EXHAUST EMISSIONS FROM UNCONTROLLED VEHICLES AND RELATED EQUIPMENT USING INTERNAL COMBUSTION ENGINES

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Charles T. Hare

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FINAL REPORT

PART I

LOCOMOTIVE DIESEL ENGINES AND MARINE COUNTERPARTS

Contract No. EHS 70-108

Prepared for

Characterization and Control Development Branch
Mobile Source Pollution Control Program
and
Air Quality Management Branch
Stationary Source Pollution Control Program
Office of Air and Water Programs
Environmental Protection Agency

October 1972

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Approved:

John M. Clark, Jr.
Technical Vice President
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ABSTRACT

This report is Part 1 of the Final Report on Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines, Contract No. EHS 70-108. Exhaust emissions from three locomotive diesel engines were measured, including: total hydrocarbons by heated FIA; light hydrocarbons by gas chromatograph; CO, CO_2, and NO by NDIR; NO and NO_x by chemiluminescence; O_2 by electrochemical analysis; and total aliphatic aldehydes and formaldehyde by the MBTH and chromotropic acid methods, respectively. In addition, smoke plume opacity was measured using a special version of the PHS smokemeter, and an attempt was made to characterize particulate using an experimental dilution-type sampling device.

The engines tested were SP Unit 1311, an EMD 12-567 switch engine; SP Unit 8447, an EMD 16-645E-3 line-haul engine; and SP Unit 8639, a GE 7FDL16 line-haul engine; and they were all operated in modes representative of real operation. For test purposes, the engines were loaded by absorbing power from their main generators using the Southern Pacific SEARCH machine facility, and all pertinent operating data were recorded. In addition to mass emissions computed from tests performed under the subject contract, other available data are used where possible in estimating emission factors and national impact.

FOREWORD

The project for which this report constitutes part of the end product was initiated jointly on June 29, 1970 by the Division of Motor Vehicle Research and Development and the Division of Air Quality and Emission Data, both divisions of the agency known as NAPCA. Currently, these offices are the Characterization and Control Development Branch of MSPCP and the Air Quality Management Branch of SSPCP, respectively, Office of Air and Water Programs, Environmental Protection Agency. The contract number is EHS 70-108, and the project is identified within Southwest Research Institute as 11-2869-01.

This report (Part 1) covers the locomotive portion of the characterization work only, and the other items in the characterization work will be covered by six other parts of the final report. Other efforts which have been conducted as separate phases of Contract EHS 70-108, including: measurement of gaseous emissions from a number of aircraft turbine engines; measurement of crankcase drainage from a number of outboard motors; and investigation of emissions control technology for locomotive diesel engines; either have been or will be reported separately.

Cognizant technical personnel for the Environmental Protection Agency are currently Messrs. William Rogers Oliver and David S. Kircher, and past Project Officers include Messrs. J. L. Raney, A. J. Hoffman, B. D. McNutt, and G. J. Kennedy. Project Manager for Southwest Research Institute has been Mr. Karl J. Springer, and Mr. Charles T. Hare has carried the technical responsibility.

The offices of the sponsoring agency (EPA) are located at 2565 Plymouth Road, Ann Arbor, Michigan 48105 and at Research Triangle Park, North Carolina 27711; and the contractor (SwRI) is located at 8500 Culebra Road, San Antonio, Texas 78284.

The successful conduct of the locomotive portion of this project would not have been possible without the full cooperation of the Southern Pacific Transportation Company, including both San Antonio personnel and those in the San Francisco corporate headquarters.

In particular, Messrs. Phil Scott, Earl Kaiser, and Jack Williams of the local Southern Pacific staff, and Messrs. Paul Garin, W. M. Jackle, and Bob Byrne of the San Francisco office were of great service to the project.

Several individuals in the locomotive industry, notably Mr. Jack Hoffman of General Electric Company, and Mr. Hugh Williams and Mr. George Hanley of General Motors, have provided technical assistance and a limited amount of supplementary emissions data.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (CONT'D.)

I. INTRODUCTION

The program of research on which this report is based was initiated by the Environmental Protection Agency to (1) characterize emissions from a broad range of internal combustion engines in order to accurately set priorities for future control, as required, and (2) assist in developing more inclusive national and regional air pollution inventories. This document, which is Part 1 of what is planned to be a seven-part final report, concerns emissions from locomotive diesel engines (and their marine counterparts) and the national impact of these emissions.

In the case of the locomotive diesels as well as many of the other engine categories investigated under this contract, very little previous emissions work which could be used as a guideline had been done prior to the subject emissions tests. Fortunately, those who had done emissions testing were cooperative in sharing their experiences, which no doubt enabled the test program to proceed more smoothly than it would have otherwise. The test procedures used were designed after discussions with locomotive and railroad people, but their intent is to gather useful research data and nothing more. Likewise, the specific exhaust constituents measured and the techniques used were mostly based on standard practice and the desire to gather meaningful data, without considering their potential applicability or usefulness in certification or surveillance testing. The major exception taken to standard practice was the use of chemiluminescent NO_x results rather than NDIR NO results for computation of NO_x mass emissions, a decision based on experience in running the two types of analyzers in parallel on a number of engines. In addition, since there is no "standard practice" for measurement of particulate emissions from locomotives, an experimental sampling system was used; and it yielded extremely doubtful results.

Since the size of the locomotive engines prohibited their being brought to the Emissions Research Laboratory for testing, a system of instrumentation was designed and a crew was organized to perform the emissions tests on-site, at the San Antonio Southern Pacific maintenance depot SEARCH (System Evaluation And Reliability CHecks) facility. These tests were conducted over a period of two weeks in April, 1972, on a two-shift basis to keep the locomotives out of service only as long as necessary.

II. OBJECTIVES

The primary objectives of the locomotive portion of this project were to collect useful emissions data on three locomotive diesel engines, and to use these data in conjunction with supplementary data on emissions, number of units in service, and annual usage to estimate emission factors and national impact. The emissions to be characterized included total hydrocarbons, light hydrocarbons, aldehydes, CO, CO_2, NO by NDIR and chemiluminescence, NO_x by chemiluminescence, O_2, smoke by a modified PHS opacity meter, and particulate by an experimental dilution-type sampling system. These emissions have been or will be measured for all diesel engines operated during this project, as required by the contract.

The objectives included implicitly the operation of the locomotive engines over a pattern of steady-state and transient conditions, and the determination of the importance of each mode in the total locomotive emissions picture. These tasks are quite simple for locomotives, since there are generally only eight throttle positions (or "notches") at which the locomotives operate (plus idle and dynamic brake). The 12-567 switch locomotive (unit 1311) was an exception, since it had a continuous throttle (no notches) and no dynamic brake capability, so artificial "notches" were set for it by specifying a certain engine speed for each mode.

In addition to the emissions measurements, sufficient engine operating data were taken to ensure that conditions repeated themselves adequately and that mass emissions could be calculated from the raw concentration data. Secondary objectives, not required by the contract, which were met included a limited evaluation of a modified large-ring smokemeter using PHS optics, design of a test procedure which is compact but still tends to eliminate the effects of directional mode changes, and an attempt at adaptation of the experimental dilution-type particulate sampler to locomotive usage.

Due to the overall brevity of the testing phase of this project, it was determined at the onset that emissions from marine counterparts of the locomotive engine would be characterized by weighting mode emissions data taken on locomotives to more closely simulate marine operation.

III. EXPERIMENTAL METHODS AND INSTRUMENTATION

In order to fulfill contract requirements for locomotive diesel engine testing, three separate analysis systems were used. Gaseous emissions, including light hydrocarbons and aldehydes, were measured by standard SAE techniques (J177 and J215) on a continuous sample drawn from inside the exhaust outlet to a point inside the SEARCH machine facility. Smoke was measured using modified PHS-type opacity meters with remote readout inside the SEARCH facility, and particulates were measured using an experimental dilution-type device which sampled from a "split" of the exhaust withdrawn through a 3-inch diameter tube. The techniques and instrumentation used for each type of analysis were quite dissimilar, so the systems will be discussed separately.

A. Gaseous Emissions Measurements

The gaseous emissions measured include: total hydrocarbons by heated FIA; CO, CO_2, and NO by NDIR; NO and NO_x by chemiluminescence; O_2 by an electrochemical analyzer; total aliphatic aldehydes (RCHO) by the MBTH method(1) and formaldehyde (HCHO) by the chromotropic acid method(2); and light hydrocarbons (CH_4 through C_4H_{10}) by gas chromatograph using a 10 ft by 1/8 inch column packed with a mixture of phenyl isocyanate and Porasil C preceded by a 1 inch by 1/8 inch precolumn packed with 100-120 mesh Porapak N. All the continuous measurements were recorded on strip-chart recorders as well as mode-by-mode data sheets, but analysis of samples for RCHO, HCHO, and light hydrocarbons was performed at the Emissions Research Laboratory. The aqueous reagents through which exhaust was bubbled for aldehyde analysis were transported in small individual flasks, and samples for light hydrocarbon analysis were transported in inert plastic bags. The instruments were located in the SEARCH machine facility, which was air-conditioned and served to isolate the instruments and crew members from the engine's heat, noise and vibration. Figure 1 shows the main gaseous emissions analysis cart, including readouts for all the instruments and the analysis sections for all except hydrocarbons. The oven shown in Figure 2 contained the HC detector and also served as the wet sample collection point for aldehydes. The sample line used was 3/8 inch O.D. stainless steel, and was heated to maintain a sample gas temperature of 360°F. Its length (to the probe exit) was 23 ft for the switch locomotive (unit 1311) and 17 ft for the two line haul locomotives, which gave response times of approximately 7 seconds and 5 seconds, respectively. The additional length for the switch locomotive was necessary because it had two exhaust stacks, and a "T" was added to the end of the fixed sample line to reach both of them, as shown in Figure 3. The vertical (unheated) stainless line which joins the sample lines at the "T" carried purge air, controlled by a remotely-operated solenoid valve (hidden behind insulation at the "T"). The air flow was considerably in excess of that required for sample line purge, so the probe lines were also being backflushed by air while the purge was occuring. The same type of system was used for the other two locomotives,

Figure 1. Main Gaseous Emissions Analysis/Readout System

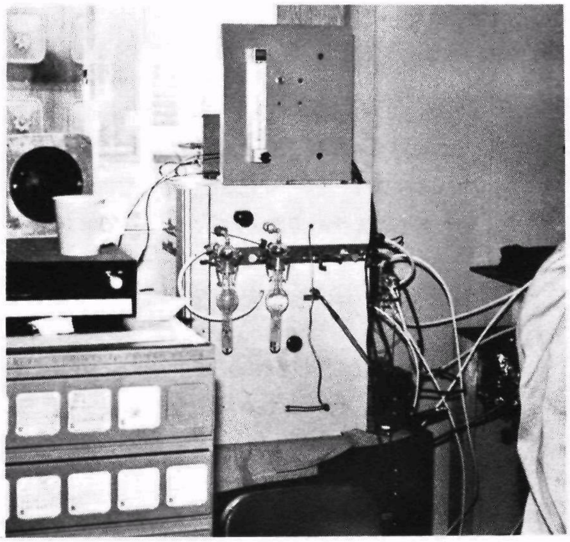

Figure 2. Oven Used for Temperature Control of FIA and Aldehyde Systems

Figure 3. Sampling Line Installation on EMD 12-567 Switch Engine (SP-1311)

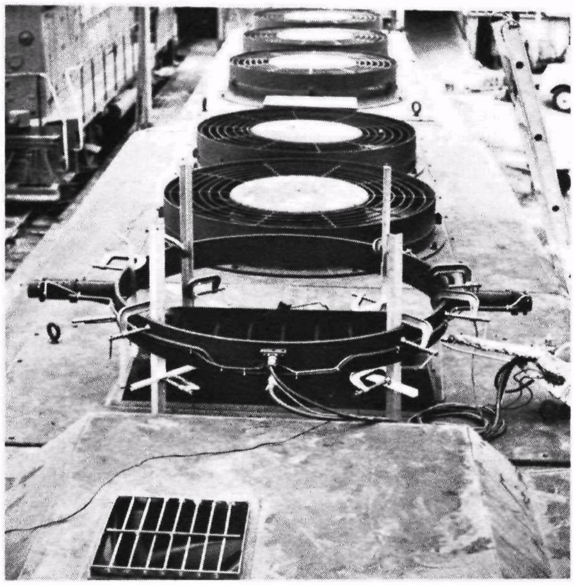

Figure 4. Sampling Line Installation on EMD 16-645E-3 Engine (SP-8447)

as shown in Figure 4 for unit 8447 (the solenoid valve appears at right, at the end of the permanent sample line).

