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ABSTRACT

This report presents the findings of a voluntary program conducted over a 10-month period during which school buses were tested for carbon monoxide (CO) levels under different climatological conditions. The objective of the test program was to determine whether or not there are any serious CO intrusion problems or indications of potential problems on a small sample of the nation's school buses. The program was not designed to gather data from a statistically significant sample size; however, 645 tests were conducted in all areas of the United States, under varying test conditions, and using test equipment with different accuracies. Test results showed, based on a recommended level of 20 parts per million (PPM), that 7.2 percent of the buses tested exceeded this level, and 5.4 percent of the buses tested had maximum CO readings above 50 PPM. Recommendations included (1) development of advisories for concerned state, local, and private school bus agencies defining necessary maintenance and inspection procedures that will reduce or eliminate the CO intrusion problem; (2) promulgation of a standard defining maximum allowable CO levels for school buses; and (3) additional CO testing under controlled conditions and with an expanded data base. (Author/MLF)

NHTSA Technical Report

DOT HS-803 705

SCHOOL BUS CARBON MONOXIDE INTRUSION

Prepared by:

U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract
This report presents the findings of a voluntary test program conducted by personnel from NHTSA, the EPA, and state or private school bus agencies. The tests were conducted over a ten month period during which school buses were tested for carbon monoxide levels under different climatological conditions. The objective of the test program was to determine whether or not there are any serious CO intrusion problems or indications of potential problems on a small sample of the nation's school buses. The program was not designed to gather data from a statistically significant sample size. 645 tests were conducted in all areas of the United States, under varying test conditions, and using test equipments with different accuracies.

Test results showed, based on a recommended level of 20 parts per million (PPM), that 7.2% of the buses tested exceeded this level, and 5.4% of the buses tested had maximum CO readings above 50 PPM.

Recommendations included (1) development of advisories for concerned state, local, and private school bus agencies defining necessary maintenance and inspection procedures that will reduce or eliminate the CO intrusion problem, (2) promulgation of a standard defining maximum allowable CO levels for school buses, (3) conduct of additional CO testing under controlled conditions and with an expanded data base.

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I. EXECUTIVE SUMMARY

A. Introduction

Several carbon monoxide poisoning incidents involving school children and school bus drivers in transit (to and from school) have been reported in recent years. Each of these incidents has focused public attention on the problem of carbon monoxide intrusion into school buses. Although to our knowledge no deaths have occurred, many instances of headache, sickness, and nausea have been reported. As a result of this public concern and Congressional inquiries the NHTSA Associate Administrator, Traffic Safety Programs, requested the Office of State Vehicle Programs to develop test procedures for measurement of carbon monoxide levels in school buses and to investigate the magnitude of the problem of CO levels in school buses. The program was planned to use local, regional, Federal, and State personnel and facilities, on a voluntary basis, to perform the testing. A program plan was sent to the regions in November 1976 which defined the test objectives, test procedures, data requirements and responsibilities of OSVP and the regional offices in carrying out the test program. Response in some regions was rapid, with initial testing beginning in November 1976 and continuing through 1977. A total of 645 tests were conducted by the various regions as shown in Table 1, "Summary of Carbon Monoxide Testing by Region."

B. Test Program Objectives

The basic objective of the school bus carbon monoxide intrusion test program was to determine whether or not there are any serious CO intrusion problems or indications of potential problems in a representative sample of the nation's school buses. In order to determine the criticality of CO intrusion, field test readings of levels were taken on school buses in different regions, so that a representative sample of school buses could be tested under varying climatological conditions.

A secondary objective was to develop inspection procedures covering the mechanical condition of school buses that could contribute to high CO intrusion levels. Condition of the exhaust system, emergency door seal, and floor pan, could all have an effect on CO levels.

Other program objectives were to evaluate various carbon monoxide test equipment in field use; to obtain data from local school districts regarding carbon monoxide incidents; and to determine what effect school bus types, age of bus, and maintenance-inspection procedures might have on CO levels.

Table 1. Summary of CO Testing by Region

Region	Tests Conducted at	Number of Buses Tested	Test Results Received at OSVP
I	Connecticut, Rhode Island	33	4 Feb 77
II	New Jersey New York City New Jersey	13 16 9	15 Mar 77 Jun 77 Jun 77
III	Delaware Pennsylvania District of Columbia Prince Georges County, Maryland Anne Arundel County, Maryland Pasadena, Maryland Snow Hill, Maryland Cumberland, Maryland	47 53 33 32 15 15 12 22	Mar 77 Mar 77 Mar 77 Apr 77 Apr 77 May 77 Jun 77 May 77
IV	Georgia, Mississippi Mississippi Mississippi	12 6 6	Feb 77 Sep 77 Oct 77
V	--	--	--
VI	Arkansas Oklahoma New Mexico Louisiana	9 105 31 45	Mar 77 Apr 77 May 77 May 77
VII	Iowa	20	Dec 76
VIII	Colorado Colorado Colorado	33 20 19	Dec 76 Apr 77 May 77
IX	Hawaii	21	Sep 76
X	Washington	18	Feb 77
	TOTAL	645	

C. Test Procedures

CO readings were taken at or near the driver's position and at or near the emergency door. Previous testing had established these two locations as potential problem areas under most operating conditions. Two types of readings were taken (1) real time readings of CO levels at any given time, (2) average CO readings where a sample was collected in an air bag over a period of time and a Time Weighted Average (TWA) calculated from the sample concentration versus time.

An inspection was made of the floor pan condition at the driver's position, the emergency door, and of the exhaust system to determine if the mechanical condition of the bus contributed to the level of CO obtained during testing. When inspection discrepancies were brought to the attention of school bus maintenance personnel during the test phase, the school buses in question were returned to the school bus service area and repairs made. In some cases, it was possible to rerun a portion of the test to verify that levels had returned to normal.

D. Test Equipment

Two basic types of carbon monoxide measuring equipment were used in the testing. The first type is a manually operated suction pump device that draws a sample of measured volume through a detector tube filled with chemicals. The concentration of carbon monoxide is proportional to the length of stain shown in the detector tube.

The second type of test equipment uses an electro chemical sensor, that reacts with carbon monoxide to produce a small electrical current. The current is then amplified and fed to a direct reading meter calibrated in parts per million (PPM).

Recommended test equipment having the desired accuracies were listed in the test plan submitted to the regions. In some regions these test equipments and necessary calibration gases were available. In other regions the carbon monoxide test equipments that were available, such as suction pump devices, are relatively inaccurate at low CO concentrations. These devices display the concentration of CO by length of stain of a detector tube and require a sizeable volume of an air sample in order to obtain any reading at all. In many cases, data sheets were returned indicating zero readings whereas all buses tested with test equipment using electrochemical sensors had readings of some level.

E. Test Results

Section IX -- Data Analysis presents a detailed discussion of the various Federal, State, and industrial health organizations standards that establish maximum allowable levels of carbon monoxide under specific working conditions. These standards promulgated by EPA, NIOSH, OSHA various State agencies, and organizations such as the American Industrial Hygiene Association are primarily concerned with the health and safety of industrial workers. As of September 1978 no standard has been developed that establishes maximum allowable carbon monoxide levels for the passenger compartments of school buses. Legislation to establish such a school bus standard was introduced by Congressman Edward I. Koch as an amendment to the Clean Air Act (Congressional Record #2727 - April 1, 1976), but was not enacted into law. This amendment proposed establishing 20 PPM as a level of significance for exposure of school children to carbon monoxide. A similar level of 20 PPM was proposed by the American Industrial Hygiene Association who recommended this level as a community air quality guide for CO exposure based on a eight hour average. This reference level of 20 PPM is used in Figures and Charts of this report as a baseline, above which it is considered to be a potential health problem.

A summary of test results using this 20 PPM reference level follow:

1. The interior CO "average" PPM readings on all buses tested showed that 7.2% of the buses exceeded 20 PPM (Figure 9).

2. The interior CO "maximum" PPM readings on all buses tested showed that 20% of the buses tested exceeded 20 PPM at some time during a run (Figure 10).

3. The interior CO "maximum" PPM readings on all buses tested showed that 5.4% of all buses tested exceeded 50 PPM at some time during a run (Figure 15).

4. The major factors affecting CO levels were:
   a. ambient CO levels
   b. condition of exhaust system
   c. firewall holes
   d. window and door seals
   e. engine idle CO
   f. leaks around emergency door caused high CO readings
   g. leaking windows tended to lower CO levels
   h. firewall holes tend to increase CO levels
   i. extension of tailpipe by 6 inches beyond rear bumper resulted in lowering of readings in rear of passenger compartment
   j. Some cases of high CO intrusion in rear of bus were corrected by replacing emergency door seal

F. Conclusions and Recommendations

1. No standard exists at the present time from any government or State agency that defines the maximum allowable carbon monoxide levels in the passenger compartments of school buses.

2. Analysis of the carbon monoxide intrusion test data indicates a potentially dangerous situation exists on a high percentage of school buses based on the 20 PPM reference level as follows:

   a. 7.2% of all buses tested had "average" readings in exesss of 20 PPM.
   b. 20% of all buses tested had "maximum" readings in excess of 20 PPM.
   c. 5.4% of all buses tested has "maximum" readings in excess of 50 PPM.

   If these percentages can be projected on a nationwide basis and using average figures of the National Safety Council relative to pupil ridership, it means that on a daily basis about 2.1 million pupils would be exposed to CO levels in excess of 20 PPM and 1.6 million pupils would be exposed to "maximum" CO levels in excess of 50 PPM.

3. Carbon monoxide levels are affected by many variables which include cold weather operation with windows up and heaters on, operation in an urban area versus a rural area, age of school bus, and high altitude operation (Denver).

4. The two factors having greatest effect on CO intrusion are "idle CO level" and "compartment integrity." Factors affecting these items include defects in exhaust system, rusted areas in bus body, tailpipe too short, and leaking seals around windows and emergency door.

5. High CO levels in nearly all cases could be attributed to high ambient CO level or mechancial condition of the bus body or the exhaust system.

6. A comprehensive maintenance and inspection program is required to control CO intrusion levels.

G. Recommendations

1. Advisories should be prepared for concerned State, local and private agencies involved with school bus maintenance and inspection that recommend necessary maintenance and inspection procedures that will reduce or eliminate the CO intrusion problem.

2. Responsible Federal or State agencies should promulgate a standard defining maximum allowable CO levels for school buses.

3. A R&D program should be developed under controlled conditions and with an expanded data base to further investigate the CO intrusion problem in all school bus areas in the U.S.

II. BACKGROUND

Several carbon monoxide poisoning incidents involving school children and school bus drivers while in transit to or from school have been reported in recent years. Each of these incidents has focused public attention on the problem of carbon monoxide intrusion into school buses. Fortunately, to date no deaths have occurred, but several incidents have been reported where the school bus driver or pupil passenger required hospitalization as a result of carbon monoxide poisoning. Each of the more serious incidents generated enough public interest that the local school board in most cases authorized an extensive test program to measure carbon monoxide levels on other school buses within their jurisdiction. Three of the more publicized incidents are presented in the following paragraphs.

One incident occurred in Shelby County, Mississippi, on the morning of October 3, 1966. (Ref. 3) A boy and his sister were found unconscious at the rear of the school bus after a 45 minute ride from their house to school. Efforts to revive the children were successful and no other children suffered any visible symptoms. Examination of the bus established the fact that the end of the exhaust pipe had been partially crushed and forced out of alignment allowing the engine exhaust gases to discharge at a point several inches short of and upward toward the rear of the bus directly under the seat occupied by the two children. Within one week of the incident the Shelby County Board of Revenue and Control authorized a test program to measure carbon monoxide levels on other buses in their school system.

The carbon monoxide tester used in these tests was a Mine Safety Appliance suction pump device that draws an air sample through a glass vial filled with chemicals and measures the carbon monoxide level by the change in the color of the chemicals. Test was made at the end of each school bus run and consisted of having the tester depressing the bulb of the testing device as he entered the bus, slowing walking to rear of bus, pausing a few seconds, and proceeding to the front and out. One hundred ninety one (191) buses were tested and carbon monoxide was found in concentrations ranging from 25 PPM to 800 PPM. Of the total number of buses tested (99) tested positive for carbon monoxide. Ninety eight (98) buses had visibly defective exhaust systems beyond the engine manifold area, and seventy nine (79) buses had faults in the engine manifold area and/or visible openings in the cab firewall or floor board in the vicinity of the driver.

Another incident occurred on December 16, 1971 in Seattle, Washington. (Ref. 16) Eight children became ill on a school bus carrying a group of children enrolled in a private school. Five of the children, one of whom was unconscious, were taken to a local hospital for treatment. Symptoms included drowsiness, head ache, and nausea which were found to be due to carbon monoxide poisoning. The Seattle-King County Department of Public Health was notified of the incident and an investigation was conducted on all of the buses owned by the school. Carbon monoxide levels ranged from 10 to 25 PPM in the five buses tested. The bus in which the children had became ill had a level of 15 PPM despite the fact that the exhaust system had been repaired.

Another incident occurred in Denver, Colorado, on December 13, 1974. (Ref. 4) Thirteen children and a driver became ill as a result of overexposure. After a brief hospitalization, all were released with no harmful after effects. Of interest in this case was the fact that even though the bus was equipped with carbon monoxide detector buttons, the buttons did not change color as they should have when exposed to a critical carbon monoxide level. Inspection of the bus disclosed a defective rear door seal and intrusion points near the driver at the brake and accelerator pedals.

There are many factors that affect carbon monoxide intrusion into school buses. The necessary frequent stops and relatively low speeds at which buses travel is a factor, particularly if the exhaust system is damaged in any way. When in motion, a school bus displaces a large amount of air thus creating a high pressure area immediately behind the bus which forces exhaust gases into the bus through any opening at or around the emergency door. Leakage of carbon monoxide from defective exhaust heat riser valves or exhaust manifold may be as serious as leakage from a defective muffler or tail pipe that is too short and does not project beyond bus frame. Openings around the accelerator, brake, and clutch pedals permit intrusion of carbon monoxide from the engine compartment.

