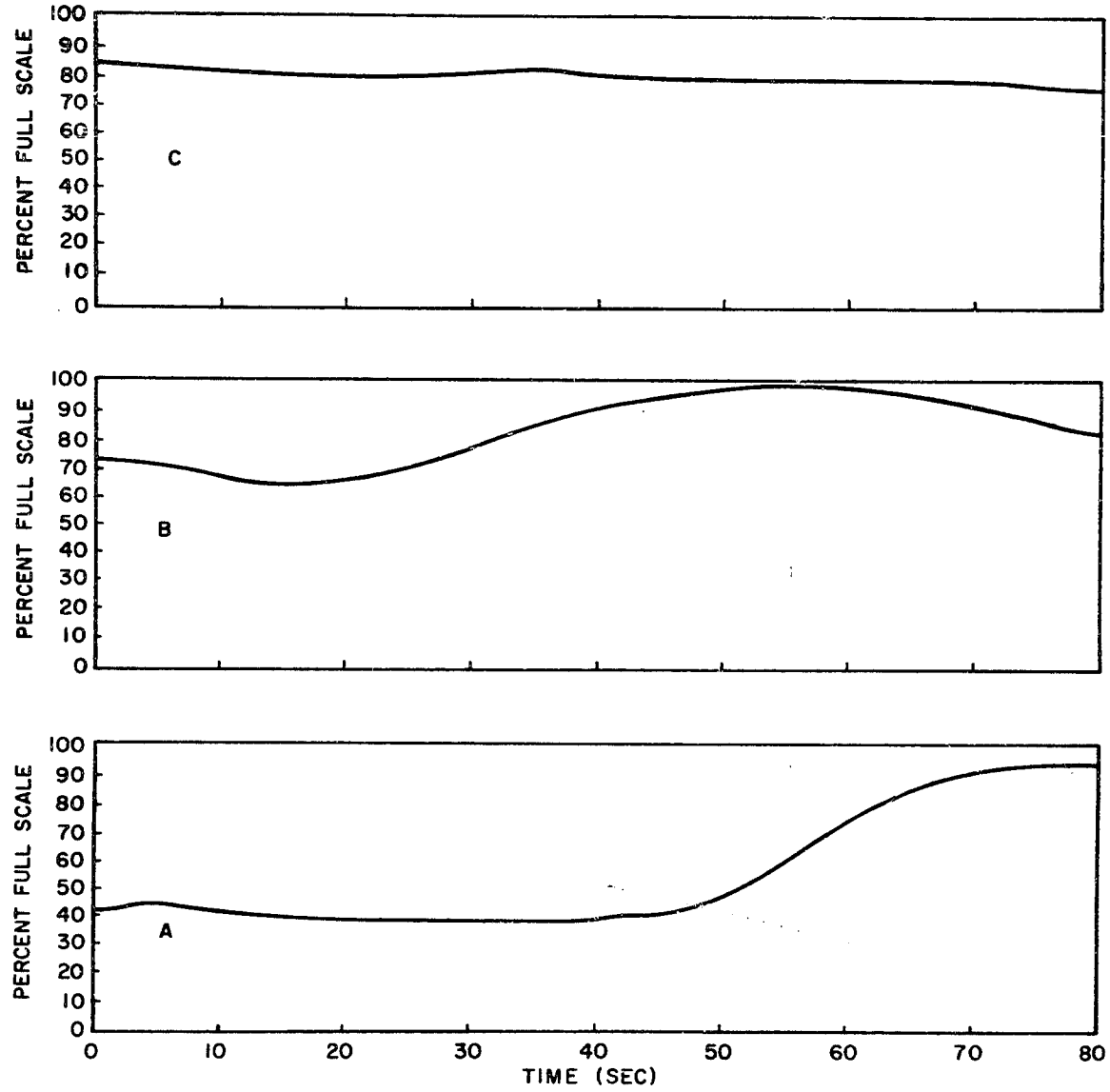

Figure 3. Extended Driving Tests for 1971 Pinto with Trunk Open. A is route 128; B is route 3; C is the residential route.

sections of Medford and Somerville, Massachusetts. Travel was at 60 mph on route 93, 40 mph on 128, 60 mph on route 3, and 25 mph in the residential area. It is interesting to note that the rising and falling of the curves in Figure 3 corresponded approximately to the changes in road grade. Increased CO concentrations were encountered on ascending a hill and decreased concentrations on descending. Before the car was checked for proper tuning, the average CO concentration for this entire test was about 57 ppm. This test was repeated after tuning the Pinto to manufacturer's specifications and an average of 55 ppm was encountered. For all the data and graphs of each individual vehicle, see Appendix F.

HIGHLIGHTS OF STUDY

A few general observations can be made concerning the levels of CO within the passenger compartment. For all the vehicles tested, under most conditions, the CO concentration was quite low. The only vehicle to yield high concentrations was the Pinto and even this vehicle had only 10 percent of its readings above 30 ppm for the two minute driving tests.

Driving the Mercury station wagon with a trailer in tow did not significantly affect the passenger compartment CO levels. The Volkswagen exhibited almost identically low readings both with and without the roof load which greatly changed the airflow and wind resistance characteristics of the vehicle. Finally, the air deflectors incorporated on the two station wagons tested proved to reduce somewhat the already generally low levels of CO contamination of the vehicles.

Although the six vehicles tested did not constitute an exhaustive study, they did represent a wide range of sizes and shapes. The results thus indicate a trend of low CO concentrations within the passenger compartment under new vehicle conditions. However, the discovery of high self-contamination in the Pinto with the trunk open, while other cars tested similarly did not show the same effect, suggests that the SAE procedure, J989, be modified to include an open trunk test.

APPENDIX A

CARBON MONOXIDE CONCENTRATION TEST PROCEDURE-SAE J989

Report of Automotive Emissions and Air Pollution Committee
approved January 1968

SAE Recommended Practice

1. Scope-The purpose of this SAE Recommended Practice is to provide a uniform standard method of testing to determine the carbon monoxide concentration in the passenger compartment of vehicles to assure that the body design and tailpipe outlet location are not causing undesirable levels of CO under normal vehicle usage. The tests are conducted at idling speed, at 25 mph, and at 70-20 mph deceleration in an outdoor area where there is a minimum amount of environmental CO. This test procedure is to be used to determine self-contamination by CO only (except as noted in the first sentence of paragraph 4.4) and is not applicable to measurement of ambient CO in traffic.

2. Equipment[1]

2.1 Mines Safety Appliance Carbon Monoxide Tester (Part 47133) with indicating tube (Part 47134) or Bacharach Monoxor Carbon Monoxide Indicator (Model 19-5008) with indicating tube (Part 19-5010).

2.2 Extension hose 1/4 in. maximum inside diameter, 48 in. maximum length.

3. Preparation

3.1 Check exhaust system for leaks.

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[1] The CO levels obtained using this procedure are not to be considered exact measurements since they differ from test to test due to variables such as wind speed, wind direction, air flow over the vehicle, and instrument error of up to 20% of the indicated CO. However, the readings do indicate if a vehicle problem exists due to the general level of CO, and the instrumentation outlined in this section is considered adequate for this purpose.

If more accuracy is desired in reading the CO level, a nondispersive infrared analyzer may be used to take direct measurements at the intervals recommended in the procedure, or to take continuous readings when used in conjunction with a recorder. The instrument should be protected from road shock and voltage variation during the test to prevent erroneous readings.

3.2 Check and set idle speed and mixture to manufacturer's specifications.

3.3 Water to heater core may be bypassed for comfort of tester, if desired.

3.4 Check and record wind velocity

3.4.1 Idle and traffic tests are not to be conducted when the wind velocity is greater than 8 mph unless vehicle is protected from the direct wind.

3.4.2 Road test is not to be conducted when the wind velocity is greater than 12 mph.

3.4.3 Test is not to be conducted when precipitation is occurring.

3.5 Warm up the vehicle by driving or idling for 15 minutes, immediately preceding test, to assure that the choke is "off."

4. Test Method

4.1 Sampling

4.1.1 In sedans take an air sample at head level at the center, rear of the front seat back.

4.1.2 In station wagons take an air sample at head level at the center, rear of the second seat back.

4.1.3 The idle readings may be taken with the observer on the outside of the vehicle, taking the sample through an extension hose having the interior end suspended at the recommended sample location.

4.1.4 The samples are to be taken at the start of the test and at 15 minute intervals until the CO concentration has reached a level exceeding 0.01% (100 ppm) or until 60 minutes have elapsed. If the CO concentration is near the 0.01% level and has not stabilized during the 60 minutes, take two more readings at 15 minute intervals. The idle, traffic, and 25 mph portions of the test may be suspended after 30 minutes if the CO concentration is 0.001% (10 ppm) or less.

NOTE: The 0.01% level of CO is indicated to protect the test personnel and is not to be used as a standard of acceptance.

4.1.5 At the completion of each test, open vehicle doors and/or windows to purge the vehicle of residual CO.

4.1.6 No tobacco smoking is permitted during the test due to the effect on the CO readings.

4.2 Information To Be Recorded-A sample data form is shown in Figure 1. The following data should be recorded for each vehicle tested:

4.2.1 Make of vehicle.
4.2.2 Model (model year, series, body style, etc.)
4.2.3 Odometer
4.2.4 Engine carburetor and emission control system description.
4.2.5 Location of tailpipe(s), outlet(s).
4.2.6 Wind velocity (average and maximum).
4.2.7 Instrumentation description.
4.2.8 Per cent CO concentration in the vehicle at the various time intervals during the test and sample volume (cc) for readings.

4.3 Idle Test

4.3.1 Park with the rear of the vehicle facing into the wind. Close all windows, outside air vents, and ventilation exhaust vents (if controllable). Position heater and blower control in "off" position and allow engine to run at the manufacturer's recommended idle speed with transmission in neutral. Measure and record the amount of CO as indicated in paragraph 4.1.

4.3.2 Park vehicle with rear of the vehicle facing into the wind. Close all windows, outside air vents, fully open outside air inlet to heater, open front door vent windows approximately 30 deg or fully open ventilation exhaust vents (if so equipped), and operate heater blower at highest speed. Allow engine to run at manufacturer's recommended idle speed with transmission in neutral. Measure and record the amount of CO as indicated in paragraph 4.1.

4.3.3 Park the vehicle with the rear facing into the wind. On vehicles with backlights which can be opened or ventilation exhaust vents, fully open the backlight or rear ventilation exhaust vent, open front door vent windows approximately 30 deg (lower both front door glasses 1 1/2 in. if doors are not equipped with vent windows), close all other windows and outside air vents and position heater control and blower switch in the "off" position. Allow the engine to run at manufacturer's recommended idle speed with transmission in neutral. Measure and record the amount of CO as indicated in

SAE CARBON MONOXIDE CONCENTRATION TEST

VEHICLE DATA

MAKE _____ MODEL YEAR _____

MODEL SERIES _____ BODY STYLE _____

VEHICLE NO. _____ ODOMETER _____

ENGINE _____ CARBURETOR _____

EXHAUST EMISSION SYSTEM _____

TAILPIPE OUTLET LOCATION(S) _____

_____

TEST DATA

WIND VELOCITY - AVG. _____ MPH MAX _____ MPH

INSTRUMENTATION _____

ELAPSED TIME MINUTES	IDLE TEST (PARA. 4.3)						TRAFFIC TEST (PARA.4.4)		25 MPH TEST (PARA. 4.5)	
	(a) CLOSED CAR		(b) HEATER ON		(c) BACKLIGHT OPEN					
	% CO	VOL CC	% CO	VOL CC	% CC	VOL CC	% CO	VOL CC	% CO	VOL CC
0 (AMBIENT)										
15										
30										
45										
60										
75										
90										

DECELERATION (PARA.4.6)		
RUN NO.	70-20 MPH	
	% CO	VOL. CC.
0 (AMBIENT)		
1		
2		
3		
4		
5		

LOCATION _____

DRIVER _____

OBSERVER _____

DATE _____

Figure 1. Sample Data Form

paragraph 4.1.

4.4 Traffic Simulation-The purpose of this step is to determine if the outside air inlet to the heater is located so as to pick up an excessive amount of CO from the exhaust of a leading vehicle. Park test car 2 ft behind and downwind from the rear of another vehicle of similar type. Close all windows, outside air vents, and ventilation exhaust vents (if controllable). Fully open outside air inlet to heater and operate heater blower at highest speed. Run engines of both vehicles at manufacturer's recommended idle speed with transmission in neutral. Measure and record the amount of CO as indicated in paragraph 4.1.

4.5 25 mph Test-Open front door vent windows approximately 30 deg (lower both front door glasses 1 1/2 in. if vehicle is not equipped with vent windows), fully open backlight or rear ventilator (if so equipped), close all other windows and outside air vents, position heater control and blower switch in "off" position, operate vehicle at 25 mph on a closed circuit (avoid heavy traffic). Measure and record the amount of CO as indicated in paragraph 4.1.

4.6 Deceleration Test-Open front door vent windows approximately 30 deg (lower both front door glasses 1 1/2 in. if vehicle is not equipped with vent windows), fully open backlight or rear ventilator (if so equipped), close all other windows and outside air vents, position heater control and blower switch in "off" position. Take an initial CO reading. Accelerate to 70 mph and decelerate with closed throttle to 20 mph in gear with a following wind. Repeat this step for a total of five decelerations, alternating between a following wind and a headwind. Measure and record the amount of CO on each deceleration. Start the sampling at 65 mph and use the sample method indicated in paragraph 4.1 excluding step 4.1.4. Take and record a one stroke sample on each deceleration when using the MSA Tester for a total cumulative volume of 250 cc (50 cc stroke). When using the Bacharach Tester, take a one stroke sample on each of the last three decelerations for a total cumulative volume of 48 cc (16 cc stroke).

APPENDIX B

VEHICLE DESCRIPTIONS

General

From the information gathered in the tests described in the section Exhaust Evaluation, the CO emission characteristics of each vehicle were known. These will be given with each description below. It should also be noted that the dwell, timing, and idle rpm's of all cars were checked against factory specifications and corrected when needed. Only the Pinto showed any significant variance with those specifications.

Vehicle One

A 1968 Chevelle four door sedan, Government license No. G1140229, with a 230 cubic inch, six-cylinder engine and automatic transmission was the first test vehicle. The exhaust tailpipe was located 8 inches behind the left rear tire, parallel to the ground and pointing outwards from the body at a 90 degree angle. The average CO concentration in the exhaust was found to be 1.8 percent over the range of speeds from idle to 60 mph. Figure B-1 gives the variation of CO and engine speed with intake manifold vacuum.

Vehicle Two

This vehicle was a 1971 Plymouth station wagon, Massachusetts license No. 349-44F, with a 360 cubic inch, eight cylinder engine and automatic transmission. The exhaust tailpipe was located at the right rear corner beneath the bumper, making a 45 degree angle both with the axis of the car and with the ground. It was equipped with an air deflector located horizontally along the top rear over the tailgate window. The average CO concentration in the exhaust was found to be 1.8 percent over the range of speeds from idle to 60 mph. Figure B-2 shows the variation of CO and engine speed with intake manifold vacuum.

