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Technical Report

Economic Commission for Europe
Inland Transport Committee
Group of Experts on the Construction of Vehicles
Group of Rapporteurs on Pollution and Energy (GRPE)

Emissions of In-Use Vehicles: Update on the U.S. Experience

By

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1. INTRODUCTION

This paper is an update to a paper transmitted for discussion at the 8th Session of GRPE, August-September 1983, entitled "New Vehicle Regulation and Emissions of In-Use Vehicles: The U.S. Experience." That paper emphasized the results which new vehicle regulations in the U.S. have achieved in terms of emissions from vehicles in general use by ordinary motorists.

At the time the previous paper was prepared, the U.S. Environmental Protection Agency (EPA) was reluctant to draw conclusions regarding in-use emissions of hydrocarbons (HC) and carbon monoxide (CO) of 1981 and newer vehicles, because the available data were limited to low mileage vehicles. In the interim, additional data have been obtained on higher mileage vehicles in this category. This paper presents information on these vehicles and describes conclusions EPA has reached regarding the likely HC and CO emissions of these vehicles in the future. EPA has also revised its assessment of the oxides of nitrogen (NOx) emissions from these vehicles. The new assessment is described.

EPA has also adopted a new conceptual approach to assessment of emissions of in-use vehicles. The approach seeks to isolate and better quantify the effects of tampering to major emission control subsystems and of the improper introduction of leaded fuel into catalyst-equipped vehicles. ("Tampering" refers to the removal, disconnection, or other interference with the proper operation of a subsystem. Examples are removal of a catalytic converter or disconnection of a fuel vapor hose.) The new approach and some of its major results are described. Further observations are also made on the phenomena of catalyst tampering and improper use of leaded gasoline, which may be of interest to countries contemplating more stringent emission standards and fuel lead content regulations.

2. TESTING AND ANALYSIS OF 1981 AND NEWER VEHICLES

EPA conducts a continuing In-Use Emission Factor Surveillance Program which borrows vehicles from their owners and tests them with the standard U.S. emission test procedure. Because of the 50% reduction in allowable emissions of NOx in 1981 and the resulting major change in emission control technology (introduction of three-way catalytic converters and computer controlled fuel mangement), 1981 and newer vehicles have been a subject of intense interest to EPA. The surveillance program began testing 1981 vehicles as soon as they were in the hands of owners. After an initial period of recruiting vehicles without respect to accumulated service, EPA began to solicit and test vehicles which had accumulated many more miles of service for their chronological age than typical for passenger cars in the U.S. This was done to learn more about the durability and emissions of 1981 vehicles at advanced mileage than would have been possible to learn otherwise except by the passage of time. In the U.S., the average age of a passenger car is about 58,000 miles when weighted for vehicle use, and EPA was concerned that emissions at that age and above might be much different than observed from younger vehicles. EPA has also been testing 1982 and 1983 vehicles, necessarily at lower mileages. Table 1 displays some information about the numbers and mileages of vehicles tested to date.

EPA has most recently completed a test program phase which emphasized 1983 vehicles. EPA selected for testing those 1983 models which represent emission control technologies that EPA and industry sources predict will dominate the U.S. fleet in future model years, especially new fuel injection applications.

Table 2 and Figure 1 show average emissions of the 1981, 1982, and 1983 vehicles tested by EPA and their average accumulated mileage. CO emission data for the 1981 and 1982 vehicles are separated into one group which were certified to meet the statutory CO emission standard of 3.4 gram per mile and another group which received a temporary waiver to a CO level of 7.0 gram per mile under another provision of the U.S. Clean Air Act.

When emission levels of individual model years are graphed with the corresponding accumulated mileages as in Figure 1, an increasing trend in emissions with mileage is apparent. There are three reasons why this apparent trend should not be taken too quickly as the true trend of emissions of all in-use 1981 and newer vehicles:

1. EPA has confirmed that the sample of test vehicles used in the surveillance program described here contains fewer cases of tampering and improper use of leaded gasoline than does the corresponding vehicle population as a whole. This underrepresentation is caused by the reluctance of owners of such vehicles to lend them to EPA for testing.

2. The 1981, 1982, and 1983 vehicles tested by EPA do not represent exactly the various mixes of emission control system types that will be sold in later model years.

3. It is more accurate to examine the relationship of emissions to mileage within each model year, than to simply compare model years as in Figure 1.

For these reasons, EPA has used another method to estimate in-use emissions of 1981 and newer vehicles. The method first estimates the emissions of vehicles that have not been subjected to certain severe forms of tampering or to improper use of leaded gasoline. For this purpose, EPA believes the data from the surveillance program are adequate. Second, an estimate of the additional or excess emissions caused by the previously excluded severe forms of tampering and by the improper use of leaded gasoline are estimated and added to the first value. These two steps will be briefly described and the results presented in the next two sections.

3. EMISSIONS OF VEHICLES NOT SUBJECT TO TAMPERING OR IMPROPER USE OF LEADED FUEL

Estimating the emissions from current technology vehicles is relatively straight forward when adequate in-use test data are available. Typically a trend in the emission levels of the vehicles versus age (usually measured in accumulated mileage) can be determined and used to predict the emission levels of in-use vehicles. When in-use data are inadequate or have only a small mileage range a modeling approach becomes necessary to predict emission levels.

An important consideration in estimating the emissions of future model years is the type of technology used to control emission levels. Starting in 1981, for example, most passenger vehicles produced in the U.S. began using feed back control or "closed-loop" systems to control the air/fuel mixture. At the same time EPA parameter control regulations limited the in-use adjustability of certain engine parameters. Both of these changes have had significant effects on the in-use emission performance of the newer model years.

A major new trend in technology that is likely to have a significant effect on in-use emission levels is the increasing use of fuel injection. As can be seen in Figure 2, EPA estimates that use of fuel injection in future model years will approach 90% of passenger cars by 1990. Figure 3 shows that changes in catalyst type will accompany the trend towards fuel injection, with fewer vehicles receiving an oxidation catalyst in addition to the three-way catalyst. Fuel injected vehicles can be expected on engineering grounds to have different emission characteristics than the carbureted vehicles common today. These differences include lower evaporative emissions due to the elimination of carburetor float bowls, lower cold start emissions due to elimination of mechanical and electrical problems of the choke mechanism, and fewer instances of catastrophic emission control failure which still allows the vehicle to be driven.

EPA has used a simple regression of the emission levels versus mileage for all of the pre-1981 model years. The emissions data set available from these vehicles is of sufficient size and mileage range to produce acceptable estimates. However, for 1981 and later model years, the significant changes in technology and the lack of emission data over a wide mileage range have caused EPA to develop a model to account for all of the factors EPA believes will affect the emission behavior of these vehicles.

For the analysis, all obviously tampered or misfueled vehicles in the data base were removed. EPA believes that tampered and misfueled vehicles are not properly represented in the vehicle test samples since the testing program is voluntary. The excess emissions in the fleet caused by tampering and misfueling are calculated separately. This calculation is described in Section 4.0.

Since technology trends show that the mix of technologies is changing rapidly, the existing emission data set from 1981 and newer vehicles is divided into four separate technologies. These are:

--Closed-Loop Carbureted with Any 3-way Catalyst
--Closed-Loop Fuel Injected with Any 3-way Catalyst
--All Open-Loop with Any 3-way Catalyst
--All Oxidation Catalyst Only

The results from the analysis of each of these technologies can then be weighted together to represent any predicted mix of the technologies. The explanation following concerns the treatment of a single technology.

For purposes of predicting HC and CO emissions, the vehicles from one technology are divided into three strata based on emission levels. The lowest stratum contains the large majority of the vehicles. It was defined to include all vehicles emitting less than 1.5 gram/mile of the HC (compared to the 0.41 allowable level) and less than 20 gram/mile of CO (compared to the 3.4 or 7.0 allowable level). Despite the rather high limits, the vast majority of cars in this stratum were found to emit very close to their allowable levels. The average emissions of cars in this stratum as a function of mileage was estimated by simple least-squares regression.