III. TEST PROGRAM OBJECTIVES

The basic objective of the test program was to determine whether or not there are any serious CO intrusion problems or indication of potential problems on a representative sample of the nation's school buses. In addition to this basic objective, the secondary objectives are:

1. Determine carbon monoxide levels in school bus interiors under varying operating conditions.
2. Determine the effect of climatological and environmental factors on carbon monoxide levels in school bus interiors.
3. Determine what effect school bus types, age of bus, and inspection/maintenance procedures have on school bus CO levels.
4. Develop inspection procedures and operating maintenance procedures for a school bus interior carbon monoxide testing program.
5. Perform analysis of data variants to determine trends, indicative of a safety problem if any.
6. Obtain data from local school districts regarding carbon monoxide incidents that would indicate excessive CO levels in school bus interiors.
7. Develop proficiency training procedures for school bus drivers to include operation of Carbon Monoxide test equipments, recognition of CO poisoning symptoms, and school bus inspection techniques to detect exhaust system faults.

NOTE: The program was designed to be voluntary with no intention of gathering a statistically significant sample size. It was hoped that there would be wide enough participation to be somewhat representative of the general condition of CO in school buses.

IV. SOURCES OF CARBON MONOXIDE

Exposure to carbon monoxide by the driving population comes primarily from three sources: the atmosphere, vehicle exhaust, and smoking. In 1968 it was estimated that 102 million tons of CO were released into the atmosphere by the major sources of emission (U.S. Department of HEW, Pub. No. AP-62, 1970). Over one-half (58%) was produced by automotive engines. Other major sources include refineries, foundries, paper mills, and other manufacturing plants.

A study conducted in 1973 by the Department of Environmental Medicine, Medical College of Wisconsin sought to determine the range of carboxyhemoglobin (COH_b) in various segments of the population of the United States. (Ref. 5) Blood samples were taken from 30,525 adults at different blood banks. About 45% of the non-smoking blood donors tested had COH_b saturations greater than 1.5 percent with 90% of the range between 0.4 and 3.7 percent. Fifty one percent of the smoking blood donors had COH_b saturations greater than 4.5 percent with 90% of the range between 0.9 to 10.4 percent. Other factors found to influence the COH_b saturation were the geographical location of the individual, his occupation, and meteorological conditions. Persons sampled in urban areas with high automobile density consistently had COH_b levels greater than those measured in persons sampled in areas of low automobile density. Figure 1 "Carbon Monoxide Blood Levels" shows the cumulative distribution of the Blood CO Concentration. (Ref. 5 - Page 24)

The amount of CO measurable in rural areas is relatively small, but can reach very high levels in urban areas. Measurements made in 1950 at the intersection of Park Avenue and 45th Street in New York City reached an average hourly reading of 17 PPM during morning traffic, with a range of 19 to 95 PPM during evening rush hour traffic. Similar tests conducted in Chicago attained readings of 21 PPM and 71 PPM during same time spans. Highest readings were attained in Los Angeles where peak CO concentrations reached 120 PPM with ranges of 20-30 PPM being consistent throughout the year. Results of a survey (14) conducted by U.S. Department of HEW (1970) which took data from various sources and combined and categorized the data into six types of areas, after which a uniform maximum eight hour averaging time concentration was calculated, is shown in Figure 2. Figure 3 shows the concentration and duration of continuous CO exposure required to produce specific blood COH_b concentrations in healthy adult males under non-working conditions.

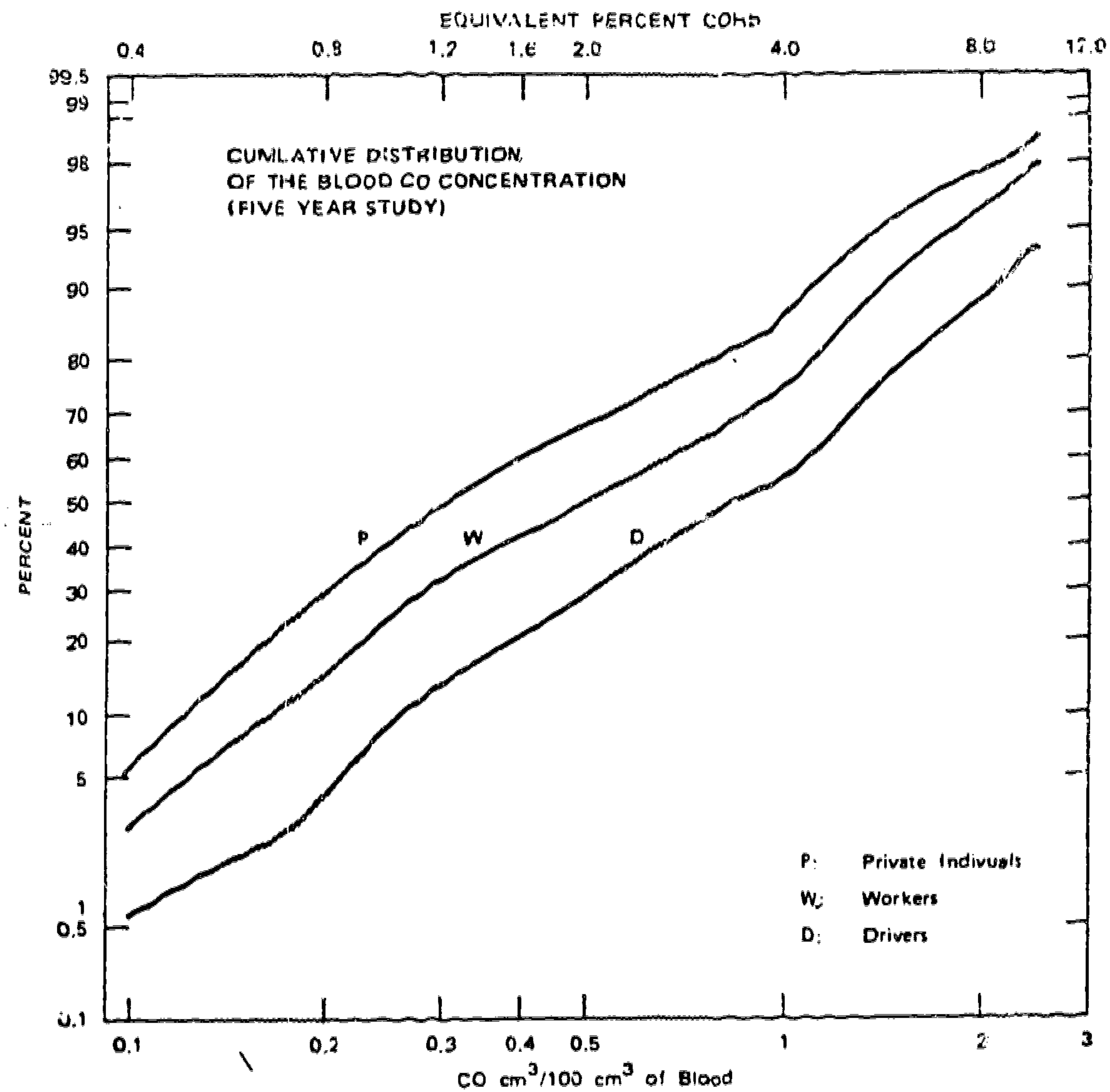

FIGURE 1. CARBON MONOXIDE BLOOD LEVELS
(Ref. 5 - Page 24)

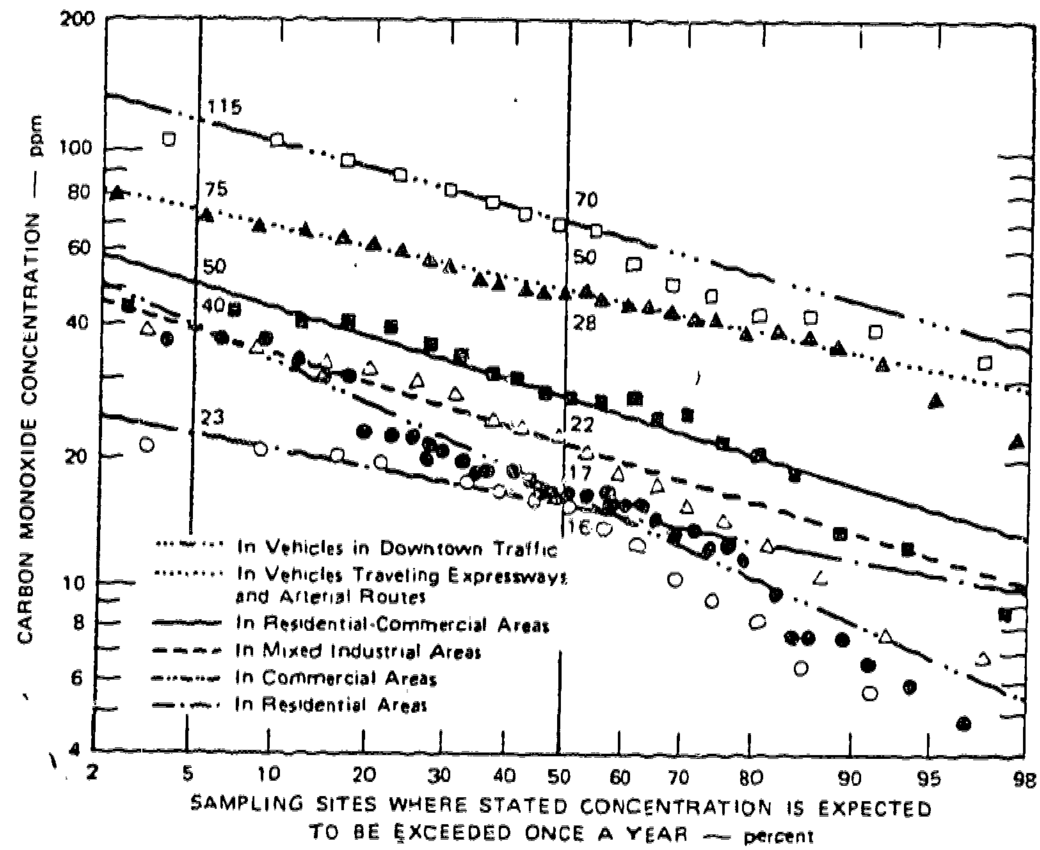

FIGURE 2. MAXIMUM ANNUAL EIGHT HOUR AVERAGING TIME CONCENTRATIONS OF CARBON MONOXIDE EXPECTED AT VARIOUS TYPES OF SITES (Ref. 5, pg. 23)

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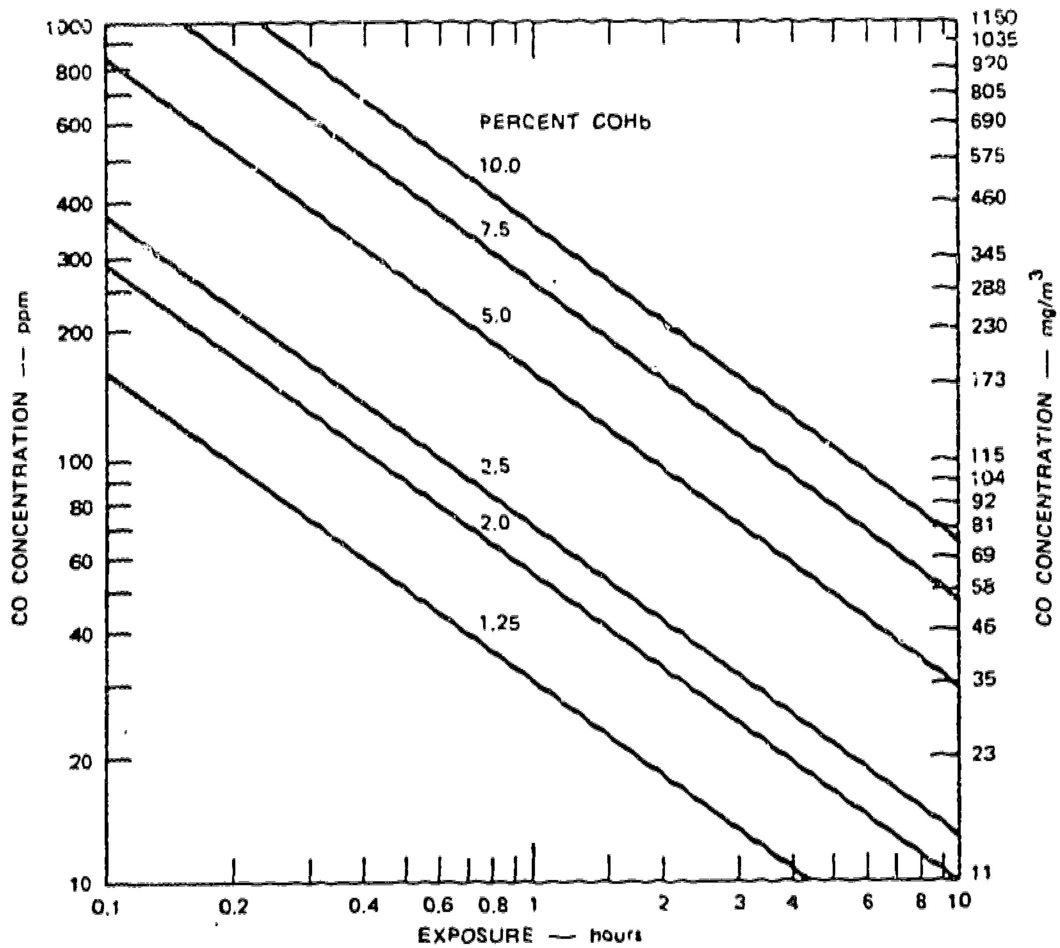

FIGURE 3. CONCENTRATION AND DURATION OF CONTINUOUS CO EXPOSURE REQUIRED TO PRODUCE BLOOD COHb CONCENTRATIONS OF 1.25, 2.0, 2.5, 5.0, 7.5, AND 10 PERCENT IN HEALTHY MALE SUBJECTS ENGAGING IN SEDENTARY ACTIVITY
(Ref. 5 - Page 22)

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V. PHYSIOLOGICAL EFFECTS OF CARBON MONOXIDE

A. Background

Carbon monoxide is a colorless, odorless, non irritating gas produced under conditions of incomplete combustion of hydrocarbons. The toxic effects of carbon monoxide are due to the combination of this gas with the hemoglobin of the blood. Hemoglobin is the substance contained in red blood cells which is responsible for the transport of oxygen. Oxygen passes into the lungs where tiny air sacs, richly supplied with blood, diffuses it into the red blood cells. Once oxygen enters the red blood cells, it forms a bond with the hemoglobin of the cells and is transported in this manner to the tissues of the body where it is released for tissue consumption. Oxygen is a basic requirement for human life and must be supplied in proper amounts in order for the body tissues to perform their functions. Carbon monoxide, however, also forms a strong bond with the hemoglobin of the blood. Since CO has 200 to 300 times the affinity of oxygen for hemoglobin, a small amount of CO rapidly and more avidly combines with hemoglobin than does a larger quantity of oxygen. This combination of CO with hemoglobin (H_b) forms the substance carboxy hemoglobin (COH_b) which very effectively blocks the uptake of oxygen by hemoglobin. The ultimate result is lack of oxygen for the tissues and different levels of physical impairment depending on the percentage of COH_b.