Sample probes used for locomotive testing were of the multi-orifice or "rake" type, patterned after those developed by engine manufacturers.[4,5] They were constructed of 3/8 inch stainless steel tubing and were oriented with holes facing upstream (not the same as some previous work). The probe locations were those determined earlier by manufacturers in most cases, with the possible exception that mixed flow was sampled near the outlet of the G. E. U33-C (unit 8639), above the crankcase eductors. The mixed flow is that which is emitted to the atmosphere, so it should be sampled if proper mixing can be established. The probes for the large locomotives had twelve 1/16 inch diameter holes, and each of the two probes used on the switch locomotive had six 1/16 inch diameter holes.

Analysis for total hydrocarbons and aldehydes was carried out on hot samples, maintained at about 375°F by the oven shown in Figure 2. These measurements are considered to be on a "wet" basis, then, without the necessity for corrections. All the other emissions were measured "dry", that is, on samples from which most of the ambient humidity and water of combustion had been removed, and the concentrations were corrected to a "wet" basis mathematically.[3] The primary water removal system consisted of ice-bath water traps, with further drying through anhydrous $CaSO_4$ canisters upstream of the NDIR NO analyzer. It is recognized that water traps tend to remove NO_2 from the gases passed through them, so checks were made to determine the extent of this removal, resulting in the conclusion that about 11% of the NO_2 was removed from calibration gases. The same check was run on NO, with no measurable loss indicated. In the reporting of results, no correction has been made for this measured loss. Such a correction would make only a very small change in composite brake specific emissions, and the results without correction are probably most directly comparable to other reported emissions results. Further development will probably enable the chemiluminescent instruments to sample wet exhaust gases, eliminating the present problems. It should also be noted in this discussion that none of the NO or NO_x numbers have been "corrected" for ambient humidity by any of the equations available for the purpose. If the reader needs such a correction, the required ambient conditions will be presented in the Appendixes.

The set of test conditions which constituted one run for locomotive tests included 24 modes distributed as shown in Table 1. This sequence was designed for duplication of all conditions except idle (which was included 6 times due to idle variability), and the cancelling of directional effects by approaching each power notch from both higher and lower power settings. These goals were realized except for notch 4, which is approached only from lower power settings, but test results were not affected by this imperfection. The EMD 12-567 switch locomotive (unit 1311) had a continuous throttle with

TABLE 1. LOCOMOTIVE EMISSIONS TEST SEQUENCE

Mode	Notch or Condition	Mode	Notch or Condition	Mode	Notch or Condition
1	Idle	9	N7	17	N5
2	N1	10	N8	18	Dynamic Brake
3	N2	11	Idle	19	Idle
4	N3	12	Dynamic Brake	20	N4
5	N4	13	Idle	21	N3
6	Idle	14	N8	22	N2
7	N5	15	N7	23	N1
8	N6	16	N6	24	Idle

no notches, so artificial notches were made based on engine rpm. Idle speed was 275 rpm for unit 1311, and rated speed was 800 rpm, so the decision was made to set notch 1 at 300 rpm and divide the speed range up to 800 rpm into roughly equal increments. The result of this arbitrary procedure is shown in Table 2, and it should also be noted that this locomotive

TABLE 2. ENGINE SPEEDS USED AS "NOTCHES" FOR UNIT 1311

Notch	Engine rpm	Notch	Engine rpm
1	300	5	584
2	371	6	655
3	442	7	726
4	513	8	800

did not have a dynamic braking provision. The procedure used for unit 1311 ended up having 21 modes, all those shown in Table 1 except 12, 13, and 18.

Although the sampling procedure was not performed on a strict time schedule, time for one run was generally 2 to 2.5 hours, or 5 to 7 minutes per mode. To avoid excessive analysis time, aldehydes and light hydrocarbons were measured only for idle, dynamic brake (where applicable), and notches 2, 4, 6, and 8. Even with the smaller number of samples taken, the relationship between aldehydes and throttle notch was fairly well established, as will be discussed later.

Since it was relatively easy to measure fuel consumption of the locomotive engines (using a weight-scale system with a heat exchanger on the return line) and quite difficult to measure airflow, it was decided that a carbon balance technique would be used to calculate mass emissions from concentrations and fuel rates. The formulas used to perform these calculations were:

$$TC = \text{total carbon} = (1 \times 10^{-4})\ (\text{ppm C} + \text{ppm CO}) + \%\ CO_2$$

$$HC\ (g/hr) = 0.0454\ (\text{ppm C})\ (\text{FUEL } lb_m/hr)\ /TC$$

$$CO\ (g/hr) = K_{CO}\ (\text{ppm CO})\ (\text{FUEL } lb_m/hr)\ /TC$$

$$NO_x \text{ as } NO_2\ (g/hr) = K_{NO_x}\ (\text{ppm } NO_x)\ (\text{FUEL } lb_m/hr)\ /TC$$

$$RCHO \text{ as } HCHO\ (g/hr) = K_{RCHO}\ (\text{ppm RCHO})\ (\text{FUEL } lb_m/hr)\ /TC$$

The "K" constants (except for K_{HC}, which is always 0.0454) depend somewhat on the fuel hydrogen/carbon ratio, and since each locomotive used a somewhat different fuel, each one required different constants. The "K" values are given in Table 3, and complete fuel specifications are given in Appendix D. The fuel H/C ratios also influenced the conversion of emissions measured on a dry basis back to a wet, or actual basis. Once the mode-by-mode emissions had been determined on a g/hr basis, brake specific values (g/bhp hr) were computed by dividing g/hr by observed power and fuel specific emissions (g/lb_m fuel) were calculated by dividing g/hr by fuel rate (lb_m/hr).

TABLE 3. VALUES OF CONSTANTS IN MASS EMISSIONS EQUATIONS

	Locomotive Number		
Constituent	SP-1311	SP-8447	SP-8639
CO	0.0924	0.0925	0.0918
NO_x as NO_2	0.152	0.152	0.151
RCHO as HCHO	0.0990	0.0992	0.0984

Thus far the analysis has only progressed to mode-by-mode concentration and mass emissions data, and in order to compute composite emissions, operating cycles which lead to mode weighting factors must be considered. Manufacturers and industry groups have worked on the duty cycle problem quite extensively, using on-board mode monitors, and the cycles which seem to represent their latest results[4, 5, 6] are summarized in Table 4. These cycles were adopted for use in this project, and composite specific emissions were calculated using these cycles as

TABLE 4. LOCOMOTIVE DUTY CYCLES

Notch or Condition	Percent of Operating Time in Notch or Condition		
	ATSF Switch(4)	EMD Line Haul(5)	*G. E. Line Haul(6)
Idle	77	41	43
Dynamic Brake	--	8	8
1	10	3	3
2	5	3	3
3	4	3	3
4	2	3	3
5	1	3	3
6	1	3	3
7	0	3	3
8	0	30	28

*This cycle is a compromise between one originally submitted by G. E. for use in smoke measurement studies and the EMD line-haul cycle.

basis. The particular relationships used to calculate cycle composite emissions were:

$$\text{cycle g/hr} = \sum_{i=1}^{n} M_i W_i;$$

M_i = individual mode emissions, g/hr, W_i = time based weighting factor, n = number of modes (21 or 24)

$$\text{cycle g/bhp hr} = \frac{\sum_{i=1}^{n} M_i W_i}{\sum_{i=1}^{n} hp_i W_i};$$

hp_i = individual mode power, hp

$$\text{cycle g/lb}_m\text{ fuel} = \frac{\sum_{i=1}^{n} M_i W_i}{\sum_{i=1}^{n} (\text{fuel rate})_i W_i};$$

$(\text{fuel rate})_i$ = individual mode fuel rate, lb_m/hr

It should be obvious that the very large amount of idle time included in the switch cycle will contribute to causing brake specific and fuel specific emissions from the switch engine to be higher than those from the two line haul engines. The EMD and G. E. cycles are so similar that the use of the other would have made only little difference in either case. If more conclusive duty cycle data are developed at some later date for either or both of the types of locomotives tested, the individual mode mass emissions (g/hr) reported here can still be used to calculate cycle composites by deriving new weighting factors (W_i).

As noted in the Appendixes, a special approach was required for calculation of cycle composite aldehyde emissions, because they were measured only at even-numbered notch positions (plus idle and dynamic brake). The method employed was to give each even-numbered notch a new weight consisting of its normal weight plus that of the next lower notch. This approach was completely arbitrary, but yielded useful results.

In addition to the steady-state emissions tests just described, emissions were also measured during engine speed and load transients and during start-up. Analysis of transient emissions, however, is limited to determining concentration as a function of time and relating changes to varying engine conditions. Since continuous sampling is necessary for meaningful results during transients, the emissions measured are limited to hydrocarbons, CO, CO_2, NO_x, and smoke opacity. The other emissions either did not have chart readouts or required a constant condition for sampling.

To calculate mass emissions from locomotive-type engines used in marine applications, an attempt will be made to re-weight individual mode emissions to simulate marine operation more closely. This analysis will be deferred until the section containing estimation of emission factors and national impact since the method is essentially the same as that described above and the mode weights will be based on information presented in Section V.

B. Smoke Measurements

Locomotive smoke measurements for this project were made with modified PHS full-flow opacity meters, utilizing standard optics and electronics. The sole modifications made were in the sizes of the rings used to hold the source and detector tubes, with a 20 inch diameter ring being used for the switch engine (SP-1311) and a 40 inch diameter ring being used for the line haul locomotives (SP-8447 and SP-8639). The smokemeter control unit and strip chart readout, which were located inside the SEARCH facility, are shown in Figure 5. Figures 6, 7, and 8 show the smokemeters mounted on units 1311, 8447, and 8639, respectively. Padding similar to that shown in Figure 8 was added under the support legs of the optical unit used on unit 8447 after Figure 7 was taken. In Figure 7, the smokemeter is shown in what was called "longitudinal" position, or aligned with the longer axis of the stack, and the position shown in Figure 8 was called "transverse".