The next, or middle, stratum was defined as including all remaining vehicles except for four vehicles with extremely high emission levels. This stratum was kept separate from the previous stratum for two reasons. First, vehicles in the lower group generally passed the type of emission short test used in the U.S. for annual inspections of in-use vehicles.

Vehicles in this middle group commonly failed these short tests. Keeping the two strata separate allowed the subsequent estimation of the benefits of annual inspection programs. Second, to use just one stratum encompassing both groups would be to assume that the available test sample represented the relative frequency of occurrence of these two vehicle types at all mileages. EPA's hypothesis was that to the contrary the relative sizes of these two groups would vary with mileage, with the middle or malfunctioning group accelerating in size at the expense of the lower, properly functioning group. In fact, this hypothesis was verified by analysis of the available data in the range of zero to about 65,000 miles, and EPA extrapolated the pattern in a piece-wise linear manner to higher mileages. The average emission level of vehicles in the middle stratum was assumed to be a constant independent of mileage, equal to the average of the vehicles tested.

The third, or upper stratum, consisted of only four vehicles. These vehicles had emission levels much higher than those of the next highest emitting vehicles, and were clearly in a different class of malperformance. EPA chose to assume that the number of such vehicles would increase with mileage but at a comparatively slower rate. The average emission level of the tested vehicles was assumed to apply independently of mileage.

There were no fuel injected vehicles tested which were in the upper stratum and only a single fuel injected vehicle in the middle stratum. However, all the fuel injected vehicles were still at low mileage, and EPA was unwilling to assume that the absence of higher emitting vehicles would continue indefinitely. Therefore, EPA estimated the population of the middle and upper strata for the fuel injection technology by reasoning backwards from observation of carbureted vehicles. That is, fuel injected vehicles were assumed to be like carbureted vehicles except that carbureted vehicles were eliminated for this purpose if they had malperformances which engineering analysis showed could not occur with fuel injection.

Once the sizes and average HC and CO emission levels of all three strata for one technology were estimated from the available data, they were arithmetically combined in a simple fashion to arrive at a prediction for the average emissions of all in-use vehicles of that technology (excluding the effects of tampering and improper use of leaded fuel). This average depends on mileage, of course.

For NOx, there appeared to be no advantage to separation into strata, and each technology was therefore represented by a single regression line of NOx emissions versus mileage.

Once emission levels of the four technologies have been estimated, they are weighted together for each model year using historical and forecasted sales fractions. The result is the overall estimate of in-use emissions from all vehicles sold in the U.S. in a given model year, but without the effects of tampering and misfueling. Figure 4 shows the results for selected model years. As can be seen, the shifts in technology mix have a small but discernable impact on predicted emissions.

4. EXCESS EMISSIONS DUE TO TAMPERING AND IMPROPER USE OF LEADED FUEL

The estimates of emissions presented thus far were prepared by first removing vehicles from EPA's data base which had evidence of certain types of tampering to the emission control system or of improper use of leaded fuel. Specifically, vehicles with evidence of catalyst removal, interference with the positive crankcase ventilation system (PCV) causing release of crankcase vapors, disconnection of the cannister used to store evaporative emissions, disconnection or removal of the air pump system, or habitual misfueling were removed. (Habitual misfueling means improper use of leaded fuel over a long enough period to have permanent and substantial adverse impact on the catalyst.) While there were some such vehicles in EPA's owner-loaned test sample, there were fewer than EPA has reason to believe are present in the U.S. fleet as a whole. Vehicles with only other forms of tampering such as electrical wire disconnections were retained, as these problems are more likely to have been inadvertant and owner reluctance to lend vehicles to EPA should be much less.

Having removed these vehicles from the data base before calculating the results displayed in Figure 4, EPA needed to add back to the emission estimates the additional or excess emissions caused by the true incidences of tampering and misfueling in the U.S. fleet.

Figure 5 shows EPA's estimates of the incidence or rate of each of the six types of tampering/misfueling in the U.S. fleet. These estimates are derived from observations of vehicles in a survey performed by EPA in approximately 10 cities per year. In this survey, vehicles are randomly selected from the traffic flow and ordered to pull to the roadside, where technicians examine the vehicles for tampering and misfueling. Under U.S. law, owners may decline this inspection, but in practice virtually all consent to it so the representativeness of the sample is believed to be good.

Figure 5 shows that tampering and misfueling are more frequent among vehicles which have accumulated more miles, i.e., those that are older. Since age and year of manufacture are related, it is not entirely certain which factor is the more important. U.S. automobile companies have stated their belief that progressively better vehicle designs will be less subject to tampering and misfueling. At present, EPA assumes that age is responsible for all of the effect shown in Figure 5. Figure 5 also shows that light-duty trucks are much more frequently tampered than passenger cars of the same age. Although used primarily for personal transportation, the same as passenger cars, the popular wisdom in the U.S. is that light trucks are commonly owned by persons less willing to accept government restrictions. Because of the small number of light-duty trucks in the survey sample, a separate regression on mileage was not considered reliable.

The rates of catalyst removal and habitual misfueling shown in Figure 5 are unfortunately high. At the average age of catalyst passenger vehicles, they are about 7 percent and 13 percent, respectively. About one-half of the vehicles from which catalysts have been removed have also been misfueled, so the combined rate is 16 to 17 percent. Vehicle owners who intend to misfuel may remove their catalysts believing that their vehicles will be further damaged if they do not remove them. However, these owners are probably misinformed or overly cautious. EPA has no reason to believe that any significant number of catalysts are being plugged because of lead residues, even though most misfueled vehicles have their catalysts present throughout the misfueling experience.

The rates of air pump disablement and EGR system disablement are also high. Roughly one-half of U.S. vehicles are not equipped with air pumps, so the rate in the U.S. fleet as a whole is about one-half that shown in the figure. Virtually all U.S vehicles have EGR, but fortunately nearly all U.S. cities have acceptable nitrogen dioxide air quality levels despite the high rate of EGR tampering. The rates of PCV and evaporative cannister disablement are very low, which is expected since the nonparasitic nature of these systems is such that owners have no reason to expect any fuel economy or performance inprovement from disabling them.

EPA has found that vehicles with one type of tampering often have multiple types. Therefore, the number of vehicles with some form of tampering is less than the sum of the separate rates in Figure 5. This pattern has been accounted for in EPA's calculations and is reflected in subsequent figures.

Figure 6 shows EPA's estimates of the emissions increases that occur with each form of tampering/misfueling. (THC denotes total hydrocarbons including nonreactive methane. Data not presented show that nearly all of the increase shown for total hydrocarbons is in species other than methane.) These estimates are developed from testing vehicles in a properly operating condition and then again with tampering or misfueling present. Figure 6 is for closed-loop three-way catalyst vehicles. The earlier oxidation-catalyst vehicles tend to have larger effects from catalyst removal and misfueling, but these are not shown.

Figure 7 shows the net effect of all the forms of tampering and misfueling combined, with correct accounting for multiple instances on one vehicle. Since tampering rates for individual components increase sharply with vehicle mileage, so does the overall excess for each pollutant. These excesses must be added to the emissions shown in Figure 4 to give total in-use emissions.

Given the high rates of catalyst removal and misfueling as shown in Figure 5 and their large impact on emissions as shown in Figure 6, one would expect them to be a large part of the total excess shown in Figure 7 as being due to all tampering and misfueling combined. This is the case. Figure 8 shows the percentage contributions of individual tampering types to the excess emissions at 50,000 miles. The contributions are nearly the same at other mileages.