B. Effects of CO on Driver Performance

Many studies have been conducted on the effects of carbon monoxide on driver performance. (Ref. 6, 7, 8, 9, 10, 11, 12) These studies have generally been single task oriented experiments conducted on healthy young males and dealt primarily with testing sensory perceptions and motor activity under varying concentrations of carbon monoxide and time exposure. Adverse effects on human performance show up as low as 5 percent COH_b concentrations and become progressively more deleterious as concentrations increase beyond 20 percent COH_b. J.H. Schulte found impairment of the higher centers of the central nervous system which controls some of the cognitive and psychomotor abilities, at levels below 5 percent COH_b. Groll-Knapp found significant effects in an acoustical vigilance test at about 3 percent COH_b. (Ref. 5)

In addition to the general tests, an entire series of visual tests have been developed to measure the effects of CO. Flicker fusion tests have resulted in conflicting findings. Some researchers found significant effects at 5 to 10 percent COH_b and 16 to 20 percent COH_b while other researchers could not find any effect in range of 5.3 to 12.9 percent COH_b. One researcher observed a decrease in performance from 3 to 5 percent with a return to normal at 7-1/2 percent COH_b. (Ref. 11)

Other visual tests that were studied for the effect of CO include visual acuity at low levels of illumination, dark adaption, and differential brightness sensitivity. It was observed that since CO reduces the oxygen supply, deprivation by CO hampers the ability to see at night. The brightness threshold was affected at a level of 4.5 percent COH_b, and the ability to match the intensity of two light sources was affected at 20 percent COH_b.

R.A. McFarland in a paper before the 1971 Automotive Air Pollution Research Symposium (Ref. 12) identified the three most critical factors in the driving task as (1) depth perception, (2) the ability to recover from bright light sources, (3) the ability to assimilate a variety of visual stimuli emanating from different parts of the environment. While performing central and peripheral vision tests at COH_b levels of 6, 11, and 17 percent it was found that when stimuli was presented in both the central field of view and the peripheral field of view (within one second of each other) the central vision information was acted on while the peripheral vision information was missed or not acted upon. Missing information or not acting on information increased as the COH_b levels increased. Both field of view deteriorated as the COH_b level increased, with the central vision being the least affected. The glare recovery threshold was found to increase at COH_b levels of 6 and 11 percent. However, depth perception was not affected even when CO was administered to levels 3.4 percent above the individual's existing level. (Ref. 5)

C. Driving Performance Tests Under Controlled Conditions

In order to obtain more realistic test results, researchers have conducted driving tests under varying CO exposure conditions. Unlike the single oriented experiments of the preceding section, these tests were designed to measure the effect of CO while a subject was simultaneously performing the multiple tasks involved in driving. Personnel being tested drove or rode for 90 minutes in heavy traffic where CO levels reached 16 to 62 PPM. Tests were then conducted in the laboratory. It was found that during simple reaction time tests, the reaction time, for both healthy young males that were driving and middle age hypoxic subjects riding as passengers, significantly increased. (Ref. 9)

In another series of tests conducted at night, three subjects were exposed to CO to bring their COH_b levels of 0, 10, and 20 percent respectively. Sensory performance tasks, normal driving tasks, and psychomotor driving performance was evaluated. Sensory performance tasks included time estimation, distance estimation, tail light and brake light brightness, and headway and peripheral detection. Normal driving tasks included repetitive cornering, gas pedal reversals, velocity, and road exit velocity. Psychomotor driving performance tests included speed holding with and without the use of a speedometer lane position, lane position with speed holding without use of the speedometer, and maintaining constant headway with the lead car driven at oscillating speeds. (Ref. 5)

VI. HISTORY OF CARBON MONOXIDE TESTING

Several tests have been conducted in recent years to measure carbon monoxide levels in school buses and passenger cars. Some of the tests were conducted under contract for the NHTSA, and others were performed by school districts or public health units. Tests were conducted in different areas of the country under varying climatic conditions and traffic densities. In some tests a complete mechanical inspection of the school bus being tested was conducted so that carbon monxide levels could be correlated with mechanical condition.

One test of carbon monoxide levels was conducted by Automotive Research Associates for NHTSA in 1972 (DOT-HS-001-1-161). (Ref. 1) The objectives of this test were to measure school bus interior carbon monoxide levels and to relate these levels to contributing factors. A total of 102 school buses were tested at Los Angeles, San Antonio, and New Orleans. Carbon monoxide levels were measured on all buses in an "as received" condition, and then measured with the tailpipe or the exhaust manifold disconnected in order to simulate exhaust system defects. A summary of test results follows:

1. Interior CO levels exceeded 25 PPM on 8% of the buses tested.
2. Interior CO levels of buses which exceeded 25 PPM averaged 36.8 PPM.
3. Interior CO levels exceeded 65 PPM on 1.8% of the buses tested.
4. Up to 25% of the school bus population could produce CO levels in excess of 65 PPM with exhaust system failures.
5. In some cases exposure levels can exceed 500 PPM in 66 passenger buses.
6. The most influential factors affecting interior CO levels are engine idle CO, firewall holes, window and door seals, and gross exhaust system defects.

Table 2 is a summary of the geographical effects on interior carbon monoxide (ICO) levels and shows percentages of buses which have significant ICO levels.

Area	Buses Tested	Average ICO As Received	Buses with ICO Over 25 PPM Actual/Percent		Average ICO Buses Over 25 PPM
1-Los Angeles	52	5.3	6	11.5	27.2
2-New Orleans	37	3.8	1	2.7	77.5
4-San Antonio	23	4.5	2	8.7	35.3
	112	4.6	9	8.0	36.8

Table 2. Summary of Buses with ICO over 25 PPM
(Ref. 1 - Page 9)

Table 3 is a summary of buses with ICO levels over 65 PPM. A carbon monoxide level of 67 PPM is considered to be the threshold limit which can cause carboxyhemoglobin saturation about the 10 percent level in healthy adult males.

		Number Buses Over 65 PPM					
Area	Buses Tested	As Received No.	As Received Percent	With Tailpipe Defect No.	With Tailpipe Defect Percent	With Manifold Defect No.	With Manifold Defect Percent
1-Los Angeles	52	0	0	2	3.7	20	38.5
2- New Orleans	37	1	2.7	0	0	3	8.1
4-San Antonio	23	1	4.3	3	13.1	5	21.7
	112	2	1.8	5	4.5	28	25.2

Table 3. Summary of Buses with ICO over 65 PPM
(Ref. 1 - Page 10)

In 1972 the Seattle Department of Health conducted a test on two fleets of buses (Ref. 16.). The first fleet of five buses was owned by a private school and had been involved in a CO poisoning incident in December 1971. An investigation disclosed that all five buses owned by the school had significant levels of carbon monoxide in the passenger compartment ranging from 10 to 25 PPM with a mean value of 15 PPM. As a result of this incident a broader investigation was conducted involving 200 school buses used in a ski school program on

Saturday and Sundays. CO levels were measured at arrival at the ski site, Snoqualmie Pass, to determine in transit levels of CO. Of the 33 buses tested, four exceeded the EPA maximum allowable concentration for an eight hour exposure. A second test was conducted on 64 buses as they sat idling in the parking lot during the lunch hour when the students returned to the buses to have their lunch and to rest. Table 4 is a summary of CO levels measured during this test.

	Number of Buses	Carbon Monoxide PPM	Percent of Total
	20	0	31
	21	1-8	32
	17	9-34	26
	3	35-49	5
	4	50-100	6
Total	64		100

Table 4. Carbon Monoxide Levels Inside Buses Parked With Engines Idling at Snoqualmie Pass During the Lunch Hour (12 to 2 PM)
(Ref. 16)

In 1976 a member of Congressman Edward I. Koch's (D-N.Y.) staff conducted a test of carbon monoxide (CO) levels on New York City school buses (Ref. 4). In 93 out of 105 tests signficant levels of CO were measured (in excess of 20 PPM). This level is considered significant when compared to the EPA standard for carbon monoxide in industrial areas, where permitted levels are 9 PPM for a one (1) hour exposure period in ambient air and 35 PPM for a one (1) hour period in an enclosed industrial area. Table 5 is a summary of these tests; CO levels were measured in the rear of empty buses, with windows closed, after about 20 minutes running time.

Number of Buses	Carbon Monoxide PPM	Percent of Total
6	0	5.7
6	1-8	5.7
26	9-34	24.8
47	35-49	44.7
20	50-100	19.1
		100.0

Table 5. Carbon Monoxide Levels of New York City Levels of New York City School Buses (1976) (Ref. 4)

As a result of an incident involving two school children who were overcome by carbon monoxide while in transit to school, the Shelby County, Alabama Board of Education conducted a test of carbon monoxide levels on their school bus fleet in October 1966. (Ref. 3) One hundred ninety-one (191) buses were tested. CO was found in concentrations ranging from a trace (25 PPM) to 800 PPM. Exposure time on each bus averaged 56 minutes. Of the total number of buses tested, 99 tested positive for carbon monoxide, 98 had visibly defective exhaust systems beyond the engine manifold area, and 79 buses had visible openings in the cab fire wall or floor board in the vicinity of the driver. The conclusions reached as a result of the test were, quote, "The data gleaned from this investigation establishes absolute correlation between a defective engine exhaust system and the presence of carbon monoxide in the atmosphere of the vehicles tested, and the large number of defective exhaust systems on relatively new buses operating under an orderly and efficient maintenance program seems to indicate the need for a comprehensive test program by bus chassis manufacturers to determine if the traditional and standard point of exhaust discharge, that is, a long tail pipe terminating at the rear of the vehicle is, in truth, the optimum point. The point of discharge is at a point just below the school bus emergency door which presents the possibility of entry of exhaust gases around the door unless the door is completely sealed." Drivers were not questioned about any symptoms but several volunteered statements that they had headaches or dizziness when they drove their buses. Several said that they had children get sick on the way to school.

An investigation of the concentration of carbon monoxide within the passenger compartment of motor vehicles was conducted by the Transportation Systems Center in 1971. (DOT-HS-829-202) (Ref. 7) This test involved six passenger cars of 1968-1971 vintage. Each vehicle was instrumented so that the ambient CO level outside the vehicle could be sampled simultaneously with the CO levels at various points inside the passenger compartment. Trunk tests were made while driving at 30 and 60 mph with different configurations of passenger car openings, at idle with passenger compartment openings closed, and using road and dynamometer tests to determine exhaust CO concentrations at typical road loads and speeds. CO concentrations for all vehicles tested were quite low under most conditions. One vehicle had 10 percent of its readings above 30 PPM during the 2 minute driving test. Different configurations were tested to determine any change in CO levels:

1. Air deflectors used on 2 station wagons reduced somewhat the CO levels in the passenger compartments.

2. One vehic' had excessively high CO readings when driving test was run with trunk open.

VII. TEST DESCRIPTION

The major objective of this NHTSA sponsored test program was to measure ambient levels of carbon monoxide in the passenger compartments of school buses under normal operating conditions. Secondary objectives were to determine the points of intrusion of carbon monoxide and to correlate the mechanical condition of the school bus with the CO level measured during testing. Testing was conducted under all possible conditions such as:

1. Cold weather operation with windows closed and heaters operating.

2. Warm weather operation with windows down.

3. School buses waiting in line, engines idling, to pick up pupils at school.

4. Short duration runs in urban areas with high ambient CO levels.

5. Long duration runs in urban areas with low ambient CO levels.

Since previous testing (Ref. 1, 7) had established that the two major areas of CO intrusion were the emergency door area and the firewall area near the driver; most readings were taken at or near these two areas. A special probe was utilized so that CO levels could be measured at the firewall gear shift boot, accelerator, and brake pedal holes in floorboard, and at the rubber seal on the emergency door. Significant elevation of CO levels were noticed whenever an intrusion point was found. Two types of samples were taken:

1. A real time meter reading that would reflect actual CO levels at any point in time.

2. An average CO reading over a one-half (1/2) to one (1) hour period.

It is necessary to measure both kinds of carbon monoxide levels to properly correlate with the CO maximum allowable levels established by EPA, under provisions of the Clean Air Act (PL 91-604). These primary and secondary standards established by the Act are:

1. 9 PPM - maximim eight hour concentration not to be exceeded more than once a year.

2. 35 PPM - maximum one hour concentration not to be exceeded more than once a year.

The EPA standard was based on criteria presented in the Air Quality of Carbon Monoxide (35 F.R. 4768). The specific data upon which the EPA based the CO standard was primarily the work of Beard and Wertheim who presented evidence that low levels of carboxy hemoglobin in human blood may be associated with impairment of ability to discriminate time intervals.

Air sampling techniques varied widely from area to area. In most cases test equipment had to be borrowed from OSHA, EPA, or a local department of health. Consequently, many different types of carbon monoxide test equipment, with different accuracies, were utilized in testing. Some of the test equipments, particularly the suction pump types, do not read below 10 PPM so the validity of some of the data received, that indicated no reading, is questionable. In many cases only one reading was taken on each school bus. This reading was generally taken after a few minutes of running the bus at idle in a school yard, without pupils aboard or the heaters on, so these readings, which generally fell between 0 PPM and 10 PPM, did not reflect true operating conditions.