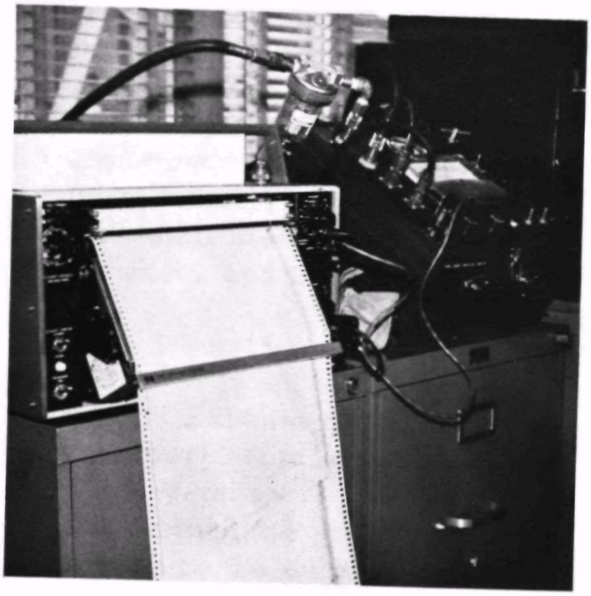

Figure 5. Smokemeter Control/Readout Unit Located Inside SEARCH Facility

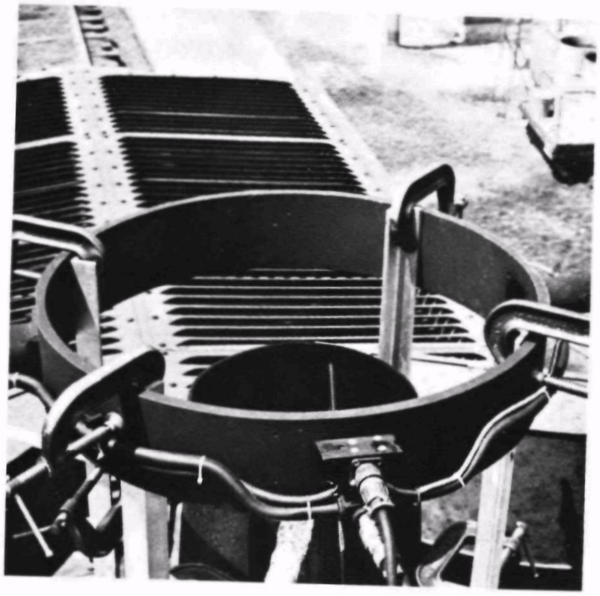

Figure 6. Smokemeter 20-inch Support Ring and Optical Unit Mounted on Unit 1311

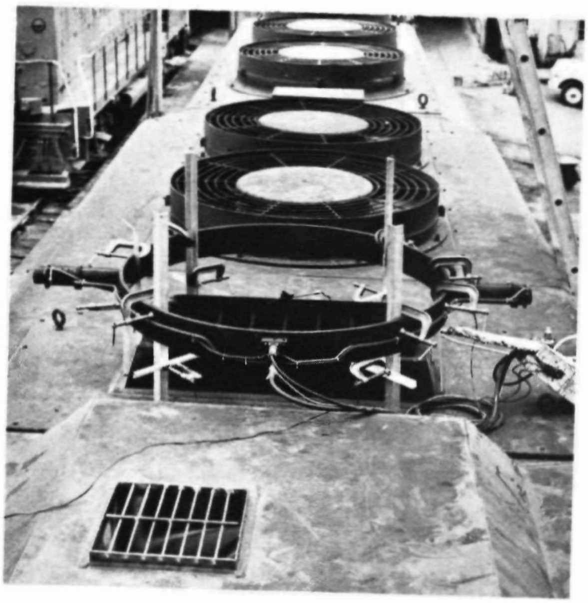

Figure 7. Smokemeter 40-inch Support Ring and Optical Unit Mounted on Unit 8447

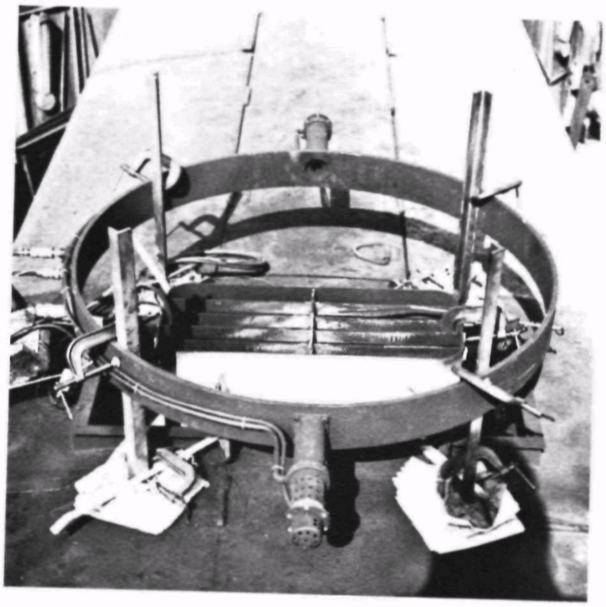

Figure 8. Smokemeter 40-inch Support Ring and Optical Unit Mounted on Unit 8639

Data on smoke opacity were taken with the optical unit in both transverse and longitudinal positions (where applicable), and smoke was measured continuously in all modes, just like gaseous emissions. The rationale for using the PHS smokemeter is that it is supposed to see smoke as nearly as possible like the human eye, and that it can follow smoke during transient conditions. It was found during calibration of the large-ring optical units that response was equivalent to that of 10 inch ring optical units (standard for small diesel engine use). Analysis of the smoke results was straightforward, and the results will be presented later in the report.

C. Particulate Measurements

Exhaust particulate from the locomotive engines was measured using an experimental dilution-type sampler developed for mobile source usage. This system was used because no standard or accepted technique was available. The immediate problem encountered was inability to place the sampler close enough to the exhaust outlet to keep the sample line short. Particles tend to deposit themselves on the walls of sample lines, making long lines extremely undesirable, so an alternative scheme was sought. The method used involved a compromise on the type of sampling used at the stack, in that a "split" of the exhaust was taken by drawing it into a 3 inch diameter duct, but not necessarily at the isokinetic rate. This compromise permitted samples to be withdrawn from the 3 inch diameter duct at the isokinetic rate without experimenting with flowrates, which made the overall sampling time shorter but reduced the credibility of the results.

The particulate sampler is shown in Figure 9 during operation on the first engine (SP-1311). The 3 inch diameter duct which carried sample down from the engine exhaust outlet appears just behind the sampler, and it curves away toward the lower left of the Figure downstream of the sampling point. The duct terminated in the orifice, valved bypass, and blower shown in Figure 10, and this control system was used to maintain a constant mass flow in the duct. The "ram" effect of exhaust gases entering the 2 inch collectors sometimes forced more gas into the duct than was desired, so in these modes the blower was removed, the open pipe end was capped, and the valve was used as a restrictor. Separate 2 inch diameter collectors, which came together at the "Y" shown above the engine in Figure 11, were used for unit 1311 so both stacks could be sampled. The duct shown in Figure 12 was used on unit 8639, and a very similar one was used for unit 8447 since they both had single stacks.

Particulate samples from the locomotives were acquired at idle, notch 4, and notch 8, each condition being repeated 4 times. The abbreviated schedule resulted from the desire to tie up the locomotives for as short a time as possible, and from analysis time considerations. Previous experience with other diesel engines on the subject contract had also shown that full load, half load, and no load conditions were generally sufficient to characterize particulate. The results of the particulate measurements will be summarized and discussed later in the report.

Figure 9. Experimental Dilution-Type Particulate Sampler Used for Locomotive Tests

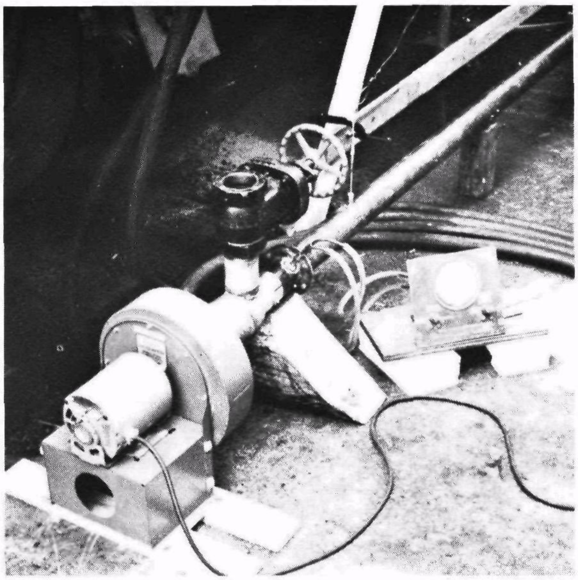

Figure 10. Control System Used to Maintain Flowrate in 3-inch Diameter Sample Duct

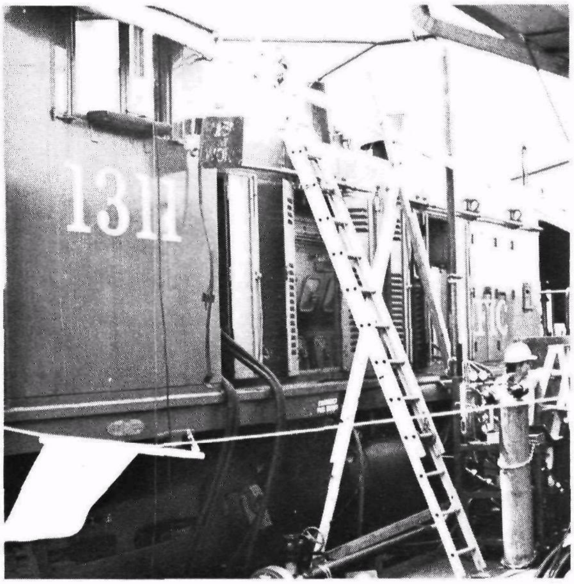

Figure 11. Arrangement of Sample Duct used on Unit 1311

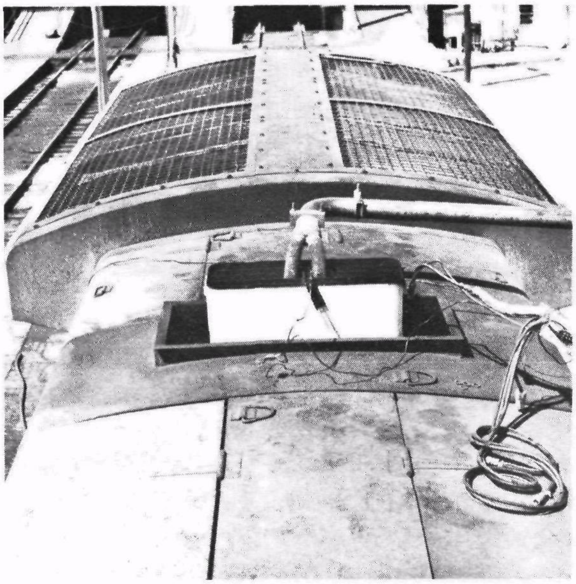

Figure 12. Arrangement of Sample Duct used on Unit 8639 (same as used on Unit 8447)

IV. EMISSIONS TEST RESULTS

The results of tests for smoke, particulates, and light hydrocarbons are summarized in this section without being included in the Appendixes. Gaseous emissions, on the other hand, are given in detail in the Appendixes, along with operation and performance data on the locomotives. These data are given in Appendix A for unit 1311 (EMD 12-567 Switch engine). In Appendix B for unit 8447 (EMD 16-645E-3 line-haul engine), and in Appendix C for unit 8639 (G.E. 7FDL16 line-haul engine). The arrangement of the Appendix tables places the two pages of data from each run on facing pages for convenience, with ambient data, operating data, and concentrations on the even-numbered page, and computed mass and specific emissions on the odd-numbered page. Note also that the Appendix data are considered to be intermediate results, and there fare significant figures in excess of the three considered reliable have been retained assuming that final results will be rounded off individually as they are obtained by averaging or further computation.