Vehicle Three

This vehicle was a 1971 Ford Pinto two door sedan, Massachusetts license No. 751-60K, with a 2,000 cubic centimeter (122 cubic inch) four cylinder engine and automatic transmission. The exhaust tailpipe was located 12 inches to the right of center of the rear bumper, parallel to the axis of the car and about 10 inches above and parallel to the ground. The average CO concentration in the exhaust was found to be 1.35 percent initially over the range of speeds from 30 to 60 mph prior to being tuned to factory specifications. After being tuned, the average CO concentration was found to be 1.3 percent, which

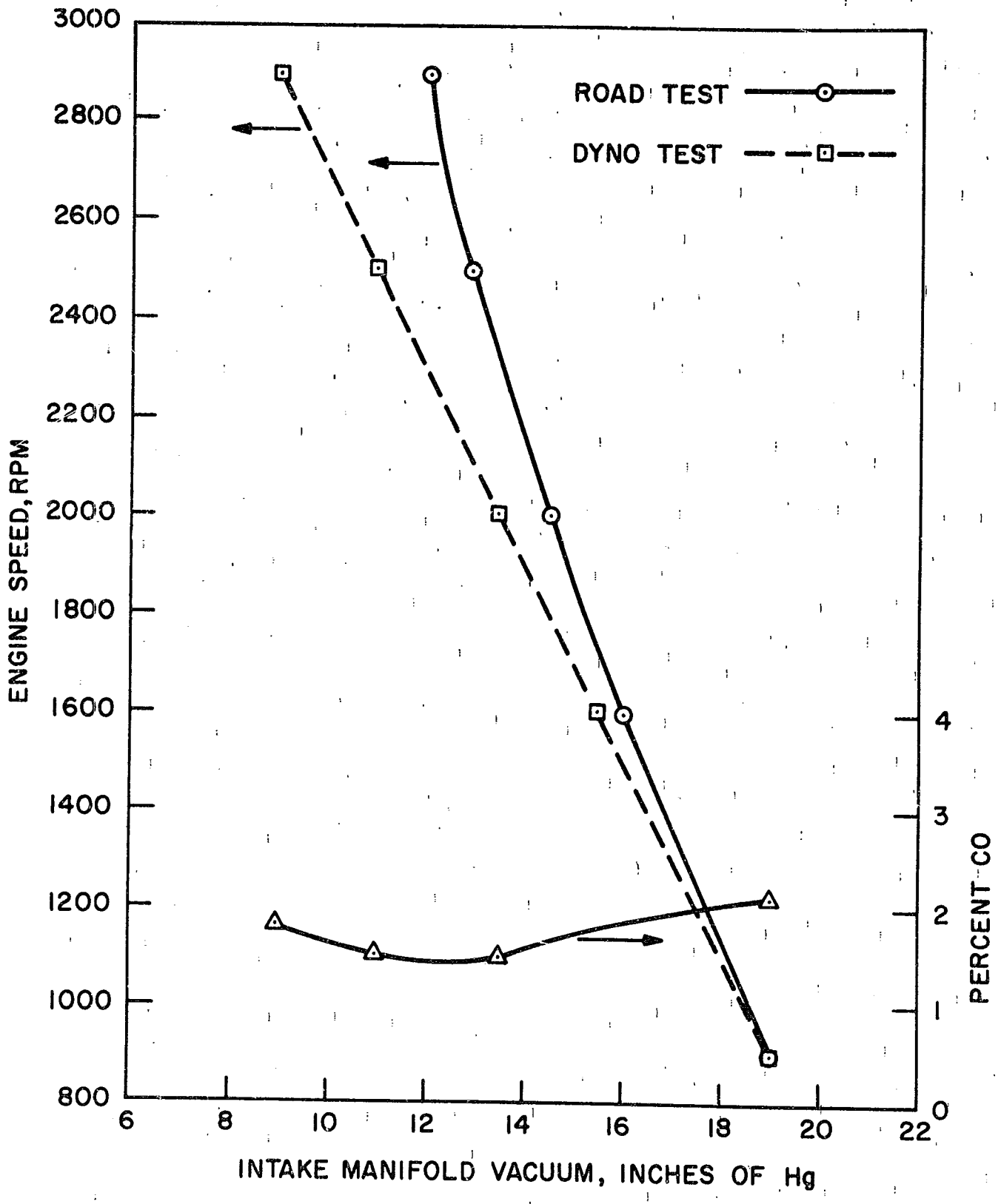

Figure B-1. Engine Speed and Percent Carbon Monoxide Versus Intake Manifold Pressure for 1968 Chevelle

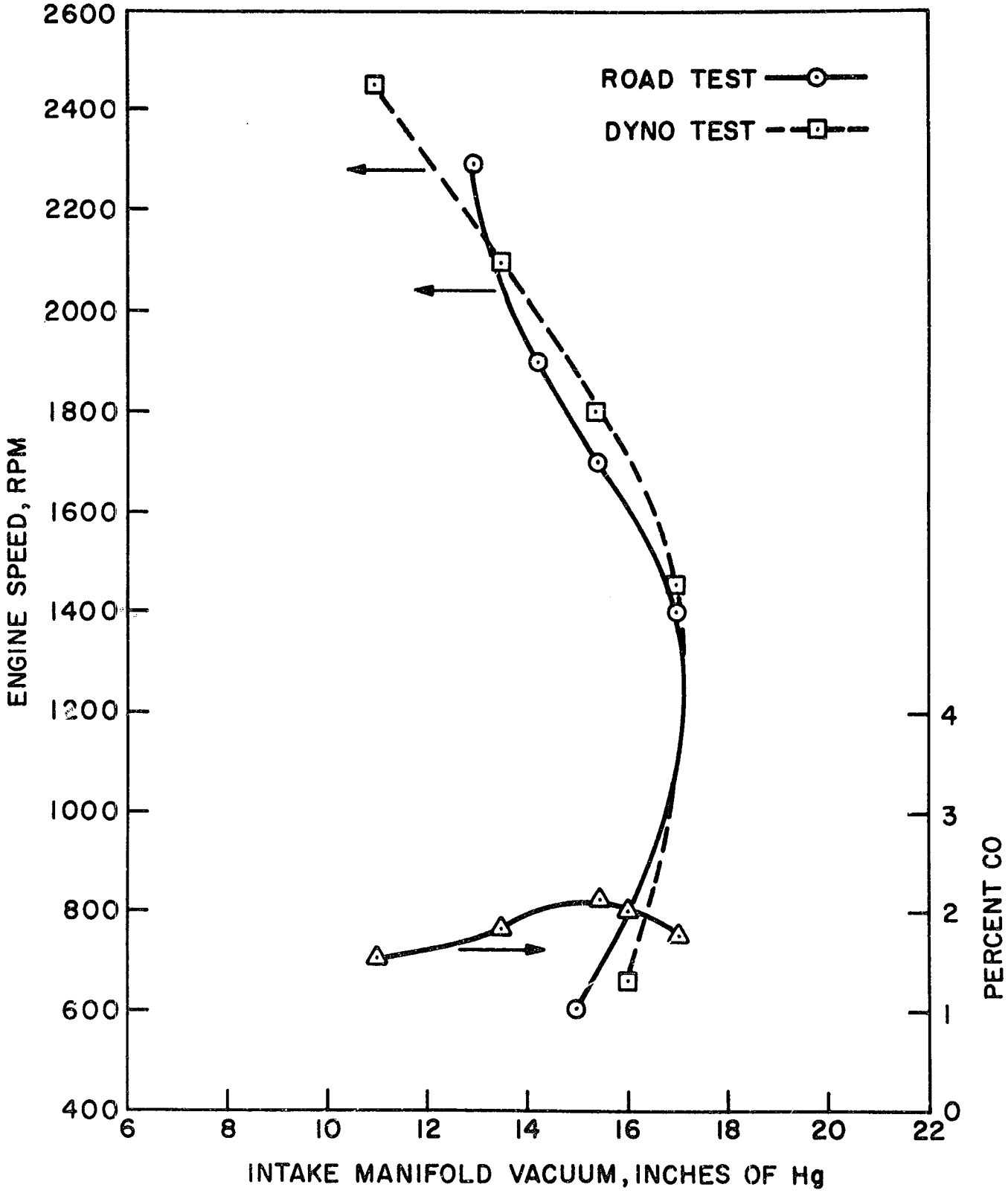

Figure B-2. Engine Speed and Percent Carbon Monoxide Versus Intake Manifold Pressure for 1971 Plymouth Wagon.

is not a significant change and is well within the experimental error of the measurement being made. Figure B-3 presents both the pre- and post-tune-up plots of CO concentration and engine speed versus intake manifold vacuum. The factory specifications and corrections made during tune-up are given in Table B-1.

Vehicle Four

A 1970 Ford Econoline Van, Massachusetts license No. C97-737, with a 240 cubic inch, six-cylinder engine and automatic transmission, served as the fourth test vehicle. The exhaust tailpipe was located 12 inches behind the right rear tire, parallel to the ground and making a 90 degree angle with the axis of the Van. The average CO concentration in the exhaust was found to be 1.7 percent over the range of speeds from idle to 60 mph. Figure B-4 gives the variation of CO and engine speed with intake manifold pressure.

Vehicle Five

This vehicle was a 1969 Mercury Marquis station wagon, Government license No. DOT-80010, with a 390 cubic inch, eight-cylinder engine and automatic transmission. The exhaust tailpipe was located 2.5 feet behind the right rear tire, parallel to the ground and making a 90 degree angle with the axis of the car. This vehicle was equipped with an air deflector located horizontally along the top rear above the tailgate window. The average CO concentration in the exhaust was found to be 2.0 percent over the range of speeds from idle to 60 mph. Figure B-5 shows the variations of CO concentration and engine speed with intake manifold vacuum.

Along with the normal operation of this car, some tests were made while towing a rented enclosed van trailer four feet wide, six feet long, and five feet high. These tests were aimed at determining the change, if any, in passenger compartment contamination resulting from aerodynamic disturbances caused by the presence of the trailer.

Vehicle Six

This vehicle was a 1969 Volkswagen "Beetle" two door sedan, Massachusetts license No. 842-72R, with a 1,500 cubic centimeter (91.5 cubic inch) four cylinder engine and four speed manual shift transmission. The two exhaust tailpipes were located 6 inches below and 8 inches either side of center of the rear bumper, and projected 4 inches beyond the rear bumper, parallel

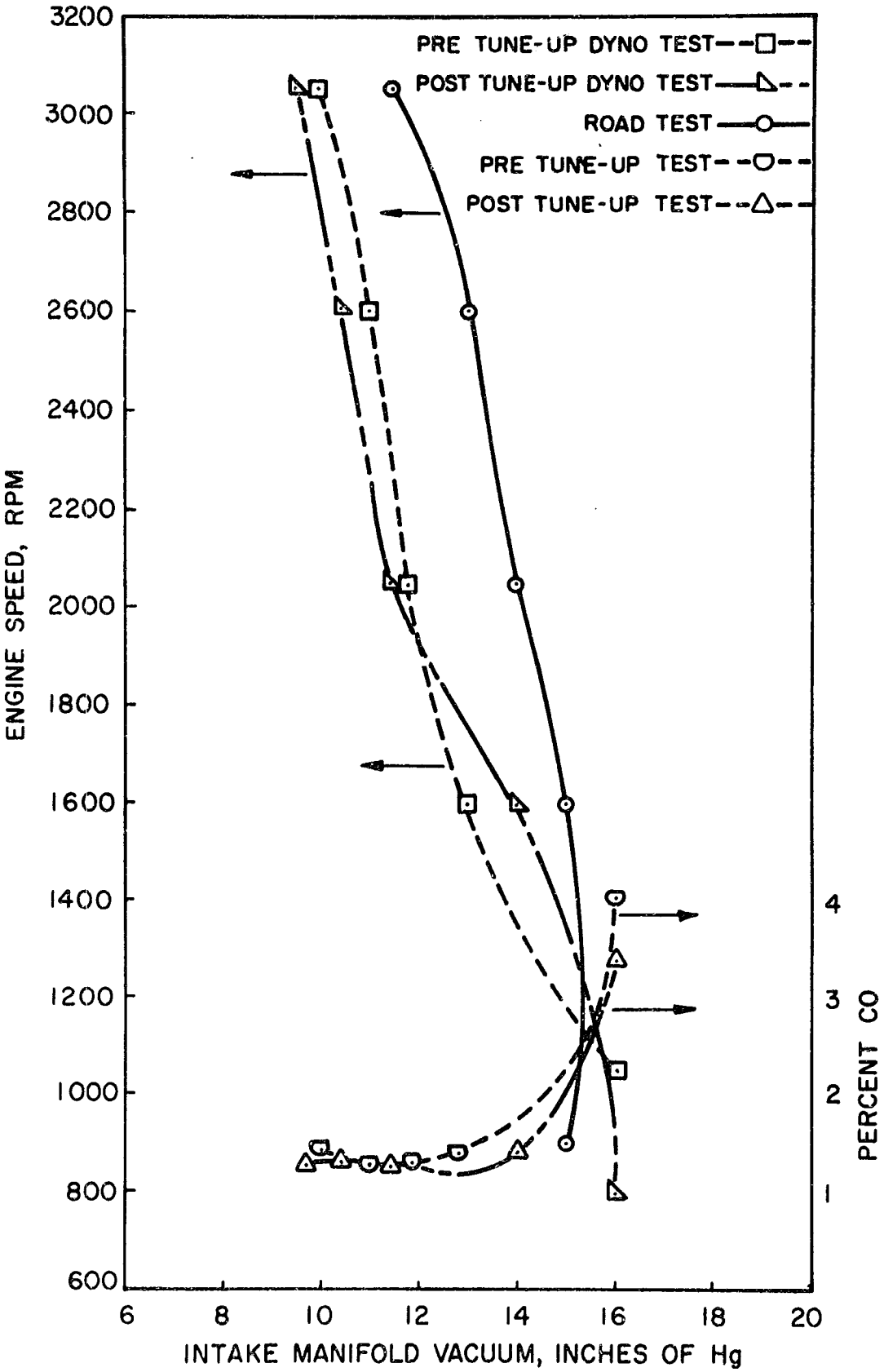

Figure B-3. Engine Speed and Percent Carbon Monoxide Versus Intake Manifold Pressure for 1971 Pinto

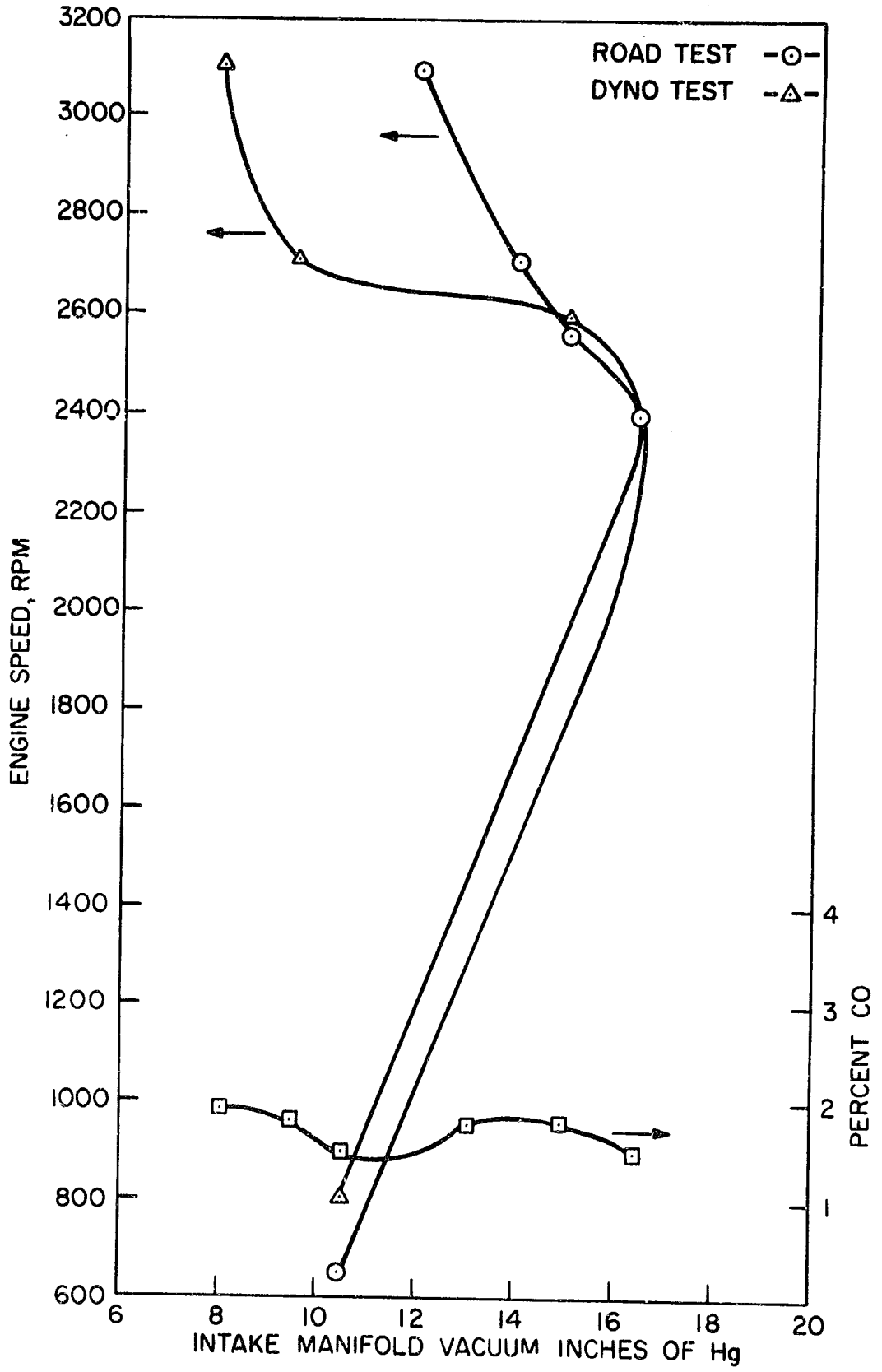

Figure B-4. Engine Speed and Percent Carbon Monoxide Versus Intake Manifold Pressure for 1970 Ford Econoline Van.