Some readings were taken using test equipment that utilized potentiostatically controlled electrochemical sensors giving a high accuracy. This equipment which displays the reading on a direct reading meter can be calibrated using a calibrated gas to a $\pm$ 2% accuracy. A special gas collection system was borrowed from EPA for use in obtaining air samples over an extended period. This collection system, consisting of a collection bag and a battery operated pump, was placed at the front or rear of the bus and run for the desired period. The collection bag was then disconnected from pump and the output fed to CO test equipment to get a PPM reading. The time weighted average (TWA) for a one hour concentration of CO could then be calculated.

Visual inspection of the school buses was performed in many, but not all of the test runs in order to determine the mechanical status of the school bus being tested. The mechanical condition of the exhaust system was an area of primary interest. A study performed for NHTSA on 1975, DOT-HS-4-00947 "Survey of Safety Related Conditions in School Buses" identified the following problem areas as common to many school bus exhaust systems.

1. Cracking of the "Y" pipe leading from the exhaust manifold. The cracking occurred at the point where the two arms of the pipe join.

2. "Pull Apart" condition where exhaust members join.

3. Bowing or bending of the tailpipe as a result of uneven expansion as the hot pipe is exposed to splashing water.

4. Hangar breakage. Failure of the exhaust pipe hangar brackets permits the pipe to hang unsupported and, in certain cases, contributed to the occurrence of "pull apart" problems. In one case, a failure of a hangar bracket resulted in the tailpipe abrading air brake lines to the rear wheels.

A simple leak check was used to inspect these types of failures. The tailpipe was temporarily blocked with a rag and a carbon monoxide probe attached to the CO tester was brought to close proximity of each joint or connection to determine if there was a leak. In addition, a visual check was made to determine the presence of such conditions as rusted out muffler or tailpipe, crushed tailpipe, broken hangars, or a tailpipe that did not project beyond the rear of the bus. The area near the driver was also thoroughly inspected for rust or holes in the firewall around the clutch, brake, accelerator pedals or at the gear shift boot that could represent a possible intrusion point. The emergency door seal was visually checked for evidence of deterioration or tears that would provide a path for CO to enter the bus. Due to the aerodynamic configuration of most buses, a low pressure area exists at the rear of a school bus, so that a leak at the emergency door combined with the pressure differential between the inside and the outside of the bus, provides ready intrusion for exhaust gases coming from the tailpipe located a few feet away.

Test were conducted by personnel from OSVP, and the Regional offices of NHTSA. Since the program was unfunded, no monies were available for contracting. Regional personnel were responsible for coordinating all activity with their region to conduct the testing. This effort involved determining suitable test sites within their respective regions to meet the desired mix of urban and rural operations, and soliciting the support of local Departments of Education, Health, or Motor Vehicles in cooperating with and participating in the program. Test equipments were acquired from EPA, OSHA, or local Health Departments. In some cases personnel from the regions, local Boards of Education, local Health Departments, and State Superintendents of Pupil Transportation rode the buses and operated the test equipment.

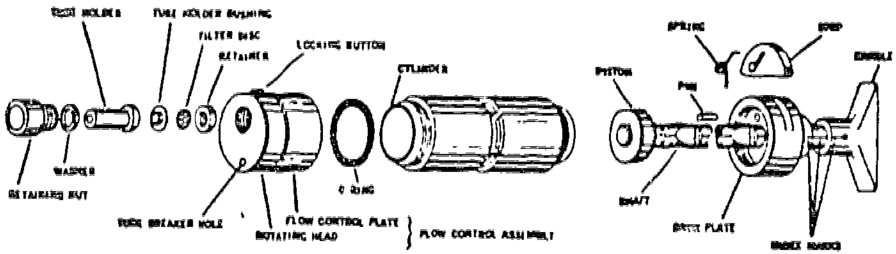
VIII. TEST EQUIPMENT

Two different techniques are used to measure carbon monoxide levels. Some equipment uses a manually operated suction pump device to draw an air sample over a chemical detector tube. The concentration of carbon monoxide is then measured by evaluation of the change in color of the chemicals or the length of stain created by the chemical reaction with CO. The second and most accurate method uses a potentiostatically controlled sensor. In this system, ambient air is continuously drawn over a catalytically active electrode where the CO present is oxidized to CO_2. The output signal is then electronically amplified and displayed on a direct reading meter in PPM.

Sampling pump devices are made by several different manufacturers. One type device is shown in Figure 4. These devices draw an air sample of measured volume through a chemical detector tube. The detector tube contains potassiumpalladosulfite which changes from yellow to brown depending on the level of carbon monoxide. Each detector tube is calibrated for use only in a particular manufacturer's device, and cannot be used with accuracy in different manufacturer's test devices. For use the glass detector tube is inserted into the sampling pump and both ends of the tube are cut off to provide a path through the pump for CO. The volume of the air sample is determined by the number of pump strokes used. As shown by the chart as the number of strokes are increased, the scale of measurement is changed. As can be seen on Figure 5 scale for 1 pump stroke, 1 inch represents almost 350 PPM. Whereas for 5 pump strokes, 1 inch represents about 70 PPM.

Another type of suction pump device uses an etched scale to measure the length of stain and then translate that length to percent (%) of carbon monoxide depending on the number of pump strokes taken (Figure 6).

The second type of carbon monoxide measuring device uses a sensor which is similar to the battery in a passenger car. It has a positive and negative terminal electrolyte, and it produces electrical energy from chemical energy. The cell produces electric current in the presence of carbon monoxide (CO). Carbon monoxide gas contained in the air being sampled is pumped from the intake, through a humidifier, and filter to the sensor cell as shown by Figure 7 - Model 70 Flow System Diagram.



The Universal Sampling Pump is an integral part of:
MSA Universal Testing Kit, Model #1, Part No. 83500
and
MSA Universal Testing Kit, Model #2, Part No. 83498

The Universal Sampling Pump is designed to permit the measurement of toxic gases and vapors for which a variety of detector tubes have been developed. Dusts, fumes, and mists, for which detection media have been developed, may be measured with the use of available accessories.

Remote Sampling —(using metal connecting tube) May be accomplished by placing detector tube in the remote end of the sampling line.

Note: For complete list of all available detection media see Summary Data Sheet, Part No. 994098.

DESCRIPTION

The MSA Universal Sampling Pump is a manually operated "piston type" pump of 100 cc air sample capacity.

Rotating Head — A rotating head on which a rubber "tube holder" is mounted permits air sampling at any of 4 distinct rates of flow through orifice holes in a stationary flow control plate. Thus, an optimum flow rate is selected for sampling any of the various contaminants for which tests can be made. The instructions included with individual packages of tubes and reagent kits list the required orifice setting. A tube breaker hole is located on the face of this part.

Flow Control Plate — The orifices in the flow control plate are individually sealed from the atmosphere by means of "O" rings. Index numbers engraved on the flow control plate relate location of orifices to the pump inlet. Rate of air flow into cylinder is controlled by that orifice which is open to the inlet in the rotating head. A spring-loaded locking button on the rotating head guarantees positive alignment between the pump inlet and selected orifice during testing procedure. Always hold locking button in forward position when turning rotating head to prevent shearing locking pin.

Filter Disc — A stainless steel porous metal disc mounted in a rubber retainer is seated in the rotating head beneath the tube holder. This serves as a filter to protect the orifices from particles of dust or dirt which might block the orifices and alter the flow rates.

Shaft — The piston shaft is calibrated at 4 volume positions, i.e., 25, 50, 75 and 100 cc volume positions. The shaft can be automatically locked in position at these volumes by means of a spring-loaded stop mounted in the back plate of the pump.

Figure 4. Universal Sampling Pump

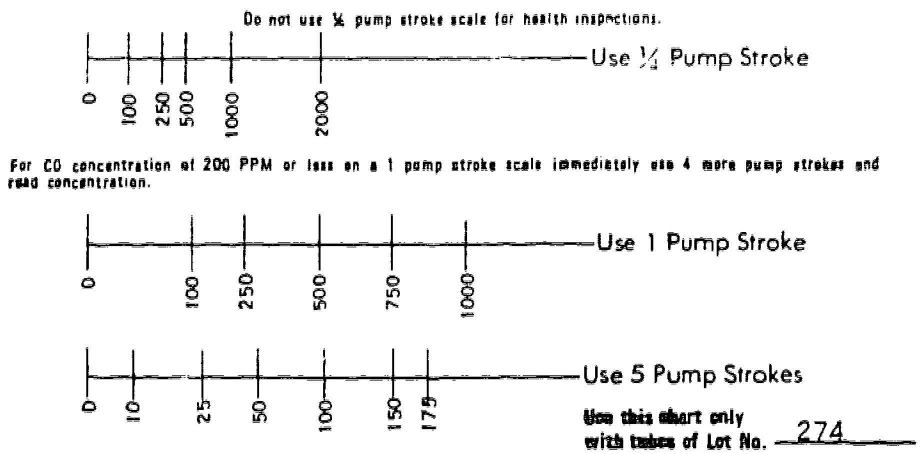
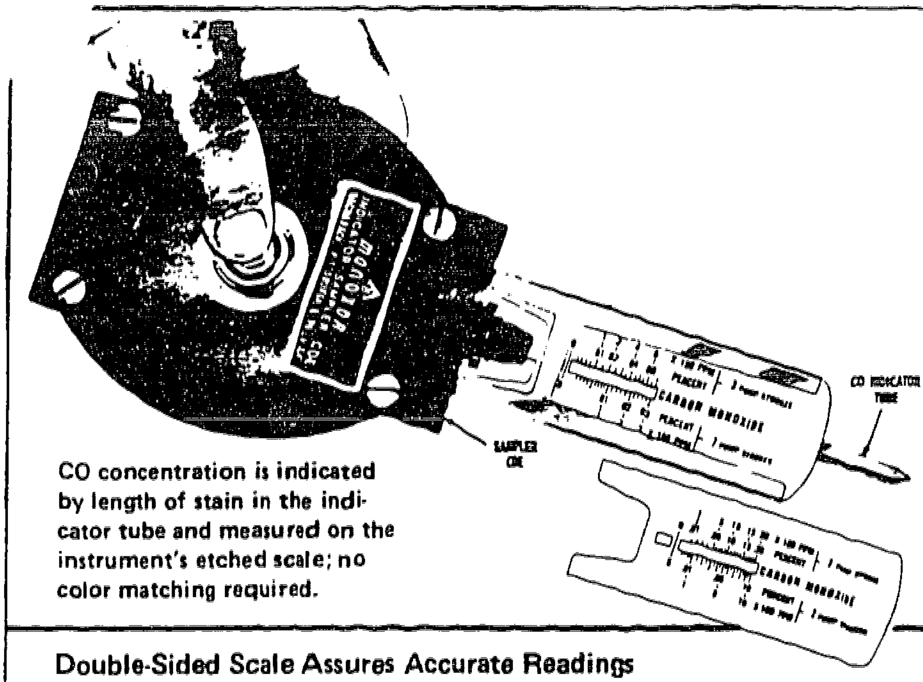


Figure 5. Calibration Scales -
PPM By Volume

Another type of suction pump device uses an etched scale to measure the length of stain and then translate that length to percent (%) of carbon monoxide depending on the number of pump strokes taken (Figure 6).



CO concentration is indicated by length of stain in the indicator tube and measured on the instrument's etched scale; no color matching required.

Double-Sided Scale Assures Accurate Readings

The etched metal scale of the MONOXOR is double-sided with the CO range segmented for use with 1 or 2 aspirator pump strokes on one side, and 3 or 7 pump strokes on the other side. Reversing the scale is a simple operation. Optimum scale readability is afforded by selecting the number of pump strokes which will produce the longest measurable length of stain for the CO concentration involved. In the table below are listed the scale ranges for the various aspirator pump strokes with the 0.2% CO MONOXOR.

ASPIRATOR PUMP STROKES	0.2% CO MONOXOR using 19-5010 TUBE CARBON MONOXIDE SCALE RANGE PERCENT	PARTS PER MILLION
1	.005 to .2%	50 to 2000 ppm
2	.002 to .1%	20 to 1000 ppm
3	.001 to .07%	10 to 700 ppm
7	.0005 to .03%	5 to 300 ppm

For the 0.5% CO MONOXOR (using 19-5015 Tube) the CO scale ranges are .005 to .5%, .002 to .25%, .001 to .17%, and .0005 to .07% for 1, 2, 3 and 7 aspirator pump strokes respectively.

Figure 6. CO Concentration Suction Pump Device

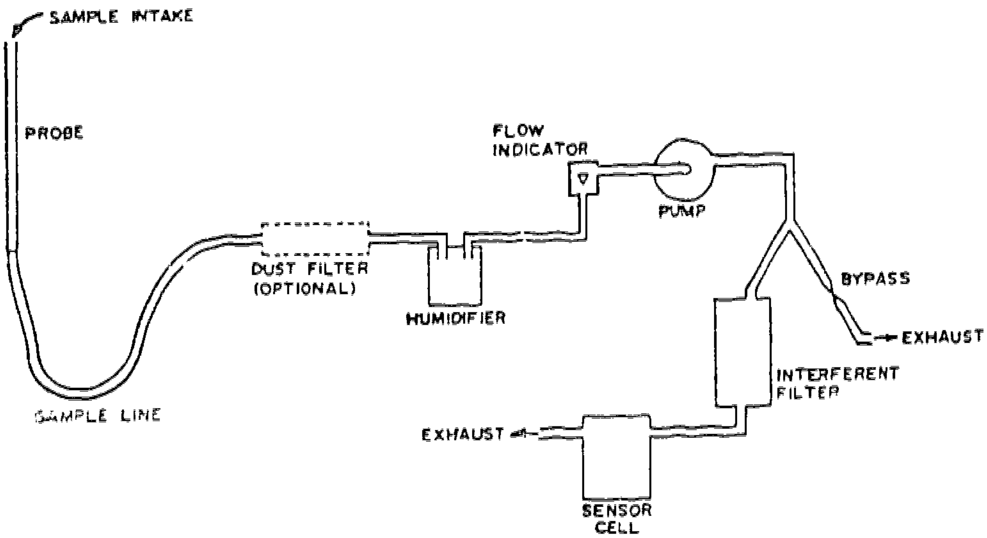


Figure 7. MSA Model 70 Flow System Diagram

The function of the CO Analyzer is to measure and display the level of carbon monoxide (CO) in the ambient air. It accomplishes this by drawing in and analyzing the air by means of an electrochemical sensor. The sensor produces an electrical current output whose magnitude represents the level of CO in the sampled air. The resulting current causes a meter indication showing the level of CO in parts per million (PPM).