Because catalyst removal and misfueling have been recognized by EPA as important concerns for some years, EPA has sought to determine why they happen. EPA has questioned vehicle owners, and EPA pays attention to statements made in the automotive repair and hobby press. The most important reason is the price difference between leaded and unleaded fuel in the U.S., which has usually been in the range of U.S. $0.04-0.06 per U.S. gallon. The immediate savings from use of leaded fuel are obvious to price-conscious buyers, and most owners are less aware of the fact that maintenance costs increase with use of leaded fuel. Other countries would be well advised to consider ways of avoiding the incentive of a large price difference in favor of leaded fuel.

Performance is the next reason motivating vehicle owners to misfuel. Some vehicles have octane requirements in excess of the octane provided by regular unleaded fuel. These are the only vehicles which should be expected to give improved performance on leaded fuel, which has higher octane in the U.S. than unleaded. (Even owners of these vehicles are purchasing leaded fuel for price reasons, since a premium grade of unleaded fuel is widely available in the U.S.) However, many owners seem to believe they get better performance from their vehicles when using leaded fuel even when knock is not present when operating on unleaded fuel. Many also believe that leaded gasoline contains more energy per gallon and that fuel economy is improved with leaded gasoline.

Misfueling tends to become habitual. About one-half of leaded fuel purchased for misfueling is purchased by owners who misfuel over 90% of the time. These owners comprise about 4 percent of all vehicle owners. A larger number of owners misfuel less often.

5. NET EMISSIONS FROM IN-USE 1981 AND NEWER VEHICLES

The U.S. paper at the 8th session included illustrations that showed how the progressively more stringent new car standards in the U.S. have achieved lower and lower emissions from passenger vehicles in service. These figures have been updated and are presented here as Figures 9, 10 and 11 for HC, CO, and NOx emissions respectively. The lines in these figures are total emissions including the effects of tampering and misfueling.

The figures show that succeedingly more stringent emission standards have achieved progressively better in-use performance. In addition, the evolution of technology following stabilization of the HC and NOx standards in 1981 and of the CO standard in 1983 is predicted to lead to still lower emissions, although only slightly.

Table 1

1981 and Newer In-Use Vehicles Tested by EPA*

Model Year	Number of Vehicles Tested	Mean Mileage	Distribution of Vehicles By Mileage			
			0-25,000	25,000-50,000	50,000-75,000	75,000
1981	852	28,506	475	202	144	31
1982	143	9,763	129	10	3	1
1983	117	17,771	92	25	0	0

Table 2

Emissions of 1981 and Newer Vehicles*

Model Year	N	CO Standard	Mean Mileage	Mean Emissions (gram per mile)		
				HC	CO	NOx
1981	408	3.4	30,168	0.60	7.37	0.84
	444	7.0	26,978	0.63	8.67	0.85
	852	Both	28,506	0.62	8.04	0.84
1982	28	3.4	5,880	0.27	2.51	0.60
	115	7.0	10,709	0.31	4.03	0.71
	143	Both	9,763	0.30	3.73	0.69
1983	117	3.4	17,771	0.37	3.46	0.73

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*As of August 10, 1984

FIGURE 1.

Light-Duty Passenger Vehicle Emissions

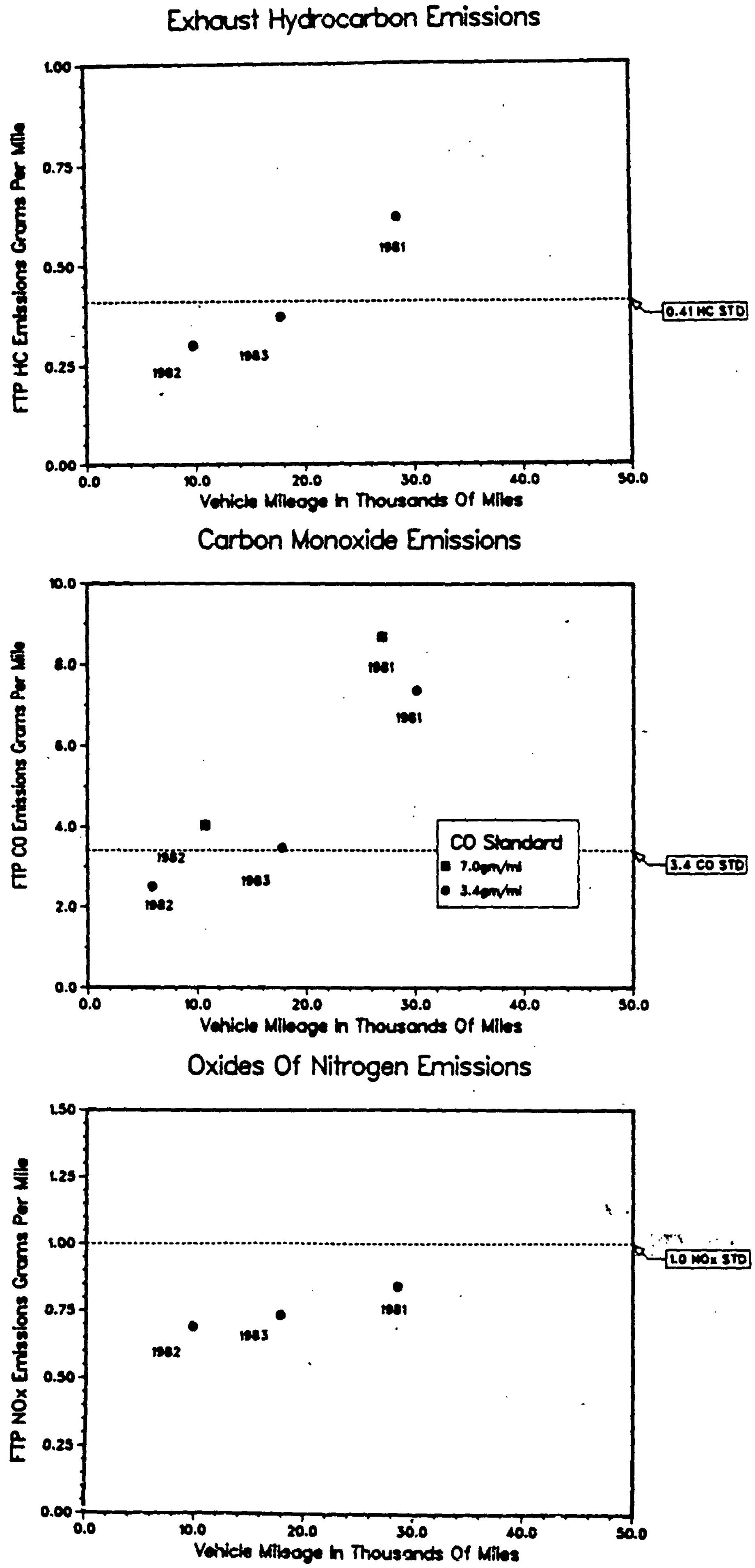


FIGURE 2.

