CONTROL OF DIESEL EXHAUST ODORS

by

Karl J. Springer, M.S., Manager
Emissions Research Laboratory
Southwest Research Institute
San Antonio, Texas

and

Ralph C. Stahman, B.S., Branch Chief
Test and Evaluation Branch
Environmental Protection Agency
Ann Arbor, Michigan

PAPER NO. 26

Presented at
Conference on Odors: Evaluation, Utilization and Control
The New York Academy of Sciences
New York, New York

October 1-3, 1973

CONTROL OF DIESEL EXHAUST ODORS

Karl J. Springer, M.S.

Southwest Research Institute

San Antonio, Texas

Ralph C. Stahman, B.S.

Environmental Protection Agency

Ann Arbor, Michigan

INTRODUCTION

Diesel engine exhaust does not have to have a noticeable odor, yet many diesel engines do under some conditions. The control of diesel odor, as with other air pollutants, depends on three "musts". First, there must be a way to measure and express the odor in simple, understandable, and repeatable terms. Second, there must be a way to effect a reduction in the odor that is feasible economically. Finally, the reduction in odor must do something positive as far as the public is concerned. Work has been in progress by government[1], industry, and independent laboratories on all of these "musts".

This paper will briefly review the major work done in these areas and then report on some recently-completed, unpublished results of odor control for municipal buses. It is the city bus that has seemed to be the major cause of complaint about diesel odor, though it is, of course, not the only cause of traffic odor nor is it the only source of diesel odor. Its proximity to large numbers of people, because of the nature of operation in both center city and residential areas, has made its exhaust odor one of the chief air pollution complaints. Although the odor itself has not been positively found a health hazard[2], it does qualify as a nuisance emission as it is an annoyance and thereby affects public welfare. The 1965 amendments to the Clean Air Act of 1963, Public Law 88-206, as amended by Public Law 89-272, identified odor and smoke from diesel-powered vehicles as of concern. It was the language in those amendments which accelerated efforts to learn more about diesel odor and ways to control it.

METHODS OF MEASUREMENT

Contrary to some other odor sources, the compounds which comprise diesel exhaust odor are so numerous and complex as to defy their complete classification and direct measurement by chemical-instrumental methods. The analytical methods that have been proposed for diesel odor measurement rely on the human nose for calibration.

Most diesel odor research has used a trained panel of observers to relate the intensity in mainly hedonic scales[3]. More highly-trained observers also evaluate the odor in terms of quality or character to better describe the odor. Although initial studies involved threshold detection, most recent work has been at suprathreshold intensities with odor realistic of actual public encounter.

Most research on diesel exhaust odor control has utilized the Environmental Protection Agency Diesel Odor Quality-Intensity Rating System[4], better known as the Turk Kit after its originator, Dr. Amos Turk. The kit, shown in Figure 1, consists of 28 plastic squeeze bottles, each partially filled with a different intensity or odor. The kit includes an overall "D" diesel odor in twelve steps in increasing concentration. Each concentration is double the preceeding in order to parallel the non-linear human response to odor. The "D" odor is made of four sub-odors or qualities. These comprise burnt smokey "B", oily "O", aromatic "A", and pungent "P" qualities each in a 1 through 4 intensity series, 4 being strongest.

Special odor sampling, dilution, and presentation facilities[5, 6] were developed about seven years ago by Southwest Research Institute (SwRI) on behalf of the EPA using design criteria obtained in field studies of atmospheric dilution of bus and truck exhaust. Horizontally-directed exhaust, at bumper height from a city bus, was found to be diluted to a minimum, reasonable level of 100:1 before being experienced by an observer. This finding was confirmed by a later project by General Motors Research[7]. Vertically-directed exhaust from trucks was found to be diluted 700 times as a reasonable minimum before being noticed by the observer.

The trained panel shown in Figure 2 routinely evaluates simultaneously-presented dilute exhaust in terms of the Turk Kit of standards.

A diesel-powered vehicle, such as a city bus, is operated on a chassis dynamometer to simulate road operation under laboratory conditions. Normally, to determine the performance of a control device, a series of odor ratings are made with the vehicle or engine in standard or unmodified condition and then, usually the next day, with the control system operative. Each series of tests involves replicate observations in random order of odor produced during different operating speeds and power levels. In addition to steady state vehicle cruise and idle, transients such as accelerations after prolonged idle, upshift-type accelerations, and decelerations from a cruise are simulated and the resultant odor levels determined.

Prediction of Observed Odor by Analytical Measurements

Although the trained panel method requires expensive and complicated sampling, dilution and presentation facilities and a trained panel of observers, the time required to perform an engine or vehicle evaluation is rather quick, usually one working day. There has long been a need, however, to extend the usefulness of the trained panel method described so that more researchers could investigate the causes and control of diesel odor.

One approach involved correlating observed odor to exhaust emissions that are normally measured by most well-equipped diesel emission laboratories[8]. Equations were developed for the prediction of odor from, for example, city buses powered by 2-stroke cycle GM

Detroit Diesel engines, one group of vehicles thus studied. For brevity, only the "D" odor intensity equation is listed on Figure 3. This curve indicates the ability of the equation to predict observed odor. Its precision is either good or not good depending on the end use of the data. Although recommended for research, such predictions may not be good enough for use in complying with an odor standard. One fundamental fact is clear, that no matter how good the instrument or analysis it can never be better than the panel in its precision. The panel in itself is not particularly precise relative to other laboratory instruments.

Thus the dilemma and one stumbling block to odor research is the lack of a relatively simple but precise indicator other than the nose. The prototype A. D. Little instrument[9] promises to do as well or better than the prediction equations; but at this writing, there is insufficient data on which to evaluate the instrument's performance with diesels in general.

ODOR CONTROL

Over the years, a number of strategies have been investigated for the control of diesel exhaust odor. Fuels, fuel additive treatment, engine make and type, type of aspiration, oxidation catalysts, dilution, fuel injector design, and engine power derating are some of the techniques tried[6, 10-14]. Most odor control methods are directed to the city bus; and, therefore, this has usually been the primary test vehicle.

To summarize the past seven years of control technology evaluation, only a few ideas have shown merit; most have not. Not enough is known about the effect of fuel composition on diesel odor; but studies to date[11] have shown the effect of a kerosene-type ASTM DF-1 grade of fuel to produce about the same overall intensity as an ASTM DF-2 with a noticeably lighter, less pungent, acrid, penetrating, and lasting odor than the heavier DF-2 fuel. This is one major reason why most of the 25,000 city buses operating in the U.S. use the more expensive DF-1 fuel. There are a number of unresolved questions regarding the influence on perceived odor of the sulfur in the fuel both in quantity and composition.

A number of odor maskant-type additives have been tried with all failing to have any substantial effect on the odor intensity. Some new odors would be introduced that would attempt to hide the predominantly burnt-smokey and pungent odors but to little avail. Occasionally, a bus transit system will use a maskant with reported success due generally as much to the public announcement and public relations activity as to the additive itself. This is not to say an additive could not be found to mask the odors, but careful research to date has revealed only slight or technical improvement.

Oxidation catalysts have, for many years, been considered a standard method for reduction of diesel odor. In many instances, this is true; but the city bus application has been the most difficult. To date, precious metal catalysts, with greater activity and efficiency, are preferred over less expensive, mostly ineffective copper oxide coatings that have been proposed for bus use[10]. The city bus poses difficult conditions for a catalyst, possible the most difficult since odor is many times associated with exhaust temperatures from the 2-stroke diesel engine that are below the catalyst activation temperature. Where mostly steady state, high exhaust temperature, operation is involved, certain commercially-available catalysts using precious metals can do an effective job of reducing odor and eye irritants.

Engine derating, the intentional lowering of an engine's power output by reducing fuel delivery, has little influence on perceived odor. Diesel odor is probably best considered a product of incomplete combustion much the same as carbon monoxide, hydrocarbons, and oxygenates, such as aldehydes and acrolein. At high odor intensities, unburned HC in the exhaust has been shown to be the simplest and best indicator of odor[8] with acrolein, aliphatic aldehydes and formaldehyde, all odorous materials, also helpful in the prediction equations. Other indicators of combustion efficiency, such as CO_2 and NO, have been helpful since exhaust odor generally is less as these increase.

From this, it is not surprising that engine and combustion chamber variables can be important. Odor data from a variety of engines have been reported[6-17] which show that most engines do produce noticeable odor but that a few do not under almost every test condition. Why these latter engines have essentially little or no noticeable odor, even at 100:1 dilution, is not clear. It is not simply a function of design choice between pre-chamber versus open chamber combustion, two-stroke versus four-stroke cycle, or turbo-charging versus normal aspiration. Nor is it an obvious association with unit or jerk type fuel injection systems or with types of injector design. All these and more have an influence singly and their combination and optimization have too long overlooked or neglected exhaust odor as an important design factor.

Example of Diesel Odor Control

As a specific example, SwRI and the San Antonio Transit System recently completed, on behalf of EPA, a two-year demonstration of several city buses equipped with General Motors Truck and Coach Division's Environmental Improvement Proposal (EIP), a kit of parts costing about $1200 and an equal sum to install[14]. Figure 5 is a rear view of one of the buses equipped with the kit. The demonstration has national importance since the kit was destined for some 25,000 in-service buses as a retrofit.