As shown in Figure 8, the electrochemical sensor in the CO Analyzer contains a sensing electrode, a counter electrode, a reference electrode, and sulfuric acid solution as the electrolyte. The electro-oxidation of carbon monoxide occurs at the sensing electrode, and the counter electrode acts as the cathode where oxygen reduction occurs. The current caused by the electrochemical oxidation of carbon monoxide flows between the sensing and the counter electrodes. The reference electrode is required for the operation of potentiostat but no signficant current flows through this electrode.

The potentiostat maintains a constant potential difference between the sensing and reference electrodes and supplies the power required for the electrochemical reaction. The anode potential is maintained at 0.15V versus the reference electrode. When air is pumped into the sensor, it is passed over the back (gas side) of the anode. The carbon monoxide diffuses to the electrocatalytic surface where it is electro-oxidized. The resulting diffusion limited current flowing between the sensing and counter electrodes is proportional to the carbon monoxide concentration in the sampled air. The carbon dioxide formed by the electrochemical reaction is removed continuously from the sensor cell at the same rate that it is formed.

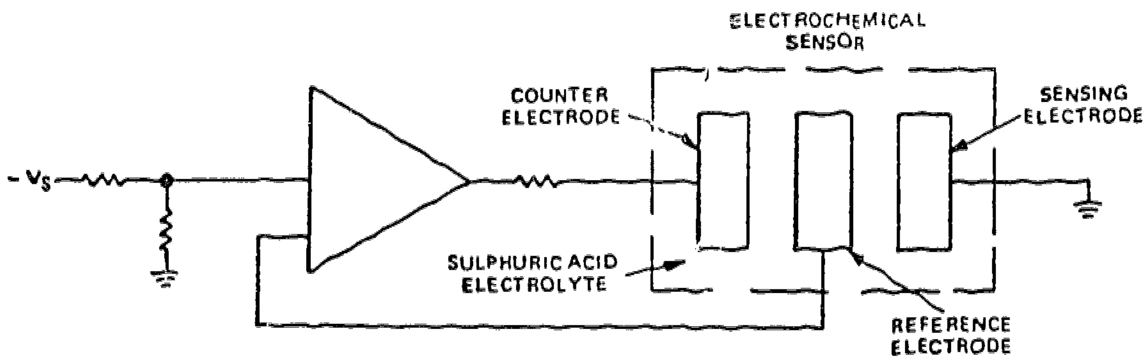


Figure 8. Potentiostat and Sensor Cell, Simplified Diagram

IX. DATA ANALYSIS

A total of 645 data sheets were received from different NHTSA Regions. Although data was received from all but one Region, some of the major metropolitan areas and the State of California were not represented. The test procedures and test equipments used to obtain carbon monoxide readings varied widely from Region to Region. In some cases (87) only suction pump type test equipments using the calibrated chemical vial were available. As covered in the section on test equipments the calibration scale of some of these equipments is 0-100 PPM in a measured length of stain of about 1/4 of an inch. The accuracy of readings taken with this equipment, particularly for readings below 20 PPM, is doubtful because a reading of 20 PPM which is considered to be a significant exposure would represent little more than 1/16 inch on the scale. Other detector tubes do not read below 10 PPM. About half of the 87 data sheets received using the detector tube method recorded a zero reading, and 23 others gave readings between 6 and 10 PPM, giving 63 test readings below 10 PPM.

Two different types of data were obtained. Data was categorized as "maximum" where only one reading was taken on a school bus either by use of suction pump type test equipment or by direct meter reading equipment. Data was categorized as "average" where several readings were taken at different time intervals during the school bus run, and then averaged over the period of time of the run to obtain an hourly - Time Weight Average (TWA). Since both methods were used during testing the data totals in the "maximum" and "average" category do not equal the total number of data sheets received (645). Categorizing data into "maximum" and "average" categories provides a means of comparing test readings against recommended maximum levels of CO prescribed by OSHA, EPA, NIOSH, and different State standards. These standards do not promulgate maximum allowable carbon monoxide concentration for school buses but apply primarily to industry workers. These standards prescribe carbon monoxide levels for both a "maximum" exposure and an "average" exposure over an eight hour period.

EPA, OSHA, NIOSH, and State pollution control agencies do not agree on the maximum allowble CO concentrations at either the maximum or average value. The primary and secondary standards for carbon monoxide promulgated by the EPA on April 30, 1971 under provisions of the Clean Air Act (PL 91-604) were:

1. 9 parts per million (PPM) maximum - 8 hour concentration not to be exceeded more than once a year.

2. 35 PPM maximum - one hour concentration not to be exceeded more than once a year.

As stated by the Administrator, EPA, "These standards were intended to protect against the occurrence of hemoglobin levels above 2 (two) percent which is considered to be the level that will provide an adequate safety margin for protection of public health, and will protect against known and anticipated adverse effects on public welfare."

The Colorado Air Pollution Control Division adjusted these levels to reflect the reduced atmospheric pressure in the Denver area, because they believed levels set for sea level conditons are not necessarily applicable for high altitudes. The levels proposed for the Denver Metro Air Quality Control Region were:

1. Maximum Time Weighted Average (TWA) for 8 hours - 10 PPM.

2. Maximum Time Weighted Average (TWA) for 1 hour - 25 PPM.

The National Institute for Occupational Safety and Health (NIOSH) in "Criteria for a Recommended Standard - Occupational Exposure for Carbon Monoxide" recommended that the maximum (TWA) exposure for an eight hour period not exceed 25 PPM. This level was defined as a significant exposure level.

The preceding standards were established for healthy adult males working in an industrial environment and would be higher than those applicable to school children and women school bus drivers. Congressman Edward I. Koch, in proposed amendment to the Clean Air Act (Congressional Record H2727 - April 1, 1976), recommended that a significant level of carbon monoxide concentration for school buses be established at 20 PPM. This figure is the same as proposed by the American Industrial Hygiene Association who recommended a community air quality guide for CO exposure of 20 PPM as an eight hour average which is stated to be the equivalent of 3 percent COH_b; this level of 20 PPM is used as a reference level for data analysis in this report.

A summary of data received is presented in Figure 9 "Carbon Monoxide Average Reading Test Summary" and Figure 10 "Carbon Monoxide Maximum Reading Test Summary." These charts categorize data into values above and below 20 PPM for each NHTSA Region. A total of 7.2% of the school buses tested had average carbon monoxide readings above 20 PPM, and a total of 20% had maximum readings above 20 PPM. Data is presented in bar chart format in Figures 11 and 12.

Region	No. of Tests	No. of School Buses Below 20 PPM	Percent of School Buses Below 20 PPM	No. of School Buses Above 20 PPM	Percent of School Buses Above 20 PPM
I	33	27	81.8	6	18.2
II	40	37	92.5	3	7.5
III	181	173	95.6	8	4.4
IV	23	23	100	0	0
V	← NO DATA SUBMITTED →				
VI	181	176	97.2	5	2.8
VII	← MAXIMUM READINGS ONLY →				
VIII	72	54	75.0	18	25.0
IX	21	21	100	0	0
X	15	14	93.3	1	6.7
Total	566	525	92.8%	41	7.2%

Figure 9. Carbon Monoxide Average Reading Test Summary

Region	No. of Tests	No. of School Buses Below 20 PPM	Percent of School Buses Below 20 PPM	No. of School Buses Above 20 PPM	Percent of School Buses Above 20 PPM
I	33	12	36.4	21	63.6
II	40	23	57.5	17	42.5
III	176	155	88.1	21	11.9
IV	23	22	95.6	1	4.4
V	NO DATA SUBMITTED				
VI	159	155	98.5	4	2.5
VII	34	25	73.5	9	26.5
VIII	72	39	54.8	33	45.8
IX	21	21	100	0	0
X	33	21	63.6	12	36.4
Total	591	473	80.0%	118	20.0%

Figure 10. Carbon Monoxide Maximum Reading Test Summary

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Figure 11. Average PPM CO Summary
Bar Chart

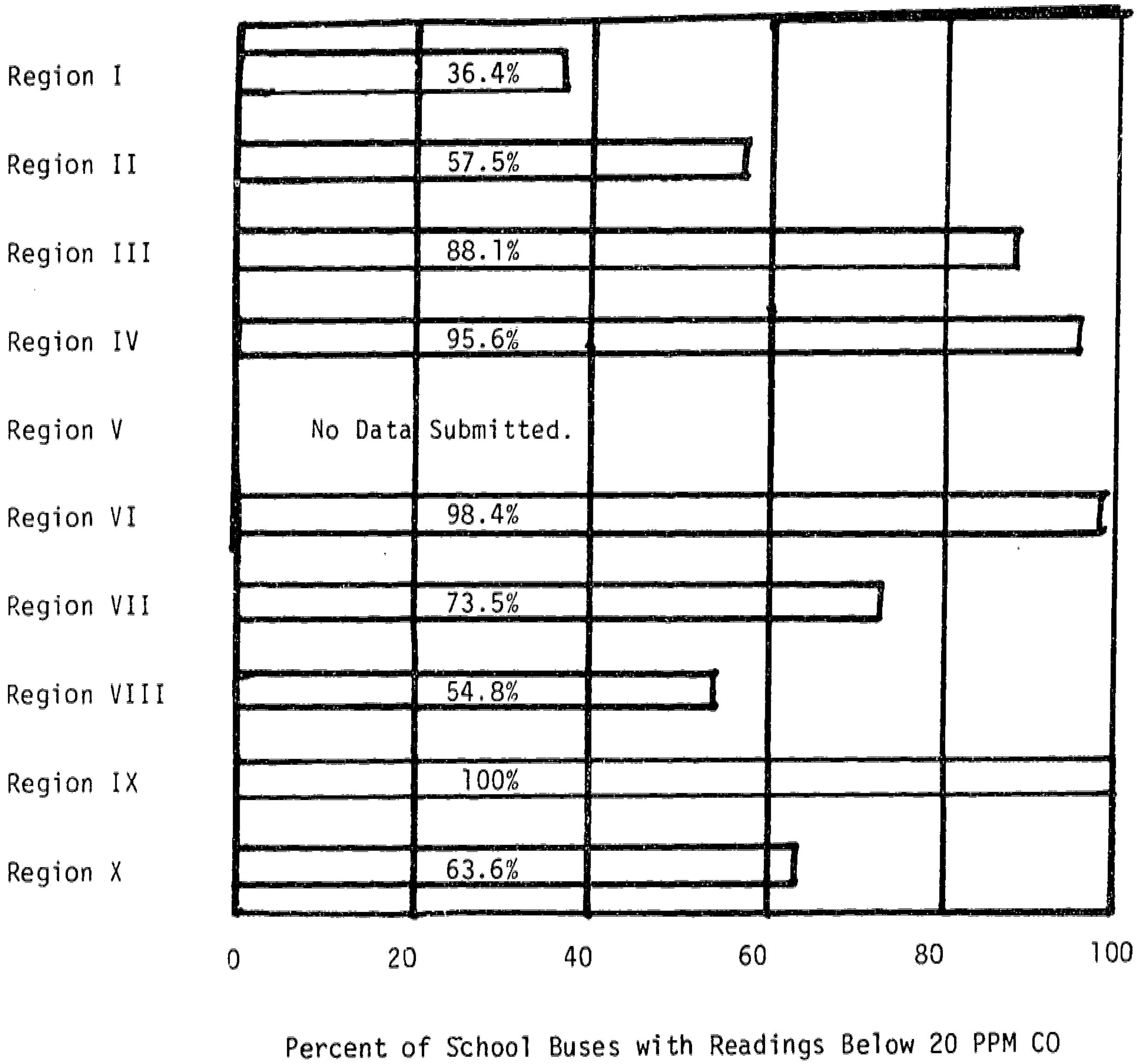
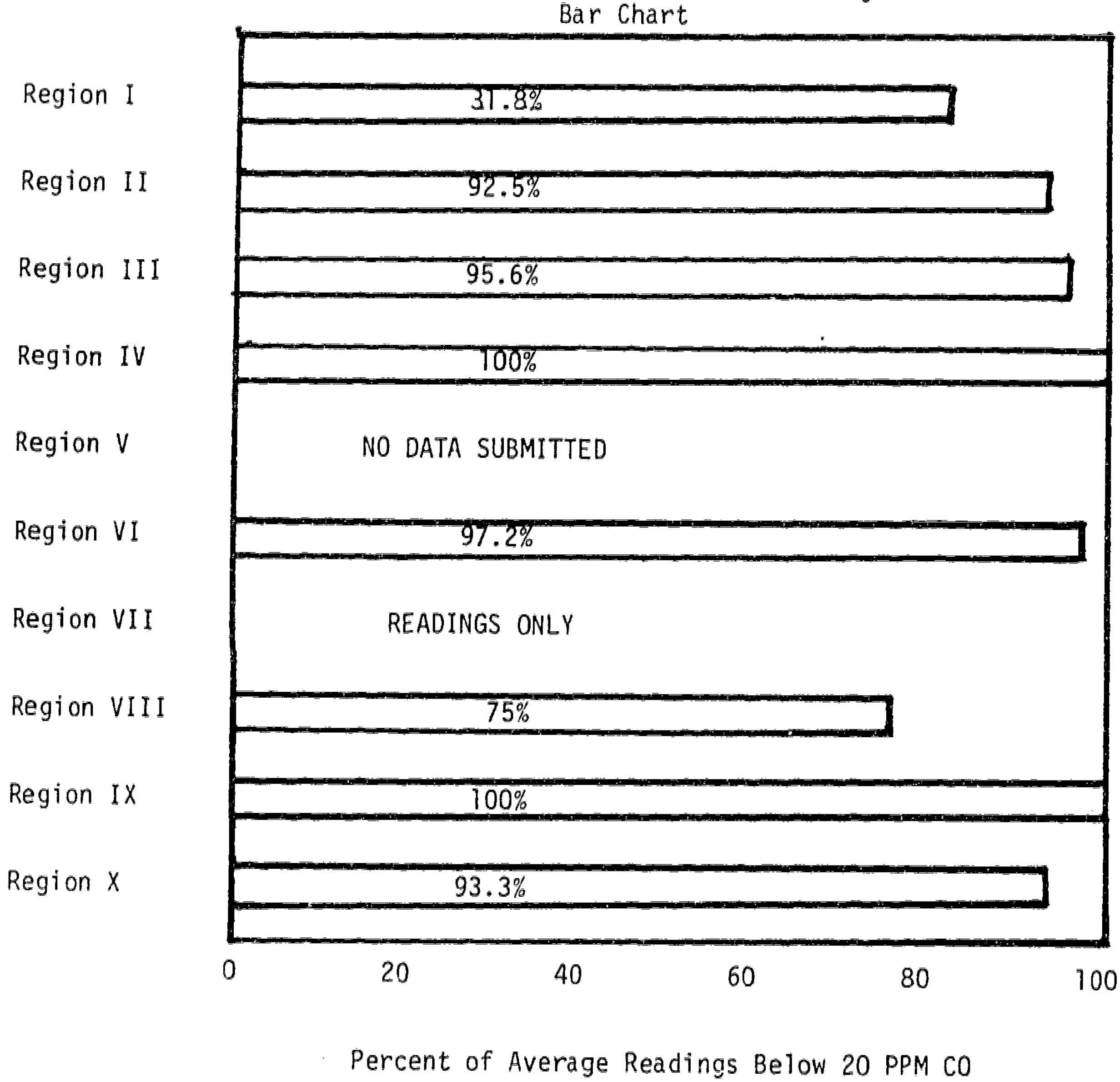