A. Gaseous Emissions Results

The discussion in this subsection is limited to steady-state runs under normal engine operating conditions. Thus transients and runs 4 and 5 on unit 8639 are specifically excluded, and will be handled in another report subsection.

As already mentioned, all gaseous emissions except light hydrocarbons are given in terms of concentrations, and HC, CO, NO_x, and RCHO are given in terms of g/hr, g/bhp hr, and g/lb_m fuel by mode, and in g/hr, g/bhp hr, and g/lb_m fuel on a cycle composite basis in the Appendixes. As a first summary of these results, Table 5 gives average mass emissions by throttle setting for the three locomotives. Perhaps a better way of examining these data is provided by Figures 13 through 16, which show the relationships between emission rates and throttle settings graphically. The hydrocarbon emissions shown in Figure 13 are perhaps a bit surprising, with the 12-567 switch engine (unit 1311) being consistently higher than the larger 16-645E-3 (unit 8447). It is assumed that the "hump" in the curve for the G. E. engine (unit 8639) is due to mismatching of engine and turbocharger in the lower power range. Figure 14 shows that the smaller, Roots-blown engine had much lower CO emissions over most of the power range than the two larger engines did. In addition, the shape of the curve for the smaller engine is conspicuously different than those for the other two, due to the absence of a turbocharger. The NO_x emissions shown graphically in Figure 15 exhibit a strong, consistent increase with power output, as expected. The aldehyde emissions given in Figure 16 show consistent trends, and it appears that the 4-stroke engine (unit 8639) was considerably higher on aldehydes than the 2-stroke engine of similar size and output (unit 8447).

Table 6 provides a look at run-to-run variability in mass emissions, brake specific emissions, and fuel specific emissions from the three engines, as well as averages. Although the composite mass emissions from unit 1311 (g/hr) are much lower than those from the other engines, the specific emissions from the switch engine are higher. This effect occurs because the cycle used for unit 1311 contains a large percentage of idle time (77%),