Claims for the kit included reduced odor, smoke, hydrocarbons, oxides of nitrogen, carbon monoxide, interior noise, and vibration. The components of the kit that were intended to reduce odor may be categorized as vehicular (catalytic muffler, vertical stack) engine (improved injectors, retarded injection timing) and operational (higher up and down shift automatic transmission shift speed and DF-1 fuel). Figure 6 is a cutaway of the catalytic muffler while some of the used catalyst is shown in Figure 7. Figure 8 is a cutaway of an LSN unit injector, and Figure 9 is a schematic of a standard 60S and a needle valve tip assembly. The dark shaded area under the valve represents the volume of fuel free to enter into the combustion chamber at odd moments during the cycle. The reduction of this residual fuel has been shown by the engine manufacturer to have substantial impact on exhaust emissions[12].

Many of the components had been evaluated and reported on singly but never as a total system. There is little doubt as to the effect of the vertical stack in dispersing and diluting the odor better than the bumper level exhaust prior to its reaching the motorist or pedestrian. Whether merely diluting or dispersing the odor constitutes an acceptable control method is unknown. If odor were considered in the group of pollutants such as carbon monoxide, then the odor would have to be destroyed. However, if odor is regarded only as a local nuisance, then dilution would be an acceptable means to reduce that nuisance. Further studies of the effect of the specific EIP vertical stack-equipped city bus on odor are in progress at SwRI.

Odor and other emissions inspections were made five times; at the beginning (1000 miles) and after five months (25,000 miles), ten months (40,000 miles), 16 months (80,000 miles), and 24 months (115,000 miles). The measurements were made in three configurations; first with stock muffler and stock 60S unit type injectors, second with the improved 60 LSN injectors, and last with the EIP catalytic muffler plus 60 LSN injectors. This experimental design was predicated on the improved injectors and catalytic muffler having the major impact. DF-1 fuel was used throughout, and its effect will be discussed later in this paper. The effect of ignition static timing on odor for the Detroit Diesel 6V-71 engine had already been investigated[13].

A significant reduction in odor was found when the improved injectors were used in all three buses under most all conditions except idle.

As an example, Figure 10 illustrates the odor results for one of the three buses. The height of each bar is the sum of "D" + "B" + "O" + "A" + "P" ratings and directly compares the stock, stock plus catalytic muffler and catalytic muffler plus improved fuel injectors. Shortly after the third inspection, the catalytic muffler was deleted from the test program due to its general ineffectiveness.

In summing the observed intensities, about equal weight or importance is arbitrarily given to the "D" diesel intensity and to the four qualities combined. Table 1 lists the specific ratings for Bus 704 for each inspection. These are reduced, average, data from the replicate runs by the 10 trained panelists. The presence of asterisk values for the Us nonparametric statistical test for difference indicates the net change to be within the spread of the experimental data and not statistically different. There is no doubt the improved LSN injectors did an excellent job, were mainly consistent, and most reductions were not only substantially but statistically different. The catalytic muffler had little or no overall net positive effect and occasionally a more penetrating pungent, sour odor was found. This has, in the past, been attributed to partial conversion of less smelly compounds into more odorous combustion intermediates.

The effect of fuel on diesel odor was studied on Bus 704, as a part of the EIP demonstration[14]. Inspection data for the three fuels, two locally available name brand DF-1 and DF-2 fuels and a name brand super premium DF-2 marketed in the Chicago area, are shown on Table 2. The only gross difference in the two DF-2 fuels was total sulfur content.

The local DF-1 and DF-2 fuels resulted in total odor ratings ("D" + "B" + "O" + "A" + "P") that were mostly the same. This is shown by the first two bars of each group on Figure 11. Table 3 is a summary of the specific ratings in which there was a statistical difference noted only in a few cases. Referring to the third bar in each group, in Figure 11, the Chicago area super premium DF-2 fuel gave a noticeably higher odor than that of either San Antonio fuels. A direct comparison of the two DF-2 fuels is made on Table 4; and in practically all instances, the difference was significant.

The panel judged the DF-1 fuel to be somewhat less harsh, penetrating, and lasting and thus less objectionable than the local DF-2 fuel. The panel also rated the Chicago DF-2 fuel much more acrid, nauseating, and objectionable than the local DF-2. Whether the increased sulfur is the reason is unknown. It is probable that the type of sulfur in the fuel is as important, if not more so, than the total sulfur content.

To conclude this odor control example, DF-1 fuel and improved fuel injectors were definite recommendations from the EIP study along with increased upshift speeds as methods to reduce city bus odor. The Urban Mass Transit Administration, of the Department of Transportation, announced on January 18, 1972 it would assist transit systems in retrofitting buses with the LSN injector and, on a lower priority, the other components of the kit exclusive of the catalytic muffler. More data and detailed discussion of this example of odor control from diesel buses is contained in Reference 14.

PUBLIC ACCEPTANCE OF DIESEL ODOR

To learn more about the third "must", a study of public objectionability to diesel odors was made. The approach was to obtain an individual's reaction to a dilute sample of diesel odor presented to him in the same way as the trained odor panel described earlier. A mobile odor-measuring facility, the Sniffmobile, was prepared, capable of simultaneous presentation of known intensities of diluted city bus-like odor to 10 participants under controlled conditions. An exterior view of this facility is shown in Figure 12.

A unique rating scale was devised which relied on facial and bodily reaction to the odor. This cartoon scale is shown in Figure 13 and was quite successful in eliciting the opinion of people with widely different ethnic and socio-economic backgrounds. The trained SwRI panel was used to calibrate the odor levels in terms of the Turk Kit and thereby remain compatible with control technology measurements. Two surveys were made; the first in 1969 involving over 3000 quota sampled individuals in five cities(18). The cities were San Antonio, Chicago, St. Louis, Philadelphia, and Los Angeles. Another survey, involving 2100 quota sampled individuals at five sites in San Antonio, was made in 1970(19). The 1970 survey differed from the 1969 survey in that only one odor intensity was presented to the participant, whereas the earlier survey presented a series of increasing odor strengths of nominal "D"-2, "D"-4 and "D"-6 intensities.

Among a number of other findings, the public opinion odor testing resulted in a dose-response relationship illustrated in Figure 14. This is typical of the upper portion of the usual "S" type dose-response odor curve. For a given reduction of, say, two "D" numbers, for example, from "D"-6 to "D"-4, the reduction in odor objectionability is from 0.9 or 90 percent to about 0.82 or 82 percent of the participants. The overall improvement or percent reduction is thus 0.9-0.82/0.9 x 100 percent or roughly 9 percent. This is not much improvement in public opinion or acceptance for a fairly substantial odor intensity reduction.

Another two "D" number reduction from, say, "D"-4 to "D"-2, gives a fraction of the participants who think the odor is objectionable of 0.58 or 58 percent. The overall improvement in this case is much greater in terms of objectionability being 0.82-0.58/0.82 x 100 percent or 29 percent. Thus, the public will recognize an improvement in diesel odor more readily if the odor intensity from the vehicle is not strong to begin with. This is because the odor generates a subjective response that increases less as odor strength is increased.

One use of Figure 14 is to assess the impact of the EIP kit odor control on public objectionability. Applying the first interim inspection results of the EIP kit to this curve (all buses and conditions averaged with equal weight given each), a reduction of odor from a "D"-5.3 to "D"-3.5 results in an 11 percent reduction in objectionability. The point then is whether the expense and trouble to retrofit city buses with the improved injector is justified for the seemingly small improvement in acceptance. The answer has been an emphatic "yes"; because until the odor intensity is reduced, additional control measures will have difficulty in measurably improving the acceptance of city bus exhaust odor.

SUMMARY

This paper has attempted to describe diesel exhaust odor control efforts over the past seven years. Odor measurement and public acceptance are necessary considerations to any discussion of odor control. A number of odor control methods have been evaluated by the Environmental Protection Agency in its continuing program of research on diesel exhaust emissions. Examples such as improved fuel injectors for city buses are bright spots among many failures that testify to the difficulty of odor control. More can and is being done by manufacturers to design and develop engines with low, essentially negligible exhaust odor. Before justifying a substantial commitment, however, most manufacturers and other researchers will require a less complicated measurement procedure as well as a specific goal to work toward. Ultimately, it will require the coordinated efforts of government and industry to remove the diesel engine as a source of odor complaint.

ACKNOWLEDGEMENT

This paper is based in part on work performed by Southwest Research Institute under Environmental Protection Agency Contract PH 22-68-23.

LIST OF REFERENCES

1. Somers, Joseph and Kittredge, George, "Review of Federally-Sponsored Research on Diesel Exhaust Odors", Air Pollution Control Association Journal, Volume 21, No. 12, December 1971.

2. Styles, H. E., Vrebos, J., and Lawther, J., "Public Health Aspects of Air Pollution From Diesel Vehicles", World Health Organization.

3. Springer, Karl J. and Ludwig, Allen C., Documentation of the Guide to Good Practice for Minimum Odor and Smoke From Diesel-Powered Vehicles, Final Report to the U.S. Public Health Service, Contract No. CPA 22-69-71, November 1969.

4. Turk, Amos, "Selection and Training of Judges for Sensory Evaluation of the Intensity and Character of Diesel Exhaust Odors", U.S. Department of Health, Education, and Welfare, Public Health Service, 1967.

5. Springer, Karl J. and Stahman, Ralph C., "An Investigation of Diesel-Powered Vehicle Odor and Smoke", National Petroleum Refiners Association, FL 66-46 presented at the Fuels and Lubricants Meeting, Philadelphia, Pennsylvania, September 15-16, 1966.