Figure 12. Maximum PPM CO Summary Bar Chart



If it can be assumed that the geographical sampling is close to representative for the entire United States then 25,200 school buses out of the approximately 350,000 (1975) total school buses would expose their pupil passengers to carbon monoxide levels in excess of 20 PPM every school day. The average bus occupancy as reported in National Safety Council "Accident Facts 1975" is upwards of 35 pupils but may rise or fall several times on a single route trip. Other figures supplied by (NSC) show that the pupils carried per route trip ranged from 26 to 72, averaging 48 pupils for route trips that ranged from 7 to 70 miles with a 33 mile average. Using these average figures provided by (NSC), and using percentages from Figure 9/10, this would mean that on a daily basis approximately 2,116,800 pupils would be exposed to "average" levels of carbon monoxide in excess of 20 PPM, and approximately 1,632,960 pupils would be exposed to "maximum" levels of carbon monoxide in excess of 50 PPM.

Figure 13 shows a summary of maximum readings in 5 PPM increments for each test site and NHTSA Regions (Figure 14). Figure 15 is a bar chart display of these maximum readings versus the percentage of school buses tested out of 591 total. 80.0% of all school buses tested had readings below 20 PPM and 20.0% had readings above. Of special significance in this chart is the 5.4% of the school buses tested that had maximum readings above 50 PPM of carbon monoxide which exceeds the allowable levels of the EPA, OSHA, NIOSH, and Colorado standards.

Figure 16 shows a summary of average readings in PPM increments for each test site and NHTSA Regions. Figure 17 is a bar chart display of the average PPM readings versus the percent of school buses tested out of a total of 566. 92.8% of the school buses tested had readings above 20 PPM and 7.2% had readings above 20 PPM. 1.8% of the school buses had average readings in excess of 35 PPM which exceeded EPA, OSHA, NIOSH, and Colorado standards.

Figures 18, 19, 20, 21 present CO concentrations in PPM as measured on a direct reading carbon monoxide meter versus duration of test. Some tests ran for 30 minutes and others for over an hour. Open windows, starting and stopping, and traffic conditions can all cause changes in the levels read. Readings were taken at five minute intervals in order to obtain the best possible average levels within a school bus over an extended period of time. As will be noticed from the curves CO levels can change greatly in short periods of time. Figure 20 shows that even though average levels remain low very high peaks can be reached for short periods. The shaded area on Figure 18, 19, and 21 represents the total data envelope within which all data points fall. These charts are included to show the wide variations on data recorded when a large number of buses are tested in one geographical location, and the test results compared with a comparable number of buses at a different geographical location.

CO CONCENTRATION IN PPM

Region	Location	NO. OF TESTS	0-5	6/10	11/15	16/20	21/25	26/30	31/35	36/40	41/45	46/50	OVR 50
I	Conn./RI	33	3	3	3	3	5	2	2	2	3	2	5
II	N.J.	15	0	1	3	1	3	2	1	2	0	0	2
	NYC	16	1	3	3	2	2	2	2	0	0	0	1
	N.J.	9	5	2	0	1	0	0	0	0	0	0	1
III	Delaware	47	19	17	4	2	2	0	0	0	0	0	3
	D.C.	33	7	8	4	5	2	2	0	1	0	2	1
	Prince Geo.	32	14	9	4	4	0	1	0	0	0	0	0
	Anne Arundel	15	1	5	1	3	0	1	0	1	0	0	3
	Allegany	22	14	4	2	1	1	0	0	0	0	0	0
	Pasadena	15	3	10	1	1	0	0	0	0	0	0	0
	Snow Hill	12	9	3	0	0	0	0	0	0	0	0	0
IV	Fulton Co., Ga.	12	6	3	2	0	0	0	0	1	0	0	0
	Harrison, Miss.	6	6	0	0	0	0	0	0	0	0	0	0
	Jackson, Miss.	5	4	1	0	0	0	0	0	0	0	0	0
V													
VI	Ark.	9	7	1	1	0	0	0	0	0	0	0	0
	Okla. City	105	52	30	15	5	1	2	0	0	0	0	0
	Louisiana	45	37	2	3	1	0	2	0	0	0	0	0
VII	Iowa	14	7	0	0	0	6	0	0	0	0	0	0
	Springfield, Mo.	20	14	4	0	0	0	0	0	1	0	0	1
VII	Denver	33	5	7	5	3	0	6	2	2	0	0	3
	Greeley	20	2	9	4	3	0	2	0	0	0	0	0
	Denver	19	0	0	0	1	1	3	2	4	0	1	7
IX	Hawaii	21	11	3	4	3	0	0	0	0	0	0	0
X	Washington State	18	1	2	5	2	3	0	1	0	0	0	4
	Washington State	15	2	3	3	3	1	0	0	0	0	1	
	Total	591	230	132	68	44	27	24	10	14	3	6	32

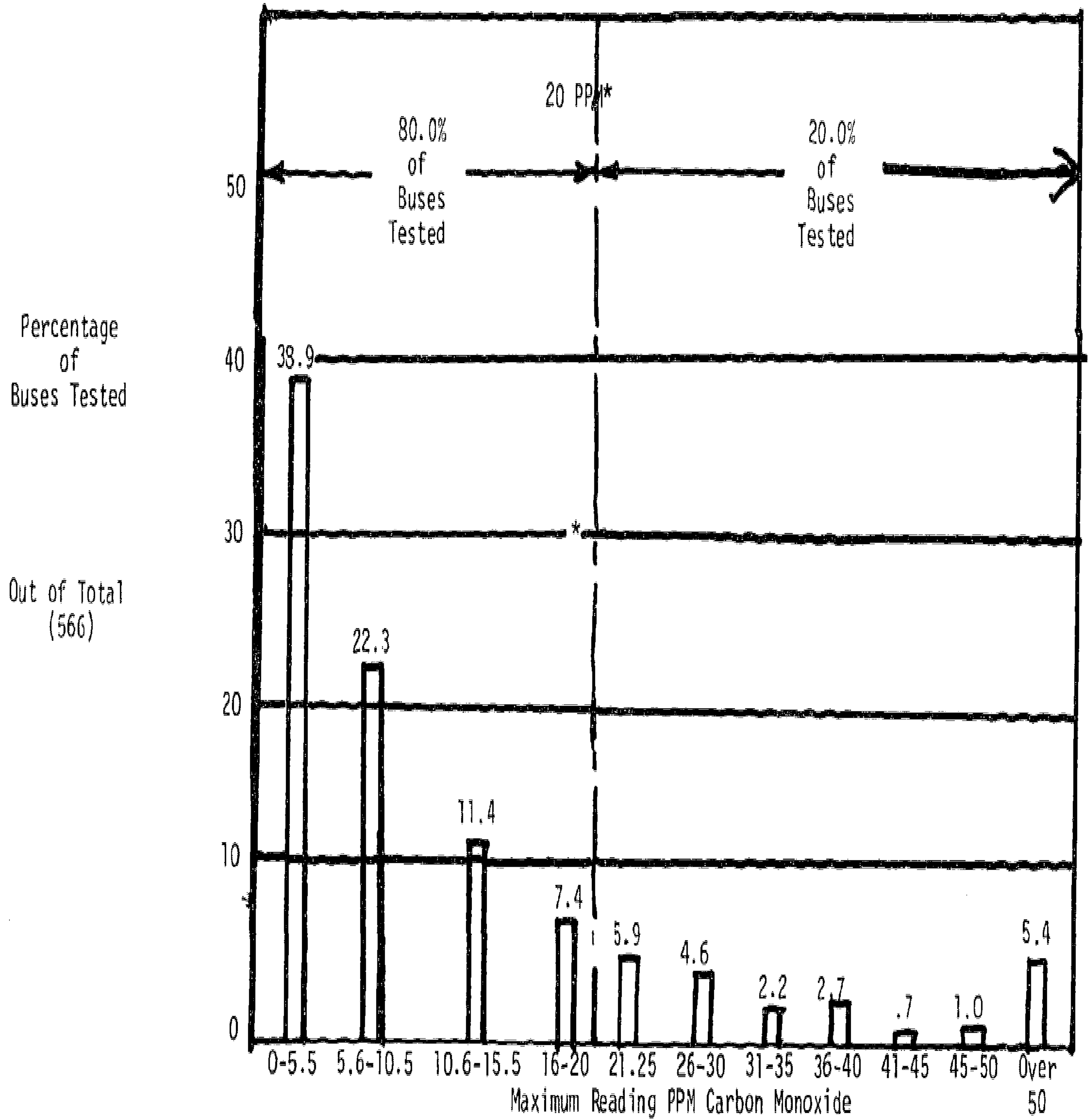
Figure 13 - Maximum Co Readings in 5 PPM Increments vs Region

CO CONCENTRATION IN PPM VS PERCENT OF TOTAL

Region	NO. OF TESTS	0-5 PPM	6-10 PPM	11-15 PPM	16-20 PPM	21-25 PPM	26-30 PPM	31-35 PPM	36-40 PPM	41-45 PPM	46-50 PPM	OVER 50
I	33	3/10	3/10	3/10	3/10	5/15	2/6	2/6	2/6	3/10	2/6	5/15
II	40	6/15	6/15	6/17.5	4/10	5/12.5	4/10	3/7.5	2/5.0	0/2.5	0/0	4/5
III	176	67/38.0	57/32.4	16/8.5	16/9.0	5/2.8	3/1.7	0/0	2/1.1	0/0	2/1.1	7/2.3
IV	23	16/69.5	8/17.4	2/8.7	0/0	0/0	0/0	0/0	1/4.3	0	0	0
V	← NO DATA RECEIVED →											
VI	159	96/60.4	34/21.4	19/11.9	6/3.8	1/6.6	4/2.5	0	0	0	0	0
VII	34	21/61.7	4/11.8	0	0	6/17.6	0	0	1/2.9	0	0	2/5.9
VII	72	7/9.7	16/22.2	9/12.5	7/9.7	1/1.4	11/15.3	4/5.6	6/8.3	0	1/1.4	10
IX	21	11/52.4	3/14.3	4/19.0	3/14.3	0	0	0	0	0	0	0
X	33	3/10.0	5/15.2	8/24.2	5/15.2	4/12.1	0	1/3.0	0	0	1/3.0	4/12.1
Total	591	230/38.9	133/22.5	68/11.5	44/7.4	27/4.6	27/4.1	10.1.7	14/2.4	3/0.5	6/1.0	32 75.41

Figure 14 - Summary of Maximum Readings in 5 PPM Increments Vs Percentage of Buses Tested

Figure 15. Maximum Parts Per Million Carbon Monoxide Readings by NHTSA Region Bar Chart