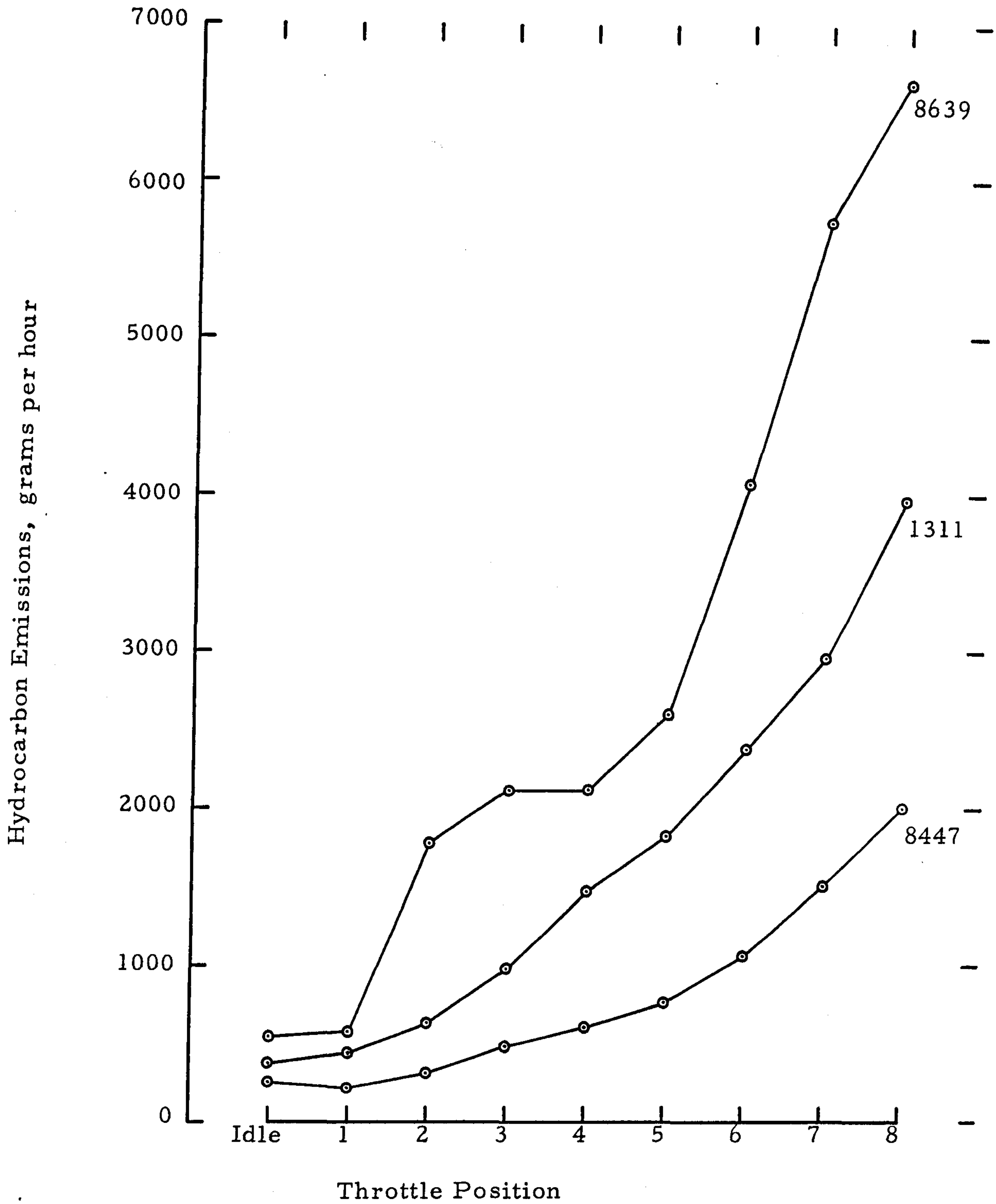

FIGURE 13. HYDROCARBON EMISSIONS (g/hr) FROM THREE LOCOMOTIVE DIESEL ENGINES AS A FUNCTION OF THROTTLE POSITION

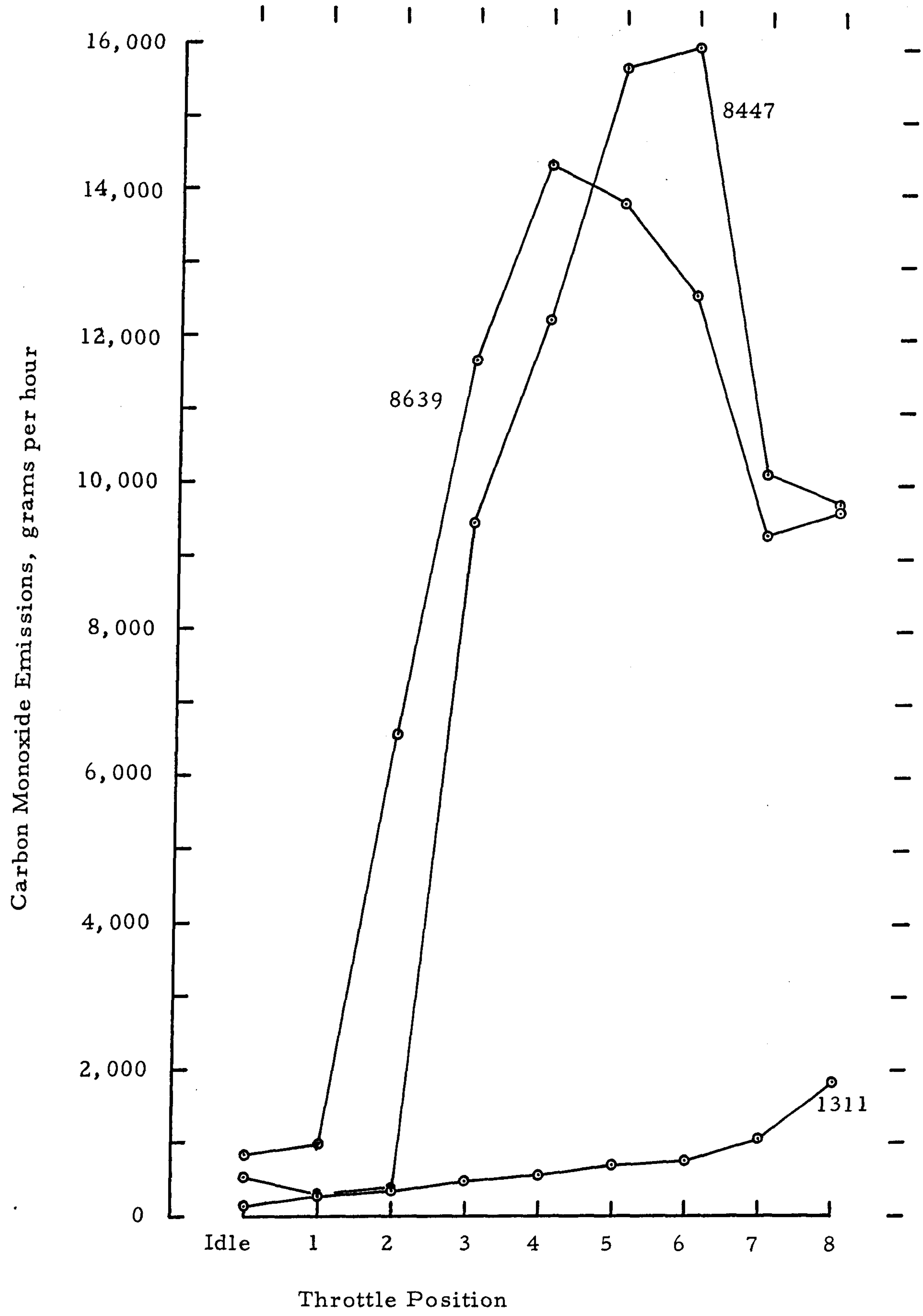

FIGURE 14. CARBON MONOXIDE EMISSIONS (g/hr) FROM THREE LOCOMOTIVE DIESEL ENGINES AS A FUNCTION OF THROTTLE POSITION

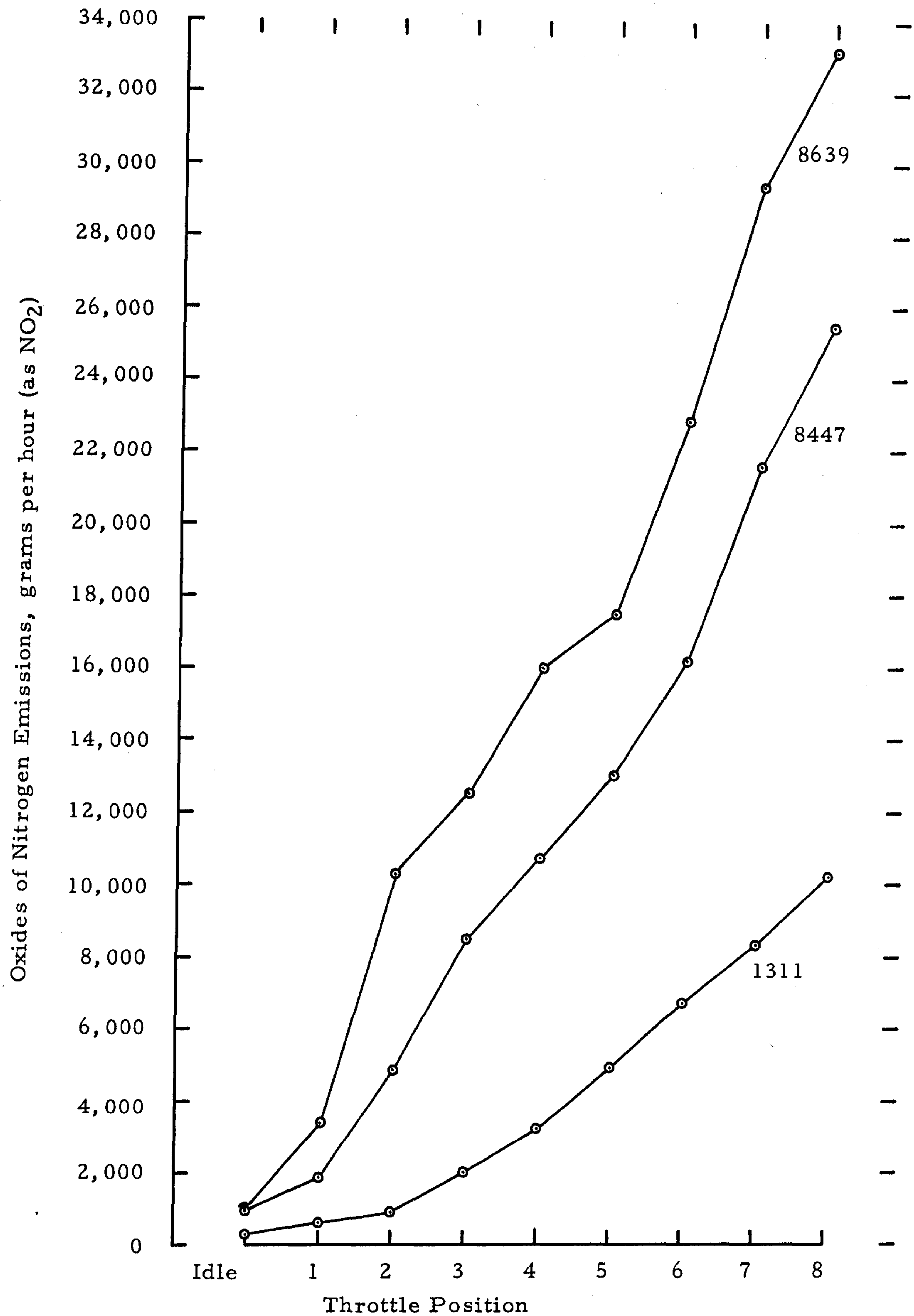

FIGURE 15. OXIDES OF NITROGEN EMISSIONS (g/hr NO_2) FROM THREE LOCOMOTIVE DIESEL ENGINES AS A FUNCTION OF THROTTLE POSITION

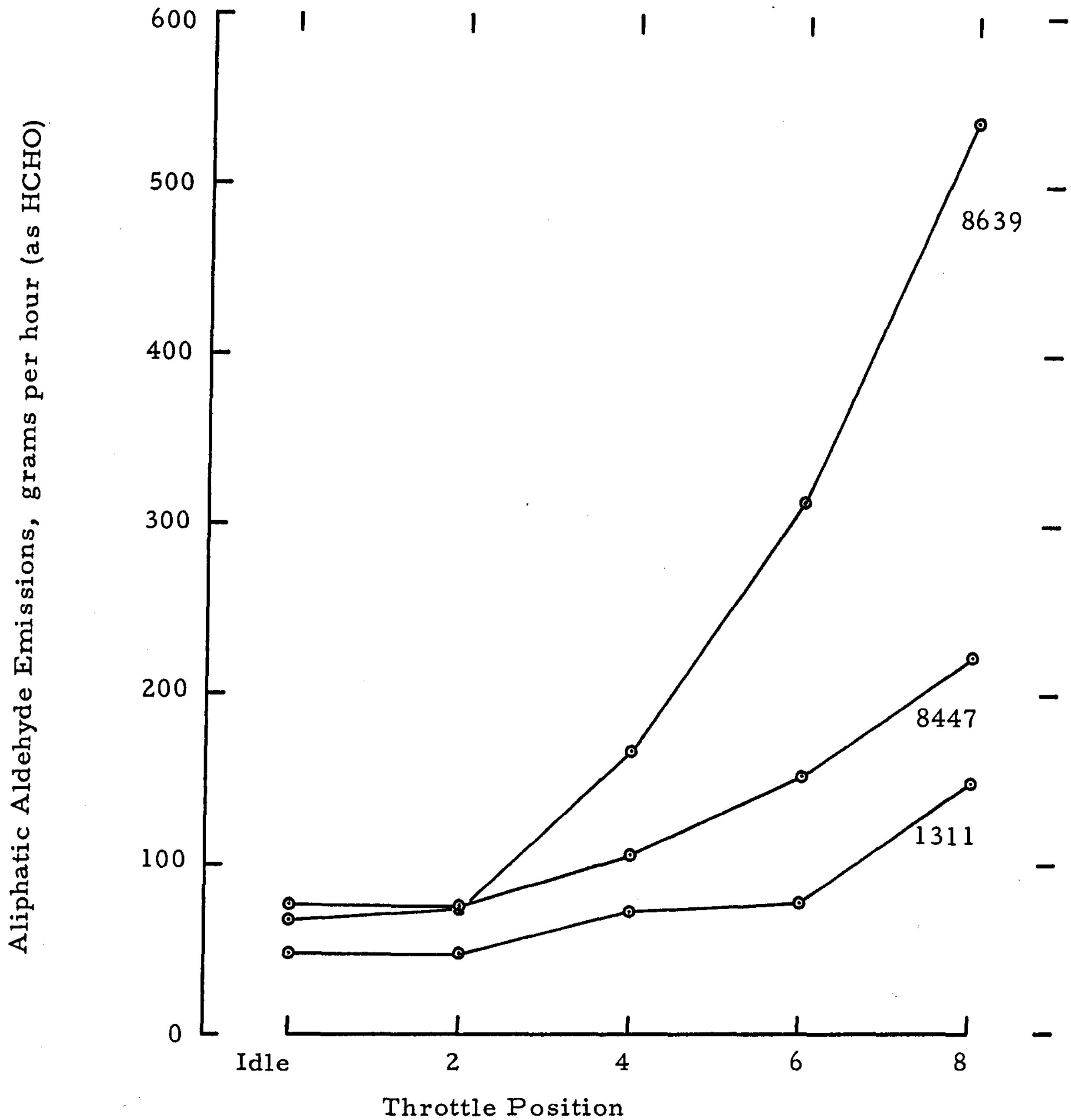

FIGURE 16. ALIPHATIC ALDEHYDE EMISSIONS (g/hr HCHO) FROM THREE LOCOMOTIVE DIESEL ENGINES AS A FUNCTION OF THROTTLE POSITION

TABLE 5. AVERAGE MASS EMISSIONS BY THROTTLE SETTING

Condition	SP-1311 Mass Rates, g/hr HC	CO	NO_x	RCHO	SP-8447 Mass Rates, g/hr HC	CO	NO_x	RCHO
Idle	387	160	335	48.2	254	523	978	76.8
Dyn. Brake	--	--	---	--	377	732	2,180	130
N1	452	273	626	--	225	293	1,870	--
N2	638	341	920	47.6	322	386	4,860	75.9
N3	984	481	2,000	--	493	9,490	8,520	--
N4	1480	560	3,220	72.9	610	12,200	10,800	106
N5	1830	702	4,950	--	766	15,700	13,000	--
N6	2390	768	6,720	78.7	1070	16,000	16,200	152
N7	2960	1050	8,370	--	1520	10,200	21,600	--
N8	3980	1840	10,200	148	2010	9,740	25,500	224

Condition	SP-8639 Mass Rates, g/hr HC	CO	NO_x	RCHO
Idle	551	828	1,030	67.5
Dyn. Brake	2400	2,050	5,200	158
N1	588	991	3,390	--
N2	1780	6,590	10,300	74.2
N3	2120	11,700	12,600	--
N4	2130	14,400	16,000	167
N5	2600	13,800	17,500	--
N6	4080	12,600	22,900	314
N7	5740	9,310	29,400	--
N8	6630	9,630	33,200	538

during which mass emissions are low and specific emissions are high. As could have been predicted from Figure 13, composite hydrocarbon emissions from unit 8639 were considerably higher than from unit 8447, and unit 8639 also emitted somewhat more NO_x and aldehydes.

Light hydrocarbon emissions from these locomotive engines were measured by the previously-described gas chromatographic method, which is reliable for 7 compounds ranging from methane through butane. No propane or butane was found in any of the samples, however, and methane was the only compound found in the exhausts of all three locomotives. Average concentrations of light hydrocarbons are given in Table 7, and all of them are extremely low. Those compounds not listed averaged less than 0.1 ppm in all modes, which is considered to be the limit of readability of the present technique. In most cases the light hydrocarbons (combustion

TABLE 6. LOCOMOTIVE CYCLE COMPOSITE EMISSIONS RESULTS

Unit	Run	Mass, g/hr HC	CO	NO_x	RCHO	Brake Specific, g/bhp hr HC	CO	NO_x	RCHO
1311	1	550	277	636	63.4	10.2	5.15	11.8	1.18
	3	423	160	616	42.7	7.82	2.95	11.4	0.79
	4	485	201	630	44.4	8.58	3.56	11.1	0.79
	Average	486	213	627	50.2	8.87	3.89	11.4	0.92
8447	1	817	4860	10,600	128	0.635	3.78	8.25	0.107
	2	872	4980	10,300	140	0.691	3.94	8.18	0.111
	3	968	5090	10,500	148	0.759	3.99	8.25	0.116
	4	897	5580	10,600	118	0.717	4.45	8.48	0.094
	Average	888	5120	10,500	134	0.700	4.04	8.29	0.107
8639	1	2880	5750	13,900	246	2.23	4.45	10.7	0.190
	2	2740	4940	13,300	295	2.12	3.83	10.3	0.228
	3	2950	5200	13,400	165	2.23	3.95	10.1	0.125
	Average	2860	5300	13,500	235	2.19	4.08	10.4	0.181

Unit	Run	Fuel Specific, g/lb_m fuel HC	CO	NO_x	RCHO
1311	1	13.6	6.85	15.7	1.57
	3	10.8	4.07	15.7	1.09
	4	12.4	5.14	16.1	1.14
	Average	12.3	5.35	15.8	1.27
8447	1	1.66	9.90	21.6	0.264
	2	1.78	10.2	21.1	0.286
	3	1.97	10.4	21.4	0.302
	4	1.83	11.4	21.7	0.241
	Average	1.81	10.5	21.4	0.273
8639	1	6.38	12.7	30.7	0.554
	2	6.06	10.9	29.4	0.653
	3	6.50	11.5	29.5	0.364
	Average	6.31	11.7	29.9	0.524

Duty Cycles Used: 1311 - Santa Fe Switch
8447 - EMD Line-Haul
8639 - G.E. Line-Haul

TABLE 7. LOCOMOTIVE LIGHT HYDROCARBON DATA SUMMARY

	Concentrations in ppm							
	Unit 1311	Unit 8447		Unit 8639				
Condition	C_2H_4	CH_4	C_2H_4	CH_4	C_2H_6	C_2H_4	C_2H_2	C_3H_6
Idle	0.2	2.2	1.3	8.0	0.0	6.6	1.3	0.0
Dyn. Brake	---	1.8	0.9	7.6	0.1	7.8	3.2	0.1
N2	0.1	1.7	0.5	24.0	0.9	18.2	5.0	3.6
N4	0.4	1.8	2.6	15.0	0.7	23.9	3.6	4.4
N6	0.8	1.4	3.0	7.8	0.3	21.2	2.2	3.5
N8	5.2	1.4	3.7	7.1	0.1	14.0	1.4	3.0

products) did not constitute large fractions of the total hydrocarbons.