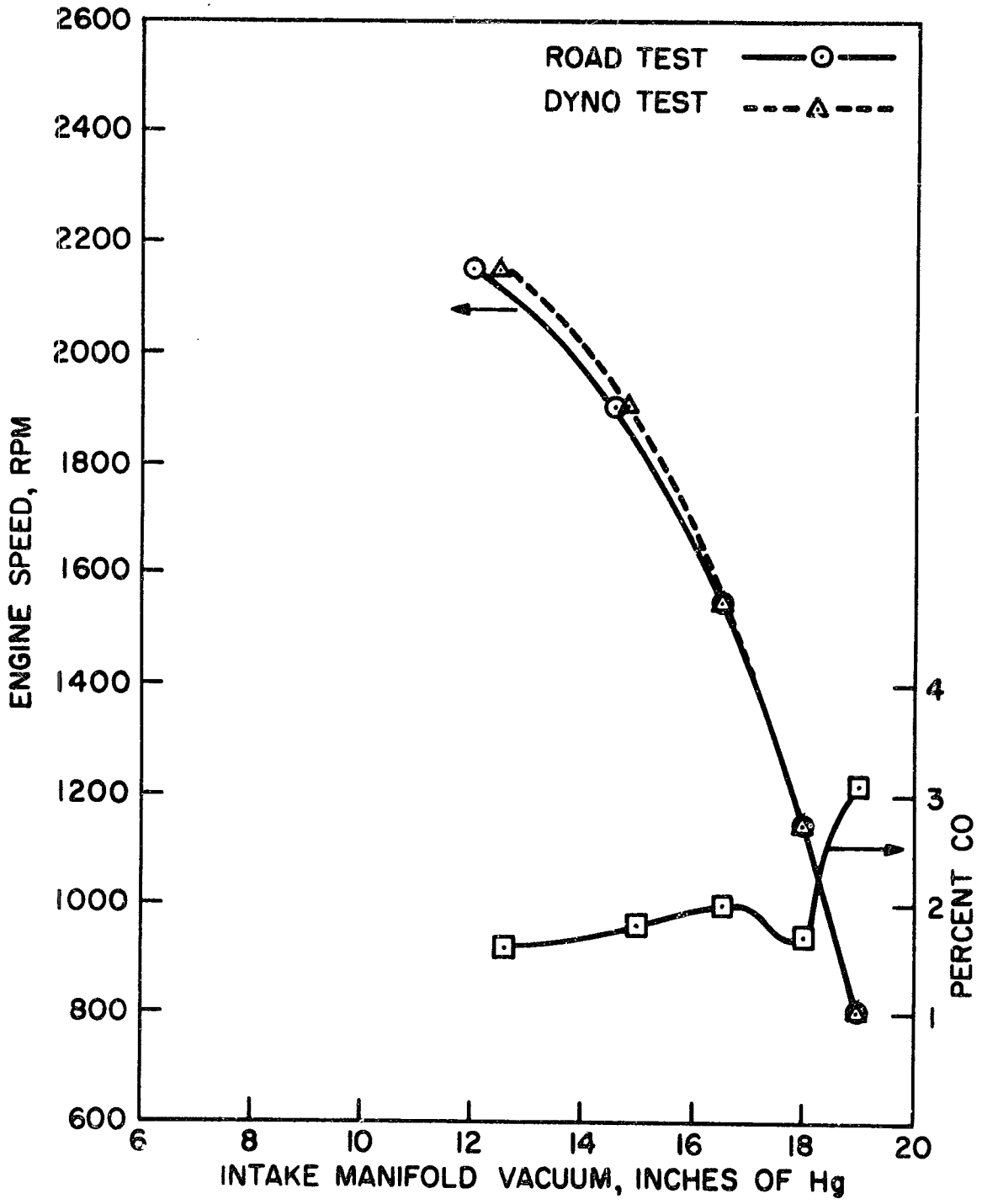

Figure B-5. Engine Speed and Percent Carbon Monoxide Versus Intake Manifold Pressure for 1969 Mercury Wagon

Table B-1
Tune-Up Data For The 1971 Pinto

PARAMETER	SPECIFIED SETTING	ACTUAL SETTING	CORRECTED SETTING
DWELL (degrees)	38--42	55.5--56	37
RPM	650	780	650
TIMING (deg.)	6 advance	1 retarded	6 advance
PLUG GAP (inches)	.032--.036	.026, .027 .026, .028	.034

Tune-up is performed with headlights on and transmission in drive.

to the ground and vehicle axis. Half of the tests with this car were made while carrying a roof rack with a box 20 inches high, 37 inches wide, and 29 inches front to back. This was done to determine the effect, if any, of the increased loading due to increased wind resistance and of the change in air flow over the body on the amount of CO inducted into the car. Due to these differences, the average CO concentration in the exhaust was found to be 1.5 percent without the roof rack and 1.6 percent with the roof rack over the range of speeds from 30 to 60 mph. Figures B-6 and B-7 show the variations of CO concentration and engine speed with intake manifold vacuum for these two cases. Note that the difference of 0.1 percent is well within the limits of experimental error.

This car was of special interest because its heating system differed fundamentally from those of the first five cars tested. The Volkswagen inducted its heating air from the rear of the car where it could be contaminated by exhaust entrained in the turbulent wake of the car. This is unlike the majority of cars which draw heater air from the supposedly clean air in front of the vehicle.

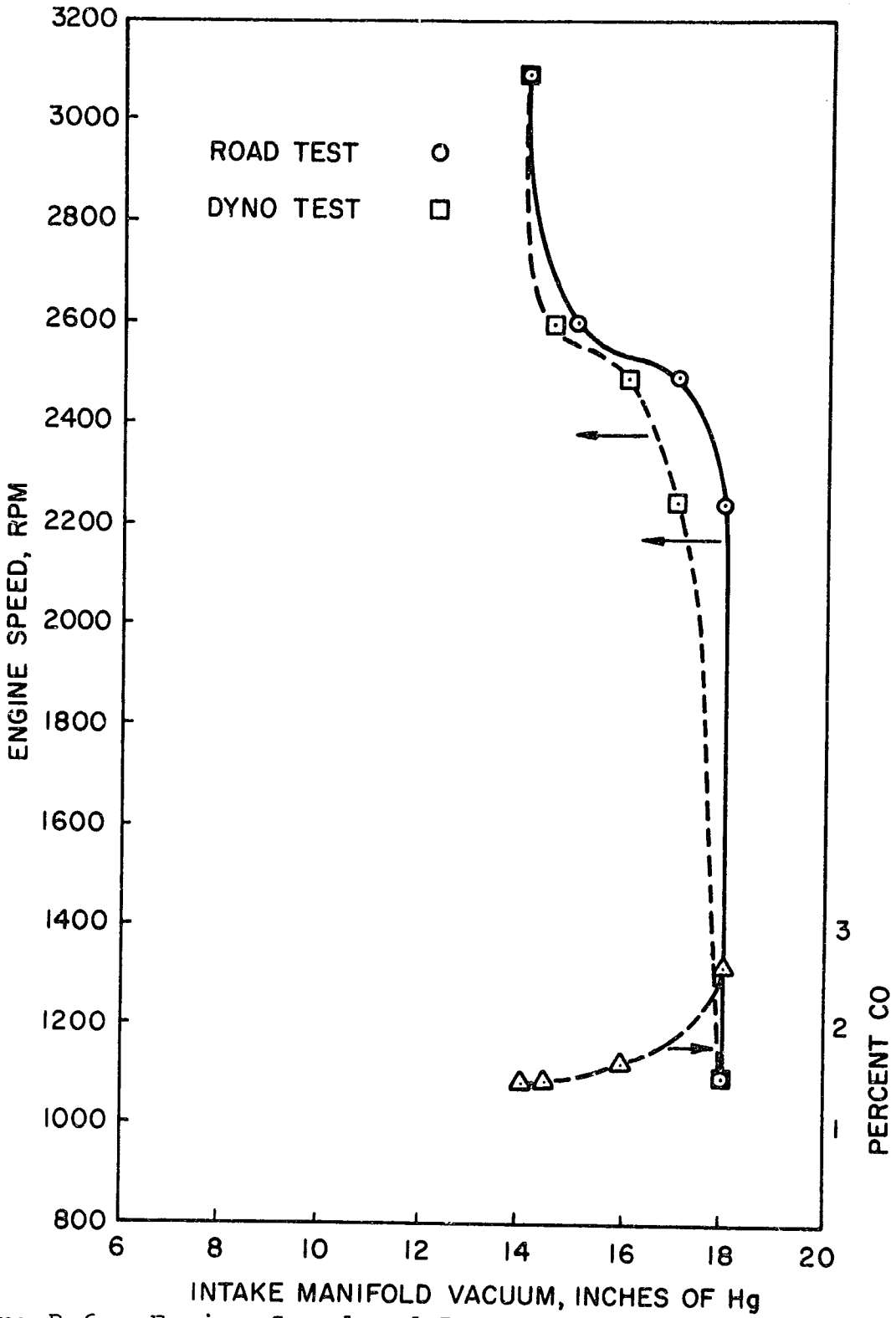

Figure B-6. Engine Speed and Percent Carbon Monoxide Versus Intake Manifold Pressure for 1969 Volkswagon.*

*Tests made without roof rack and box.

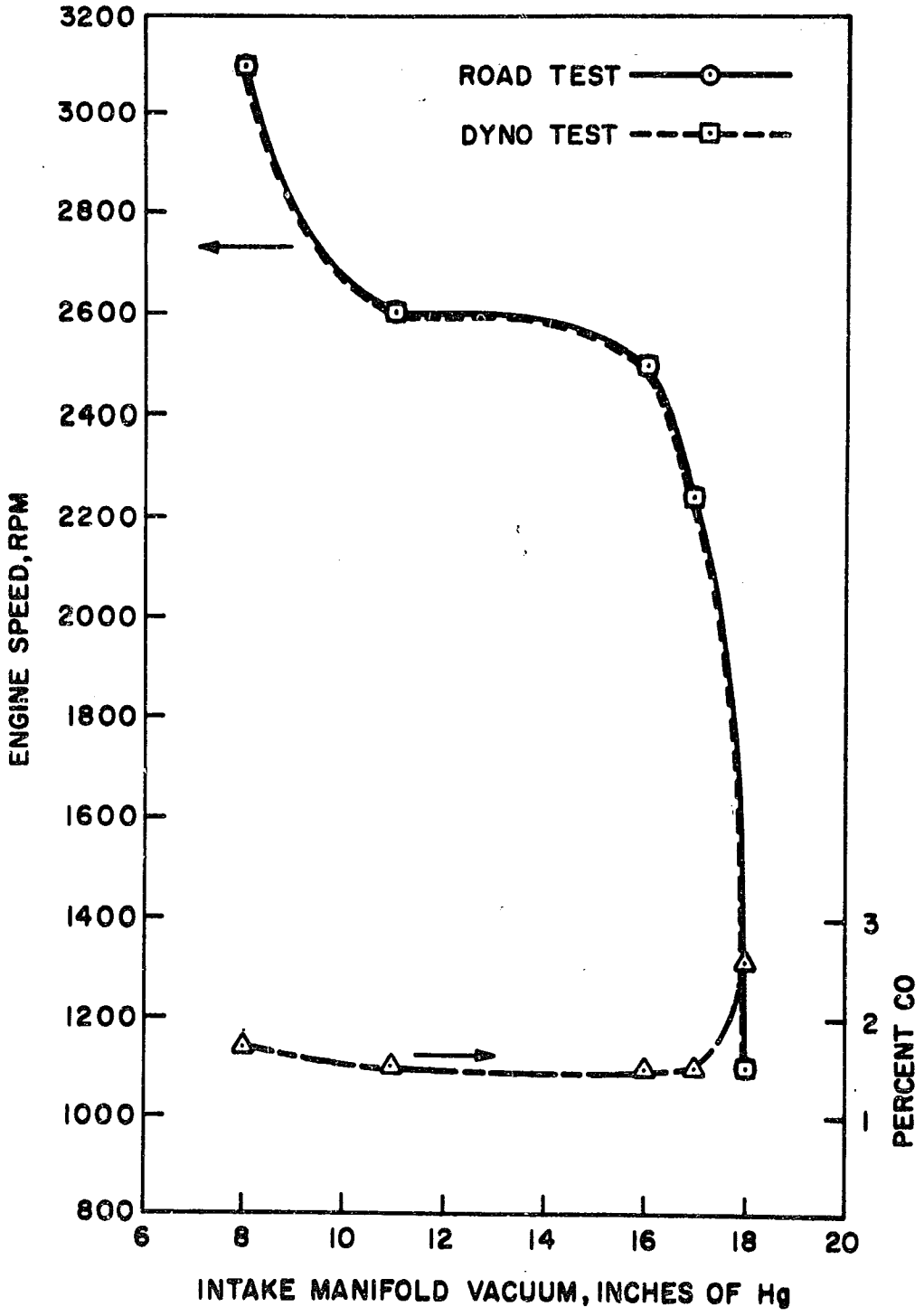

Figure B-7. Engine Speed and Percent Carbon Monoxide Versus Intake Manifold Pressure for the 1969 Volkswagon*

*Tests made with roof rack and box.

APPENDIX C

INSTRUMENTATION

CO Analyzer

The basic instrument around which the sample handling system was designed was the Bacharach Model U.S. 400L CO analyzer. The CO analysis performed by the instrument is based on the following chemical reaction:

$$CO + HgO(vapor) \xrightarrow{400°F} CO_2 + Hg(vapor)$$

The mercury vapor is measured by ultraviolet absorption. The instrument was calibrated and checked daily with standard calibration gases for a range of 0-100ppm CO. The calibration curve appears in Figure C-1 and is for dry gases at a flow rate of 300cc/min. The zero point is obtained with a flow of pure Nitrogen (N_2). The sample gas passes through a drying tube which is filled with a phosphorus pentoxide compound to remove the water vapor. The sample then passes through a second tube containing 8-14 mesh activated charcoal to remove hydrocarbons. Both tubes must be changed daily. The CO content of any given sample can be read off directly or can be recorded. A Rustrak Model 288 DC recorder with a 0-3 volt range and chart speed of 6 inches per minute was used to record readings for long term tests. A buffer amplifier was used to prevent the recorder from loading the CO analyzer output.

Sample Handling System

A sample handling system was designed to meet several requirements. The system had to be capable of collecting either one sample continuously and monitoring it from any point inside or outside the car or up to six different samples simultaneously followed by sequential analysis of each such sample. Thus the system had the flexibility to perform long term driving test monitoring, to measure amounts of CO in traffic situations, or to determine how much of the CO in the passenger compartment was due only to the particular vehicle involved. This last objective, which was the main emphasis of this work, was achieved by making measurements of the ambient air and the air within the car simultaneously. The major components of this system are shown in Figure C-2. Air from up to six locations was drawn continuously through the 3/4 inch tygon tubing, labeled A, B, C, D, E, and F in Figure C-2, by the 12VDC-150CFM blower and vented outside the car. A control panel with appropriate valving connected these flow lines with six acrylic bottles containing 3 liter plastic bags around which the pressure could be varied from a few psi above to