6. Stahman, Ralph C., Kittredge, George, and Springer, Karl J., "Smoke and Odor Control for Diesel-Powered Trucks and Buses", SAE Paper No. 680443, Mid-Year Meeting, Detroit, Michigan, May 20-24, 1968. Also SAE Transactions.

7. Springer, Karl J., Field Demonstration of General Motors Environmental Improvement Proposal (EIP) - A Retrofit Kit for GMC City Buses, Final Report for Environmental Protection Agency, Contract No. PH 22-68-23, December 1972.

8. Dietzmann, Harry E., Springer, Karl J., and Stahman, Ralph C., "Diesel Emissions as Predictors of Observed Diesel Odor", SAE Paper No. 720757, National Combined Farm, Construction & Industrial Machinery and Powerplant Meetings, Milwaukee, Wisconsin, September 11-14, 1972. Also SAE Transactions.

9. "A Diesel Exhaust Odor Analysis System", A. D. Little, Inc., Cambridge, Massachusetts, January 26, 1973, Developed under CRC-APRAC Project CAPE -7-68.

10. Springer, Karl J. and Hare, Charles T., "Four Years of Diesel Odor and Smoke Control Technology Evaluations - A Summary", an ASME Publication No. 69-WA/APC-3.

11. Springer, Karl J., An Investigation of Diesel-Powered Vehicle Odor and Smoke, Part III, Final Report, Contract No. 22-68-23, October 1969.

12. Ford, H. S., Merrion, D. F., and Hames, R. J., "Reducing Hydrocarbons and Odor in Diesel Exhaust by Fuel Injector Design", SAE Paper No. 700734, Presented at Combined National Farm, Construction, and Industrial Machinery and Powerplant Meetings, Milwaukee, Wisconsin, September 14-17, 1970.

13. Springer, Karl J. and Dietzmann, Harry E., An Investigation of Diesel-Powered Vehicle Odor and Smoke, Part IV, Final Report, Contract No. 22-68-23, April 1971.

14. Springer, Karl J., Field Demonstration of General Motors Environmental Improvement Proposal (EIP) - A Retrofit Kit for GMC City Buses, Final Report, Contract No. 22-68-23, December 1972.

15. Springer, Karl J., An Investigation of Diesel-Powered Vehicle Odor and Smoke, Part II, Final Report, No. AR-644, Contract No. 86-67-72, February 1968.

16. Springer, Karl J., Emissions From a Gasoline- and Diesel-Powered Mercedes 220 Passenger Car, Report No. AR-813, Contract No. CPA 70-44, June 1971.

17. Springer, Karl J. and Ashby, H. Anthony, "The Low Emission Car for 1975 - Enter the Diesel", Paper No. 739133, Presented at the Intersociety Energy Conversion Engineering Conference, Philadelphia, Pennsylvania, August 13-16, 1973.

18. Springer, Karl J. and Hare, Charles T., A Field Survey to Determine Public Opinion of Diesel Engine Exhaust Odor, Final Report, Contract No. PH 22-68-36, February 1970.

19. Hare, Charles T. and Springer, Karl J., Public Response to Diesel Engine Exhaust Odors, Final Report, Contract CPA 70-44, April 1971.