Fuel System

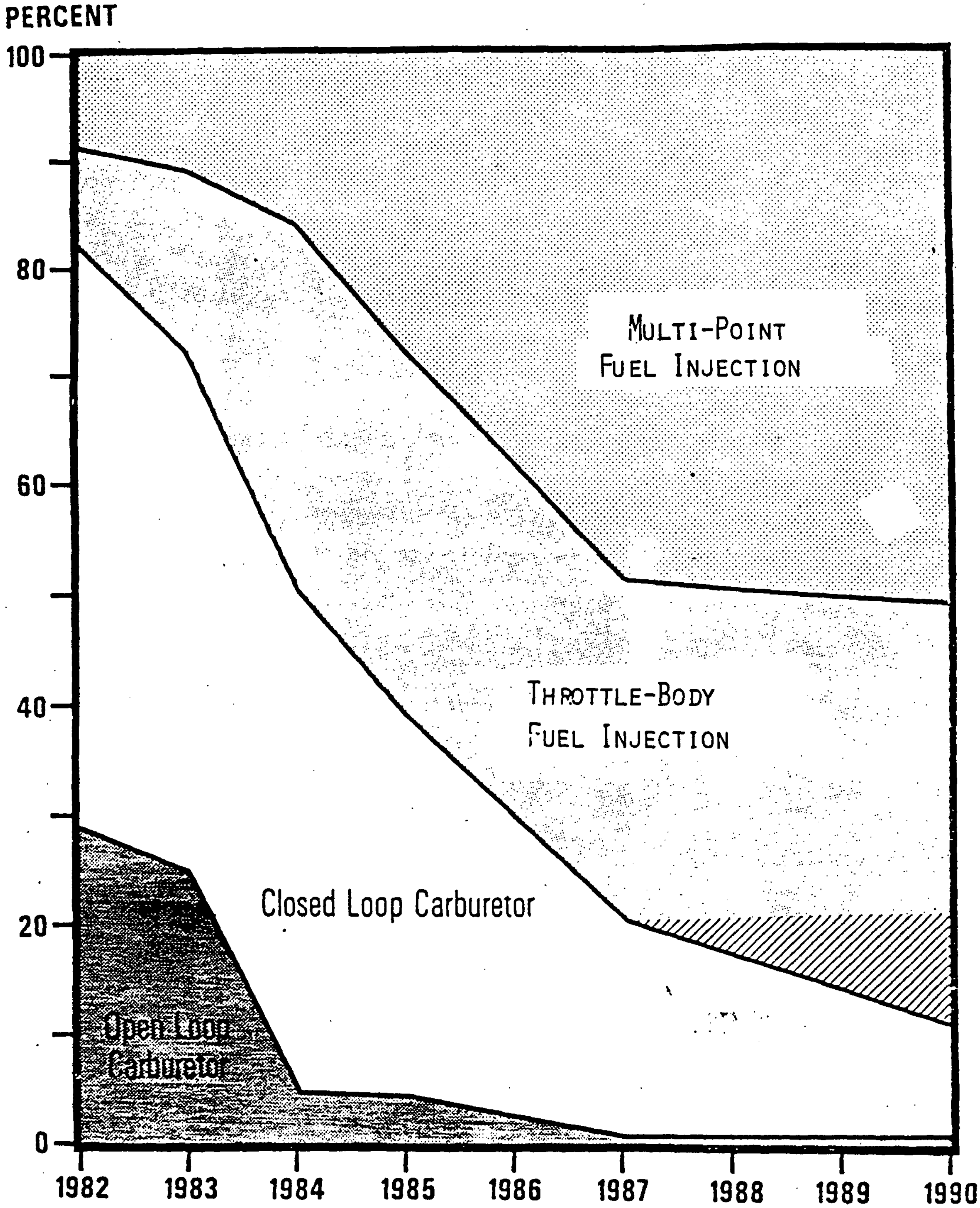


FIGURE 3.

Catalyst System

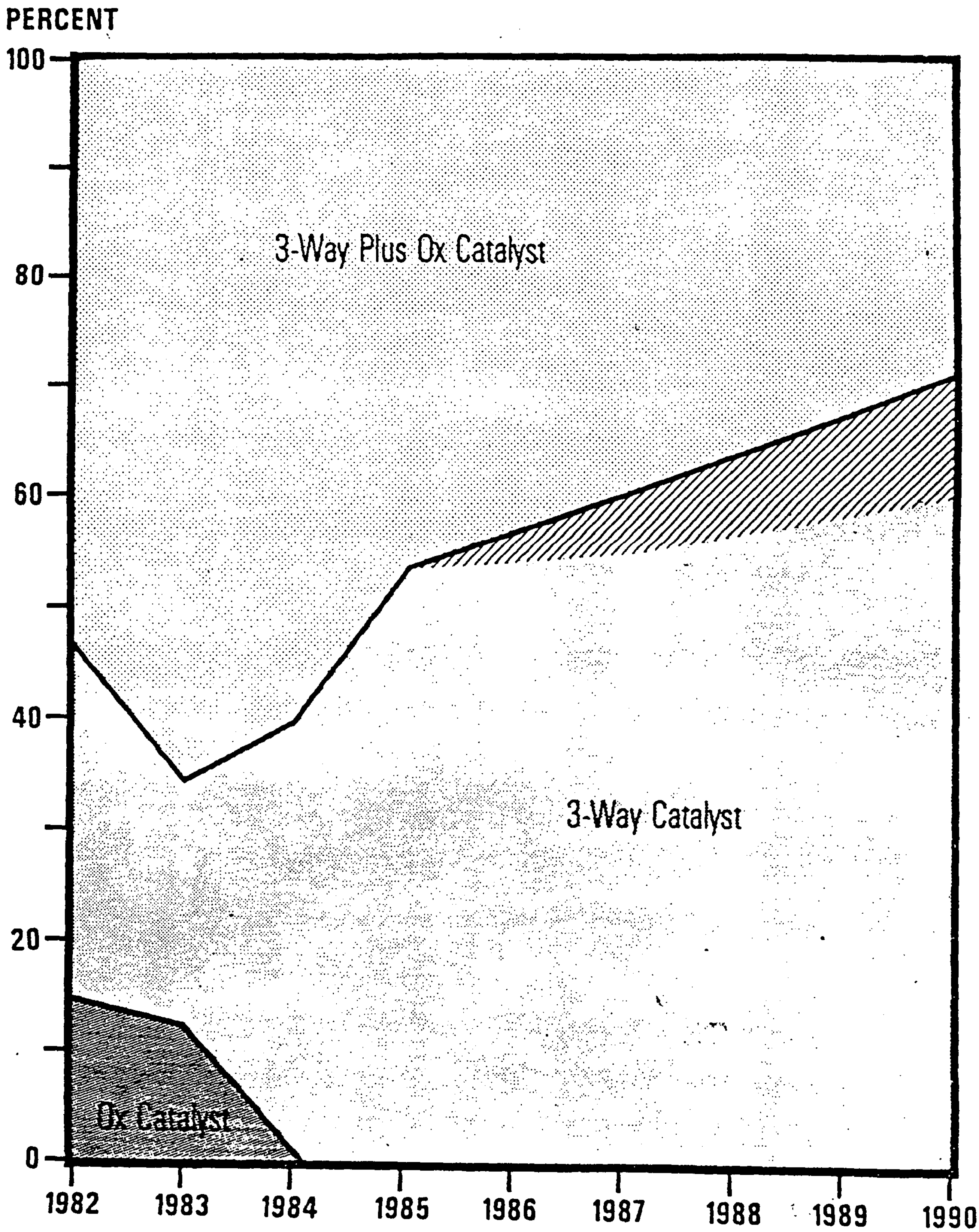
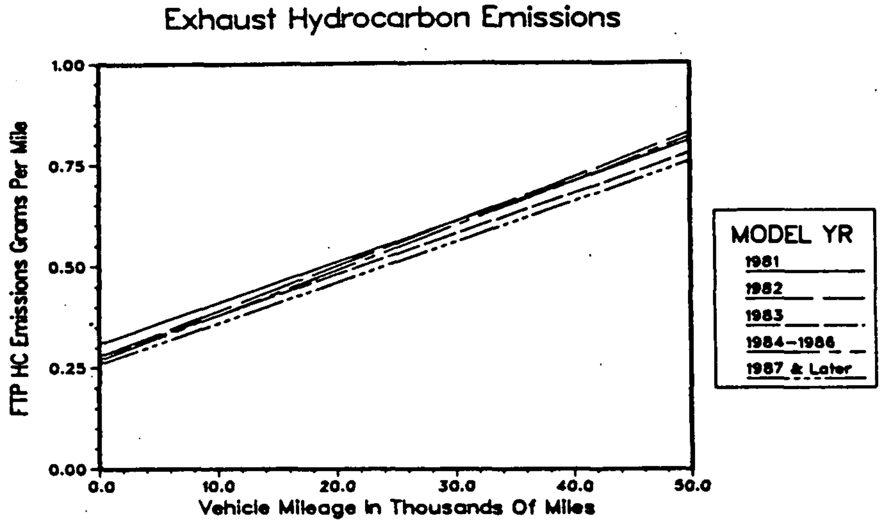
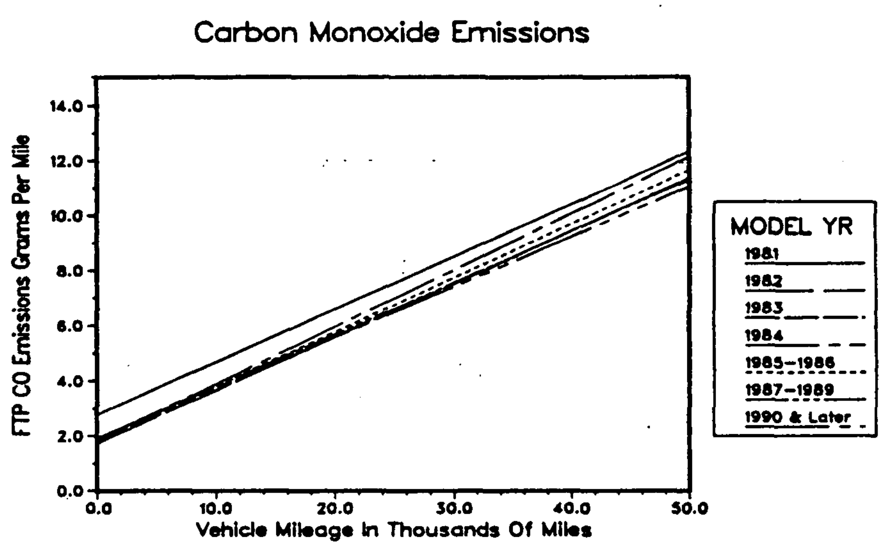