B. Smoke Results

Smoke data were recorded during steady-state conditions in terms of percent opacity using two modified smokemeters based on PHS optics, as explained in subsection III. B. These data were taken concurrently with gasoline emissions data, and the averages are given in Table 8. For unit 1311, which had two stacks, two complete runs were made on each stack with virtually identical results from the two stacks. All the results were averaged, so the idle numbers are averages of 24 data points and the remaining numbers are averages of 8 data points.

TABLE 8. SUMMARY OF LOCOMOTIVE STEADY-STATE SMOKE DATA

Condition	Average % Opacity Unit 1311	Average % Opacity Unit 8447		Average % Opacity Unit 8639	
		Transverse	Longitudinal	Transverse	Longitudinal
Idle	1.5	1.7	2.2	3.7	6.7
Dyn. Brake	--	2.0	3.8	4.0	8.2
N1	2.8	2.1	2.3	4.9	8.9
N2	3.2	4.5	5.2	14.8	28.0
N3	2.7	11.2	22.8	15.1	29.2
N4	2.0	11.1	22.0	12.1	25.8
N5	2.0	12.1	21.4	9.8	19.5
N6	1.9	9.1	18.4	6.4	13.0
N7	2.2	5.5	11.2	4.6	9.0
N8	2.8	6.4	10.0	4.8	9.2

For unit 8447, two runs were made in the transverse position and two in the longitudinal position (transverse is the short path across the stack), so idle numbers are averages of 12 points and the others are averages of 4 points. Two runs (or 12 data points at idle, and 4 data points elsewhere) are represented by the numbers for unit 8639 in the transverse position, and one run (or 6 idle data points, and 2 data points on other conditions) by the numbers for the longitudinal position. In the case of unit 1311, the nominal optical path length through the smoke plume was 10 inches, and identical for all runs. For unit 8447, the exhaust outlet was 11.5 inches (transverse) by 29.75 inches (longitudinal), and the corresponding dimensions for the exhaust outlet on unit 8639 were 11.5 inches and 26.5 inches, respectively. More so for unit 8447 than for the other two locomotives, however, the exhaust gases were underexpanded at the outlet for the several highest notches, leading to a rapid divergence upon entering the atmosphere. This divergence was an important enough factor, at least in the case of unit 8447 at higher power conditions, to cause variation in the optical path length through the smoke plume as conditions varied, making the length an undetermined variable. This divergence is one reason why no mathematical correlation of transverse and longitudinal results has been attempted, and another is that the geometric characteristics of the smoke plume change quite rapidly after entering the atmosphere, making the perception of the plume density more equal in all directions. Further perceptual effects occur, of course, with wind or motion of the locomotive. In order to make path lengths more nearly equal for test purposes, the installation of a standardized stack was considered, but time and financial constraints did not permit this extension beyond the intended scope of work. Such a duct might be 27 to 30 inches in diameter and circular at its outlet, shaped enough at its base to conform somewhat to the standard stack and prevent leaks, and long enough to produce a relatively uniform flow at its outlet (perhaps 36 to 48 inches). Another alternative for possible future use would be to devise an equitable, accurate, particulate sampling procedure, and thereby eliminate stack geometry as a factor.

C. Particulate Results

As mentioned previously, results of the locomotive particulate measurements were less than satisfactory due to the sampling method which had to be employed. The experimental method was an adaptation of that developed for general use in the characterization work, and was used because no standard or accepted technique was available. To explain the situation more fully, the experimental sampler which has been used on this project weighs several hundred pounds and is physically quite large (ref. Figure 9) so it was impractical to lift it to the top of each locomotive to keep the sample line short. It was likewise impractical to use a long, constant-diameter sample line (3/8 inch O. D.) due to particle deposition on the tube walls. A good solution would have been to withdraw a "split" of the exhaust isokinetically into a fairly large tube (the larger the tube, the less wall area per unit volume), and then to sample isokinetically from that tube via a short sample line at ground level. The reason this procedure was not followed is that each condition would have required: (1) an accurate exhaust velocity measurement; (2) adjustment of blower controls to achieve an isokinetic sample rate, taking temperature changes, etc., into account; and (3) calculation of sampling rate for the particulate system based on the conditions in the larger tube. Since the particulate measurements had to be taken separately from the other measurements, the additional time and personnel required to set the sampling conditions simply could not be justified. The compromise which was employed was to maintain a constant mass flow rate in the 3 inch diameter duct, and sample from it into the sampler itself at the isokinetic rate. This technique required only the setting of one control on the 3 inch duct (the bypass valve) and allowed the use of the same sample rate for all runs.

The problem with the system as used was that sampling into the 3 inch duct was subisokinetic at higher power settings to such an extent that considerably more heavy particles were sampled than the number representative of the exhaust stream. This effect was most pronounced for unit 1311, which had relatively large cinders in its exhaust, especially at high power. It could be speculated that the cinders were agglomerations of carbon which had built up on the inside surfaces of the exhaust system, and that they were dislodged while the engine ran at high power. Such particles could build up over a period of time if the operational history of this particular locomotive did not include much running at "notch 8". To further support this theory, no cinders were observed in the exhausts of the other two engines (which very probably operated at high power settings much more than the switch engine did) and examination of the filters used for particulate sampling showed no large cinder-type particles. These observations seem to correlate with the test results summarized in Table 9, which show that the measured particulate concentrations tended to

TABLE 9. SUMMARY OF LOCOMOTIVE PARTICULATE EMISSIONS DATA

NOTE: THESE PARTICULATE DATA ARE NOT CONSIDERED RELIABLE FURNISHED FOR DOCUMENTATION PURPOSES ONLY

Unit No.	Condition	Individual Results, mg/SCF Exhaust				Avg. Result, mg/SCF	Avg. % Opacity
1311	Idle	0.308	0.412	0.519	--	0.413	1.5
	N4	3.42	2.78	1.69	1.69	2.40	2.0
	N8	21.6	25.1	18.9	12.7	19.6	2.8
8447	Idle	1.62	2.17	1.35	1.75	1.72	1.7
	Dyn. Brake	2.53	0.823	1.40	--	1.58	2.0
	N4	2.59	2.50	0.862	--	1.98	11.1
	N8	2.80	2.22	1.65	2.75	2.36	6.4
8639	Idle	1.12	1.31	1.34	--	1.26	3.7
	Dyn. Brake	4.05	3.71	2.74	2.13	3.16	4.0
	N4	1.45	2.77	3.15	2.37	2.44	12.1
	N8	3.27	2.69	2.81	2.44	2.80	4.8

increase with exhaust velocity (or exhaust mass flow) regardless of the trend in smoke density (or opacity). It should also be recognized that some particulates measured on the filter (taken at about 90° F) may have been gases as they left the stack, tending to further decrease the correlation between particulate weight and smoke density.

Due to the reservations expressed above about the data acquired on particulates during this program, the subject results will not be used to estimate emission factors or national impact for locomotives. While the attempt to obtain reliable data within the time and financial constraints of the program failed, the efforts and experience should be valuable to those attempting further such work. It may be necessary to standardize the type of exhaust stack used for particulate sampling in somewhat the same manner as the standardization suggested for smoke measurements, just to get a flow of exhaust which is acceptably directional for sampling. In any case, the need for precisely isokinetic sampling has been demonstrated quite vividly, along with the need for development of suitable instrumentation and procedures.

D. Special Test Results

Runs 4 and 5 on unit 8639, the 16-cylinder G. E. locomotive, type U-33 C, were designated "special runs" because some of the speeds at which the engine ran were altered for test purposes. These speed changes were made in response to a suggestion by G. E. technical personnel to operators in California that smoke might be reduced if the engine speeds were changed in several notch positions. The two special runs were conducted immediately after run 3, on the same day, to avoid keeping the locomotive out of service an extra day.

The altered engine operation schedule was designed to retain approximately the same power output in each notch as with the standard schedule, but to run notches 1, 2, and 3 at the standard speed for notch 5 (783 rpm) and notches 4 through 8 at the standard speed for notch 8 (1077 rpm). The effect of these changes was to leave idle, dynamic brake, and notch 8 unchanged, and raise engine speeds in notches 1 through 7. The increased engine speeds resulted in small increases in fuel usage proportional to the increases in gross horsepower.

To examine the effectiveness of the higher engine speeds as a control measure for unit 8639, Table 10 has been prepared to compare mass emissions by throttle setting for the standard and revised schedules. A cursory examination of Table 10 shows that the revised conditions (notches 1-7) tended to produce higher hydrocarbons, slightly higher NO_x and aldehydes, and much lower CO than the standard conditions. The overall effects of the revised conditions on gaseous emissions can be seen in Table 11, and after weighting of the modes it appears that for the experimental runs hydrocarbons, NO_x and aldehydes were about the same as for the standard runs and CO was

TABLE 10. AVERAGE MASS EMISSIONS FROM A G.E. 7FDL16 LOCOMOTIVE ENGINE USING STANDARD AND REVISED ENGINE SPEEDS

Condition	Emissions at Standard Speeds (g/hr)				Emissions at Revised Speeds (g/hr)			
	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
Idle*	551	828	1,030	67.5	517	650	888	53.4
Dyn. Brake*	2400	2,050	5,200	158	2280	1780	4,800	125
N1	588	991	3,390	--	1120	932	4,100	--
N2	1780	6,590	10,300	74.2	2300	2480	10,500	109
N3	2120	11,700	12,600	--	2410	4300	12,800	--
N4	2130	14,400	16,000	167	3750	3240	16,700	202
N5	2600	13,800	17,500	--	4400	3870	20,500	--
N6	4080	12,600	22,900	314	5730	5260	24,400	319
N7	5740	9,310	29,400	--	6690	6200	28,300	--
N8*	6630	9,630	33,200	538	6650	8620	32,000	466

*Condition identical for all runs.

significantly lower than for the standard runs (changes in HC, NO_x, and aldehydes were measurable, but hardly significant).