FIGURE 1. U.S. PHS (EPA) DIESEL ODOR QUALITY-INTENSITY STANDARDS

FIGURE 2. SwRI TRAINED ODOR PANEL

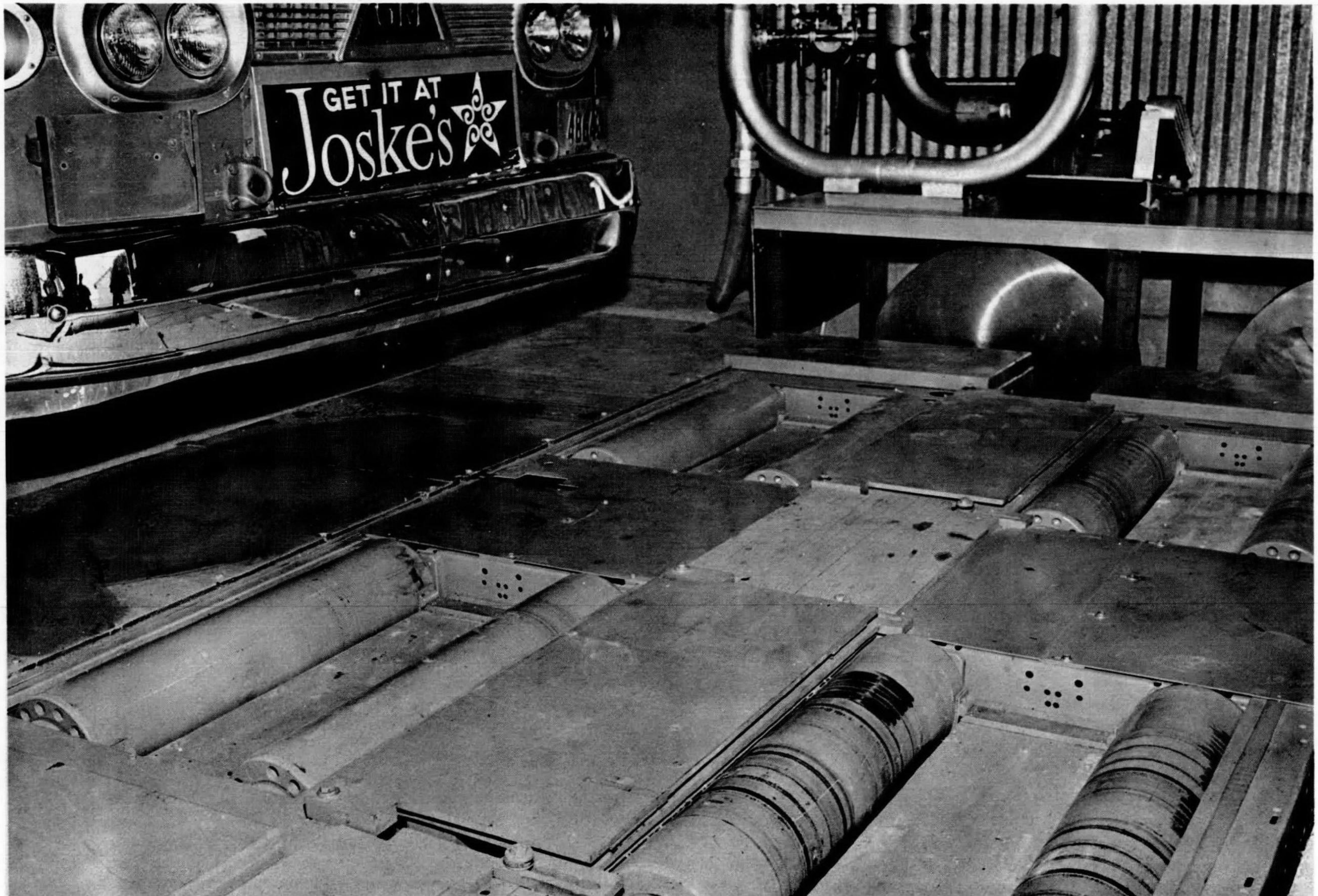

FIGURE 3. SwRI BUS-TRUCK CHASSIS DYNAMOMETER

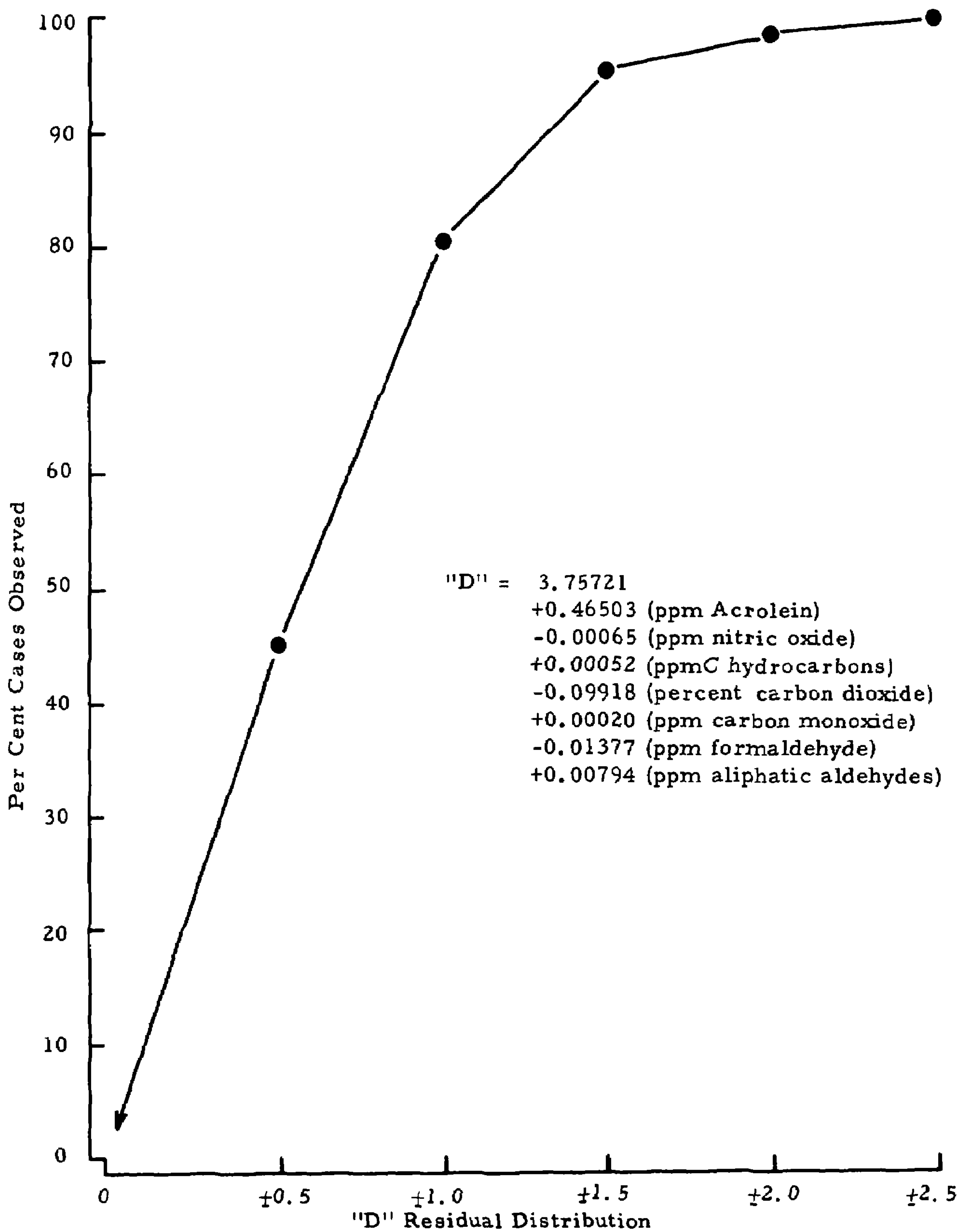

FIGURE 4. "D" VALUE PREDICTABILITY FROM EQUATION GENERATED FROM A 25-BUS CORRELATION STUDY

FIGURE 5. EIP EQUIPPED GM CITY BUS

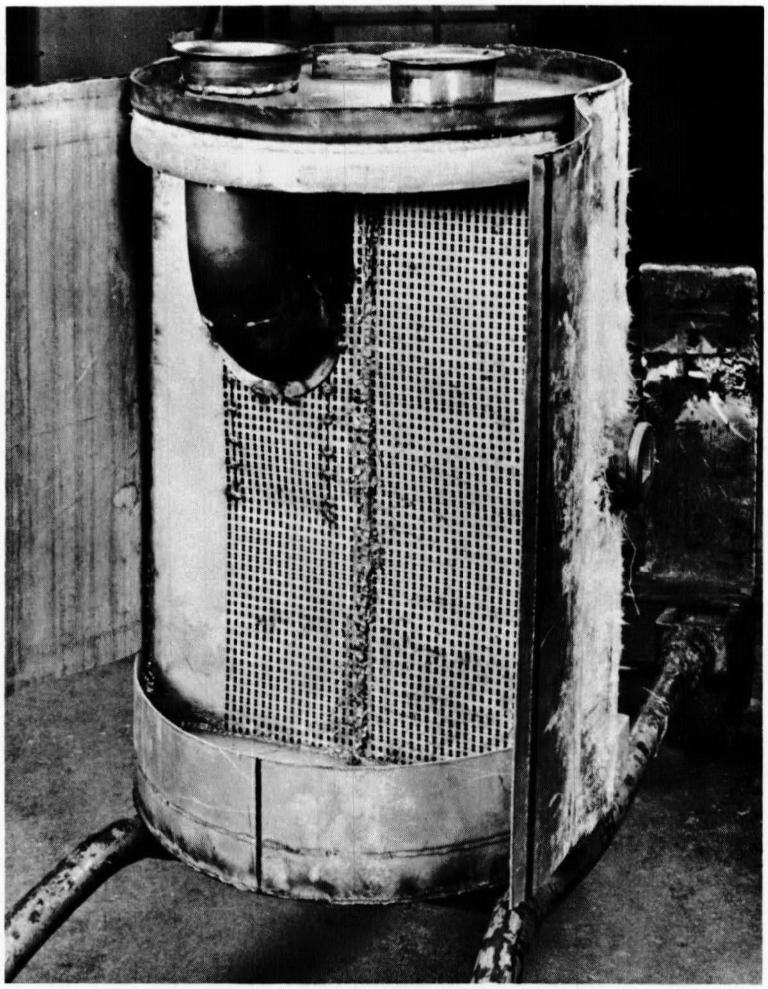

FIGURE 6. CUTAWAY OF CATALYTIC MUFFLER
(Photo Furnished by GMC)