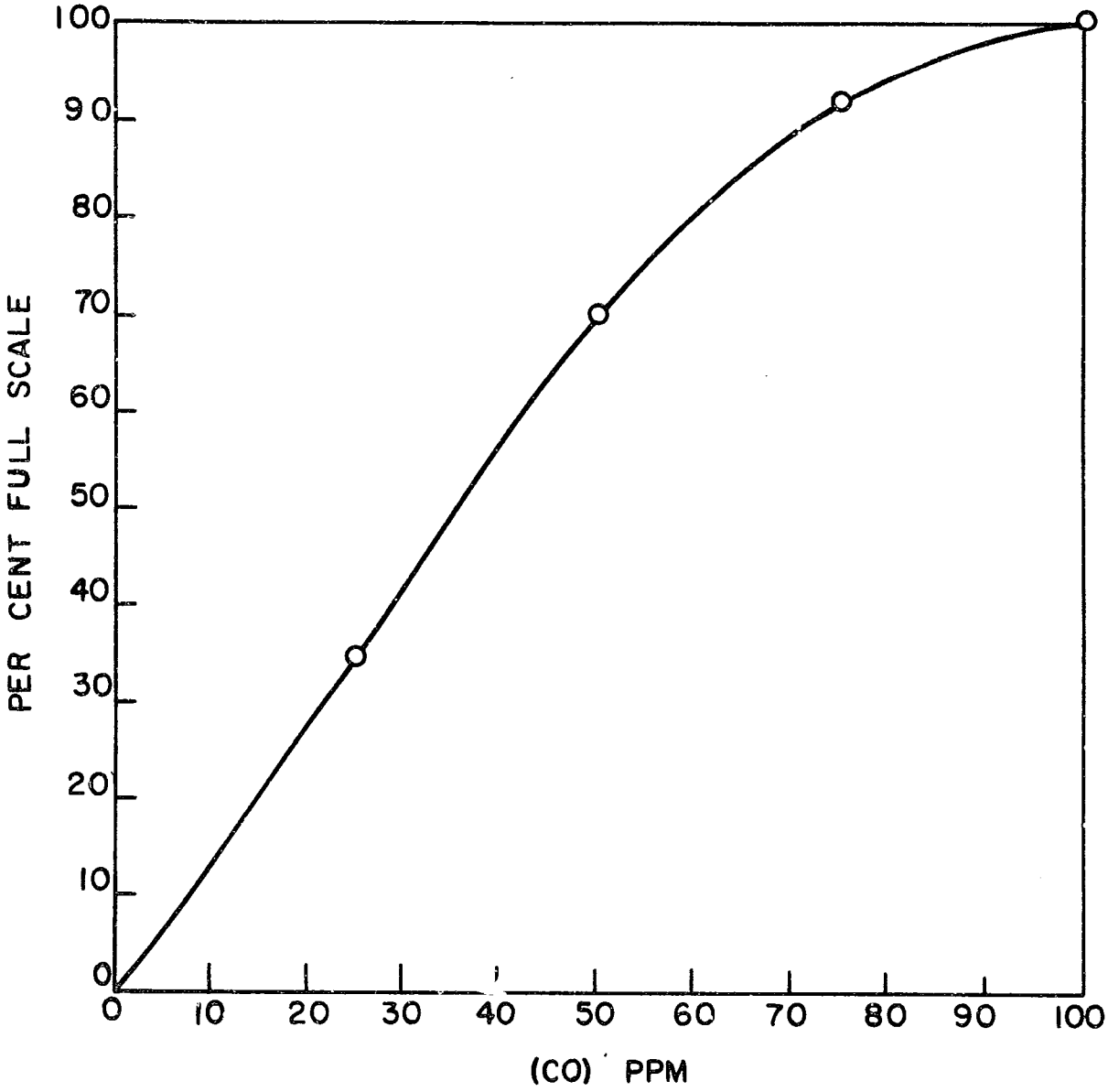

Figure C-1. Carbon Monoxide Analyzer Calibration Curve

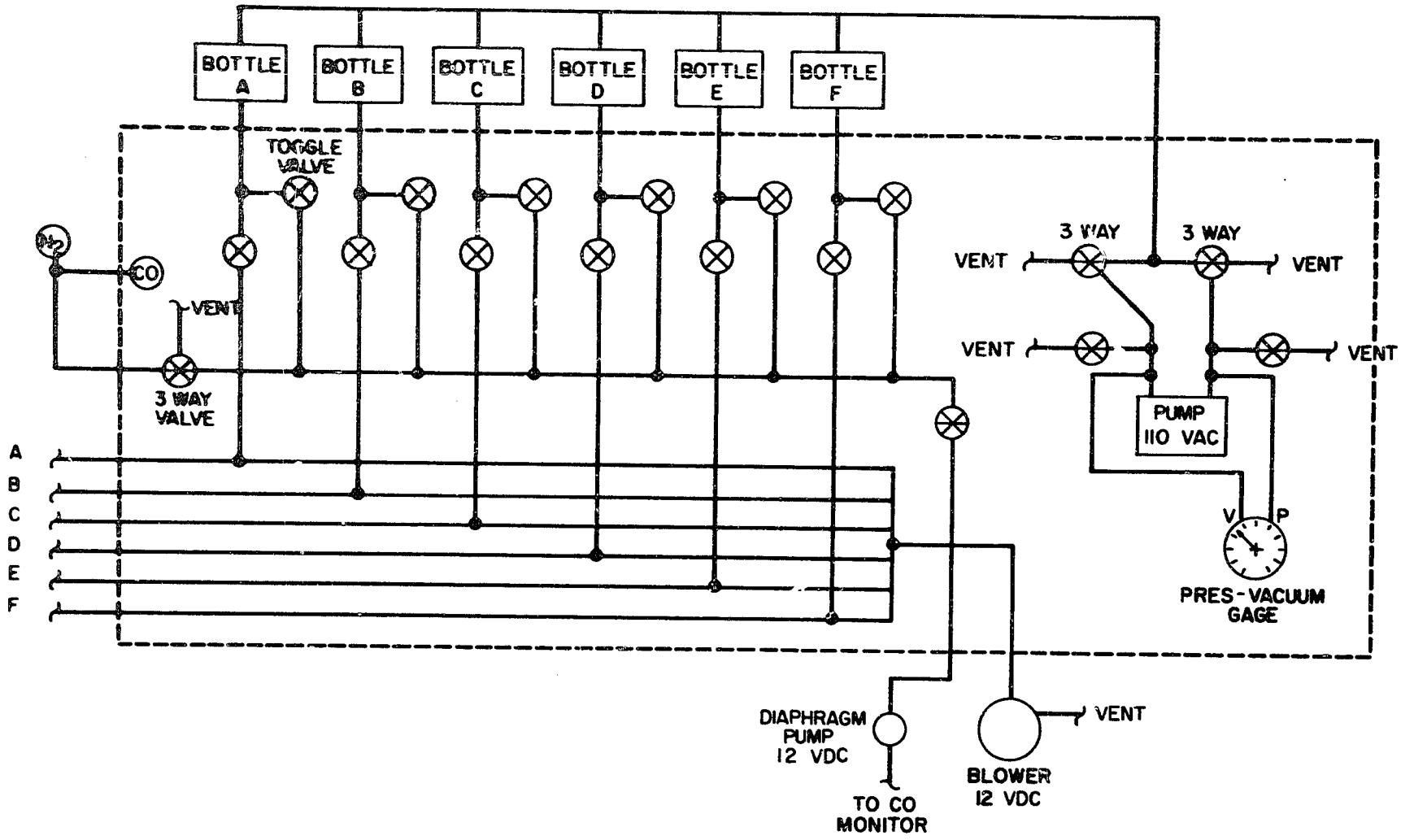

Figure C-2. Schematic of Sample Handling System

a few psi below atmospheric by using a 110VAC pressure-vacuum pump. A 12VDC diaphragm pump was utilized to maintain proper sample flow through the CO analyzer. Finally, bottles of N_2 and CO were used for calibration of the instrument at frequent intervals.

Figures C-3 and C-4 are pictures showing the outside and inside views respectively of the first car as instrumented for testing. In Figure C-3 three of the five sample points can be seen located on the right front fender and on the back rest in the center of the front and back seats. Figure C-4 is a view of the CO analyzer with five sample storage units on top. On the left is the control panel and in the right foreground the CO and N_2 calibration tanks. On the right side of the car is the large black exhaust hose connected to the 12VDC blower.

Electrical Power Sources

Power was supplied by a Terado Model 50-191 12VDC to 110VAC square-wave inverter with a 300 watt capacity and a Heathkit Model MP-14 12VDC to 110VAC square-wave inverter with a 500 watt capacity. The 300 watt inverter was connected to the car battery in each case, as was the 12VDC blower, and powered the 110VAC pressure-vacuum pump. The 500 watt inverter was connected to two auxiliary 96 amp-hour car batteries and powered the CO analyzer (and buffer amplifier, when used). The separate batteries were used to isolate the CO analyzer from the voltage fluctuations which occur in the vehicle's electrical system. The batteries required daily recharging when in use. In order to obtain proper operation of the CO analyzer control circuits, the voltage output of the 500 watt inverter had to be increased to 160VAC to duplicate the peak of a normal 120VAC sine-wave electrical source.

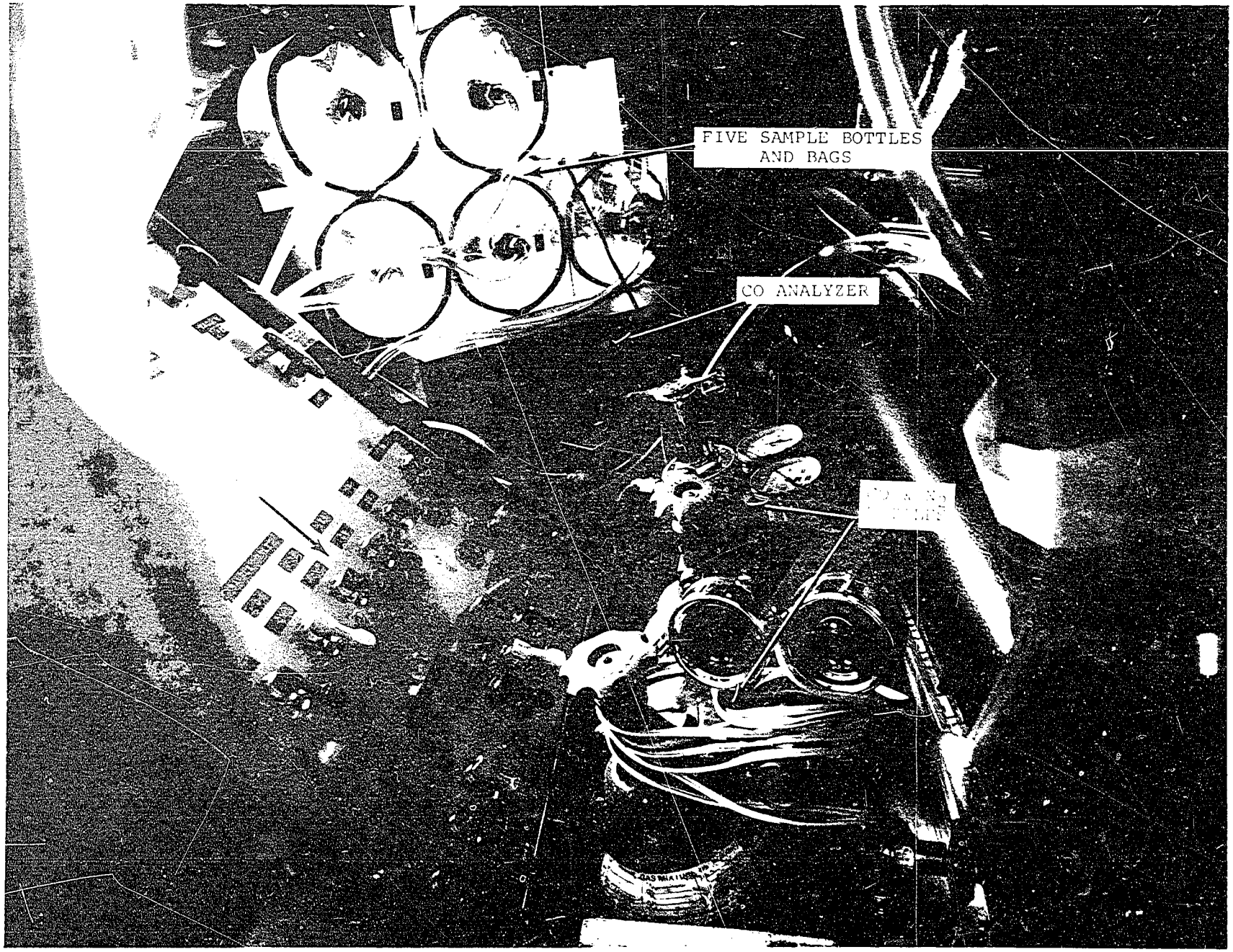

Figure C-3. Inside View of Instrumented Chevelle

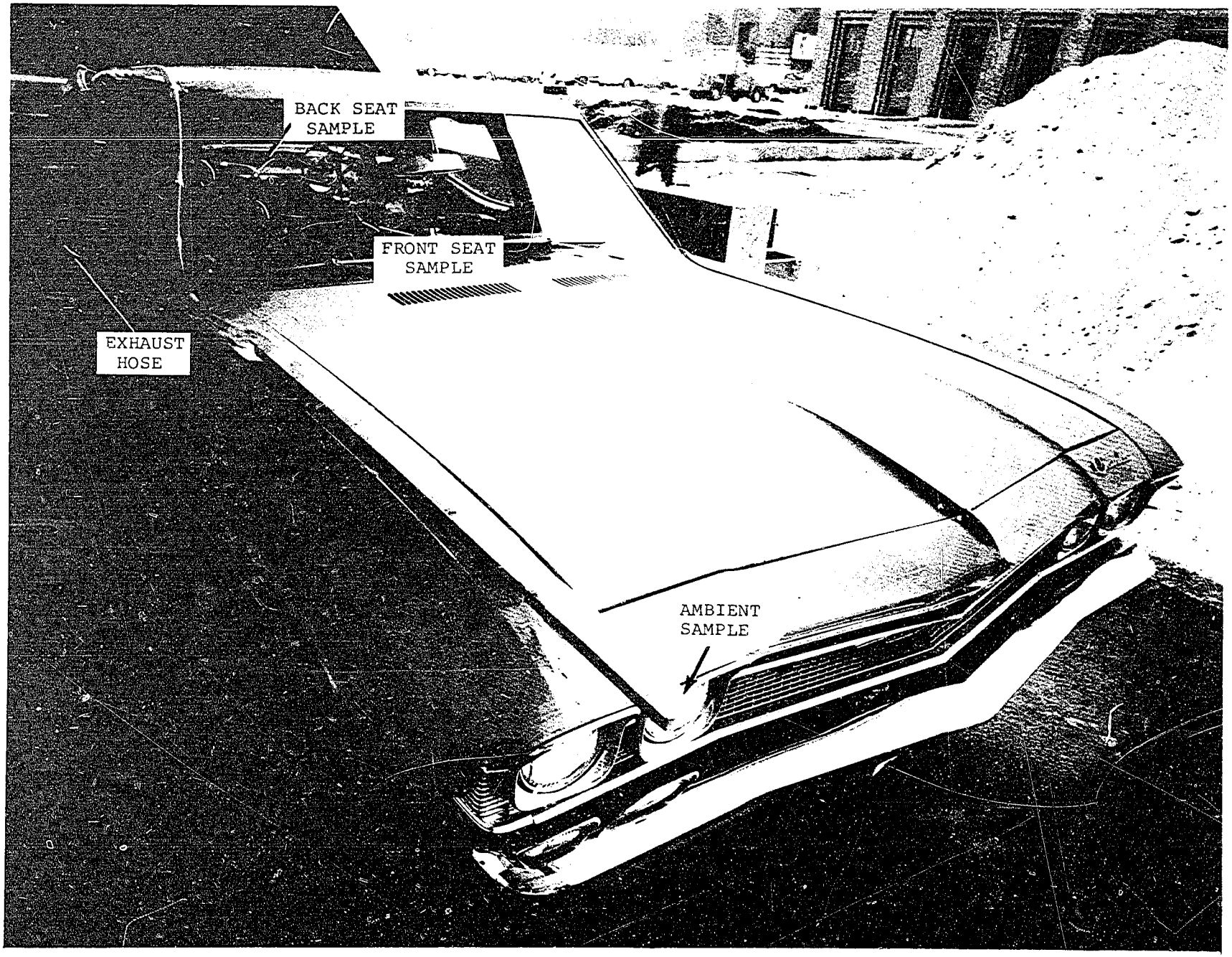

Figure C-4. Outside View of Instrumented Chevelle

APPENDIX D

SAMPLE COLLECTION PROCEDURE

General Sequence

In preparation for collecting simultaneous samples, the pressure around the bags is increased so that they collapse. At the desired instant, the pressure is reduced to below atmospheric and the toggle valves for the desired number of sample lines are opened simultaneously and a portion of the air flowing through each hose flows into a sample bag, filling up to five bags in two minutes. The toggle valves are then closed to isolate the samples. The pressure surrounding the bags is then increased above atmospheric and the samples are discharged one at a time through the CO analyzer.

Idle Tests

These tests utilized the above mentioned sequence, but with only two sample locations: one inside at the center of the front-seat back rest and one outside. They were made with the engine idling, vehicle closed and stationary in a large building (over 40 feet high - building 311, Army Material and Mechanics Research Center, Watertown, Massachusetts). Exhaust was vented normally from the exhaust pipe without use of a hose leading outside the building. The increase of CO both inside and outside the car was measured as a function of time at five-minute intervals. If the CO concentration within one hour had leveled off below 10ppm, the test was ended there. If the CO level went above 10ppm, the test was extended another 30 minutes (J989 recommends stopping the test after 30 minutes if the 10ppm level has not been reached).

Continuous Single Point Sampling

When it was desired to monitor the air at any one point for extended periods of time, the general procedure was modified as follows. The pressure around the bag for the point being monitored was maintained at atmospheric and both the inlet and outlet valves were opened allowing the continuously flowing air sample to be drawn from the 3/4 inch hose through the inlet and outlet valves and then through the CO analyzer by using the 12VDC diaphragm pump. The strip chart recorder was connected to the CO analyzer to keep a record of the CO concentration as a function of time.

Driving Tests

Driving tests made at 30 and 60mph and for the various

configurations in Table 1 utilized the general sequence outlined at the beginning of this section in two different ways. For the first five vehicles, the desired test speed was attained and the samples immediately collected. After the samples were collected, the car was stopped and the measurements made, followed by another test at either a new speed or new configuration of passenger compartment openings. For car number six this procedure was followed with one addition. After taking the initial sample and measuring the amount of CO in it, the same speed and configuration were repeated. This time the car was driven for ten minutes in this test mode before sample collection was begun. The remainder of the process remained unchanged. In Tables F-8 and F-9, which are in Appendix F, these two sets of data are differentiated by being called 0 minute readings (those taken immediately upon attaining test speed) and 10 minute readings (those taken after driving at test speed for 10 minutes). This second set of data was collected to see how much, if any, build-up of CO occurred within the passenger compartment over a period of time. It served as a check on the validity of previous tests.