Since the experimental runs were intended to investigate a smoke reduction technique, smoke was measured by a modified PHS opacity meter with the results presented in Table 12. The engine speed revisions did seem to reduce smoke quite significantly in notches 1-7, although the engine smoked slightly less during runs 4 and 5 even in conditions which were not revised. The most dramatic reductions in smoke were for notches 2 through 6, the same notches in which large reductions in CO were in evidence.

No particulate or light hydrocarbon measurements were made during the two runs using the experimental speeds, primarily to keep the overall time requirement reasonable. Although the speed changes had to be made manually for these tests, the regular engine speed control system could be modified so that positioning the throttle control in the normal way would automatically set the ending speed at the new value.

E. Emissions During Transients

Emissions were measured during changing speed and load conditions on each engine, generally prior to each day's operation. The continuous measurements made during these transients included hydrocarbons, CO, CO_2,

NO_x by chemiluminescence, and smoke opacity. The reason for making these measurements was primarily to determine whether or not transient emissions were sufficiently different than steady-state emissions so as to change the overall emissions picture significantly. The types of conditions

TABLE 11. CYCLE COMPOSITE EMISSIONS FROM A G.E. 7FDL16 LOCOMOTIVE ENGINE USING STANDARD AND REVISED ENGINE SPEEDS

	Mass, g/hr				Brake Specific, g/bhp hr			
Run	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
4	3160	3610	13,500	211	2.33	2.66	9.96	0.156
5	2960	3640	13,000	--	2.19	2.69	9.59	--
Average Revised Runs 4 & 5	3060	3620	13,200	211	2.26	2.68	9.78	0.156
Average Standard Runs 1-3	2860	5300	13,500	235	2.19	4.08	10.4	0.181

	Fuel Specific, g/lb_m fuel			
Run	HC	CO	NO_x	RCHO
4	6.69	7.66	28.6	0.447
5	6.38	7.83	27.9	--
Average Revised Runs 4 & 5	6.54	7.74	28.2	0.447
Average Standard Runs 1-3	6.31	11.7	29.9	0.524

investigated were engine acceleration through the notches with load, deceleration with load, and cold starts.

Emissions during transients were taken to be of no special significance if concentrations changed smoothly between initial and final steady-state values, a result termed "smooth transition". Without exception, such changes were the case for all decelerations of the engines from notch 8 to idle. Some cold starts were run also, with no significant excursions of gaseous emissions due to engine start-up, very little drift in CO, CO_2, or NO_x, and about 15%

downward drift in hydrocarbons during a 15-minute idle following startup. One significant smoke puff was observed at engine startup, ranging up to 95% peak opacity, with a duration of about 2 seconds.

The accelerations from idle to notch 8 produced most of the excursions from smooth transitions which were observed, but the durations of peaks

TABLE 12. SMOKE EMISSIONS FROM A G.E. 7FDL16 LOCOMOTIVE ENGINE USING STANDARD AND REVISED ENGINE SPEEDS

Condition	% Opacity, Standard Engine Speeds		% Opacity, Revised Engine Speeds	
	Transverse	Longitudinal	Transverse	Longitudinal
Idle*	3.7	6.7	2.7	5.8
Dyn. Brake*	4.0	8.2	2.6	5.0
N1	4.9	8.9	3.0	5.0
N2	14.8	28.0	6.8	12.8
N3	15.1	29.2	7.1	14.0
N4	12.1	25.8	3.5	7.0
N5	9.8	19.5	3.2	6.8
N6	6.4	13.0	3.0	7.2
N7	4.6	9.0	3.0	7.0
N8*	4.8	9.2	4.0	8.5

*"revised" engine speeds same as standard

were very short in most cases. Table 13 summarizes the results of the acceleration tests in terms of concentrations and peak durations. The durations were taken to be the time during which the concentrations (or opacities) were 10% or more over the final steady-state values, and maximum values are expressed as peak value divided by final steady-state value. No significant excursions were observed for either CO_2 or NO_x, so they were not included in the table. For unit 1311, the peaks occurred within a few seconds after initial throttle movement, and only a single peak occurred for each constituent. The picture was a bit more complex for unit 8447, with the first set of peaks (CO and smoke) being observed going into notch 3, and with subsequent smaller peaks going into each notch through 8. The peaks observed for unit 8639 were of much longer duration, as shown in Table 13, and they occurred late in the accelerations (beginning around notches 6 to 8).

The values given in Table 13 are representative of 6 to 10 repetitions made with each locomotive, as are the comments made on decelerations. The charts were examined carefully, and 2 runs were picked for analysis to minimize computation time. The analysis of transient emissions shows that they are probably not important in the overall locomotive emissions picture due to the short time in which emissions are outside those expected from steady-state operation. At this point we have no rigorous way of determining mass emissions during transients, so these results will not be used in estimating emission factors and national impact.

TABLE 13. LOCOMOTIVE EMISSIONS DURING ACCELERATION TRANSIENTS

	Peak Value ÷ Final Value			Peak Duration, sec.		
Unit	HC	CO	Smoke	HC	CO	Smoke
1311	2	35	10	7	7	5
8447	-	4	10	-	4	4
8639	-	5	10	-	20	16

V. ESTIMATION OF EMISSION FACTORS AND NATIONAL IMPACT

Emission factors for locomotives are to be estimated based primarily on the tests conducted as part of the subject program, although results of other studies will be referenced and taken into consideration. If it is shown later that the engines tested were not representative, or if additional, more comprehensive data become available, the factors and impact estimates can be updated using the subject techniques as a guide. Factors will be estimated on both brake specific and fuel specific bases, and parallel impact calculations will be made using independent locomotive utilization and fuel usage data.

Emission factors for the marine counterparts of locomotive diesel engines will be estimated from much less comprehensive information, and will be treated separately.

A. Emission Factors and Emission Estimates for Locomotive Diesel Engines

As a prerequisite to determining emission factors, the composition of the locomotive population must be known so the proper weight can be given to each size category and each type of operation. The most recent population data available are as of January 1, 1972,[7] and Table 14 shows these data in their most useful form. These figures are intended to be for the 48 states only, but slight errors may have occurred in separating U.S. from non-U.S. railroads.

The first use of the data in Table 14 will be to calculate percentages of total yearly railroad diesel fuel usage which can be attributed to engines represented by each of those tested under this project. These calculations will be used along with national fuel consumption figures[11] and fuel specific emissions data from Table 6 to calculate emission factors and impact. Pursuing the fuel-based calculations, available data[10] indicate that 25.9% of active locomotives were engaged in yard service in 1971, and that 70.0% were in freight service and 4.1% were in passenger service. Since it is not known just which particular locomotives were in yard service (6,951 total), the assumption will be made that they were the 6,951 smallest locomotives listed in Table 14. In terms of a cut-off point, this assumption means that 1437 of the 1500 hp units and all those smaller than 1500 hp are assumed to be in yard service. If a second assumption is made to the effect that the average power of the "under 1000 hp" units is 750 hp, the total horsepower in yard service comes out to 7,032,150 (or 1012 hp per unit) and that in road service to 45,295,750 (or 2278 hp per unit).

The next item is determination of load factors for road and yard operations, defined as average power produced during operation divided by available power. Based on power measurements taken during this project, the load factor for the EMD line-haul cycle is 0.397, that for the G.E. line-haul cycle is 0.365, and that for the switcher cycle is 0.0507. Another necessary item of information is operating time per year for each category

TABLE 14. U.S. LOCOMOTIVE POPULATION BY POWER CLASS AND BUILDER

Horsepower Class	Builder: EMD	Alco	G. E.	GMD	MLW	BLH	FM	Others	Totals
5000	45	-	66	-	-	-	-	-	111
3600	1359	31	97	-	-	-	-	-	1487
3300	1	-	373	-	-	-	-	-	374
3000	2211	77	435	3	16	-	-	-	2742
2800	-	-	236	-	-	-	-	-	236
2750	-	115	-	-	-	-	-	-	115
2700	-	18	-	-	-	-	-	-	18
2500	1555	76	549	-	-	-	-	-	2180
2400	306	168	-	-	-	-	26	-	500
2350	-	-	-	-	-	-	8	-	8
2300	77	-	-	-	-	-	-	-	77
2250	1217	-	155	-	-	-	-	-	1372
2000	1413	142	-		-	13	-	-	1568
1850	138	-	-	-	-	-	-	-	138
1800	329	534	9		29	2	-	-	903
1750	3898	-	-	2	-	2	-	-	3902
1600	22	712	-	-	25	77	63	2	901
1500	4471	152	-	21	-	32	2	14	4692
1400	-	4	-	-	-	-	-	-	4
1350	39	-	-	-	-	-	-	-	39
1300	2	-	-	-	-	-	-	-	2
1200	1639	38	-	1	-	233	153	-	2064
1000	985	1136	-	-	3	163	50	2	2339
Under 1000	720	223	67	23	-	25	-	8	1066
Totals	20,427	3426	1987	50	73	547	302	*27	*26,839

* Includes one engine with no power class given

Abbreviation	Builder Name
EMD	Electro-Motive Division, General Motors Corp.
G. E.	General Electric
GMD	Diesel Division, General Motors of Canada
MLW	MLW Industries, Canada
BLH	Baldwin-Lima-Hamilton
FM	Fairbanks-Morse

of application, and 1971 statistics[10] also yield this information. For road freight and passenger service combined, some 64.4 x 10^6 locomotive hours were used, and for all switching operations about 39.3 x 10^6 locomotive hours were used. The foregoing figures yield about 2015 x 10^6 hp hours for switching operation and about 57,400 x 10^6 hp hours for road operation during 1971. Converted to percentages, some 96.6% of locomotive hp hours were used in road service, leaving 3.39% for switching operations. Assuming that fuel usage is directly proportional to work produced, the estimate is made that these latter percentages also represent fuel consumed in road and switching operations, respectively. Since no data are presently available on load factors for passenger service, they are being assumed as equal to those for freight service.

The latest available fuel consumption figure for railroad diesels is for 1970[11], and it totals 3804 x 10^6 gallons, or approximately 27,100 x $10^6 lb_m$ (at 7.12 lb_m gal). This figure when divided by the total hp hours above, yields an average brake specific fuel consumption for all railroad operations of 0.456 lb_m/bhp hr, which sounds somewhat high, but may be reasonable in view of the relatively large fractions of time spent at idle. Another error may be inherent in this BSFC calculation because undoubtedly some of the diesel fuel used by railroads is used in equipment other than locomotives. In order to calculate factors and impact as accurately as possible, the switch engine population will be considered to be 75% 2-stroke engines and 25% 4-stroke engines (on a horsepower basis). These smaller 2-stroke engines are probably characterized adequately by unit 1311, but the 4-strokes are not yet represented. To overcome this problem, mode emissions from runs 1 through 3 on unit 8639 have been re-weighted according to the ATSF switcher cycle, with the results shown in Table 15. Table 15 also contains emissions from unit 1311, reweighted according to the EMD line-haul cycle (except that dynamic brake was omitted and the other mode weights were increased by a factor of 100 ÷ 92 = 1.087) for use

TABLE 15. SUMMARY OF REWEIGHTED EMISSIONS FROM UNITS 1311 AND 8639

Unit	Cycle	Contaminant	Mass, g/hr	Brake Specific g/bhp hr	Fuel Specific g/lbm fuel
1311	EMD line-haul	HC	1820.	3.95	9.43
		CO	809.	1.76	4.20
		NO_x	4360.	9.45	22.6
		RCHO	44.1	0.096	0.229
8639	ATSF switch	HC	766.	4.96	9.33
		CO	2000.	12.9	24.3
		NO_x	2560.	16.6	31.2
		RCHO	79.4	0.514	0.967

in estimating emissions from line-haul 2-stroke engines which are Roots-blown rather than turbocharged. The estimated breakdown of locomotives used in road service is 37% Roots-blown 2-strokes, 37% turbocharged 2-strokes, and 26% 4-strokes, on a horsepower basis.