* 20 PPM/HR Reference Level
Negative Impact on Health

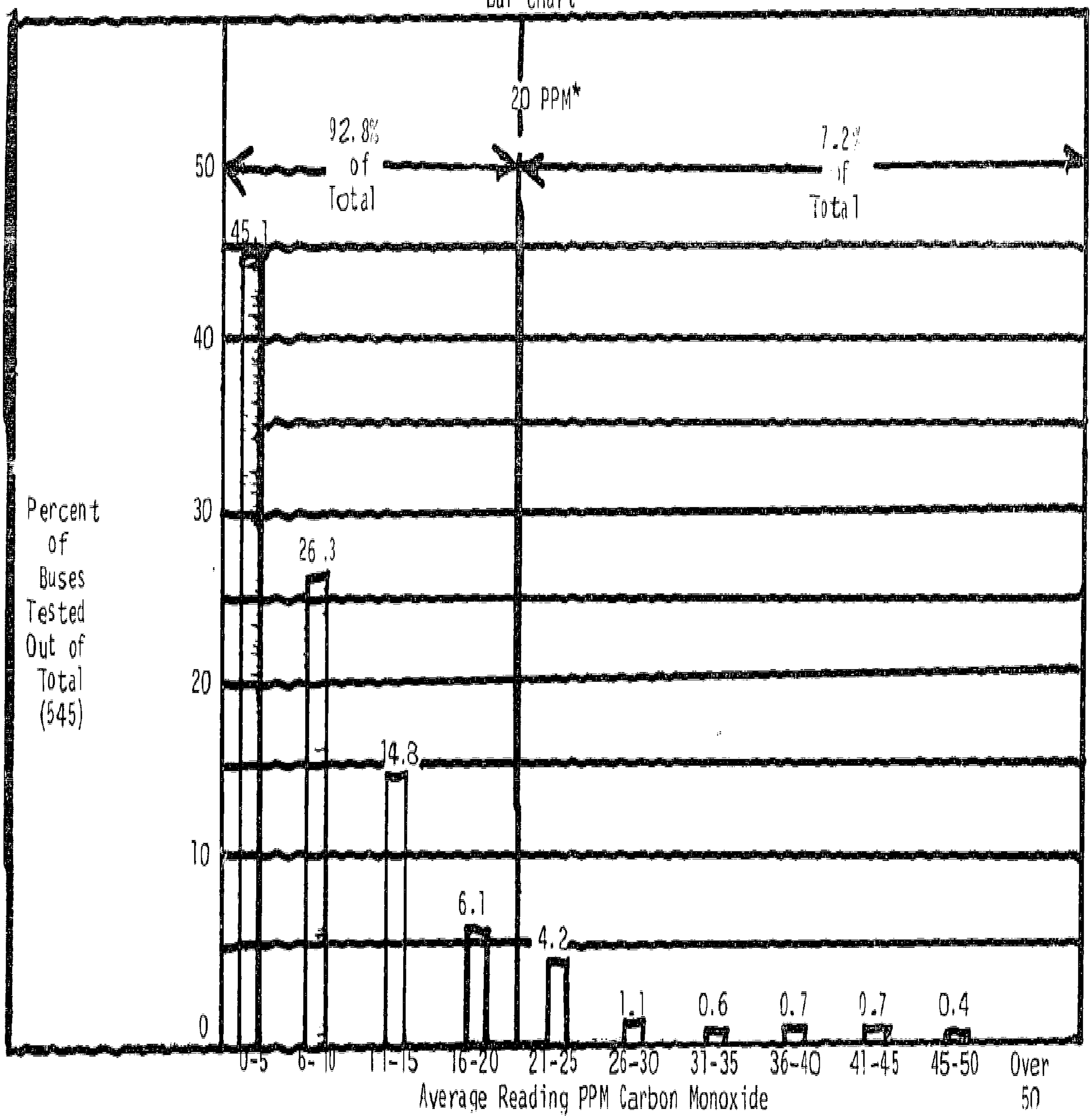
Region	Location	No. of Tests	PPM										
			0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	Over 50
I	CONN., R.I.	33	6	5	9	7	5	0	0	1	0	0	0
	PERCENTAGE		18.2	15.2	27.3	21.2	15.2			3.0			
II	New Jersey	15	0	4	7	3	0	0	1	0	0	0	0
	New York City	16	1	4	7	2	2	0	0	0	0	0	0
	New Jersey	9	2	5	2	0	0	0	0	0	0	0	0
	TOTAL	40	3	13	16	5	2	0	1	0	0	0	0
	PERCENTAGE	--	7.5	32.5	40	12.5	5.0	0	2.5				
III	Pennsylvania	53	18	20	10	1	4	0	0	0	0	0	0
	D.C.	32	8	15	4	2	1	1	0	0	1	0	0
	Prince Geo., Md.	32	23	7	2	0	0	0	0	0	0	0	0
	Anne Arundel, Md.	15	4	8	1	1	0	0	1	0	0	0	0
	Allegany Co., Md.	22	14	5	2	1	0	0	0	0	0	0	0
	Pasadena, Md.	15	9	6	0	0	0	0	0	0	0	0	0
	Snow Hill, Md.	12	11	1	0	0	0	0	0	0	0	0	0
	TOTAL	181	87	62	19	5	5	1	1	0	1	0	0
	PERCENTAGE	--	48.2	34.3	10.5	2.8	2.8	.55	.55		.55		
IV	Fulton Co., Ga.	12	8	3	1	0	0	0	0	0	0	0	0
	Harrison Co., Miss.	6	5	1	0	0	0	0	0	0	0	0	0
	Jackson, Miss.	5	4	0	0	1	0	0	0	0	0	0	0
	TOTAL	23	17	4	1	1	0	0	0	0	0	0	0
	PERCENTAGE	--	74.0	17.5	4.3	4.3							
V													
VI	Oklahoma City	105	52	30	17	3	3	1	1	0	0	0	0
	New Mexico	31	19	9	0	2	0	1	0	0	0	0	0
	Louisiana	45	40	1	3	0	1	0	0	0	0	0	0
	TOTAL	181	111	40	20	5	4	2	1	0	0	0	0
	PERCENTAGE	--	61.2	22.2	11.1	2.75	2.2	1.1	.55	0	0	0	0

Figure 16. Summary of Average Readings in PPM by Region vs. Percentage of Buses Tested

Region	Location	No. of Tests	PPM										
			0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	Over 50
VII													
VIII	Denver	33	8	10	4	6	2	1	0	1	0	1	0
	Greeley, Colo.	20	9	3	6	1	1	0	0	0	0	0	0
	Denver	19	0	0	4	3	5	2	0	2	2	1	0
	TOTAL	72	17	13	14	10	8	3	0	3	2	2	0
	PERCENTAGE	--	23.8	18.0	19.5	14.9	10.5	4.2	0	4.2	2.8	2.8	0
IX	Hawaii	21	11	3	4	3	0	0	0	0	0	0	0
	Percentage		52.4	14.3	19.0	14.3	0	0	0	0	0	0	0
X	Washington State	15		7	2	0	0	0	0	0	1	0	0
	Percentage		33.3	46.6	13.3								
	TOTAL	566	257	147	85	36	24	6	3	4	4	2	0
	PERCENTAGE		45.4	26.0	15.0	6.4	4.2	1.1	0.5	0.7	0.7	0.4	

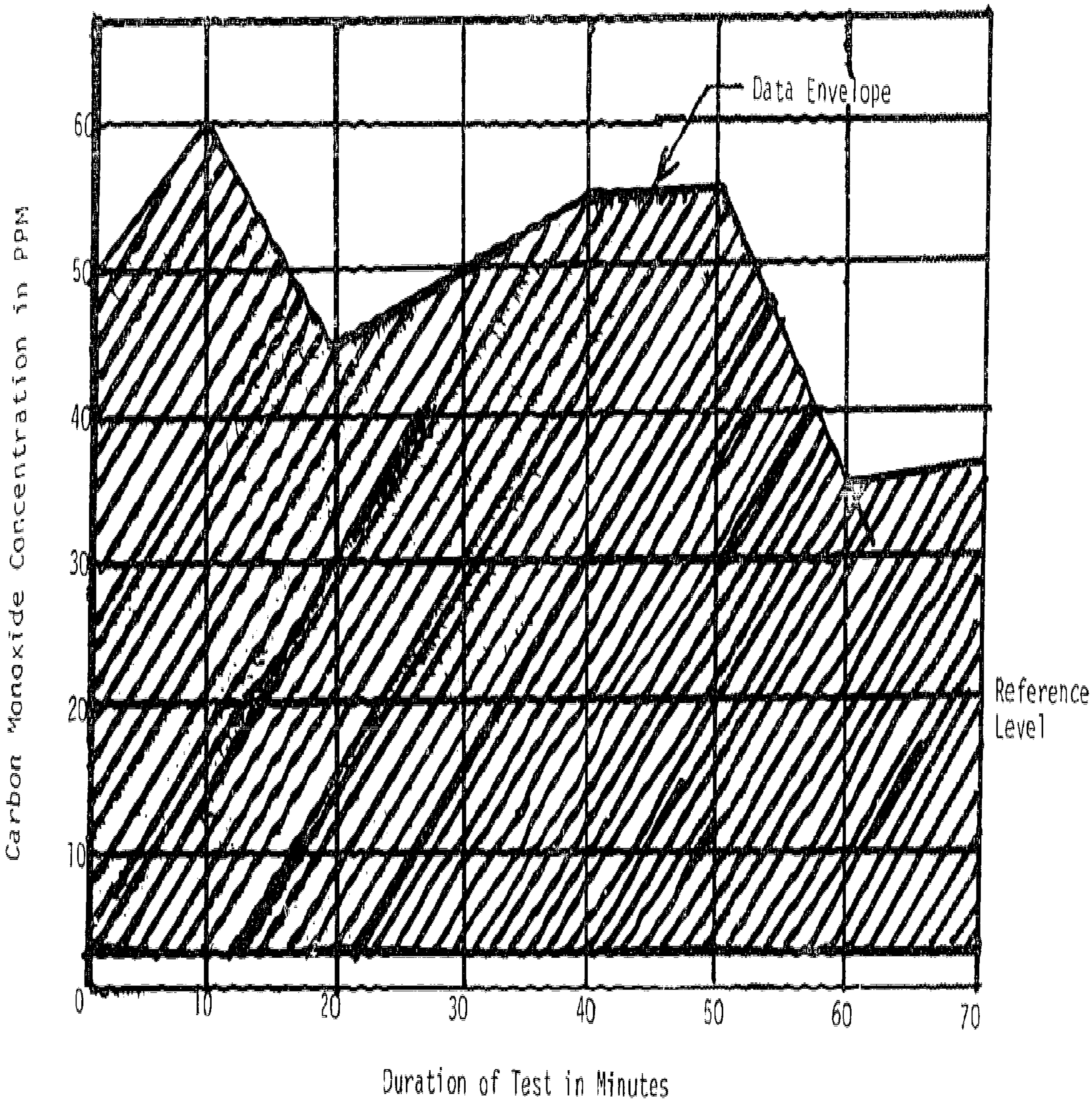
Figure 16. Summary of Average Readings in PPM by Region vs. Percentage of Buses Tested

Figure 17. Average Parts Per Million Carbon Monoxide Readings by NHTSA Region Bar Chart



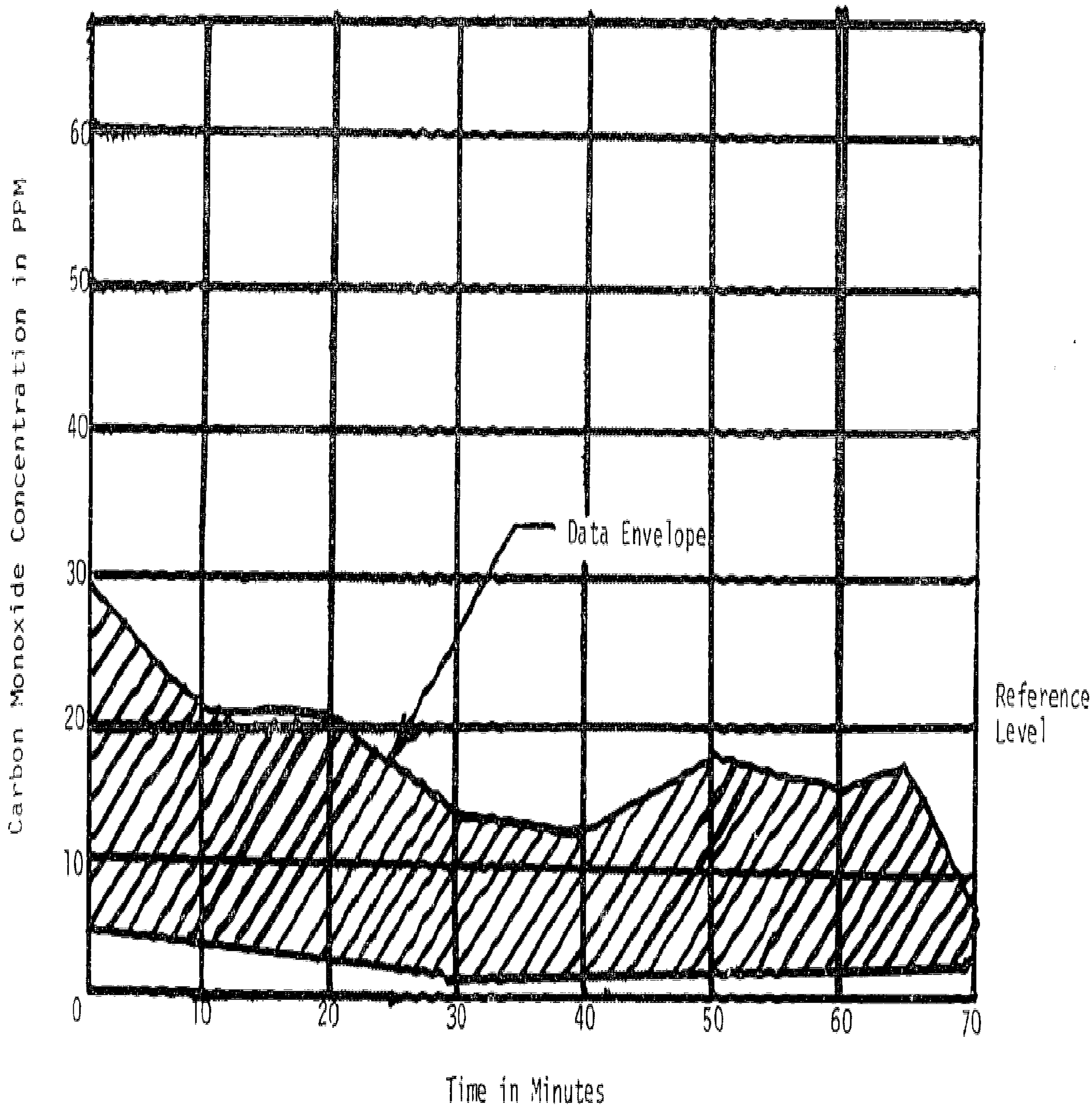
* 20 PPM/HR - Reference Level Negative Impact on Health

Figure 18. Washington State
February-March 1977
18 School Buses



Shaded area represents the data envelope within which all data points fall.

Figure 19. Greeley, Colorado
March 1977
20 School Buses



Shaded area represents the data envelope within which all data points fall.