APPENDIX E

TEST ROUTE

Route Description

The test route upon which all moving tests were made is shown in Figure E-1. The section used was Route 3 beginning at Route 128 in Burlington, Massachusetts and proceeding north to the intersection of Routes 3 and 111 in Nashua, New Hampshire. This section of the highway passes through gently rolling hills and has two lanes of traffic in each direction. Vehicular travel is light between 9:30 a.m. and 4:00 p.m. on weekdays.

Wind and Weather Conditions

The prevailing wind was northerly at about 3-6mph with occasional 10mph winds. This means the wind encountered usually was either a head or tail-wind. The wind speed and direction was recorded several times during the test day using a Dwyer hand-held wind meter with two ranges - one from 0-10mph and one from 0-60mph. None of the tests were made under rainy conditions, but many days were overcast. The ambient temperature ranged from about 50°F to 90°F for all tests.

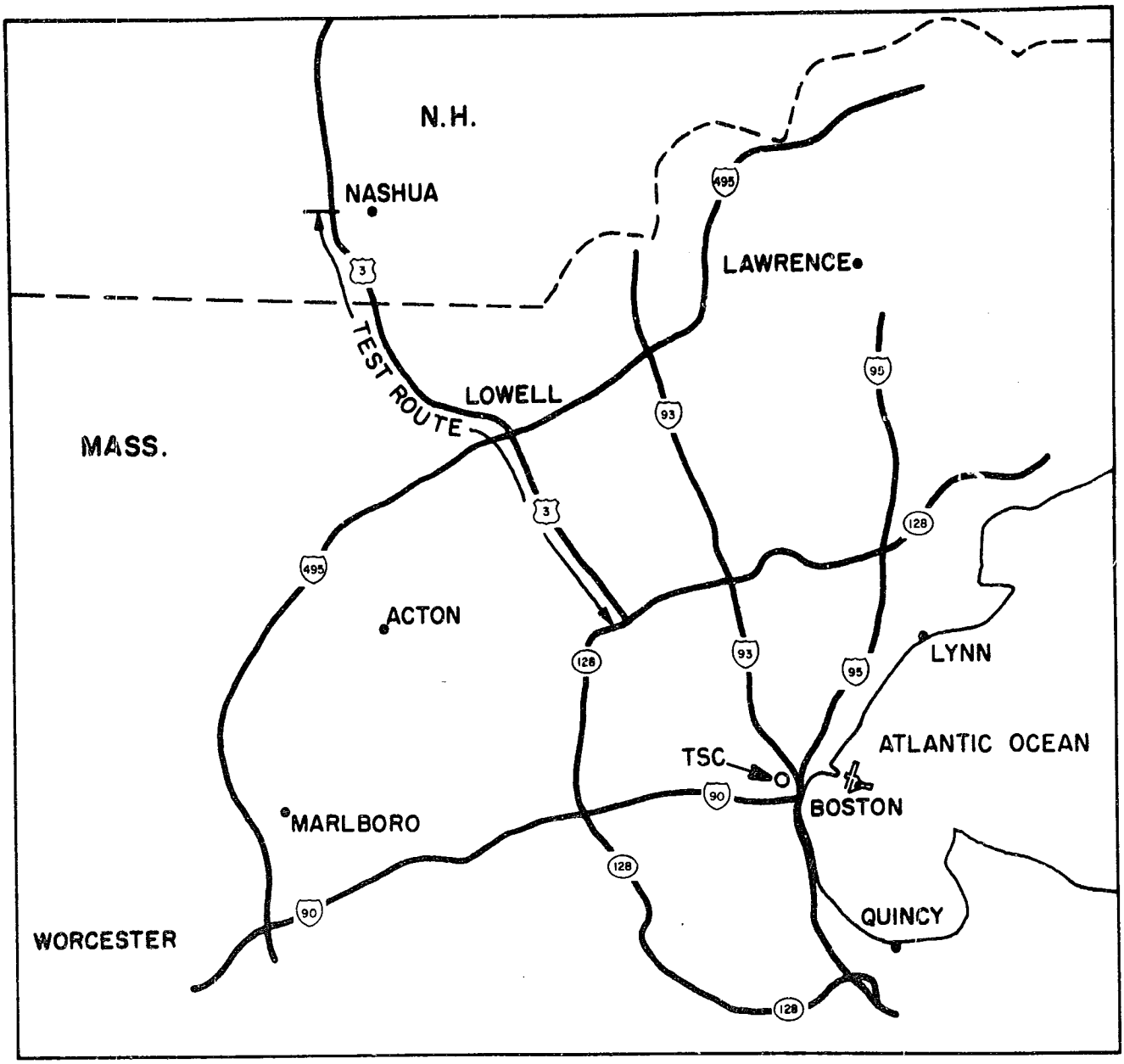

Figure E-1. Vehicle Test Route

APPENDIX F

DATA

The data used in compiling Figure 2 are given for each car in Tables F-1 through F-9. These tables contain the following information: (1) the configurations of Table 1 which apply to the particular car, (2) the locations of the sample points, and (3) the CO concentrations measured in ppm at each sample location for the various configurations. If there is more than one such table for a particular vehicle it is because tests were made under two or more different conditions; i.e., with and without trailer or roof rack or with the air deflector operating or removed.

If all the parameters for a particular configuration given in Table 1 were applicable to a particular vehicle, that configuration was used on the vehicle. For those cars without front window vents, the front window was opened as per instruction for the window vent. One further consideration is that configurations 15 and 16 were used only for the Volkswagen due to the fact that it draws its heating air from the rear of the vehicle, with the possibility of inducting exhaust gases entrained in the wake following the car.

The test point locations given in these Tables are defined as follows:

(1) Ambient: This sample location was on the right front fender for the 1968 Chevelle and 1970 Econoline Van, over the hood at roof level for the 1971 Plymouth and 1969 Mercury wagons, and outside the right front window for the 1971 Pinto and 1969 Volkswagen.

(2) Front Seat: All cars had this sample location at the center of the back rest of the front seat.

(3) Back Seat: All cars except the Econoline had this sample location and it was at the center of the back rest of the back seat.

(4) Trunk: This location was used on the Chevelle and Pinto and was positioned at the top center inside the trunk.

(5) Wagon Deck: The Plymouth and Mercury used this location which was on the floor in the center rear of the deck area of the wagon.

(6) Van Compartment: This sample location applied to the Econoline van and was positioned at roof level at the inside center of the cargo area.

The data from Tables F-1 through F-9 was used to draw distributions of inside car readings of CO versus frequency of occurrence for each of the cars. These distributions appear in Figures F-1 through F-13 and are similar to Figure 2 which is a composite of all data contained in Figures F-1 through F-13.

The last set of data is contained in Tables F-10 through F-15 and is for the idle tests. This data was used to draw Figure 3 already discussed.

Table F-1
Measured CO Concentrations for 1968 Chevelle

CONFIGURATION	SPEED MPH	TEST POINT READING, PPM			
		AMBIENT	FRONT SEAT	BACK SEAT	TRUNK
1	30	0	4	4	7
1	60	6	10	9	13
2	30	0	0	0	0
2	60	0	0	0	3
3	30	0	3	3	5
3	60	0	2	2	5
4	30	0	0	0	0
4	60	0	0	0	0
5	30	0	3	3	4
5	60	0	3	3	5
9	30	0	0	2	3
9	60	2	5.5	6	6
11	30	0	0	0	2
11	60	0	0	2	5
12	30	0	2	2	6
12	60	0	0	0	0
13	30	0	0	0	5
13	60	0	2	3	6

Table F-2
Measured CO Concentrations for 1971 Plymouth Wagon

CONFIGURATION	SPEED MPH	TEST POINT READINGS, PPM*			
		AMBIENT	FRONT SEAT	BACK SEAT	WAGON DECK
1	30	0	4	3	5
1	60	0	3	2	3
2	30	0	3	3	5
2	60	0	5	3	6
3	30	0	5	3	6
3	60	0	2	3	3
6	30	0	5	3	6
6	60	0	5	3	8
7	30	0	5	3	6
7	60	0	3	2	3
8	30	0	7	6	9
8	60	1	5	2	6
9	30	0	5	5	6
9	60	0	3	3	5
10	30	1	2	2	3
10	60	0	2	1	2
11	30	1	5	3	7
11	60	0	1	1	2
12	30	1	3	2	5
12	60	0	2	1	3
13	30	1	2	2	3
13	60	1	2	2	2
14	30	0	1	1	0
14	60	0	0	0	0

*These tests performed with air deflector operating as installed by the manufacturer.

Table F-3
Measured CO Concentrations for 1971 Plymouth Wagon

CONFIGURATION	SPEED MPH	TEST POINT READING, PPM							
		AMBIENT		FRONT SEAT		BACK SEAT		WAGON DECK	
		*	**	*	**	*	**	*	**
6	30	0	0	5	7	3	3	6	8
6	60	0	0	5	6	3	4	8	7
7	30	0	0	5	4	3	4	6	5
7	60	0	1	3	3	2	1	3	4
8	30	0	0	7	20	6	18	9	22
8	60	1	0	5	18	2	8	6	15
9	30	0	0	5	21	5	15	6	24
9	60	0	0	3	15	3	9	5	15
10	30	1	0	2	3	2	1	3	3
10	60	0	1	2	1	1	3	2	3
14	30	0	0	1	1	1	2	0	1
14	60	0	0	0	1	0	1	0	0

*designates tests performed with air deflector operating as installed by the manufacturer

**tests performed with air deflector rendered inoperative

Table F-4
Measured CO Concentrations for 1971 Pinto

CONFIGURATION	SPEED MPH	TEST POINT READINGS, PPM			
		AMBIENT	FRONT SEAT	BACK SEAT	TRUNK
1	30	0	4	5	10
1	60	1	3	4	13
2	30	1	6	11	19
2	60	1	5	9	15
9	30	1	13	21	23
9	60	1	44	72	90
12	30	1	4	9	22
12	60	2	4	10	23
13	30	0	3	3	11
13	60	0	2	3	15

Table F-5
Measured CO Concentrations for 1970 Ford Econoline Van

CONFIGURATION	SPEED MPH	TEST POINT READING, PPM		
		AMBIENT	FRONT SEAT	VAN COMPARTMENT
1	30	1	5	5
1	60	1	3	4
2	30	0	3	3
2	60	1	3	3
4	30	1	2	1
4	60	1	3	3
9	30	0	3	3
9	60	2	3	4
12	30	1	3	3
12	60	0	3	3
13	30	0	2	2
13	60	0	2	3

Table F-6
Measured CO Concentrations for 1969 Mercury Wagon

CONFIGURATION	SPEED MPH	TEST POINT READING, PPM							
		AMBIENT		FRONT SEAT		REAR SEAT		WAGON DECK	
		*	**	*	**	*	**	*	**
1	30	1	0	11	6	7	12	13	10
1	60	2	1	7	7	5	8	6	8
2	30	1	2	3	7	3	7	3	6
2	60	1	2	4	5	3	5	5	5
3	30	1	0	3	3	2	4	3	4
3	60	0	1	1	2	1	2	1	2
4	30	0	1	5	4	3	4	5	4
4	60	1	1	8	3	9	3	12	3
5	30	0	0	3	3	3	2	3	3
5	60	0	2	5	4	3	3	3	3
6	30	0	0	2	15	1	15	2	14
6	60	1	0	5	6	3	6	3	5
7	30	1	0	2	15	2	22	4	32
7	60	1	2	2	7	2	9	2	10
8	30	1	0	5	20	8	20	5	18
8	60	0	0	3	8	5	8	3	7
9	30	0	1	10	26	9	27	8	22
9	60	1	0	4	8	3	6	3	5
10	30	0	1	4	3	3	5	5	4
10	60	0	0	3	3	3	2	4	3
11	30	0	1	9	6	6	7	12	12
11	60	1	1	6	3	5	3	9	3
12	30	0	0	7	9	5	7	6	8
12	60	0	2	3	4	3	4	3	5
13	30	0	0	2	2	2	2	3	3
13	60	1	1	3	4	3	3	4	5
14	30	0	1	4	2	3	3	5	4
14	60	0	0	6	3	3	2	7	5

* Designates tests performed with air deflector operating normally.
**Designates tests performed with air deflector removed.

Table F-7
Measured CO Concentrations for 1969 Mercury Wagon with Trailer

CONFIGURATION	SPEED MPH	TEST POINT READING, PPM							
		AMBIENT		FRONT SEAT		BACK SEAT		WAGON DECK	
		*	**	*	**	*	**	*	**
1	30	2	2	8	9	6	8	9	9
1	60	2	0	6	27	4	30	6	30
2	30	0	2	3	17	2	18	5	15
2	60	0	1	2	8	2	6	3	11
3	30	0	1	3	15	2	12	3	14
3	60	1	1	4	3	3	2	4	3
4	30	1	1	3	5	3	6	4	6
4	60	1	1	5	5	4	5	6	6
5	30	0	1	1	16	2	14	0	19
5	60	0	1	3	1	3	3	4	2
6	30	1	1	3	9	2	8	3	10
6	60	1	1	3	9	4	6	5	13
7	30	0	0	3	11	3	9	3	13
7	60	1	1	2	8	1	6	3	12
8	30	1	1	4	8	3	5	5	8
8	60	1	1	3	5	2	3	2	8
9	30	0	0	3	1	3	0	5	0
9	60	1	1	3	1	3	3	3	0
10	30	1	1	5	3	3	2	5	6
10	60	1	1	4	4	2	3	3	4
11	30	1	1	5	17	5	20	9	32
11	60	1	1	3	19	3	17	3	28
12	30	1	0	3	24	2	24	3	35
12	60	1	1	4	32	3	32	4	39
13	30	0	1	3	17	3	7	4	7
13	60	0	1	4	18	3	12	5	10
14	30	0	1	5	4	3	2	3	1
14	60	1	0	4	2	3	5	3	2

* Designates tests performed with air deflector operating normally.
**Designates tests performed with air deflector removed.

Table F-8
Measured CO Concentrations for 1969 Volkswagen

CONFIGURATION	SPEED MPH	TEST POINT READING, PPM					
		AMBIENT		FRONT SEAT		BACK SEAT	
		0 MIN	10 MIN	0 MIN	10 MIN	0 MIN	10 MIN
1	30	1	1	5	5	5	5
1	60	0	0	3	3	3	4
2	30	1	1	3	3	5	3
2	60	0	0	3	3	3	4
4	30	0	0	4	3	5	5
4	60	1	1	3	3	5	4
12	30	0	0	4	3	4	5
12	60	1	0	4	3	3	3
13	30	0	0	1	1	2	2
13	60	1	0	2	2	3	2
15	30	1	1	7	6	8	8
15	60	1	1	5	6	7	8
16	30	0	0	4	5	5	5
16	60	0	1	3	3	3	3

Table F-9
Measured CO Concentrations for 1969 Volkswagen with Roof Load

CONFIGURATION	SPEED MPH	TEST POINT READING, PPM					
		AMBIENT		FRONT SEAT		BACK SEAT	
		0 MIN	10 MIN	0 MIN	10 MIN	0 MIN	10 MIN
1	30	0	0	3	3	4	4
1	60	0	0	2	3	2	2
2	30	0	0	3	2	5	4
2	60	0	0	3	3	3	4
4	30	0	0	3	3	4	4
4	60	0	0	3	4	5	5
12	30	0	0	3	3	3	3
12	60	0	0	3	3	4	4
13	30	2	1	2	1	2	1
13	60	0	0	0	0	0	0
15	30	1	1	3	4	4	4
15	60	1	1	3	4	4	3
16	30	0	0	2	3	3	3
16	60	1	1	3	3	3	3

Table F-10
CO Concentrations at Idle for 1968 Chevelle

TIME Minutes	IN CAR ppm	AMBIENT ppm
0	0	0
5	0	5
10	4	5
15	5	8
20	6.5	8
25	8	8
30	8	8
45	8	8
60	8	8

Table F-11
CO Concentrations at Idle for 1971 Plymouth Wagon

TIME Minutes	IN CAR ppm	AMBIENT ppm
0	2	1
5	3	1
10	6	2
15	7	4
20	9	5
25	10	6
30	11	6
45	12	6
60	12	6
90	12	6

Table F-12
CO Concentrations at Idle for 1971 Pinto

TIME Minutes	IN CAR ppm	AMBIENT ppm
0	0	0
5	3	3
10	4	5
15	8	7
20	9	9
25	11	10
30	13	12
45	15	13
60	15	13
90	15	13

Table F-13
CO Concentrations at Idle for 1970 Ford Econoline Van

TIME Minutes	IN CAR ppm	AMBIENT ppm
0	0	0
5	4	2
10	4	2
15	4	3
20	5	3
25	6	4
30	5	3
45	6	4
60	6	4

Table F-14
CO Concentrations at Idle for 1969 Mercury Wagon

TIME Minutes	IN CAR ppm	AMBIENT ppm
0	0	0
5	4	2
10	7	3
15	10	3
20	12	4
25	14	4
30	15	4
45	20	5
60	19	4
90	20	5

Table F-15
CO Concentrations at Idle for 1969 Volkswagen

TIME Minutes	IN CAR ppm	AMBIENT ppm
0	0	0
5	2	0
10	3	1
15	3	2
20	3	3
25	3	2
30	3	2
45	3	2
60	3	2