FIGURE 4.

In–Use Emission Levels of 1981 & Newer Vehicles Not Subject to Tampering or Improper Use of Leaded Fuel (By Model Year)





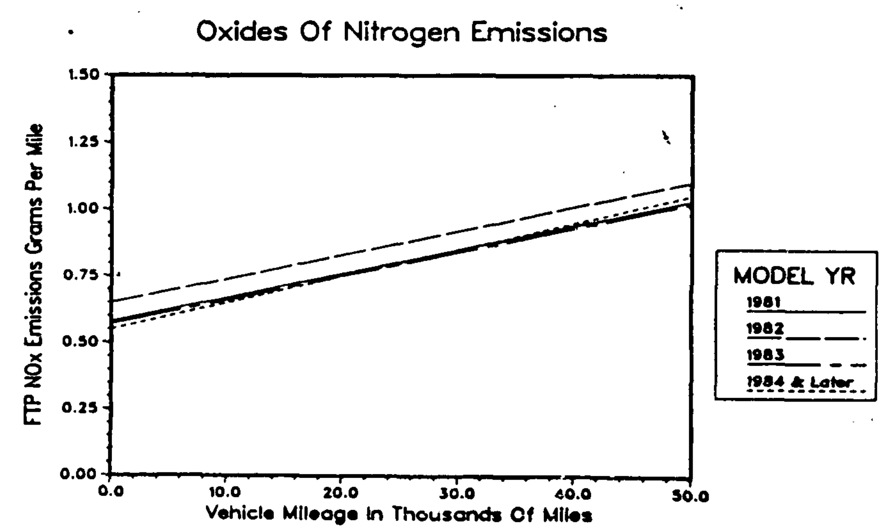


FIGURE 5.

Rates of Tampering And Improper Use of Leaded Fuel

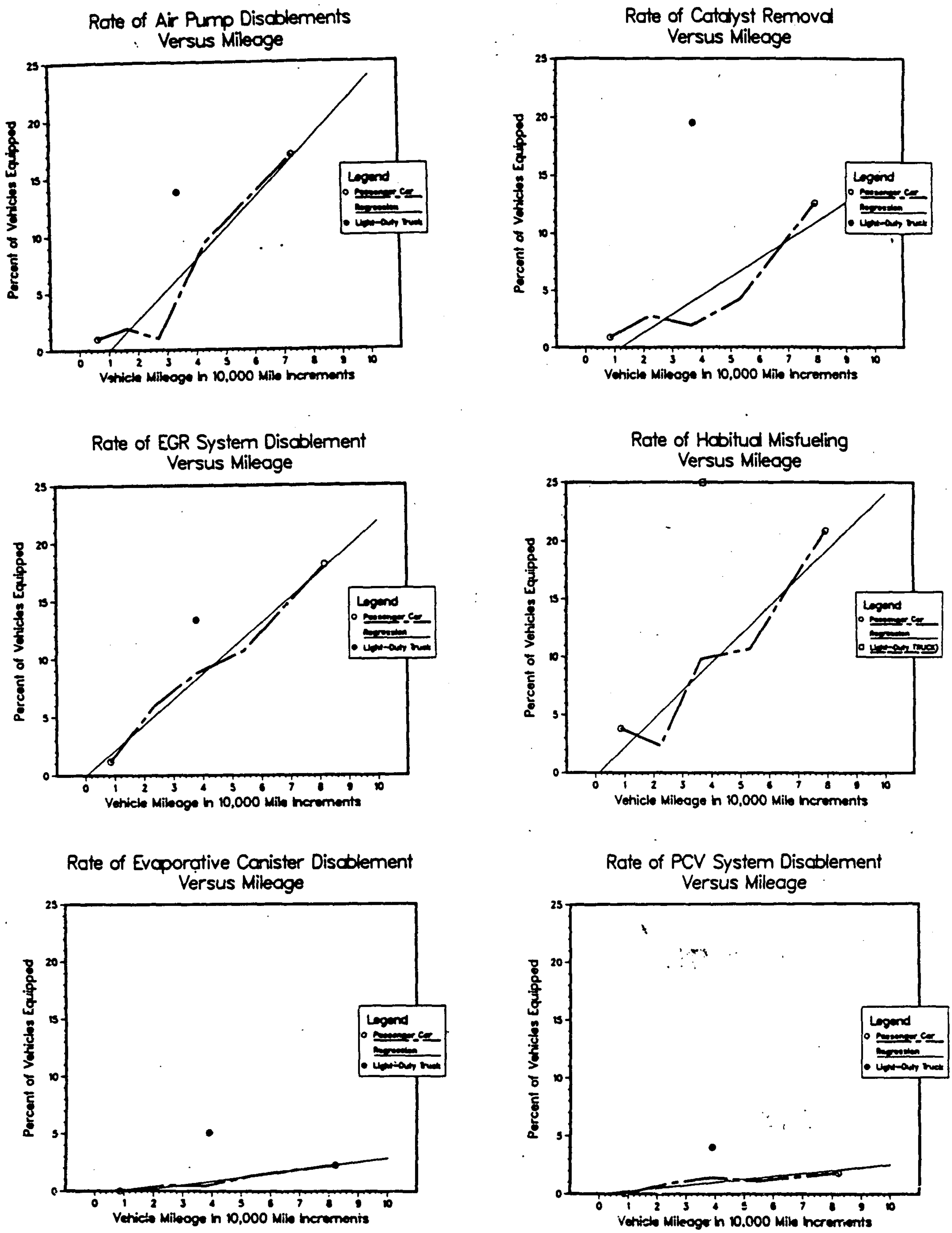


FIGURE 6.