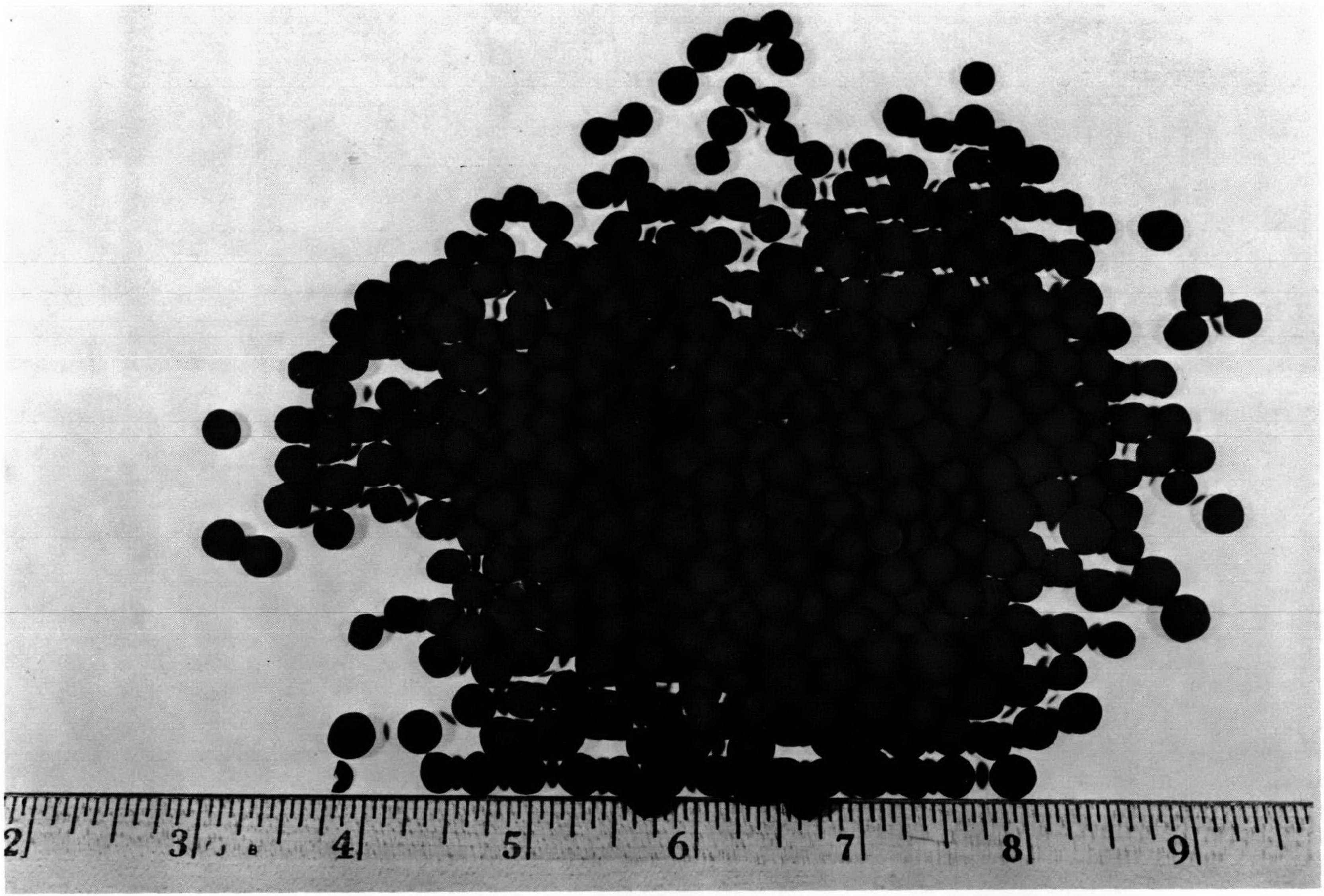

FIGURE 7. COPPER OXIDE ON ALUMINA TYPE OXIDATION CATALYST - USED

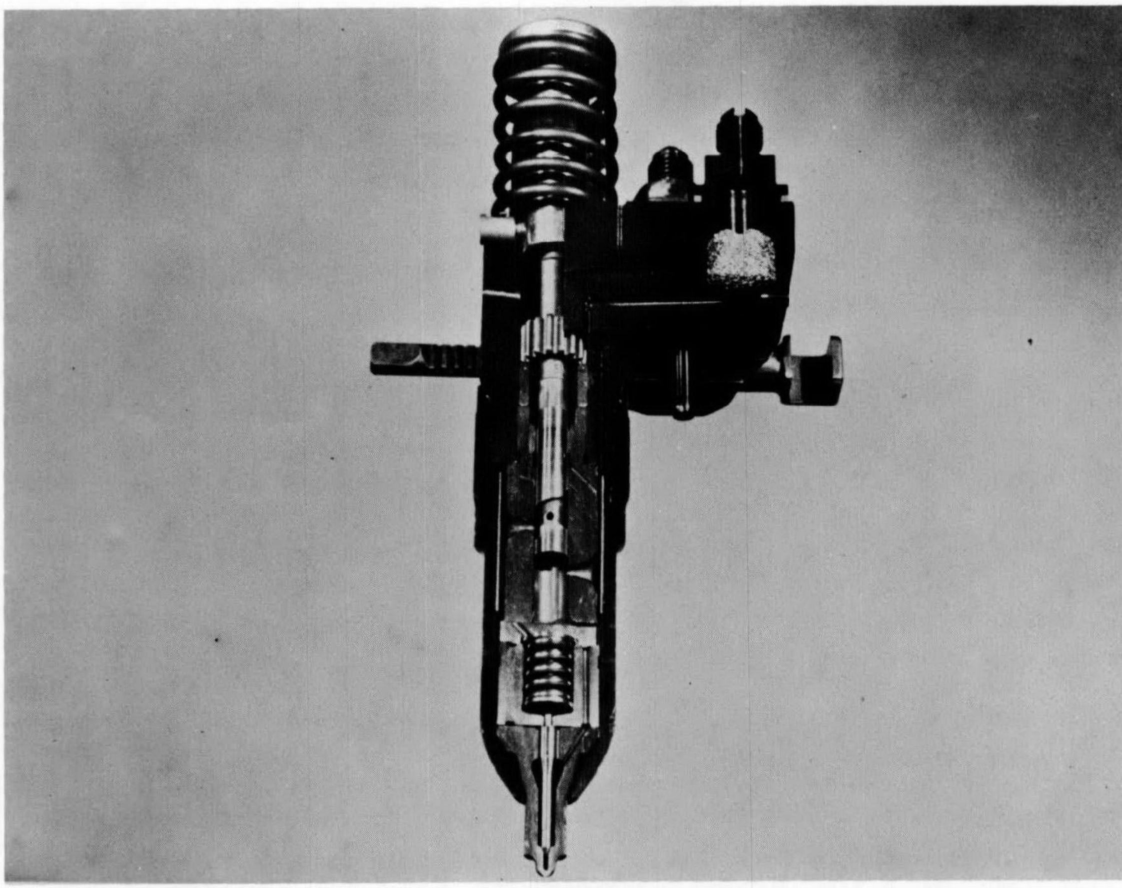

FIGURE 8. CUT-AWAY OF LSN UNIT INJECTOR
PHOTO FURNISHED BY GMC

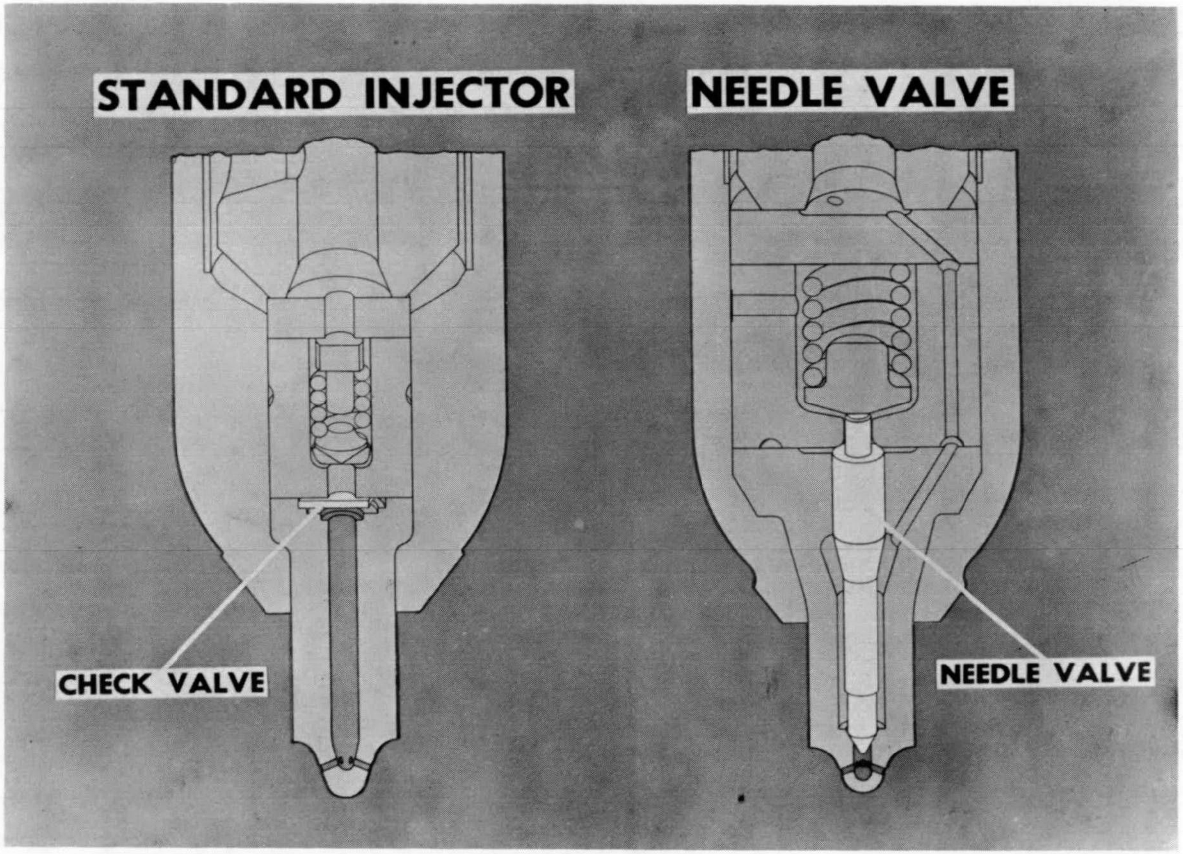

FIGURE 9. SCHEMATIC OF CROWN (STANDARD) AND NEEDLE VALVE INJECTOR TIPS

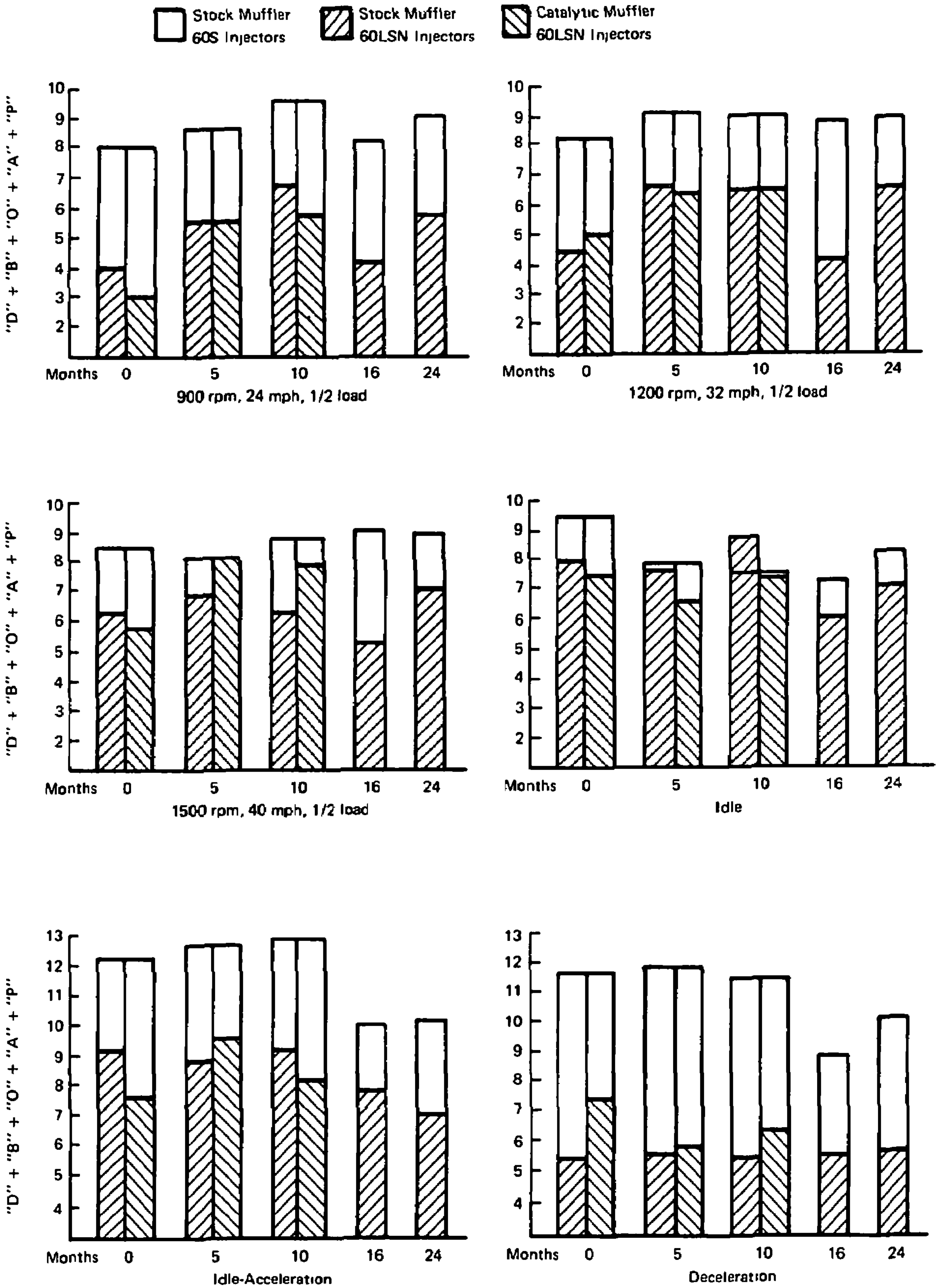

FIGURE 10. ODOR EVALUATION COMPARISON - BUS 704
TWO YEAR SUMMARY

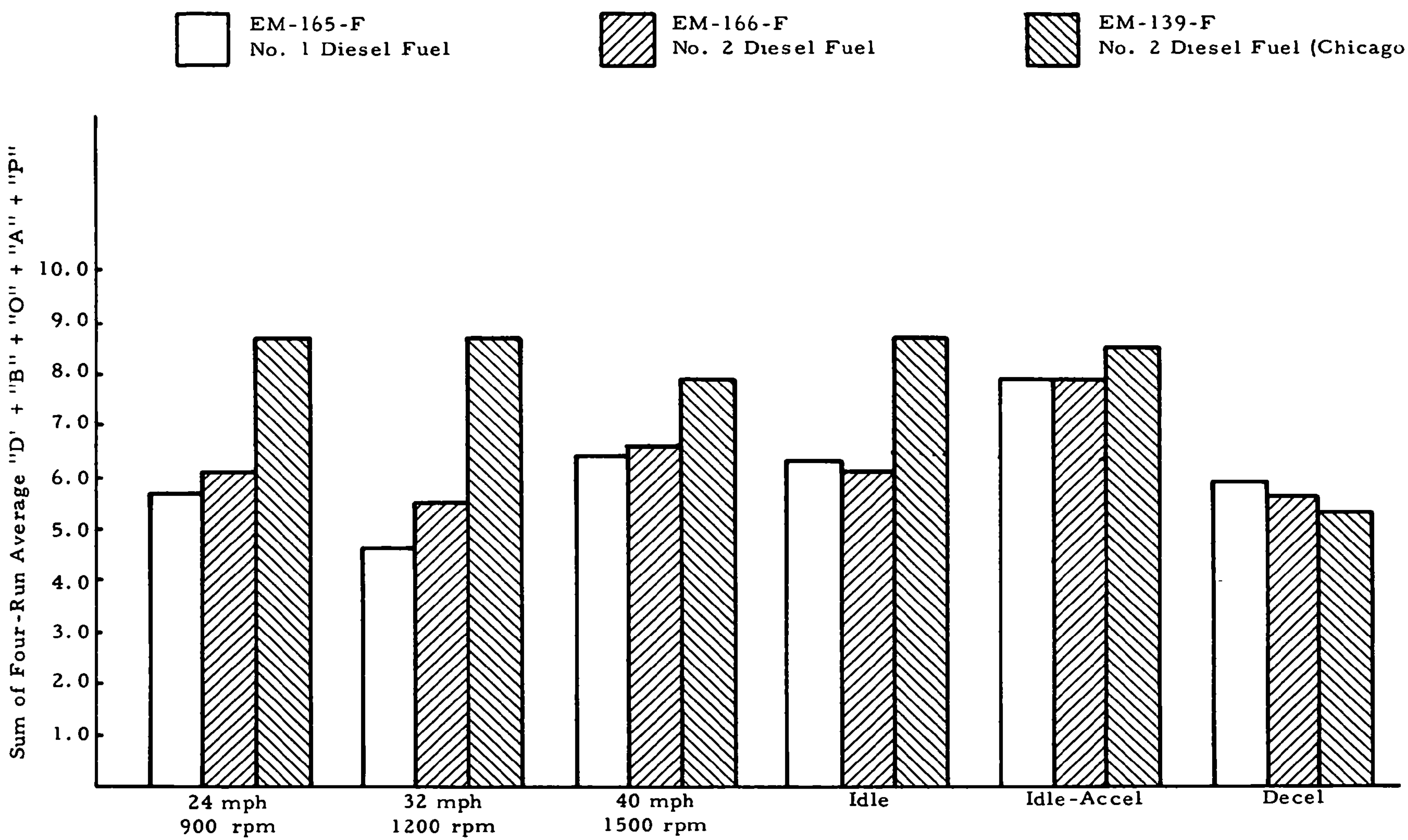

FIGURE 11. ODOR FROM BUS 704 OPERATING ON THREE DIFFERENT FUELS

FIGURE 12. SNIFFMOBILE USED IN ODOR TESTING SURVEY

Next, a series of different odor levels will be presented. Please check the appropriate box under the figure which best expresses your feeling.