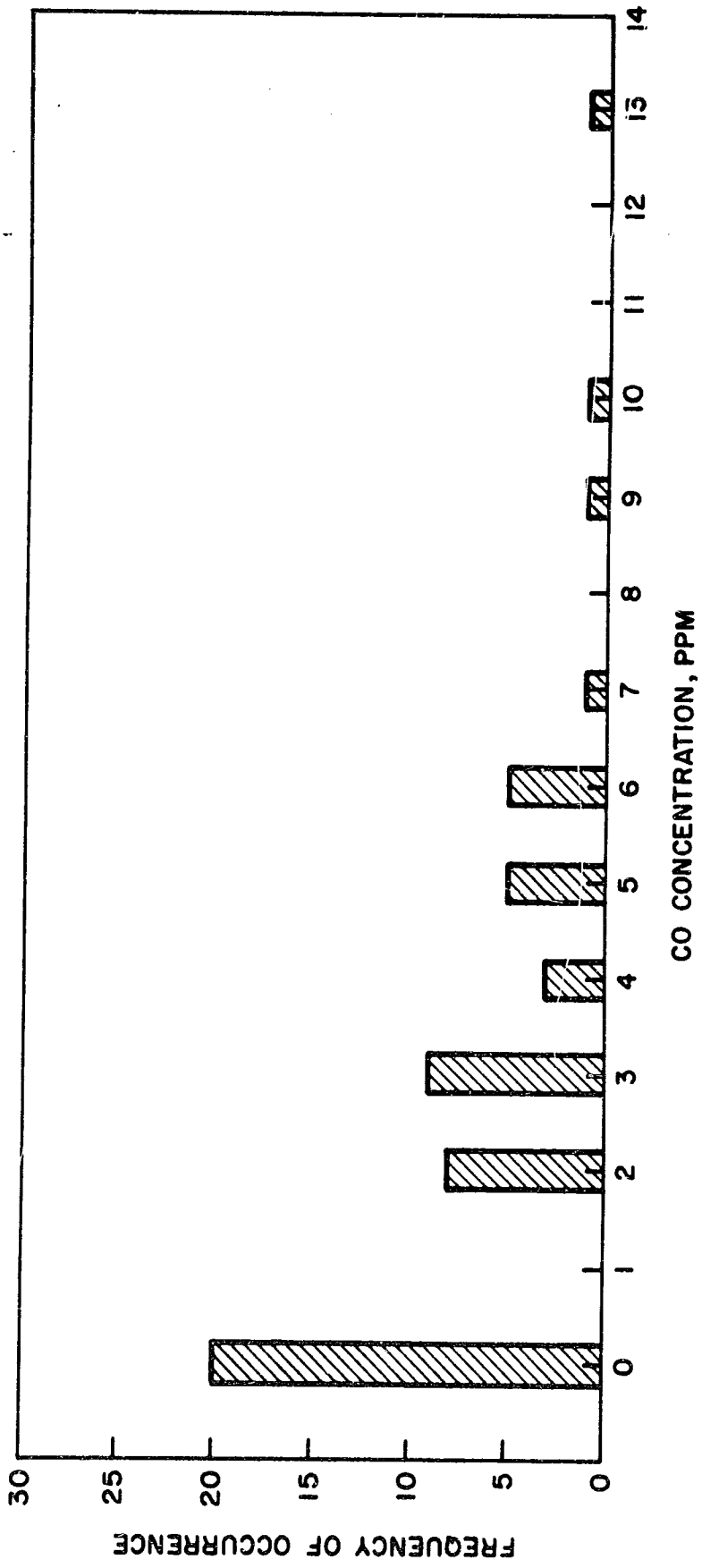

Figure F-1. Distribution of Readings Inside 1968 Chevelle

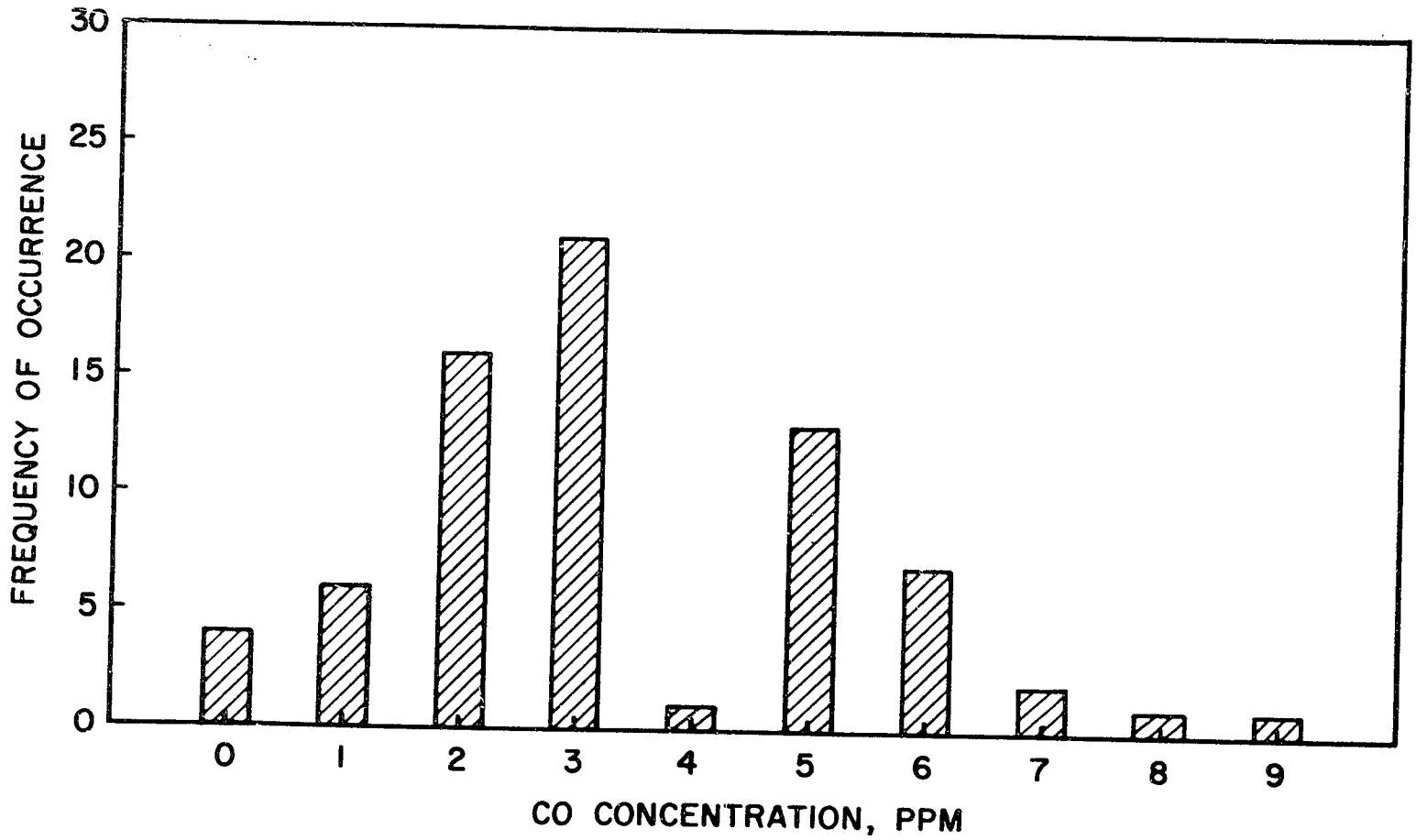

Figure F-2. Distribution of Readings Inside 1971 Plymouth Wagon with Normal Air Deflector Operation

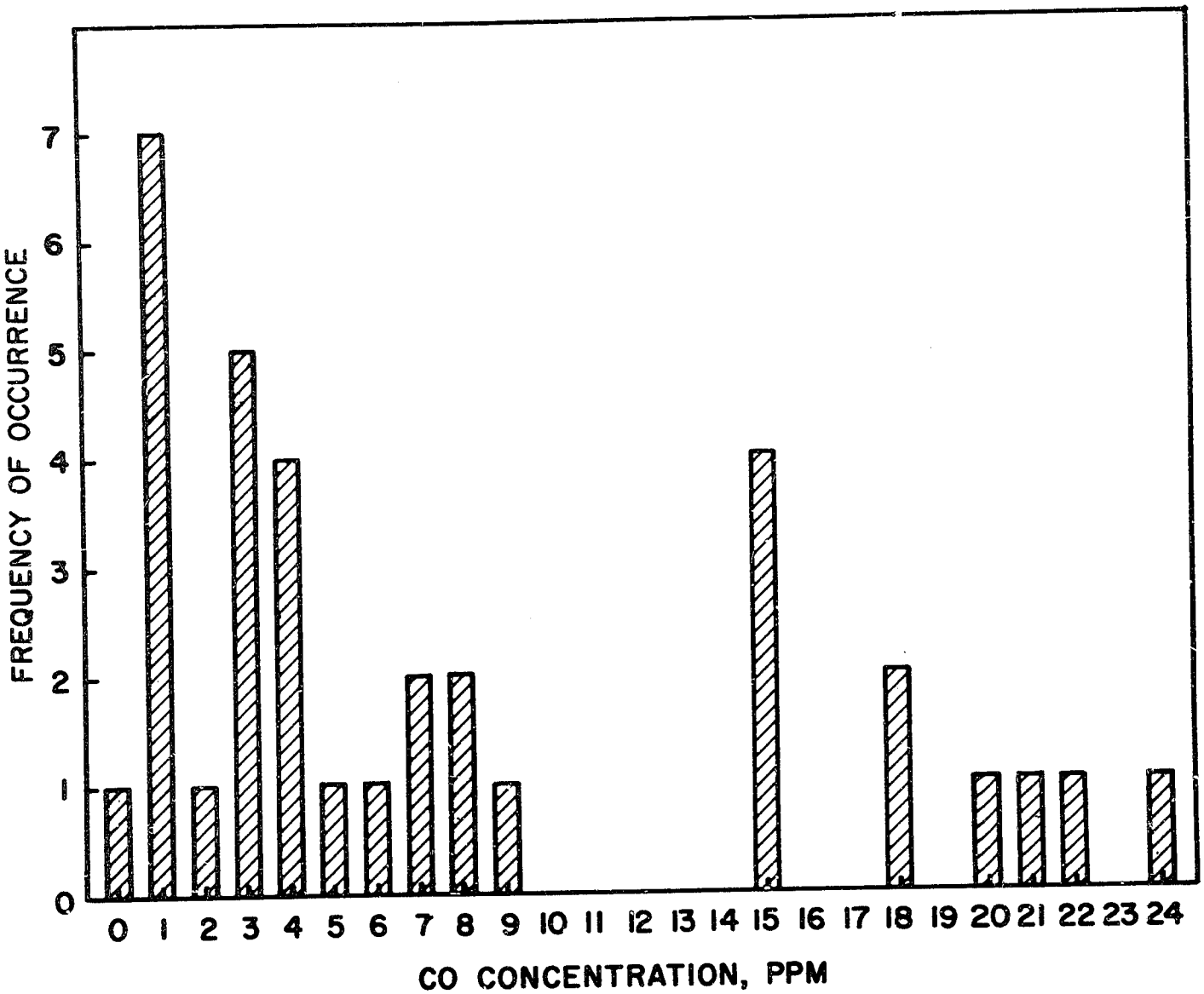

Figure F-3. Distribution of Readings Inside 1971 Plymouth Wagon with Air Deflector Rendered Inoperative

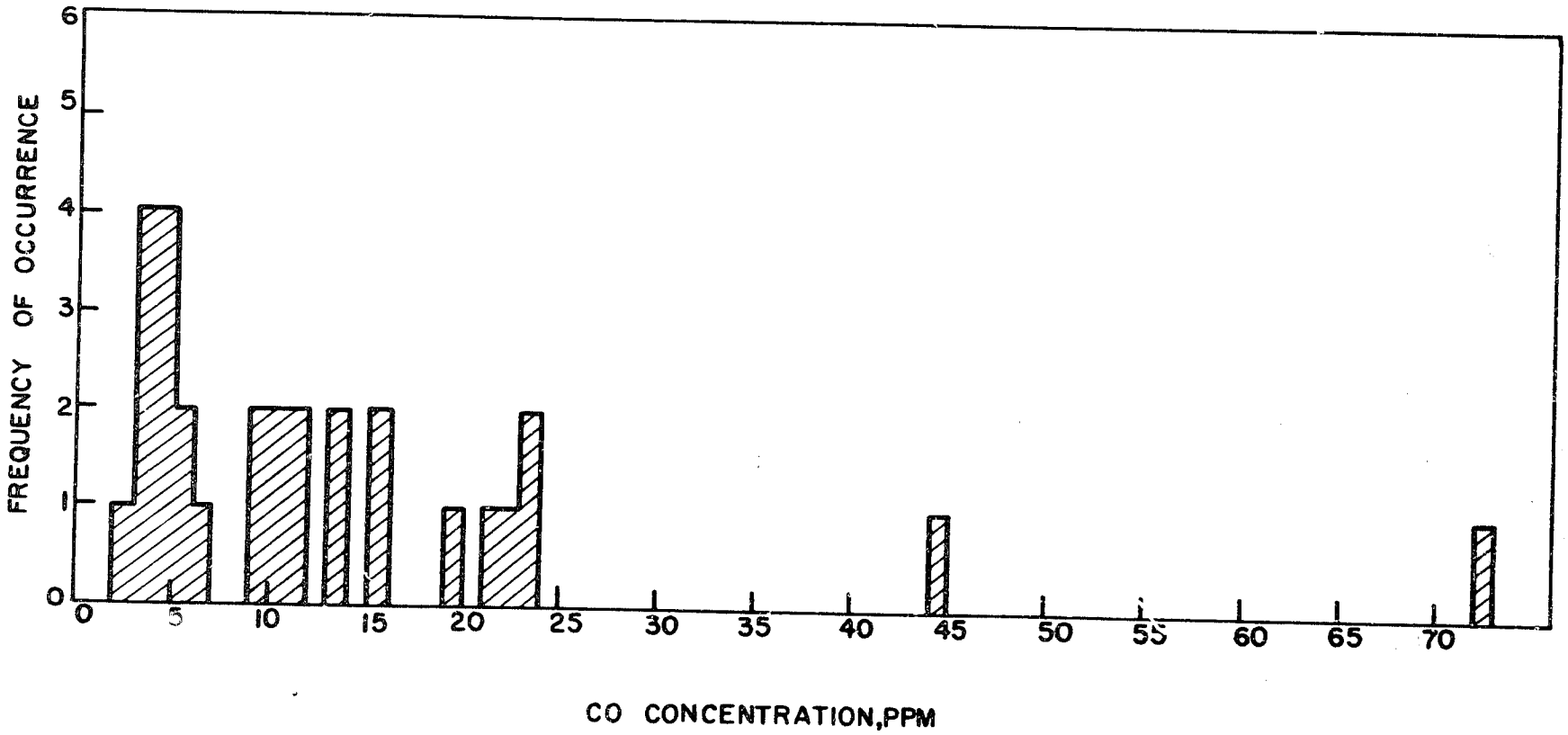

Figure F-4. Distribution of Readings Inside 1971 Pinto
(One Reading at 90ppm Not Included)