Average Effects of Tampering And Improper Use of Leaded Fuel On A 1981 or Later 3WC Vehicle

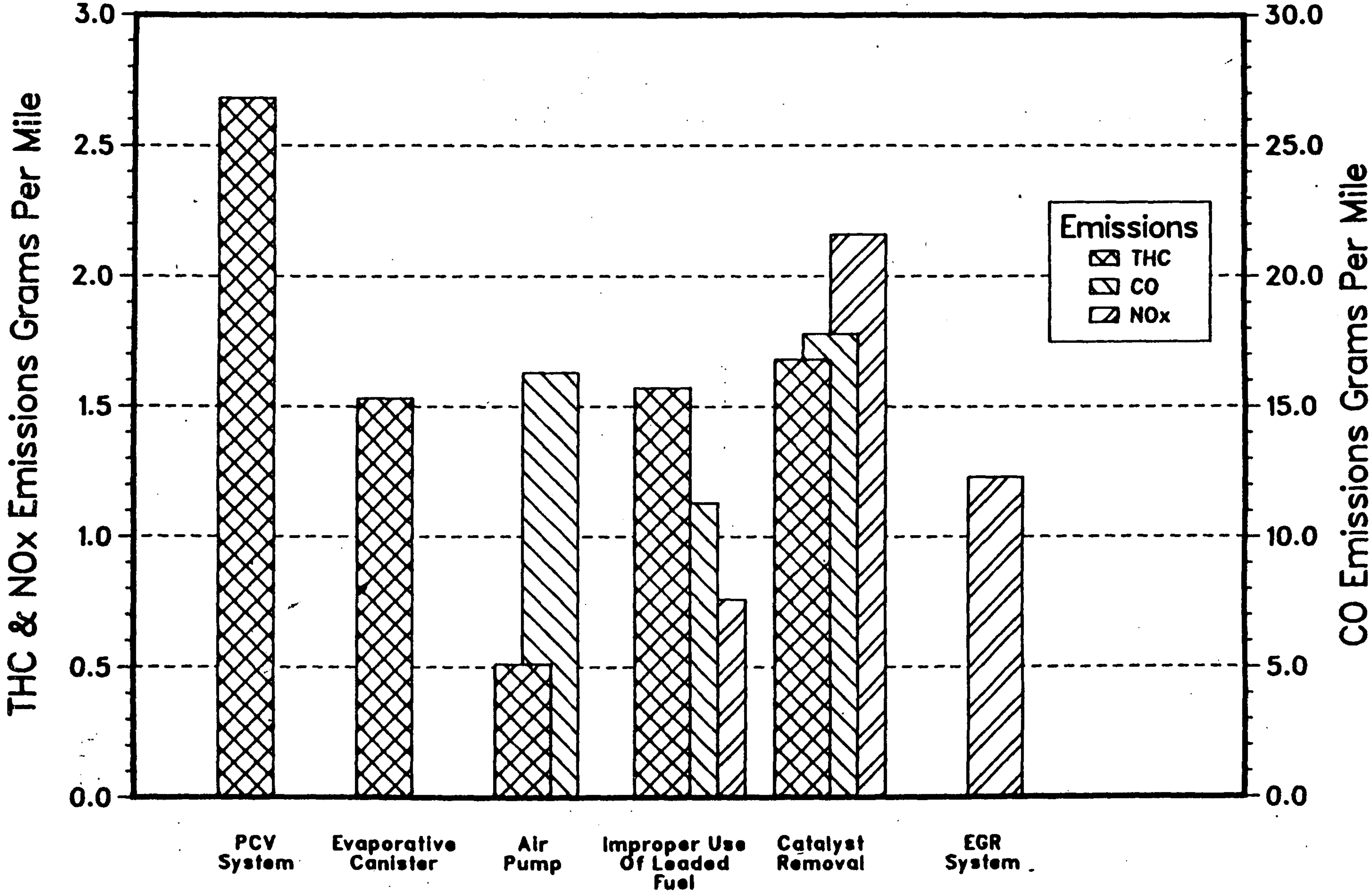
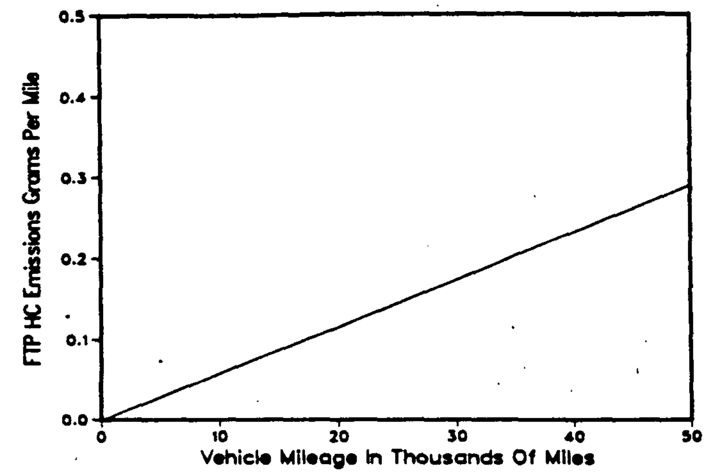


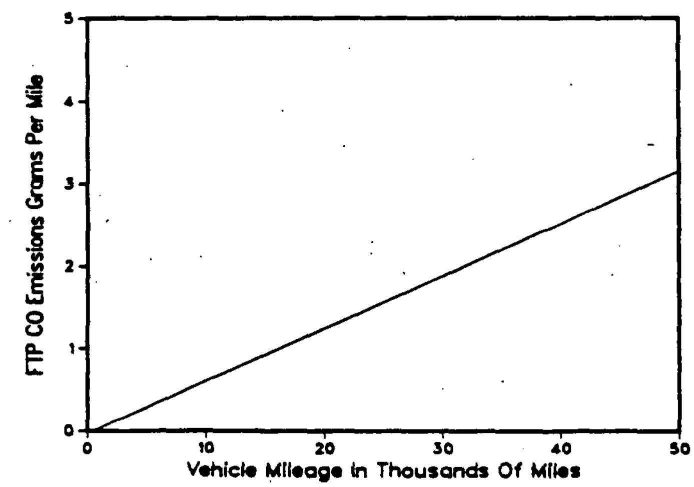
FIGURE 7.

Excess Emission Levels for 1981 & Newer Vehicles Due to Tampering And Improper Use of Leaded Fuel