	Pleasant	Neutral	Unpleasant	Very Unpleasant	Unbearable
Test 1	☐	☐	☐	☐	☐
Test 2	☐	☐	☐	☐	☐
Test 3	☐	☐	☐	☐	☐

Are any of these odors so bad that someone should take steps to reduce them?

No–None of them	☐
Yes–Test 1	☐
Yes–Test 2	☐
Yes–Test 3	☐

How often do you experience odors like these?

Very often	☐
Fairly often	☐
Occasionally	☐
Never	☐

FIGURE 13. 1969 SURVEY MULTIPLE ODOR TEST QUESTIONNAIRE - BACK SIDE

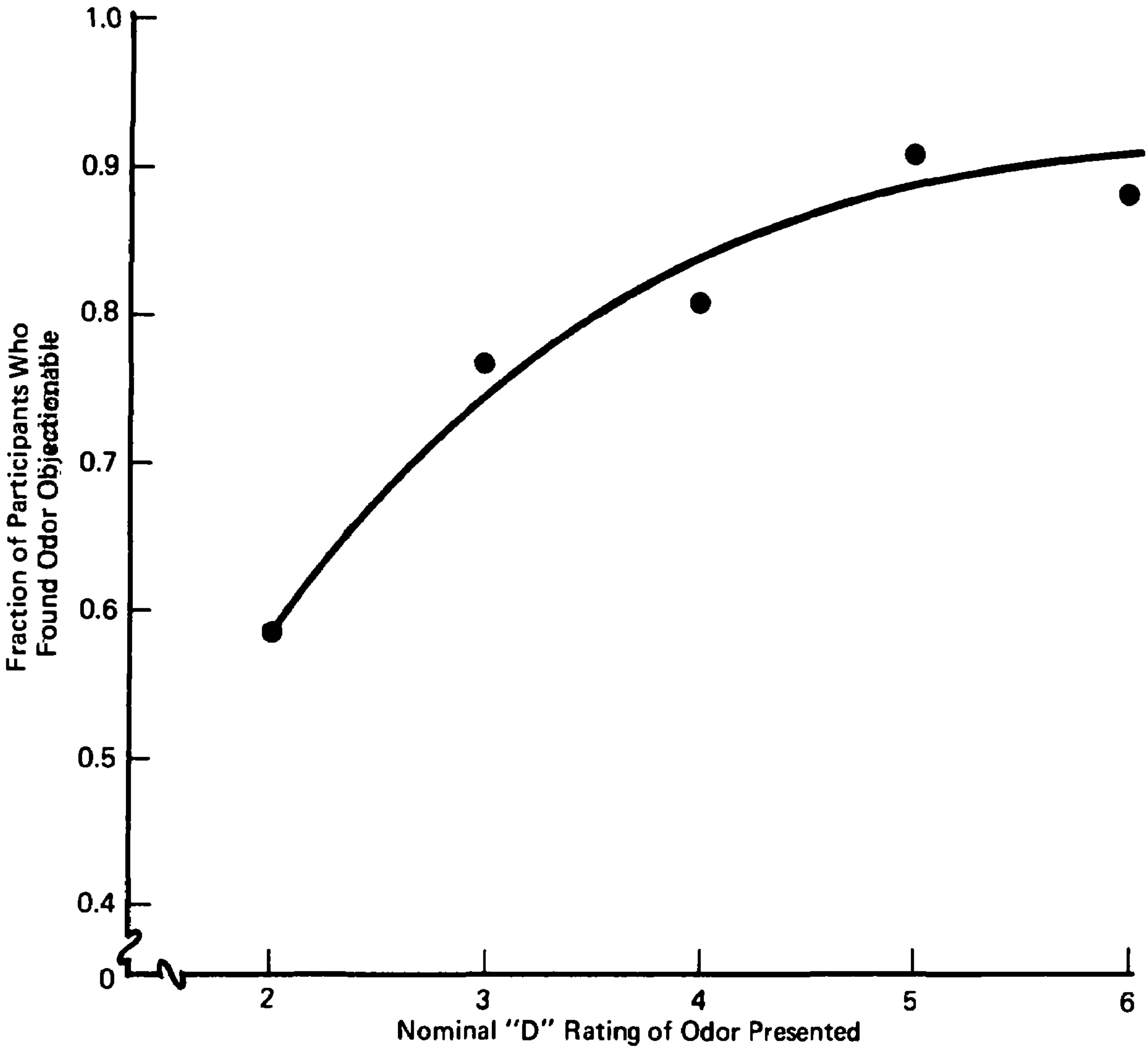

FIGURE 14. ODOR DOSE - PUBLIC RESPONSE TO BUS-LIKE DIESEL EXHAUST ODOR

TABLE 1. OVERALL SUMMARY OF ODOR EVALUATIONS, TWO-YEAR FLEET TEST OF GM-EIP KIT (Bus 704)