Figure 20. Bellevue, Washington
April 29, 1977
Bus #44

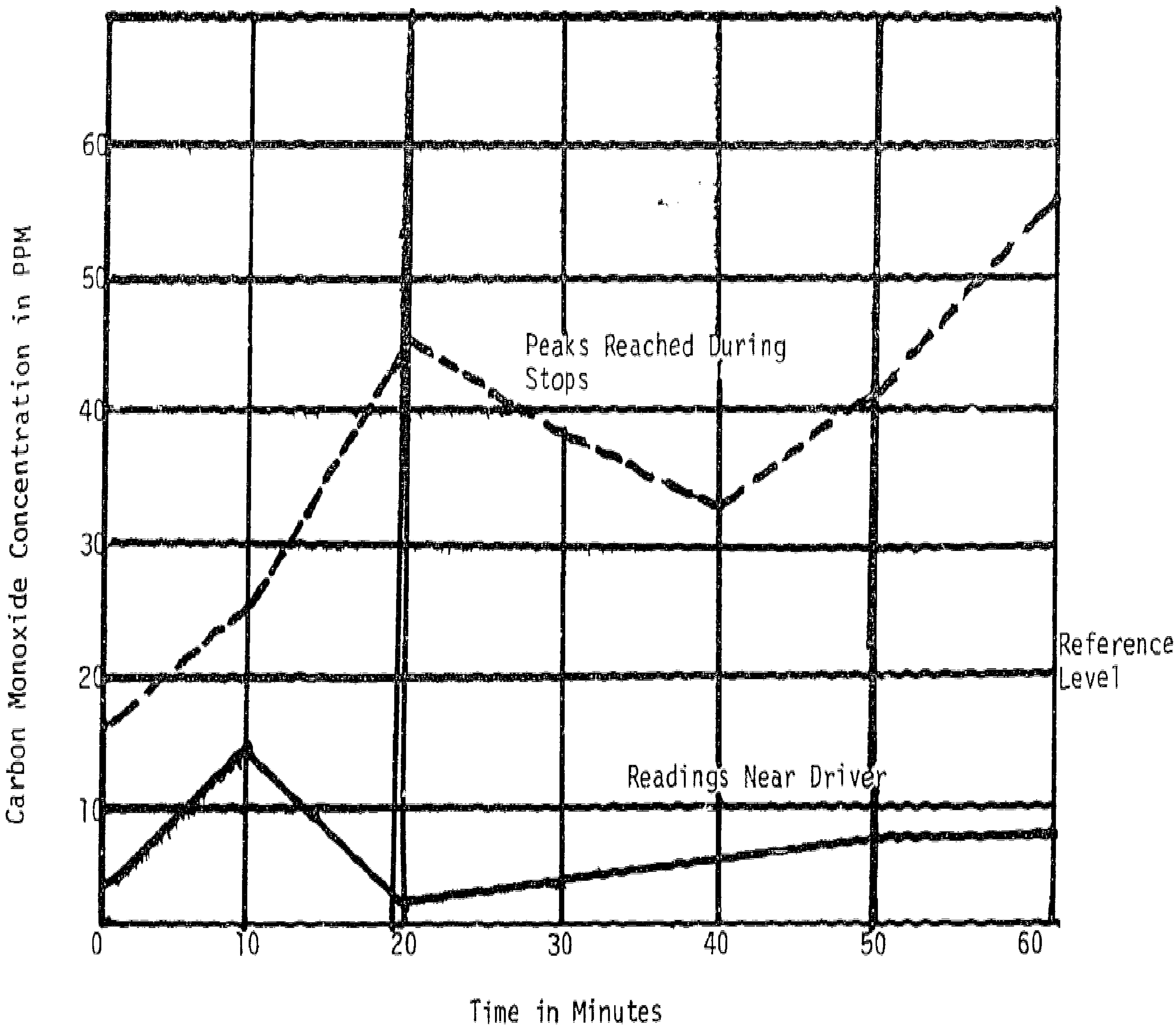
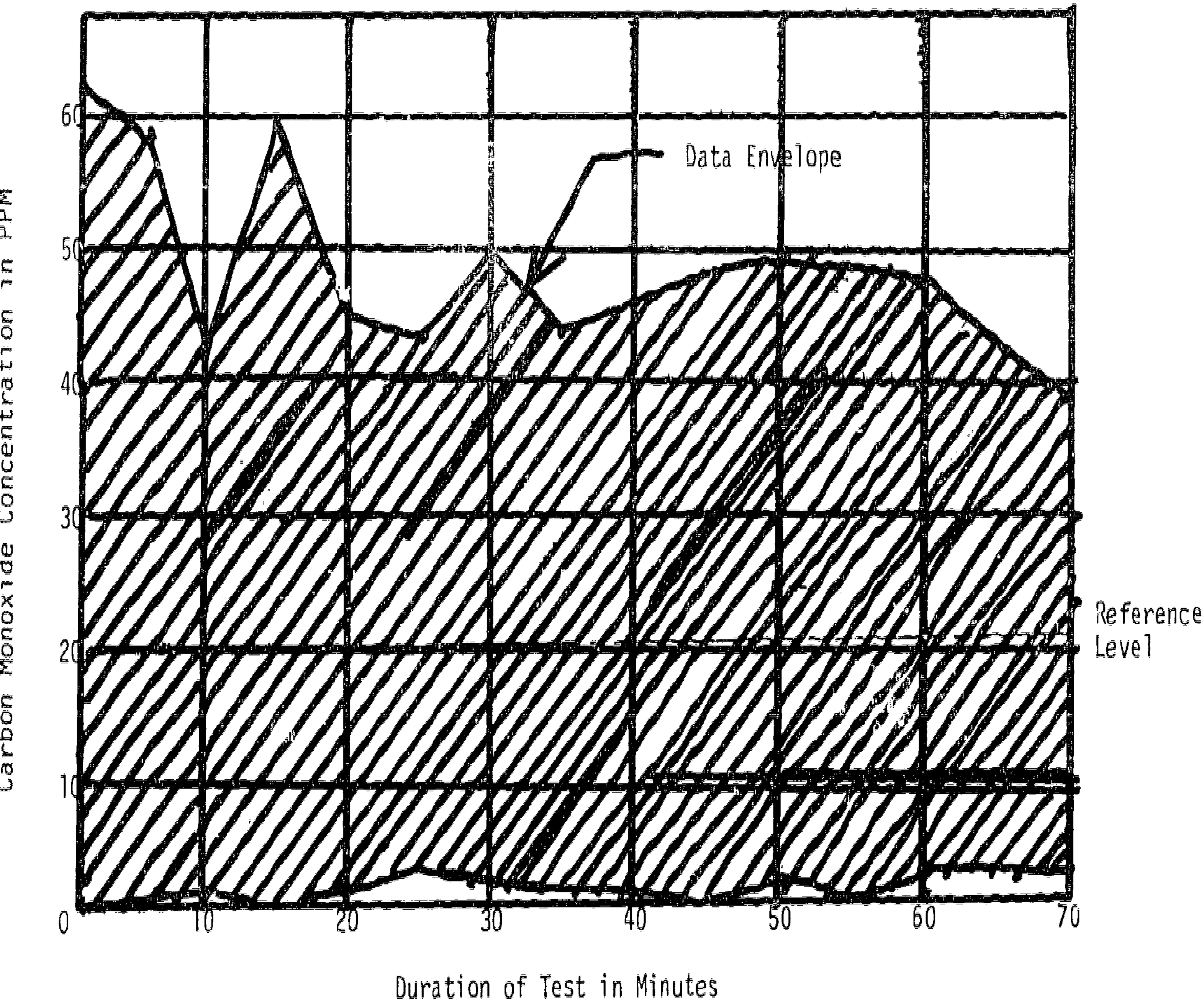


Figure 21. Connecticut-Rhode Island
December 1976
33 School Buses



Shaded area represents the data envelope within which all data points fall.

X. CONCLUSION AND RECOMMENDATIONS

1. At the present time a standard determining the maximum allowable levels for carbon monoxide in the passenger compartment of school buses has not been promulgated by any Federal or State agency. Existing standards of EPA, OSHA, NIOSH and other Federal and State agencies determine maximum allowable levels for industrial workers over an eight hour period, and although these standards can partially serve as guidelines, these are not directly applicable to school children and women bus drivers. An urgent requirement exists to institute a program to determine the critical exposure level of school children to carbon monoxide in the school bus environment.

2. Results of analyses of test data indicates that a potentially dangerous situation exists on many school buses in daily use due to carbon monoxide intrusion levels in excess of the 20 PPM reference level in the passenger compartments of these school buses. Although in most cases, with proper maintenance and inspection there is no carbon monoxide problem, test data disclosed that a relatively high percentage of the buses tested exceeded the 20 PPM reference level in both the "average" and "maximum" reading categories:

   a. 7.2% of all buses tested had average readings in excess of 20 PPM. (Figure 9)

   b. 20.0% of all buses tested had maximum readings in excess of 20 PPM at some time during a run. (Figure 9)

   c. 5.4% of all buses tested had maximum readings in excess of 50 PPM at some time during a run. (Figure 10)

   Data supplied by the National Safety Council in "Accident Fact-1976" shows there are about 350,000 school buses in the continental United States that travel 2.5 billion miles a year while transporting 22,000,000 pupils daily. Average occupancy for all bus mileage, including deadheading, is estimated at about 35 pupils. Miles per route trip ranged from 7 to 70 miles, averaging 33 miles. Pupils carried per route trip ranged from 26 to 72 averaging 48 pupils. Route trips per bus ranged from 1 to 3 averaging 1.8 trips daily.

   Using the average figures provided by the National Safety Council and assuming that the percentages obtained during the test program are representative of the total school bus population this would mean that on a daily basis approximately 2,116,800 pupils would be exposed to "average" levels of carbon monoxide in excess of 20 PPM, and approximately 1,632,960 pupils would be exposed to "maximum" levels of carbon monoxide in excess of 50 PPM.

3. Carbon monoxide levels were affected by the following variables:

   a. Cold weath[illegible] tests where windows were up and the heaters on were generally higher than readings obtained during summer months.

   b. Levels in urban areas particularly on heavily traveled streets were significantly higher than in rural areas.

   c. Older model buses particularly those over 6 years old and with more than 50,000 miles on the odometer generally produced higher readings.

   d. Buses that made frequent stops in urban areas on heavily traveled streets would have wide changes in CO levels as opposed to bus runs of over 30 minutes duration where readings were relatively constant.

4. The two factors having the greatest effect on interior carbon monoxide levels were "idle CO level" and "compartment integrity." In general high idle CO levels resulted in high interior CO levels. These levels were significantly higher in the drivers areas when a defect existed in the floor pan or there were holes in the firewall that permitted CO to enter the passenger compartment. Defects that increased t[illegible] idle CO level included:

   a. holes in the tailpipe or muffler

   b. rusted out areas in floor of bus

   c. Openings in floor pan or the firewall in the drivers areas

   d. tailpipe too short and not projecting beyond rear of the bus

   e. broken pipe hangers that allowed exhaust system to sag and cause leaky joints at points of connection.

   Compartment integrity was affected by rubber seals around the front door, emergency door, and windows. In some cases when the bus was moving these defects resulted in increased air flow with the passenger compartments thus lowering the CO levels. In other cases, particularly in traffic, exhaust fumes were drawn into the school bus increasing the CO levels. A major point of intrusion was in and around the emergency door. A leak of any kind at the emergency door seal resulted in increased CO intrusion due to the pressure differential between the inside and outside of the bus. CO levels would noticeably increase when a bus would decelerate or come to a stop.

5. In nearly all instances where a level of 20 PPM was exceeded for any time period the high level of carbon monoxide could be attributed to a high ambient CO level or a bus maintenance problem. The effect of high ambient CO levels was particularly noticeable in urban areas where the maximum reading would reach 50-60 PPM on streets such as Capitol Street in Washington, D.C., and then drop down to a level of 10-15 PPM when the bus was traveling in a residential area. When high levels of CO were measured in the driver area, problem could be traced to leaks in firewall near clutch, brake, or gearshift openings. High levels of CO measured in rear of bus could be traced to leaks in and around the emergency door or door seal, combined with a tailpipe that did not extend beyond rear bumper.

6. School bus inspections are conducted twice a year in most areas. Some inspections are conducted at commercial garages, others under the supervision of a State Police or department of motor vehicle inspector, and others by inspectors working for the local school district. These inspections generally consist of a walkaround type inspection and seldom include a thorough inspection of the exhaust system. In most States, one inspection is performed prior to a school bus being put in operation in the fall, and the second inspection may not occur until the following spring. An exhaust system can deteriorate rapidly during the winter months and a significant increase in CO levels can occur before a noticeable defect such as a noisy muffler or hole in a tailpipe is detected. A proper maintenance and inspection program is essential in order to maintain the integrity of the exhaust system and passenger compartment.

7. An analysis of data collected showed that different makes of buses and body types had an effect on the CO levels measured. An analysis of school buses by age and mileage disclosed that higher concentrations of CO are measured on older buses, with a very noticeable jump in levels measured for buses 6 years or older and more than 50,000 miles on them. Higher concentrations of carbon monoxide were measured in the rear as compared to the front or middle of the bus.

It is recommended that the following actions be initiated:

a. Request that responsible Federal agencies such as EPA or NIOSH take action to determine maximum allowable level of carbon monoxide in a school bus and promulgate the necessary standards or regulations.

b. Prepare advisories to State ar local school boards of education and State agencies responsible for school bus inspections defining problems associated with school bus carbon monoxide intrusion and recommended maintenance and inspection procedures to control or eliminate the problem.

c. Develop an R&D test program that would include more controlled test procedures and test equipments, and would be expanded to cover a bus populaticn of 5,000 to 15,000 buses over a 2 year period.

The data summarized in previous sections compares favorably with data obtained from "Field Evaluation of Carbon Monoxide Levels in School Buses" (1972, Ref. 1). This study of 112 buses showed that 9 buses or 8% had carbon monoxide levels over 25 PPM and the average interval carbon monoxide (ICO) level for all buses that read over 25 PPM was 36.8 PPM. The study also showed that when exhaust system defects were simulated by disconnecting the tailpipe and the exhaust manifold, the "as received" level of 4.6 PPM increased to 8.8 PPM with the tailpipe disconnected, and 35.2 PPM with the manifold disconnected. The percentage of buses exceeding 25 PPM CO level also increased as exhaust system changes were made. From an 8% "as received" condition, the percent of CO increased to 13.7% with the tailpipe disconnected and to 48.4% with the manifold disconnected.

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