Excess Total Hydrocarbon Emissions



Excess Carbon Monoxide Emissions



Excess Oxides Of Nitrogen Emissions

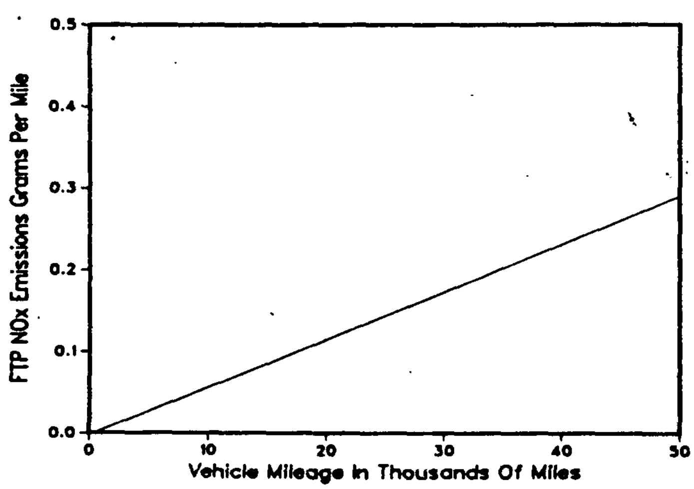
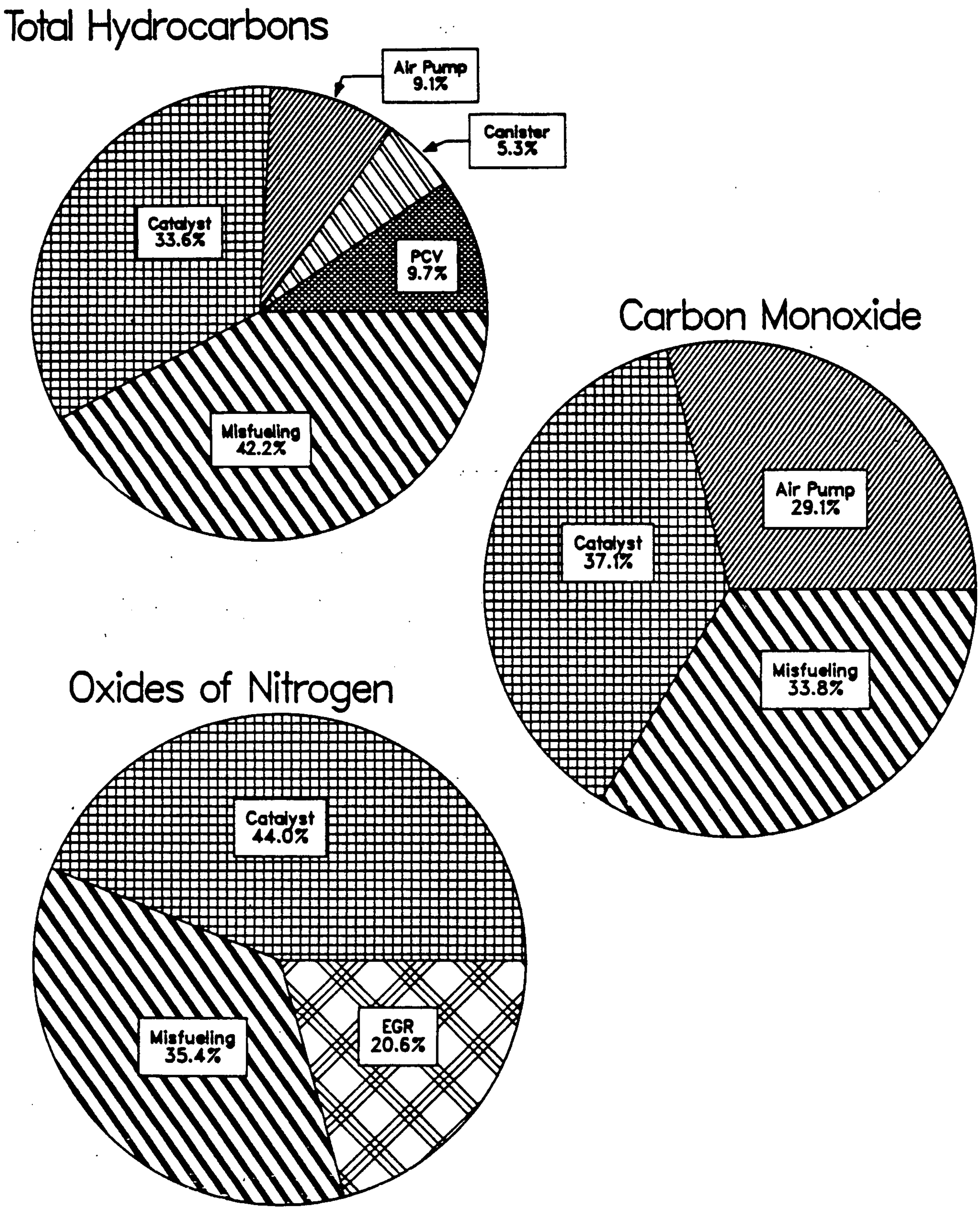


FIGURE 8.

Excess Emission Levels for 1981 & Newer Vehicles Due to Tampering And Improper Use of Leaded Fuel



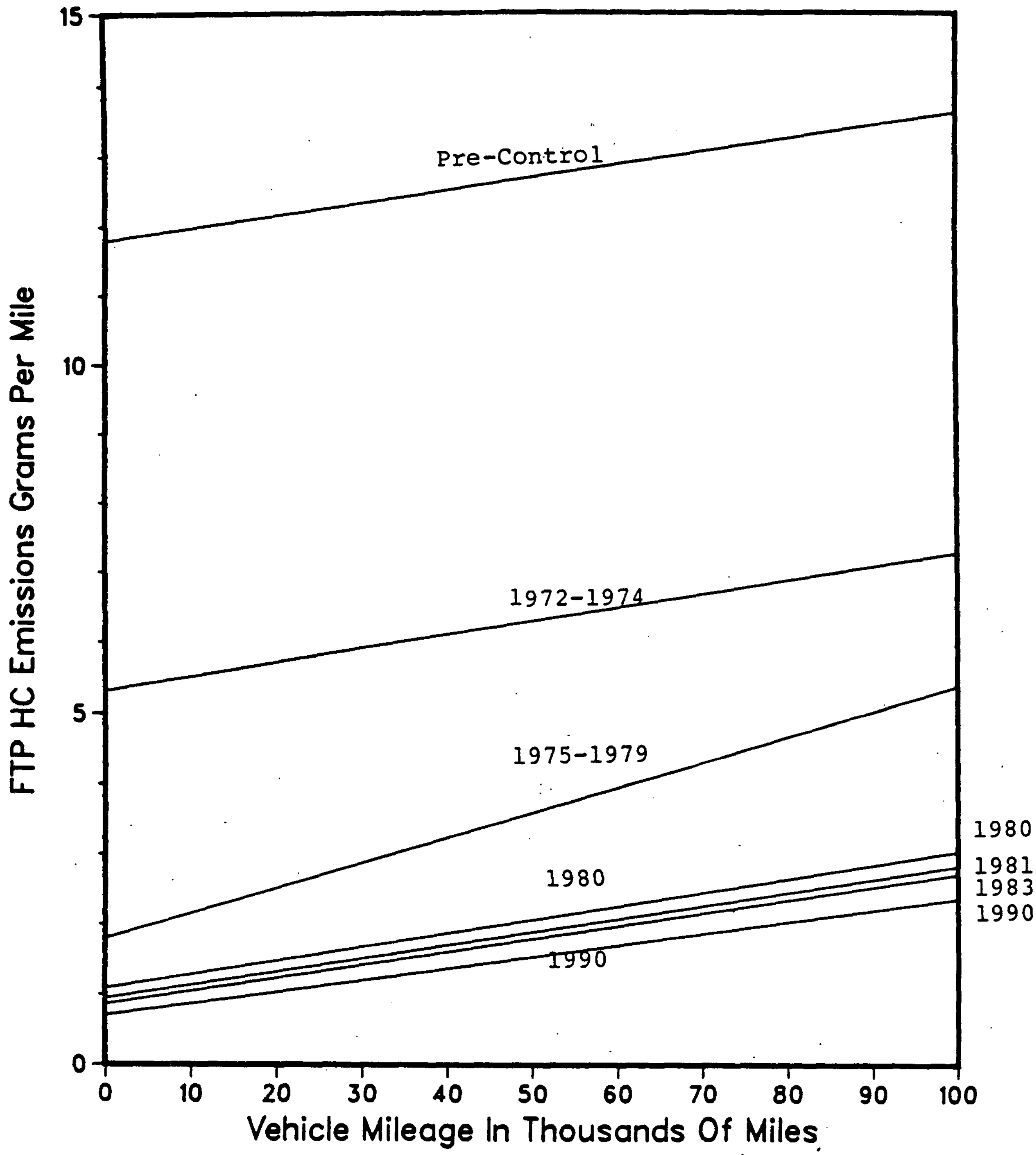


Figure 9 - Hydrocarbon (HC) Emissions of In-Use Passenger Vehicles Produced Under U.S. Emissions Standards