Operating Condition	Test Miles	Engine Hours	Test Date	Test Configuration	"D" Composite Modifications		"B" Burnt Modifications		"O" Oily Modifications		"A" Aromatic Modifications		"P" Pungent Modifications	
					LSN	LSN + Cat	LSN	LSN + Cat	LSN	LSN + Cat	LSN	LSN + Cat	LSN	LSN + Cat
24 mph	1,073	98	9/17/70	Stock, S	4.5	4.5	1.4	1.4	1.2	1.2	1.0	1.0	0.8	0.8
900 rpm			9/15, 9/14/70	Modification	2.4	2.9	0.9	1.0	0.7	0.9	0.7	0.9	0.2	0.2
1/2 load				Net Change	-2.1	1.6	-0.5	-0.4	-0.5	-0.3	-0.3	-0.1	-0.6	-0.6
				U_s Statistic	0	0	0	0	0.5	*	1.5	1.5	0	0
	25,193	2,063	4/16/71	Stock, S	4.4	4.4	1.4	1.4	1.1	1.1	1.0	1.0	0.8	0.8
			4/14, 4/13/71	Modification	2.7	2.7	1.0	1.0	1.0	1.0	0.7	0.6	0.2	0.3
				Net Change	-1.7	-1.7	-0.4	-0.4	-0.1	-0.1	-0.3	-0.4	-0.6	-0.5
				U_s Statistic	0	0	1	2	1	1.5	0	0	0	1
	42,274	3,267	7/30/71	Stock, S	4.8	4.8	1.5	1.5	1.2	1.2	1.0	1.0	1.0	1.0
			7/28, 7/27/71	Modification	3.4	2.9	1.1	1.0	1.0	0.9	0.7	0.6	0.5	0.4
				Net Change	-1.4	-1.9	-0.4	-0.5	-0.2	-0.3	-0.3	-0.4	-0.5	-0.6
				U_s Statistic	0	0	0	0	0	0	0	0	0	0
	79,722	6,125	2/24/72	Stock, S	4.0		1.2		1.1		1.0		0.9	
			2/23/72	Modification	2.1		0.8		0.8		0.4		0.1	
				Net Change	-1.9		-0.4		-0.3		-0.6		-0.8	
				U_s Statistic	0		0		1		0		0	
	117,606	8,351	11/2/72	Stock, S	4.6		1.6		1.1		0.9		0.9	
			11/1/71	Modification	2.8		1.0		1.0		0.6		0.4	
				Net Change	-1.8		-0.6		-0.1		-0.3		-0.5	
				U_s Statistic	0		0		*		0		0	
32 mph	1,073	98	9/17/70	Stock, S	4.1	4.1	1.3	1.3	1.2	1.2	1.0	1.0	0.6	0.6
1200 rpm			9/15, 9/14/70	Modification	2.2	2.4	0.8	0.8	0.7	0.9	0.6	0.8	0.1	0.1
1/2 load				Net Change	-1.9	-0.7	-0.5	-0.5	-0.5	-0.3	-0.4	-0.2	-0.5	-0.5
				U_s Statistic	0	0	0	0	0	0.5	0	1	0	0
	25,193	2,063	4/16/71	Stock, S	4.7	4.7	1.5	1.5	1.1	1.1	1.0	1.0	0.9	0.9
			4/14, 4/13/71	Modification	3.3	3.1	1.1	1.1	1.0	1.0	0.7	0.7	0.5	0.4
				Net Change	-1.4	-1.6	-0.4	-0.4	-0.1	-0.1	-0.3	-0.3	-0.4	-0.5
				U_s Statistic	2	2	1	1.5	2	*	*	0.5	*	1.5
	42,274	3,267	7/30/71	Stock, S	4.5	4.5	1.5	1.5	1.1	1.1	1.0	1.0	1.0	1.0
			7/28, 7/27/71	Modification	3.2	3.2	1.0	1.2	1.0	0.9	0.8	0.6	0.4	0.5
				Net Change	-1.3	-1.3	-0.5	-0.3	-0.1	-0.2	-0.2	-0.4	-0.6	-0.5
				U_s Statistic	0	*	0.5	*	1.5	*	0.5	0.5	0	0
	79,722	6,125	2/24/72	Stock, S	4.4		1.5		1.1		1.0		0.9	
			2/23/72	Modification	2.0		0.9		0.7		0.4		0.1	
				Net Change	-2.4		-0.6		-0.4		-0.6		-0.8	
				U_s Statistic	0		0		0		0		0	
	117,606	8,351	11/2/72	Stock, S	4.5		1.5		1.2		0.8		1.0	
			11/1/72	Modification	3.1		1.1		1.0		0.8		0.5	
				Net Change	-1.4		-0.4		-0.2		0		-0.5	
				U_s Statistic	0		0		0		*		0	
40 mph	1,073	98	9/17/70	Stock, S	4.3	4.3	1.3	1.3	1.0	1.0	1.0	1.0	0.8	0.8
1500 rpm			9/15, 9/14/70	Modification	3.1	2.9	1.0	0.9	0.9	0.9	0.9	0.6	0.3	0.4
1/2 load				Net Change	-1.2	-1.4	-0.3	-0.4	-0.1	-0.1	-0.1	-0.4	-0.5	-0.4
				U_s Statistic	0	0	0	1	2	*	2	0	0	1.5
	25,193	2,063	4/16/71	Stock, S	4.0	4.0	1.2	1.2	1.0	1.0	1.0	1.0	0.9	0.9
			4/14, 4/13/71	Modification	3.4	4.1	1.1	1.3	1.0	1.0	0.8	0.9	0.5	0.8
				Net Change	-0.6	+0.1	-0.1	+0.1	0	0	-0.2	-0.1	-0.4	-0.1
				U_s Statistic	0	*	*	*	*	*	*	*	0	*
	42,274	3,267	7/30/71	Stock, S	4.5	4.5	1.3	1.3	1.1	1.1	1.0	1.0	1.0	1.0
			7/28, 7/27/71	Modification	3.1	4.0	1.0	1.2	0.9	1.0	0.7	0.9	0.5	0.8
				Net Change	-1.4	-0.5	-0.3	-0.1	-0.2	-0.1	-0.3	-0.1	-0.5	-0.2
				U_s Statistic	0	2	0	*	1.5	*	0	2	0	2
	79,722	6,125	2/24/72	Stock, S	4.5		1.6		1.1		1.0		0.9	
			2/23/72	Modification	2.5		1.0		0.7		0.7		0.3	
				Net Change	-2.0		-0.6		-0.4		-0.3		-0.6	
				U_s Statistic	0		0		0		0		0	
	117,606	8,351	11/2/72	Stock, S	4.5		1.4		1.3		0.9		0.9	
			11/1/72	Modification	3.5		1.1		1.0		0.8		0.6	
				Net Charge	-1.0		-0.3		-0.3		-0.1		-0.3	
				U_s Statistic	0		*		1.5		*		0	

TABLE 1. (Cont.) OVERALL SUMMARY OF ODOR EVALUATIONS, TWO-YEAR FLEET TEST OF GM-EIP KIT
(Bus 704)