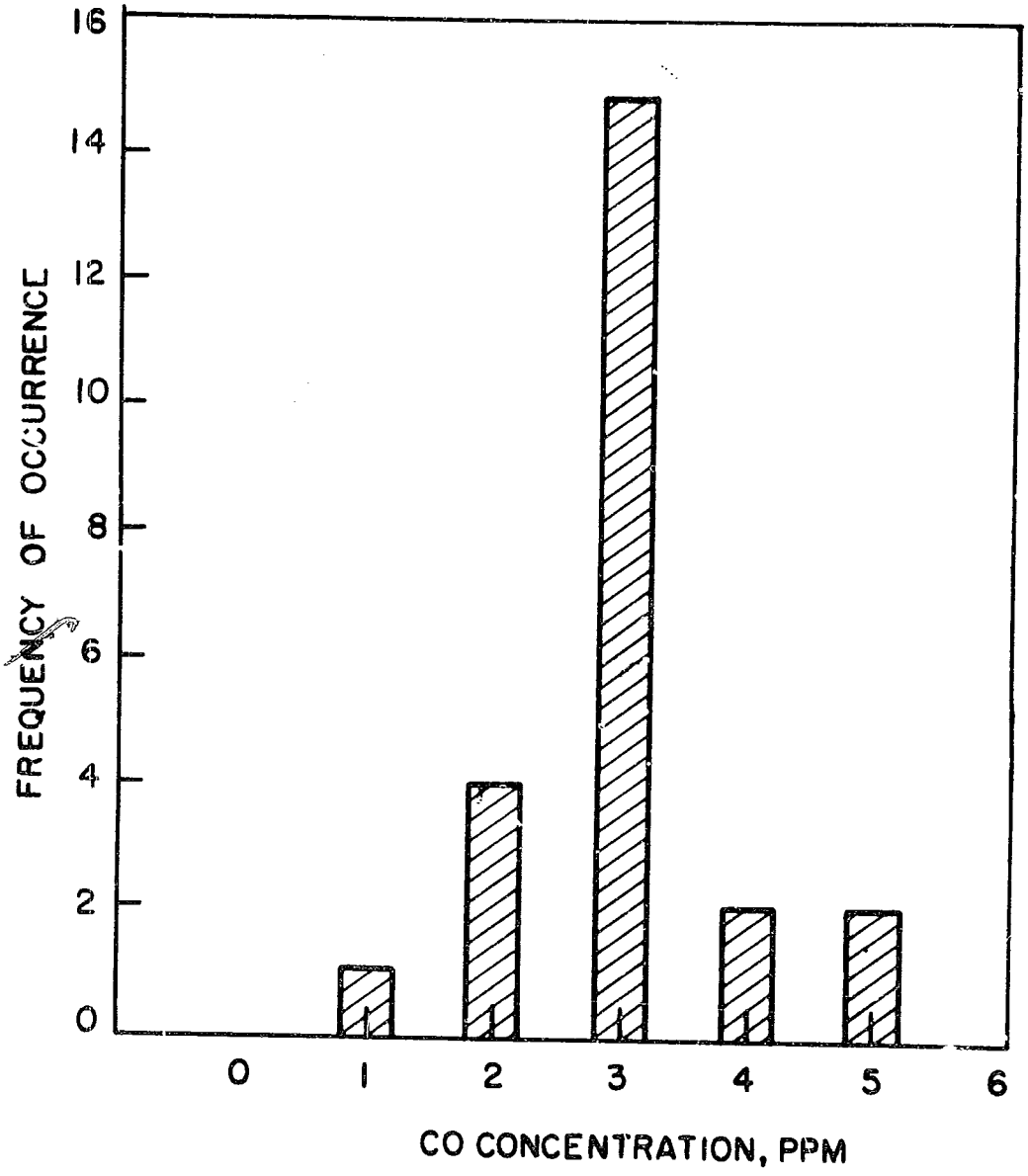

Figure F-5. Distribution of Readings Inside 1970 Ford Econoline Van

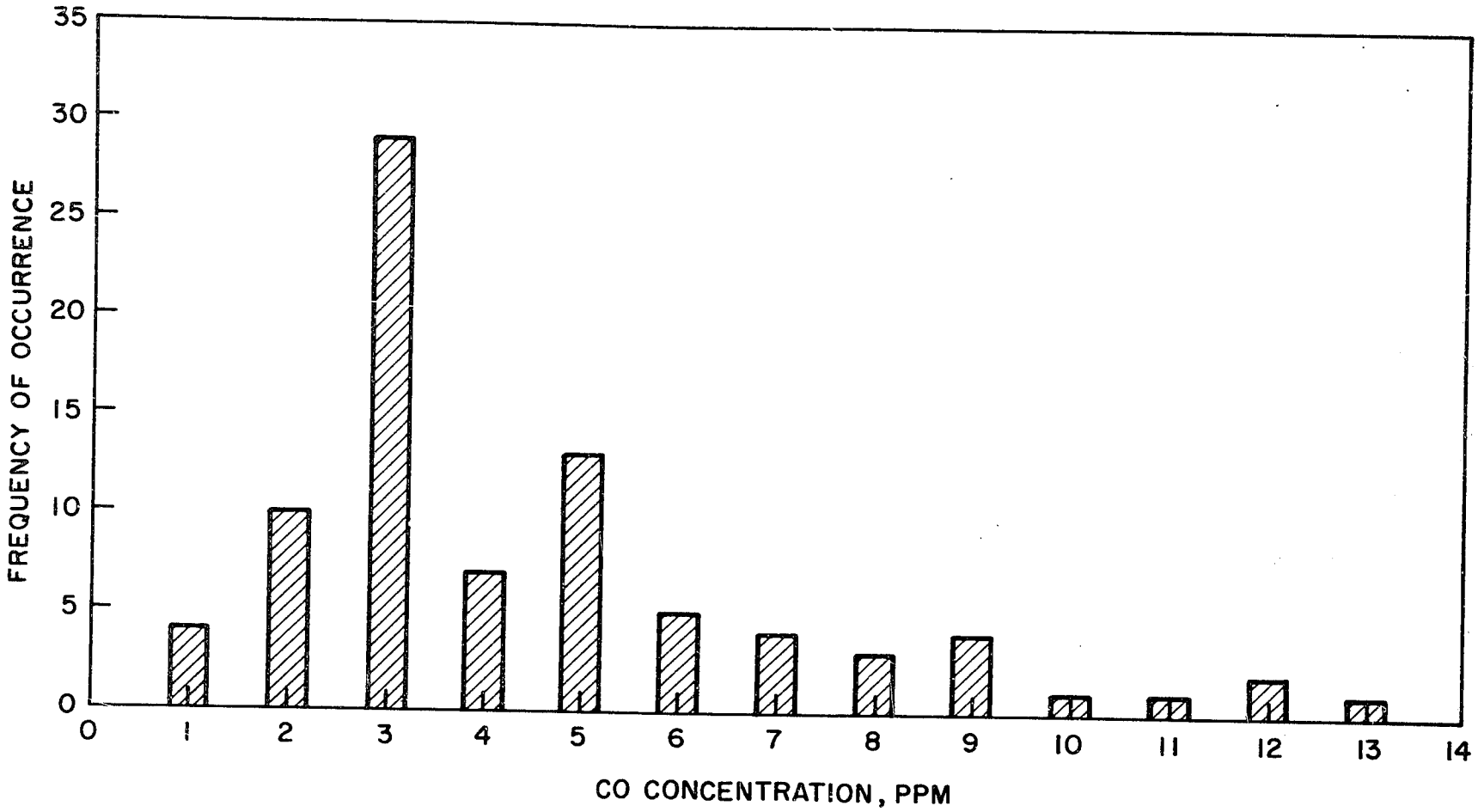

Figure F-6. Distribution of Readings Inside 1969 Mercury Wagon with Air Deflector Operating Normally

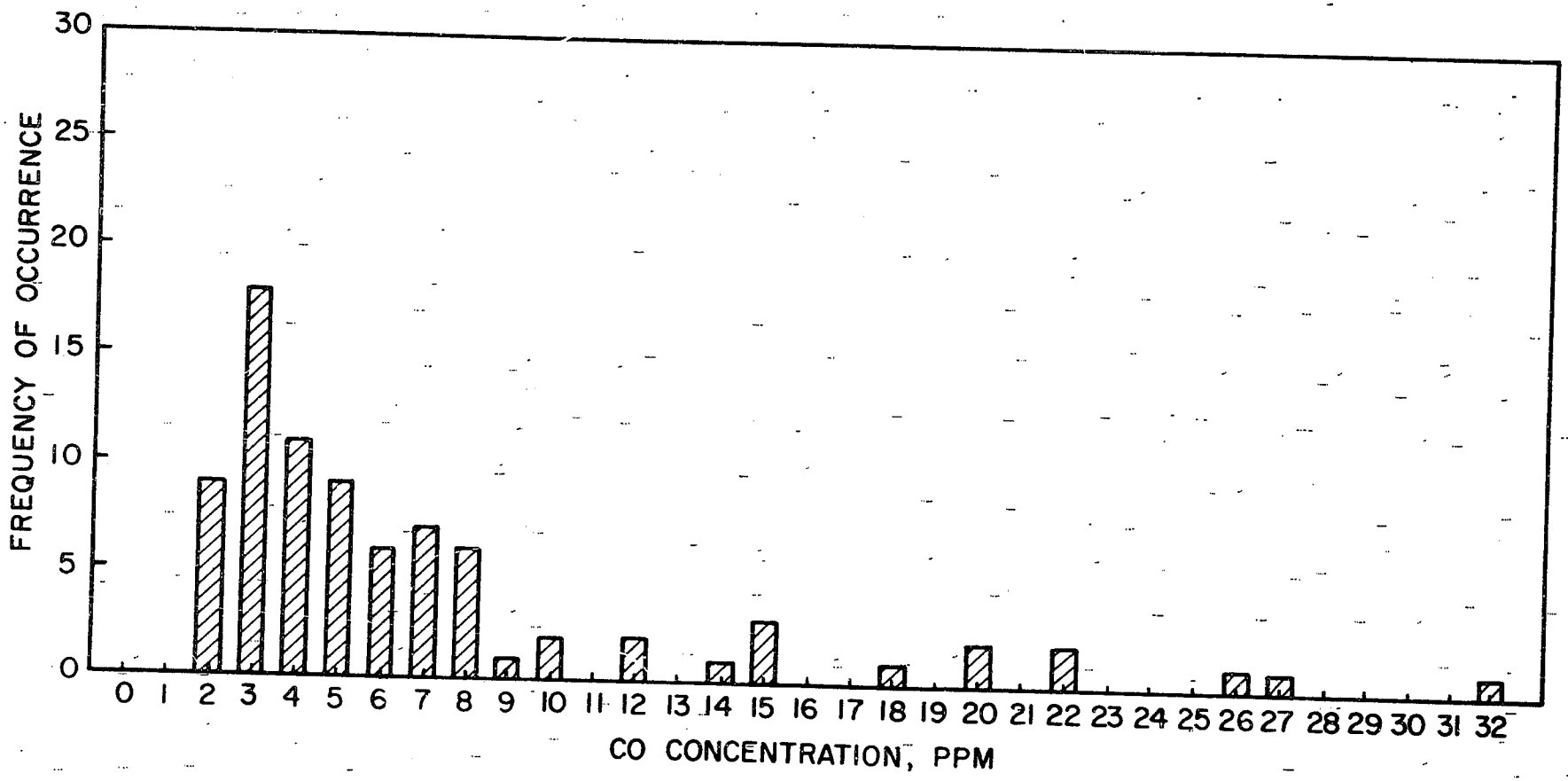

Figure F-7. Distribution of Readings Inside 1969 Mercury Wagon with Air Deflector Removed

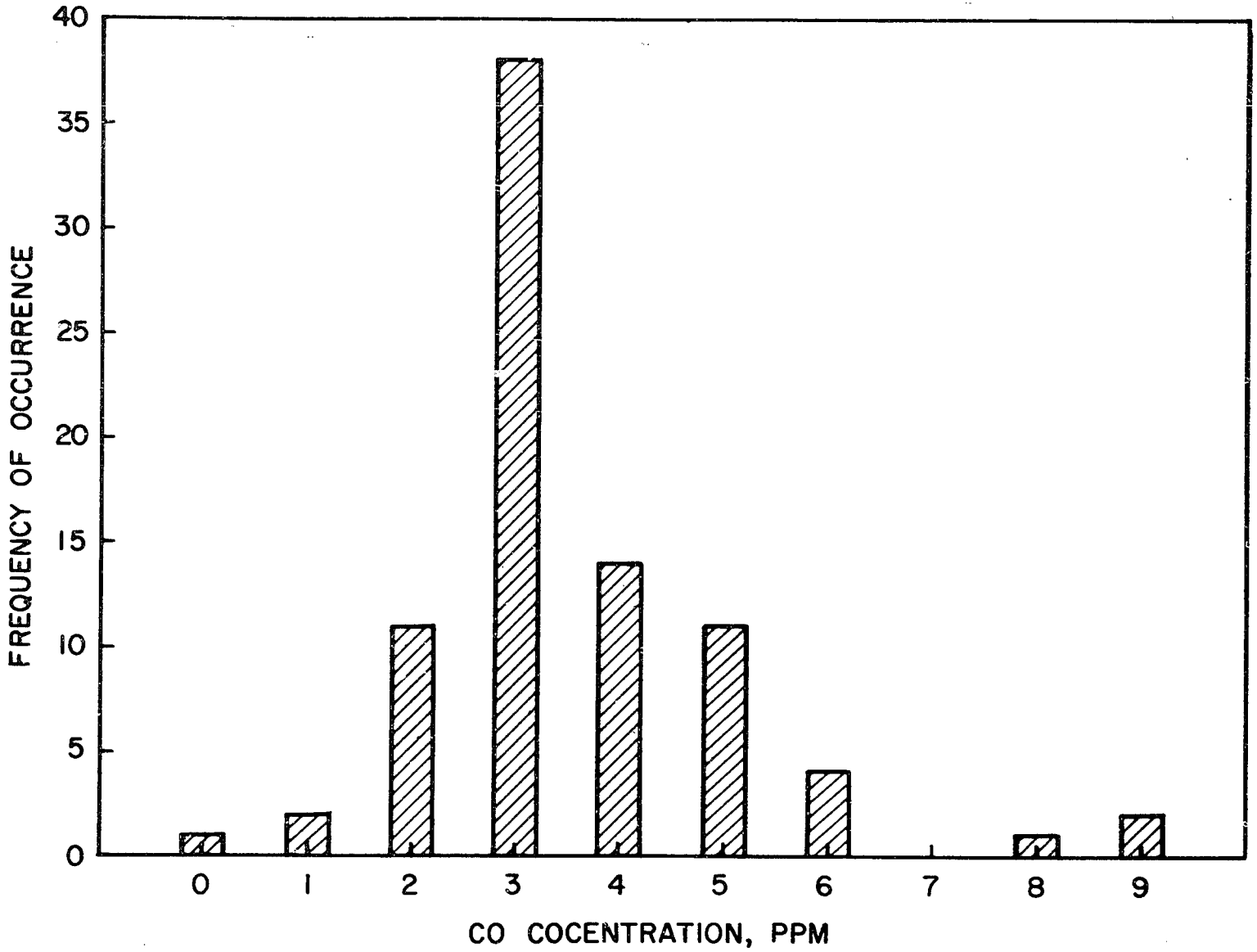

Figure F-8. Distribution of Readings Inside 1969 Mercury Wagon with Air Deflector Operating Normally and Trailer in Tow

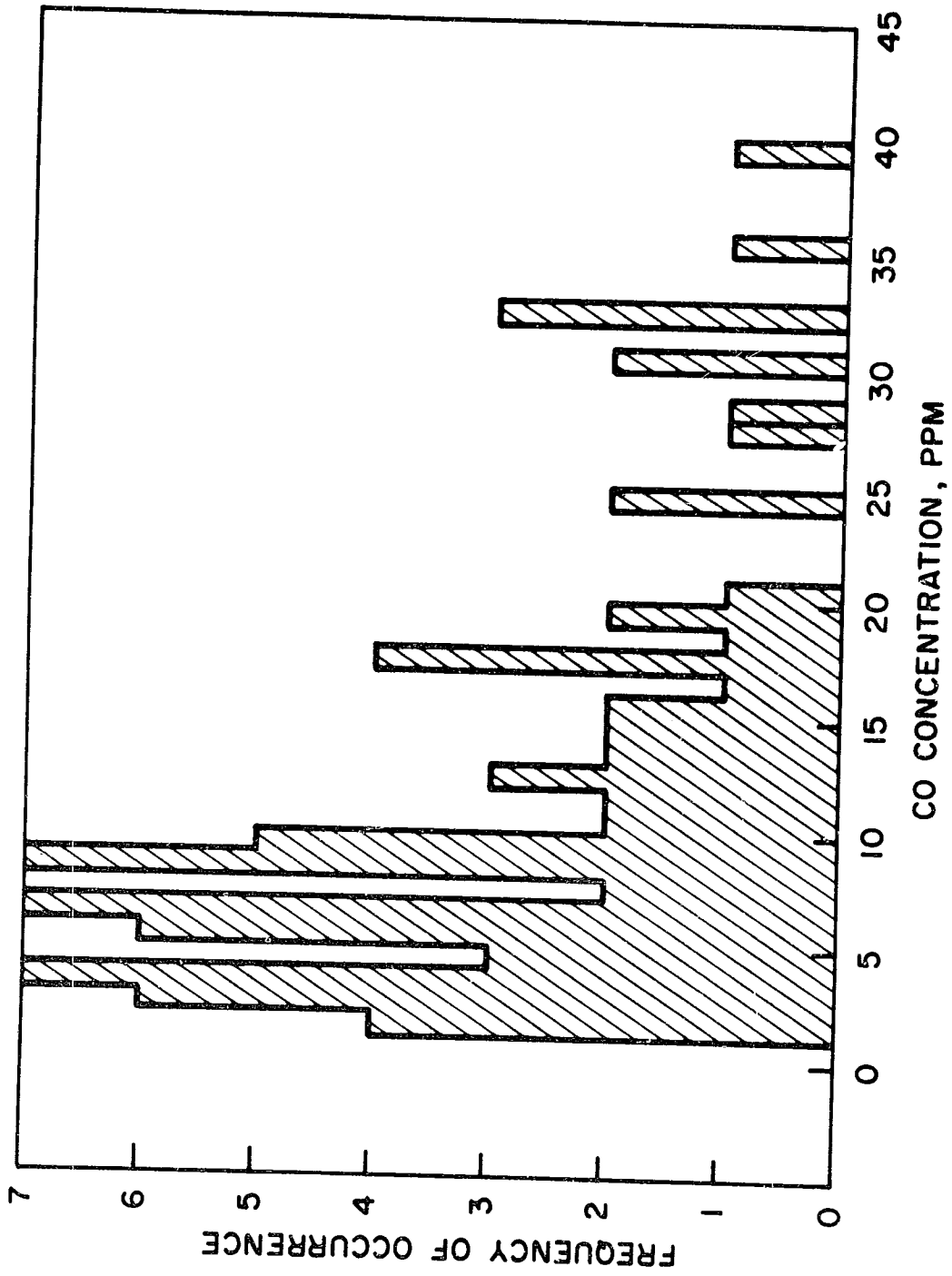

Figure F-9. Distribution of Readings Inside 1969 Mercury Wagon with Air Deflector Removed and Trailer In Tow