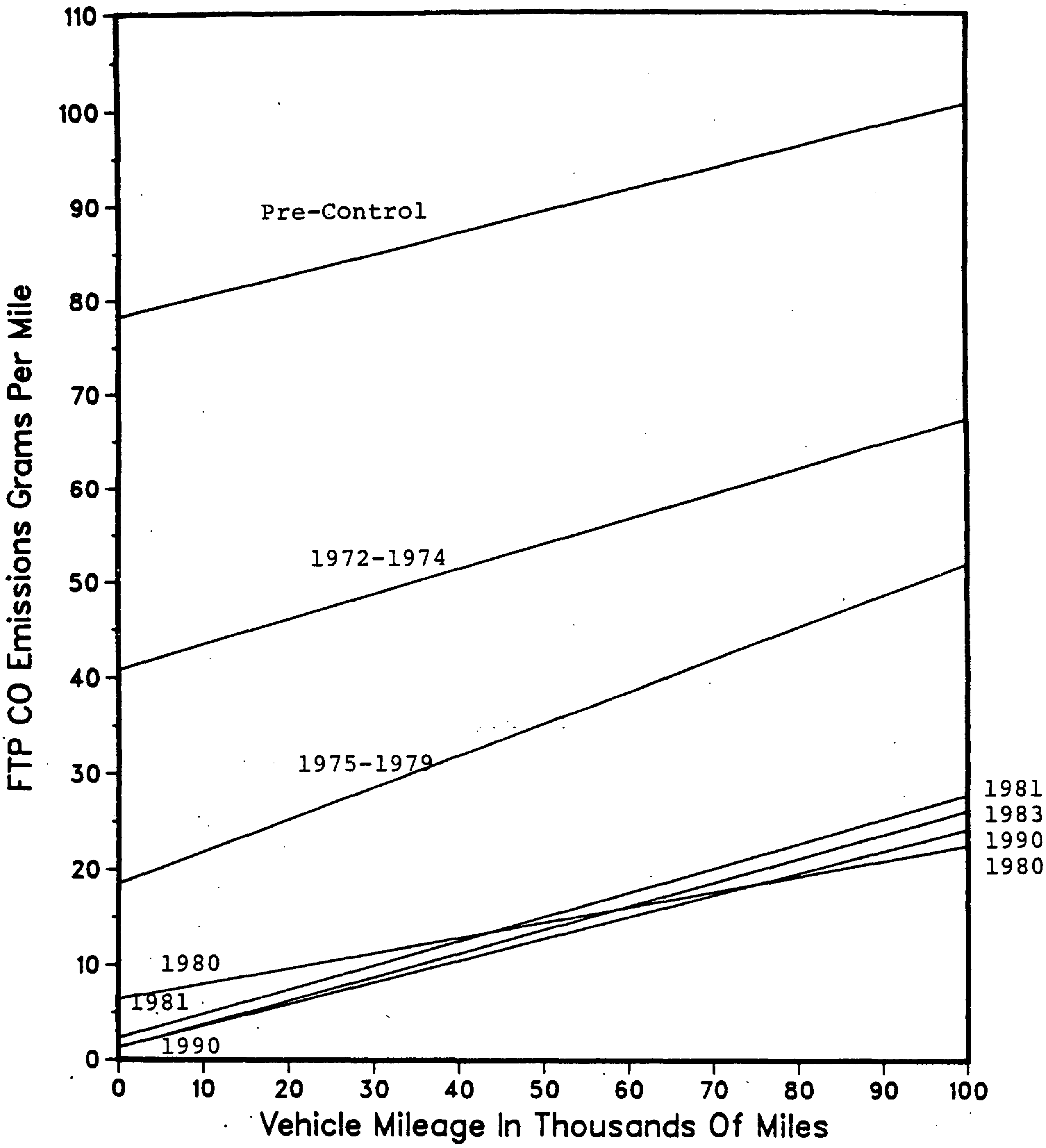


Figure 10 - Carbon Monoxide (CO) Emissions of In-Use Passenger Vehicles Produced Under U.S. Emissions Standards

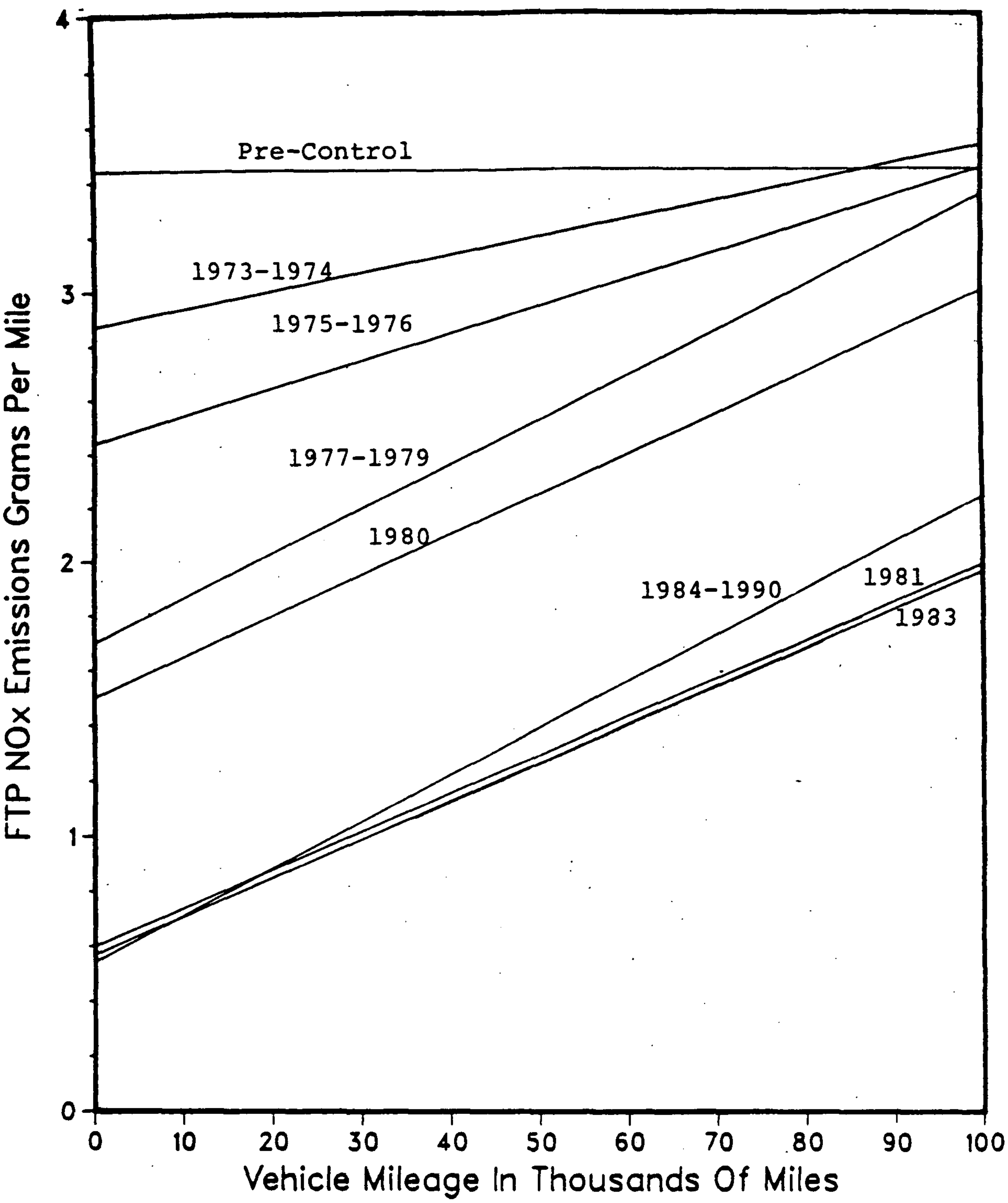


Figure 11 - Oxides of Nitrogen (NOx) Emissions of In-Use Passenger Vehicles Produced Under U.S. Emissions Standards