Operating Condition	Test Miles	Engine Hours	Test Date	Test Configuration	"D" Composite Modifications		"B" Burnt Modifications		"O" Only Modifications		"A" Aromatic Modifications		"P" Pungent Modifications	
					LSN	LSN + Cat	LSN	LSN + Cat	LSN	LSN + Cat	LSN	LSN + Cat	LSN	LSN + Cat
Idle	1,073	98	9/17/70	Stock, S	4.7	4.7	1.5	1.5	1.1	1.1	1.1	1.1	0.9	0.9
			9/15, 9/14/70	Modification	4.0	3.7	1.1	1.2	1.0	0.8	1.0	0.9	0.8	0.7
				Net Change	-0.7	-1.0	-0.4	-0.3	-0.1	-0.3	-0.1	-0.2	-0.1	-0.2
				U_s Statistic	0	0	0	1	•	•	2	•	•	•
	25,193	2,063	4/16/71	Stock, S	3.9	3.9	1.2	1.2	1.0	1.0	0.9	0.9	0.8	0.8
			4/14, 4/13/71	Modification	3.8	3.1	1.1	1.0	0.9	1.0	0.9	0.8	0.9	0.5
				Net Change	-0.1	-0.8	-0.1	-0.2	-0.1	0	0	-0.1	+0.1	-0.3
				U_s Statistic	•	1.5	•	•	•	•	•	•	•	•
	42,274	3,267	7/30/71	Stock, S	3.7	3.7	1.1	1.1	1.0	1.0	0.9	0.9	0.7	0.7
			7/28, 7/27/71	Modification	4.4	3.7	1.3	1.1	1.1	1.0	1.0	0.8	0.9	0.7
				Net Change	+0.7	0	+0.2	0	+0.1	0	+0.1	-0.1	+0.2	0
				U_s Statistic	0	•	1	•	•	•	•	•	•	•
	79,722	6,125	2/24/72	Stock, S	3.5		1.1		1.0		1.0		0.6	
			2/23/72	Modification	2.8		1.1		0.8		0.8		0.5	
				Net Change	-0.7		0		-0.2		-0.2		-0.1	
				U_s Statistic	0		•		0.5		1		•	
	117,606	8,351	11/2/72	Stock, S	4.0		1.3		1.1		1.0		0.8	
			11/1/72	Modification	3.5		1.0		1.0		0.9		0.7	
				Net Change	-0.5		-0.3		-0.1		-0.1		-0.1	
				U_s Statistic	•		0		•		•		•	
Idle–Accel	1,073	975	9/17/70	Stock, S	6.0	6.0	2.0	2.0	1.6	1.6	1.2	1.2	1.3	1.3
			9/15, 9/14/70	Modification	4.6	3.8	1.4	1.3	1.1	1.0	1.0	0.8	1.0	0.7
				Net Change	-1.4	-2.2	-0.6	-0.7	-0.5	-0.6	-0.2	-0.4	-0.3	-0.6
				U_s Statistic	0	0	0	0	0	0	0	0	0	0
	25,193	2,063	4/16/71	Stock, S	6.4	6.4	2.1	2.1	1.7	1.7	1.1	1.1	1.5	1.5
			4/14, 4/13/71	Modification	4.4	4.7	1.4	1.7	1.0	1.2	1.0	1.0	0.9	0.9
				Net Change	-2.0	-1.7	-0.7	-0.4	-0.7	-0.5	-0.1	-0.1	-0.6	-0.6
				U_s Statistic	0	0	0	1	0	0	•	2	0	0
	42,274	3,267	7/30/71	Stock, S	6.3	6.3	2.0	2.0	1.9	1.9	1.1	1.1	1.5	1.5
			7/28, 7/27/71	Modification	4.6	4.2	1.4	1.2	1.2	1.1	1.0	0.8	1.0	0.8
				Net Change	-1.7	-2.1	-0.6	-0.8	-0.7	-0.8	-0.1	-0.3	-0.5	-0.7
				U_s Statistic	0	0	1	0	0	0	•	•	0	0
	79,722	6,125	2/24/72	Stock, S	4.9		1.7		1.3		1.0		1.1	
			2/23/72	Modification	3.9		1.1		0.9		0.9		1.0	
				Net Change	-1.0		-0.6		-0.4		-0.1		-0.1	
				U_s Statistic	•		0		0.5		•		•	
	117,606	8,351	11/2/72	Stock, S	5.0		1.8		1.2		0.9		1.2	
			11/1/72	Modification	3.5		1.0		1.1		0.7		0.7	
				Net Change	-1.5		-0.8		-0.1		-0.2		-0.5	
				U_s Statistic	0		0		•		•		0	
Decel	1,073	98	9/17/70	Stock, S	5.9	5.9	2.0	2.0	1.4	1.4	1.2	1.2	1.2	1.2
			9/15, 9/14/70	Modification	2.6	3.6	1.0	1.2	0.9	1.0	0.5	0.9	0.4	0.6
				Net Change	-3.3	-2.3	-1.0	-0.8	-0.5	-0.4	-0.7	-0.3	-0.8	-0.6
				U_s Statistic	0	0	0	0	0	0	0	0	0	0
	25,193	2,063	4/16/71	Stock, S	5.9	5.9	2.0	2.0	1.4	1.4	1.2	1.2	1.3	1.3
			4/14, 4/13/71	Modification	2.8	3.0	1.0	1.1	1.0	1.0	0.6	0.5	0.2	0.3
				Net Change	-3.1	-2.9	-1.0	-0.9	-0.4	-0.4	-0.6	-0.7	-1.1	-1.0
				U_s Statistic	0	0	0	0	0	0	0	0	0	0
	42,274	3,267	7/30/71	Stock, S	5.8	5.8	1.9	1.9	1.4	1.4	1.1	1.1	1.3	1.3
			7/28, 7/27/71	Modification	2.7	3.2	1.0	1.0	0.8	0.9	0.7	0.6	0.2	0.5
				Net Change	-3.1	-2.6	-0.9	-0.9	-0.6	-0.5	-0.4	-0.5	-1.1	-0.8
				U_s Statistic	0	0	0	0	0	0	0	0	0	0
	79,722	6,125	2/24/72	Stock, S	4.3		1.4		1.1		1.0		1.0	
			2/23/72	Modification	2.7		0.9		0.8		0.8		0.3	
				Net Change	-1.6		-0.5		-0.3		-0.2		-0.7	
				U_s Statistic	0		0		1.5		•		0	
	117,606	8,351	11/2/72	Stock, S	5.0		1.7		1.2		1.1		1.1	
			11/1/72	Modification	2.8		1.0		0.9		0.6		0.4	
				Net Change	-2.2		-0.7		-0.3		-0.5		-0.7	
				U_s Statistic	0		0		0		0		0	

TABLE 2. FUEL INSPECTION DATA FOR LOCAL AND CHICAGO AREA DIESEL FUELS

Fuel Code	EM-165-F	EM-166-F	EM-139-F
ASTM Designation	(DF-1)	(DF-2)	(DF-2)
Source of Fuel	Local	Local	Chicago
Distillation:			
IBP°F	330.0	396.0	360.0
10%	360.0	428.0	398.0
20%	370.0	438.0	416.0
30%	380.0	450.0	436.0
40%	390.0	470.0	460.0
50%	416.0	488.0	480.0
60%	426.0	502.0	498.0
70%	438.0	520.0	520.0
80%	448.0	542.0	550.0
90%	460.0	570.0	584.0
EP	508.0	624.0	632.0
% Recovered	99.5	99.5	99.5
% Residue	0.5	0.5	0.5
% Dist. Loss	0.0	0.0	0.0
FIA Analysis:			
Aromatics, %	15.6	26.6	34.3
Olefins, %	1.4	nil	0.6
Saturates, %	83.0	73.4	65.1
Gravity, API at 60°F	44.5	36.2	35.0
Total Sulfur, %	0.00	0.07	0.48

TABLE 3. COMPARISON OF ODOR RATINGS (Locally Available Name Brand Diesel Fuels)

Vehicle Bus 704 | Date: August 3 & 4, 1971

Run Condition	Fuel	"D" Composite	"B" Burnt	"O" Oily	"A" Aromatic	"P" Pungent
24 mph	EM-165-F (DF-1)	2.7	1.0	0.8	0.8	0.4
900 rpm	EM-166-F (DF-2)	2.9	1.0	0.9	0.8	0.5
1/2 load*	Net Change	+0.2	0	+0.1	0	+0.1
	U_s Statistic	†	†	†	†	†
32 mph	EM-165-F (DF-1)	2.3	0.9	0.7	0.6	0.1
1200 rpm	EM-166-F (DF-2)	2.8	1.0	0.8	0.7	0.2
1/2 load	Net Change	+0.5	+0.1	+0.1	+0.1	+0.1
	U_s Statistic	0.5	†	1.5	†	†
40 mph	EM-165-F (DF-1)	3.1	1.0	1.0	0.8	0.5
1500 rpm	EM-166-F (DF-2)	3.3	1.0	0.9	0.7	0.7
1/2 load	Net Change	+0.2	0	-0.1	-0.1	+0.2
	U_s Statistic	†	†	†	†	†
Idle	EM-165-F (DF-1)	3.2	1.0	0.9	0.7	0.5
	EM-166-F (DF-2)	3.1	1.0	0.8	0.7	0.5
	Net Change	-0.1	0	-0.1	0	0
	U_s Statistic	†	†	†	†	†
Idle-Acceleration	EM-165-F (DF-1)	3.9	1.2	1.0	1.0	0.8
	EM-166-F (DF-2)	4.0	1.1	1.0	0.9	0.9
	Net Change	+0.1	-0.1	0	-0.1	+0.1
	U_s Statistic	†	†	†	†	†
Deceleration	EM-165-F (DF-1)	2.9	1.0	0.9	0.7	0.4
	EM-166-F (DF-2)	2.9	0.9	0.7	0.7	0.4
	Net Change	0	-0.1	-0.2	0	0
	U_s Statistic	†	†	0.5	†	†

*Engine operated at a fuel rate midway between maximum and no load fuel rate.
†U_s greater than 2, no statistical difference apparent.

TABLE 4. COMPARISON OF ODOR RATINGS (Locally Available DF-1 and Chicago Area DF-2 Fuels)

Vehicle Bus 704 | Date August 4 & 6, 1971

Run Condition	Fuel	"D" Composite	"B" Burnt	"O" Oily	"A" Aromatic	"P" Pungent
24 mph	EM-165-F (DF-1)	2.7	1.0	0.8	0.8	0.4
900 rpm	EM-166-F (DF-2)	4.4	1.4	1.1	1.0	0.8
1/2 load*	Net Change	+1.7	+0.4	+0.3	+0.2	+0.4
	U_s Statistic	0	0	0	†	0.5
32 mph	EM-165-F (DF-1)	2.3	0.9	0.7	0.6	0.1
1200 rpm	EM-166-F (DF-2)	4.4	1.3	1.1	1.0	0.9
1/2 load	Net Change	+2.1	+0.4	+0.4	+0.4	+0.8
	U_s Statistic	0	0.5	0	0.5	0
40 mph	EM-165-F (DF-1)	3.1	1.0	1.0	0.8	0.5
1500 rpm	EM-166-F (DF-2)	3.9	1.2	1.0	1.0	0.8
1/2 load	Net Change	+0.8	+0.2	0	+0.2	+0.3
	U_s Statistic	1	†	†	0.5	†
Idle	EM-165-F (DF-1)	3.2	1.0	0.9	0.7	0.5
	EM-166-F (DF-2)	4.4	1.3	1.1	0.9	1.0
	Net Change	+1.2	+0.3	+0.2	+0.2	+0.5
	U_s Statistic	0	0	2	†	0
Idle-Acceleration	EM-165-F (DF-1)	3.9	1.2	1.0	1.0	0.8
	EM-166-F (DF-2)	4.3	1.3	1.0	1.0	0.9
	Net Change	+0.4	+0.1	0	0	+0.1
	U_s Statistic	†	†	†	†	†
Deceleration	EM-165-F (DF-1)	2.9	1.0	0.9	0.7	0.4
	EM-166-F (DF-2)	2.7	1.0	0.8	0.5	0.3
	Net Change	-0.2	0	-0.1	-0.2	-0.1
	U_s Statistic	†	†	†	†	†

*Engine operated at a fuel rate midway between maximum and no load fuel rate
†U_s greater than 2, no statistical difference apparent