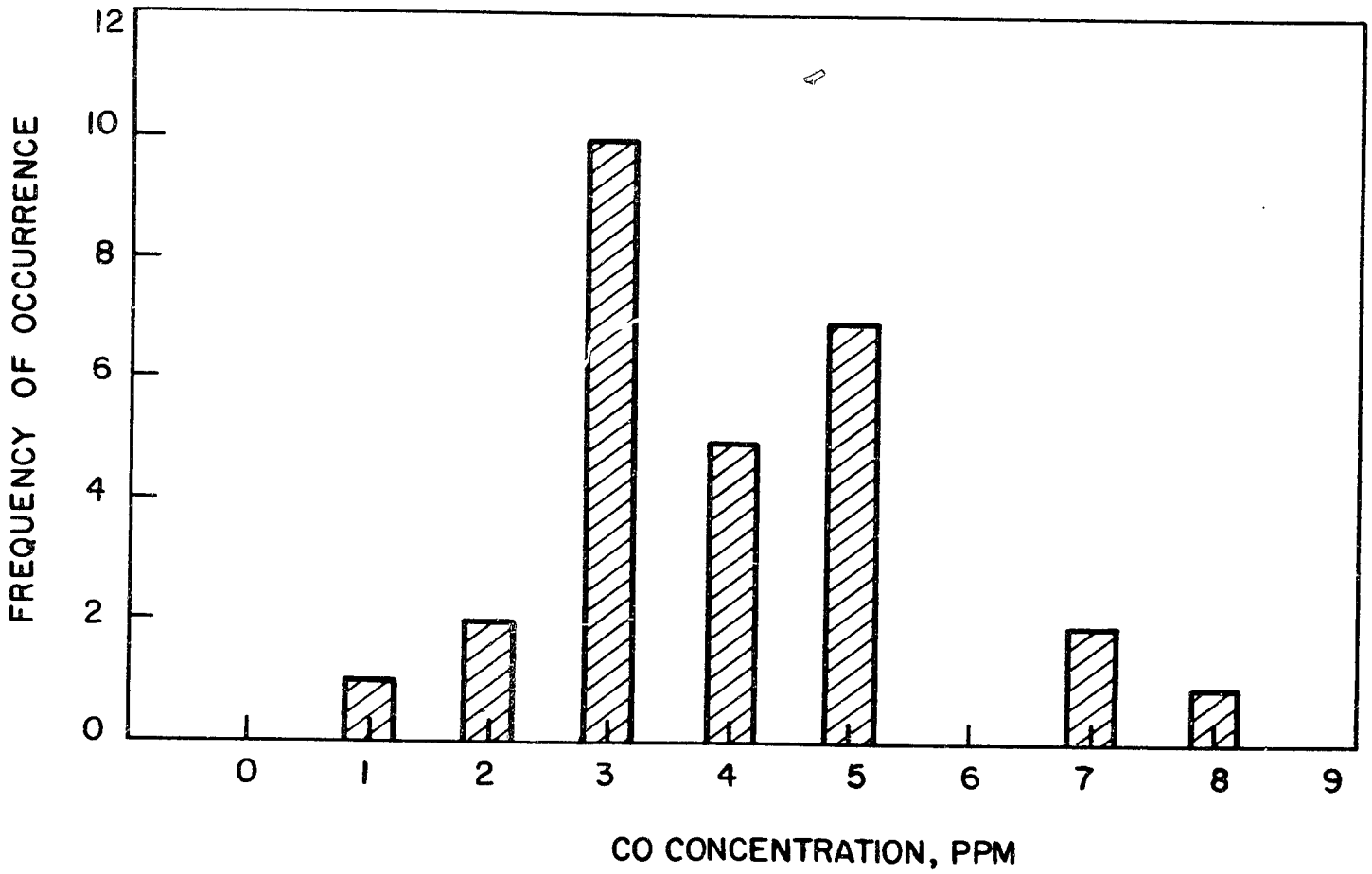

Figure F-10. Distribution of Readings Inside 1969 Volkswagen Taken Immediately Upon Attaining Test Speed

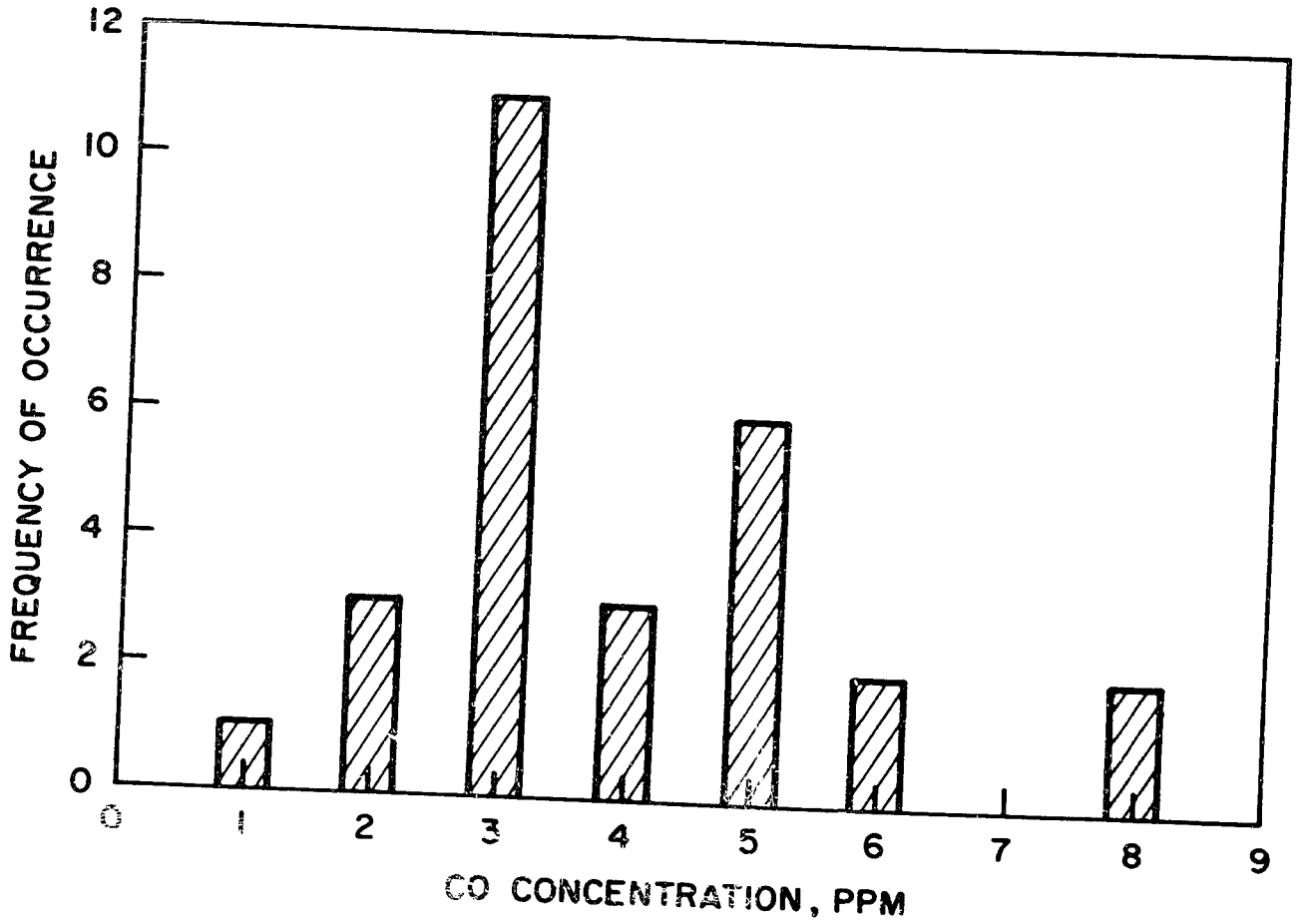

Figure F-11. Distribution of Readings Inside 1969 Volkswagen Taken After Traveling at Test Speed for Ten Minutes

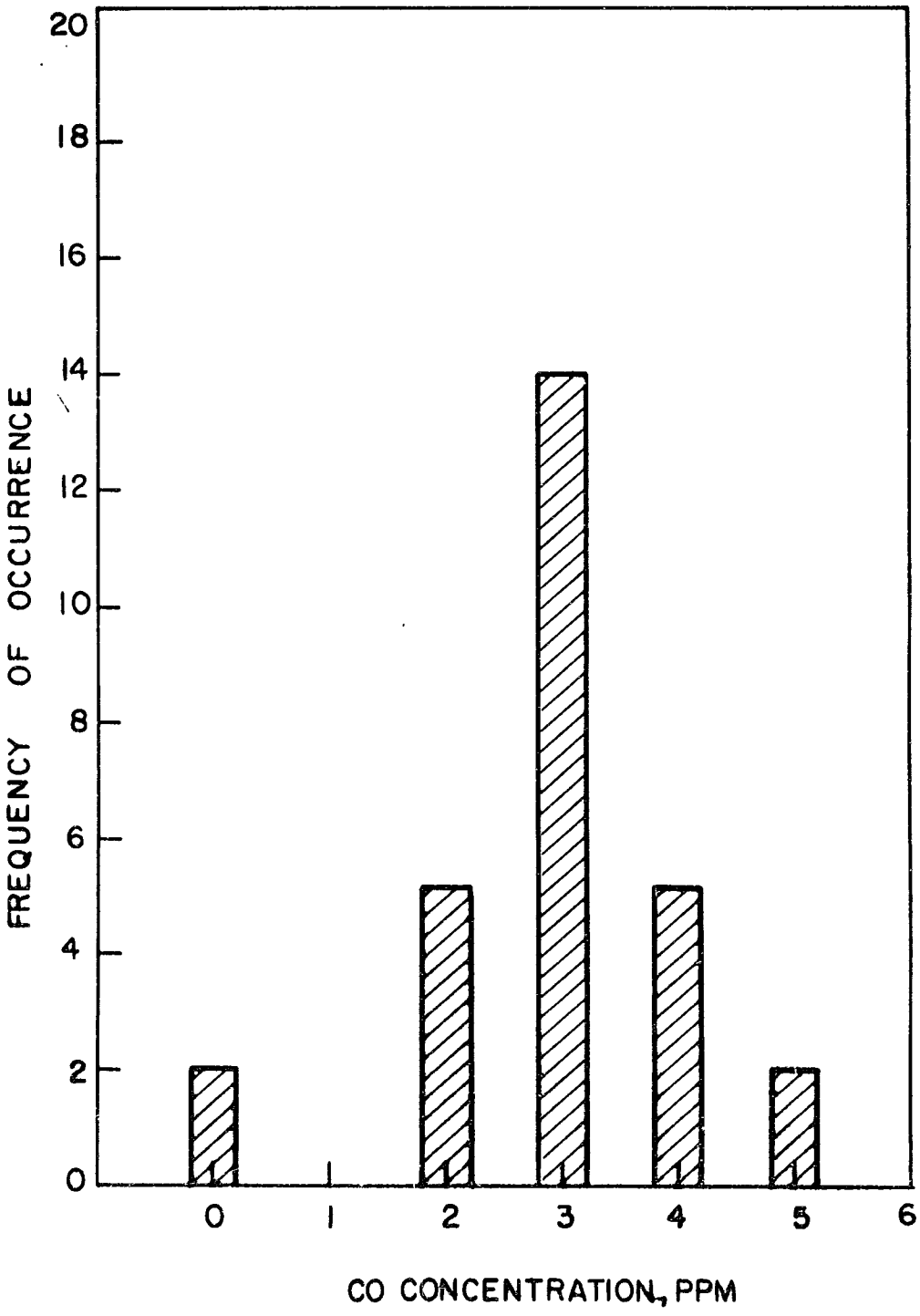

Figure F-12. Distribution of Readings Inside 1969 Volkswagen Taken Immediately Upon Attaining Test Speed While Carrying Top Load

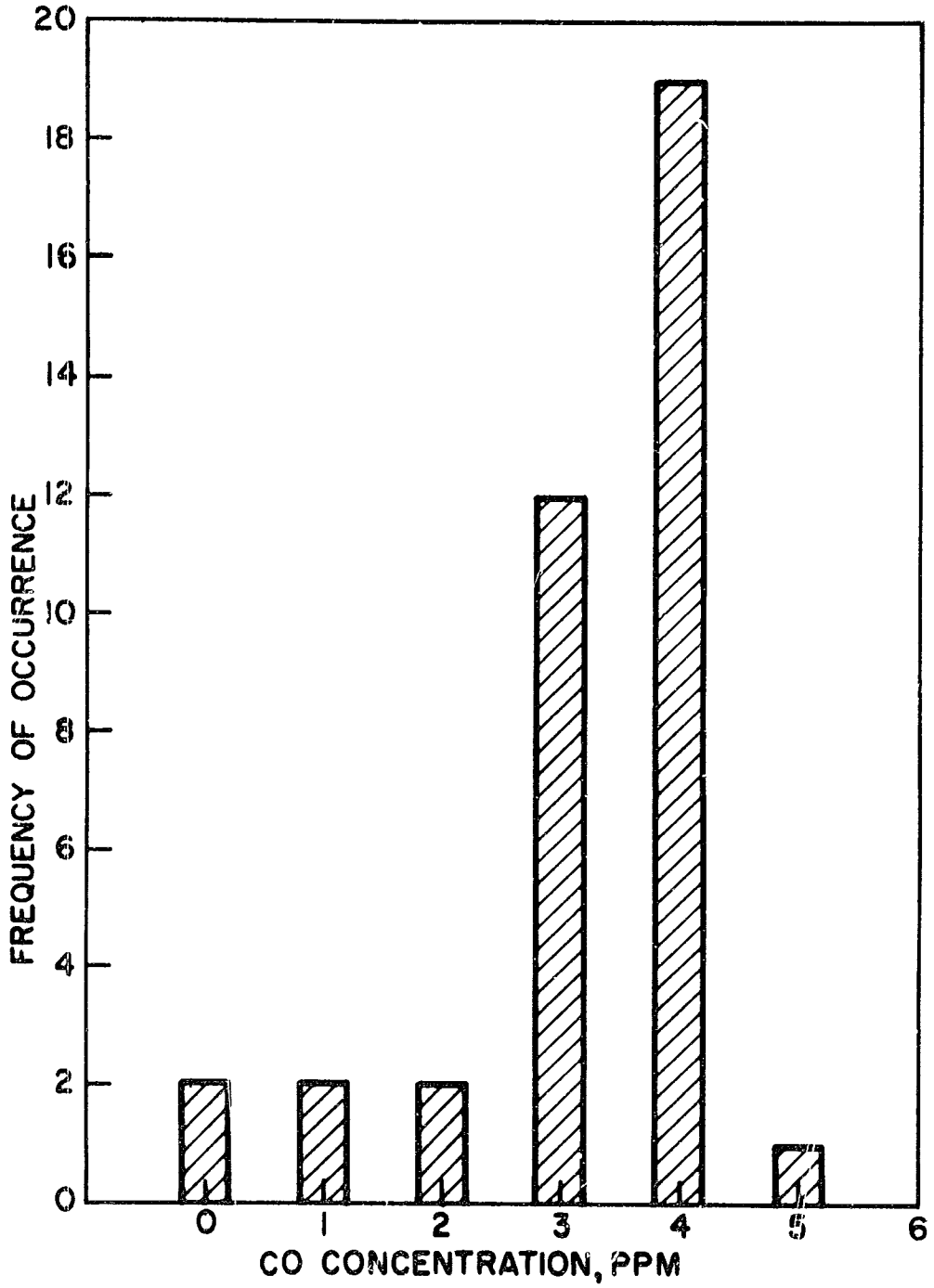

Figure F-13. Distribution of Readings Inside 1969 Volkswagen Taken After Traveling Ten Minutes at Test Speed While Carrying Top Load

REFERENCES

1. "Carbon Monoxide Concentration Test Procedure - SAE J989," Report of Automotive Emissions and Air Pollution Committee, January 1968. -- CF. Appendix A for text.

2. Dinman, Bertram D., "Basic Physiology of Carbon Monoxide," *Medical Aspects of Air Pollution*, SAE 710300, January 14, 1971, p.34.