Five engine categories have been defined in the process of arriving at a calculation technique for mass emissions based on fuel usage, and each of the five is represented by emission factors shown in either Table 6 or Table 15. The total weight for each category is the fraction of all fuel used by engines in that category, and these weights multiplied by the proper emission factors yield quantities which sum to composite emission factors for the whole locomotive population. A summary of the results of this analysis is shown in Table 16, and it is a simple matter to progress to total mass emissions (or impact) by multiplying the composite factors by total fuel usage. This step will come later in the report. Mass emissions for each engine category can be determined by multiplying the category factors by total fuel usage.

To calculate emission factors on a brake specific basis, the analysis is the same as the foregoing down to the point where fractions of total horsepower hours produced by engines in each category were taken to be equal to fractions of total fuel used. In the brake specific case, this last assumption is not necessary, and Table 17 shows the results of brake specific emissions factor calculations. To determine impact from the brake specific data, the factors can be multiplied by the total work (horsepower hours) produced per year, which was derived earlier.

Emissions of sulfur oxides have not been mentioned as yet because SO_x was not measured, but sulfur oxides have been calculated on a basis of 0.35% by weight fuel sulfur content, assuming that all the sulfur is oxidized to SO_2. Particulate emissions have been discussed earlier, but the particulate results generated by this study are not considered accurate enough for use in estimating factors and impact, so no improvement can be made on the latest EPA figures. Impact estimates based on the above procedures and factors are given in Table 18, and these estimates are compared with recent EPA nationwide estimates in Table 19. With the exception of the SO_x estimate, which was calculated from fuel usage only, the more accurate factors and estimates are probably those derived on a brake specific basis. The reason for a degree of lack of confidence in the fuel-based numbers is simply that the overall fuel consumption figure has a lot of room for error, since in some cases accurate data may not be kept on how much fuel is used in locomotives and how much in other engines.

One positive feature of the fuel-based calculations, however, is that they can be updated very quickly if it is assumed that the locomotive population and its operation do not change greatly (probably a valid assumption over 5 years or so). The calculations based on work output (brake specific) are not difficult, either, if information on operating hours per

TABLE 16. SUMMARY OF FUEL-BASED EMISSION FACTOR CALCULATIONS

Engine Category	Fraction of Total Fuel Used	Emission Factors for Category (g/lb_m fuel)				Weighted Factors for Category (g/lb_m fuel)			
		HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
2-s (Blown) Switch	0.0254	12.3	5.35	15.8	1.27	0.312	0.136	0.401	0.0323
4-s Switch	0.00848	9.33	24.3	31.2	0.967	0.0791	0.206	0.265	0.00820
2-s (Blown) Road	0.3575	9.43	4.20	22.6	0.229	3.37	1.50	8.08	0.0819
2-s (T.C.) Road	0.3575	1.80	10.4	21.2	0.271	0.644	3.72	7.58	0.0969
4-s Road	0.2512	6.31	11.7	29.9	0.524	1.59	2.94	7.51	0.132
$\sum$ = composite factor, g/lb_m fuel						6.00	8.50	23.84	0.351
composite factor, lb_m/1000 gal fuel						94.2	133.	374.	5.51

TABLE 17. SUMMARY OF BRAKE SPECIFIC EMISSION FACTOR CALCULATIONS

Engine Category	Fraction of Total hp hours	Emission Factors for Category, g/bhp hr				Weighted Factors for Category, g/bhp hr			
		HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
2-s (Blown) Switch	0.0254	8.87	3.89	11.4	0.92	0.225	0.0988	0.290	0.023
4-s Switch	0.00848	4.96	12.9	16.6	0.514	0.0421	0.109	0.141	0.00436
2-s (Blown) Road	0.3575	3.95	1.76	9.45	0.096	1.41	0.629	3.38	0.034
2-s (T.C.) Road	0.3575	0.695	4.00	8.22	0.104	0.248	1.43	2.94	0.0372
4-s Road	0.2512	2.19	4.08	10.4	0.181	0.550	1.02	2.61	0.0455
$\sum$ = composite factor, g/bhp hr						2.48	3.29	9.36	0.144

TABLE 18. NATIONAL IMPACT ESTIMATES FOR LOCOMOTIVE EMISSIONS

Contaminant	Total Estimated Emissions, 10^6 tons per year: Fuel Specific Basis	Brake Specific Basis
HC	0.177	0.162
CO	0.247	0.215
NO_x	0.698	0.613
RCHO	0.010	0.00943
SO_x	0.0947	0.0947
Particulate	*	*

*EPA figure not improved upon

TABLE 19. COMPARISON OF SUBJECT NATIONAL IMPACT ESTIMATES WITH EPA NATIONWIDE AIR POLLUTANT INVENTORY DATA

	EPA Inventory Data, 1970, 10^6 tons/yr(17)			Subject Estimates of % of	
Contaminant	All Sources	Mobile Sources	Railroads	All Sources	Mobile Sources
HC	34.7	19.5	0.093	0.467	0.831
CO	147.	111.	0.100	0.146	0.194
NO_x	22.7	11.7	0.142	2.70	5.24
RCHO	--	--	--	--	--
SO_x	33.9	0.986	0.124	0.279	9.60
Particulate	25.4	0.655	0.047	*0.185	*7.18

*EPA figure

year continues to be available. The only major change in railroad operation occurring at the present time is the institution of Amtrak. Separate statistics on Amtrak may be available later, and they could be used to supplement information available from AAR and other sources. As was mentioned earlier, some 96.6% of locomotive horsepower hours are produced in road service, and it seems logical that a similar percentage of total locomotive emissions (at least 90 to 95%) could be classed as "rural" rather than "urban or suburban". Without doing an analysis of commercial traffic which is really outside the intent of the current project, it can only be assumed that most locomotive pollutants are emitted between the larger areas, or in "commercial corridors", if that is an acceptable term. These emissions should have little connection with peak traffic hours, season of year, or other factors normally associated with detailed impact analysis.

Up to this point, the results of other studies of locomotive emissions[4, 5, 12, 13, 14] have not been mentioned specifically. All the information in these references stems from either in-house research at EMD or G. E. or the study funded jointly by AAR, Santa Fe, Southern Pacific, and Union Pacific (called the "Richmond" study). In general terms, the emissions results generated under this program agree fairly well with the other published information, although the NO_x emissions observed during the San Antonio tests are consistently somewhat lower than most of the EMD and Richmond results. The NO_x results used in calculating impact for this study were those generated by the chemiluminescent analyzer, which generally gave somewhat lower results than the NDIR NO analyzer, which can be verified by examining the data in Appendixes A through C. The use of the chemiluminescent results is a best judgement decision based on experience using both types of analyzers in parallel on a variety of engines.

B. Emission Factors for the Marine Counterparts of Locomotive Diesel Engines

Since early in this project, it has been anticipated that one of the weakest areas would be population and usage information on vessels in the class between pleasure boats and ocean-going craft. Although a considerable amount of effort has been expended, a general lack of comprehensive data is still the case, but limited information is available. Data retrieved from one publication[19] indicate that there may be as few as 3230 commercial vessels using diesel engines between 500 and 4000 horsepower (1970), having an aggregate rated horsepower of about 2.26×10^6. This source shows total diesel merchant vessel horsepower as about 6.62×10^6, excluding ocean-going ships. Other data indicate that all diesel merchant vessels (excluding ocean-going vessels) use about 6.7×10^8 gallons of diesel fuel per year. If 3000 hours' operation per year are assumed for the 500-4000 hp class of vessels, along with a load factor of 0.5 and a brake specific fuel consumption of 0.4, fuel consumption for the class could be estimated at about 1.9×10^8 gallons per year. This figure is about 28% of the merchant vessel fuel consumption noted above, while the 500-4000 hp class has about 34% of the diesel merchant vessel horsepower, so the agreement is not too bad.

Some confirmation of the assumptions made on diesel vessels is provided by independent data developed by the U. S. Army Corps of Engineers[20] and information obtained by direct contacts with boat operators[21, 22, 23, 24]. The Corps of Engineers' data indicates that about 2500 vessels fulfilling the above engine criteria were operated in transportation service (not including fishing, dredging, etc.) in U. S. waters during 1970. The information from the commercial boat operators indicates load factors from 0.56 to 0.9 (mostly estimates rather than hard data), usage up to 500 hours per month, and specific data showing wide usage of EMD and Fairbanks-Morse engines similar to those used in locomotives.

It should be obvious that the population and usage data are quite shaky for this category of engine application, so only little credibility can be attached to the resulting emission factors. The duty cycles of the vessels are likewise substantially undefined, but perhaps a reasonable guess would be 10% idle, 20% full load, and 10% at each of the seven intermediate load conditions (although such notches do not exist for marine applications). The assumption is also made that the emissions from these marine engines can be characterized by re-weighted locomotive emissions, and emission factors based on the cycle above are shown in Table 20. It will also be

TABLE 20. RE-WEIGHTED LOCOMOTIVE EMISSION FACTORS USED TO CHARACTERIZE EMISSIONS FROM THEIR MARINE COUNTERPARTS

	Fuel Specific, g/lb_m fuel				Brake Specific, g/bhp hr			
Engine	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
Unit 1311 (2-s Blown)	8.78	3.69	21.9	0.378	3.50	1.47	8.74	0.151
Unit 8447	1.49	13.6	20.7	0.217	0.561	5.11	7.79	0.0815
Unit 8639 (4-s T.C.)	5.84	15.9	31.9	0.457	2.02	5.49	11.0	0.158

assumed for calculation purposes that marine units under 1000 hp can be represented by unit 1311, and that units over 1000 hp can be represented by a 50-50 weighting of factors based on units 8447 and 8639. Since more is known about the population of marine units in service than about fuel consumption at this point, calculation of composite emission factors will proceed on the brake specific basis rather than the fuel specific basis. The results of this analysis are shown in Table 21, but they probably have only order-of-magnitude accuracy, at best. It might be noted, however, that most of the emissions would occur either in ports, cities where river or lake commerce is common, or further off shore where fishing boats run. The emissions probably have a seasonal nature only where harbors are impassable in winter, in areas where industries employing the vessels have seasonal transportation needs, or where fishing is seasonal.

TABLE 21. ESTIMATED COMPOSITE EMISSION FACTORS 500-to-4000-HP DIESEL-POWERED U.S. FLAG MERCHANT VESSELS

Pollutant	Composite Factor g/bhp hr
HC	3.42
CO	2.30
NO_x	9.65
RCHO	0.159

VI. SUMMARY

This report is on a study of locomotive emissions, and constitutes Part 1 of a planned seven-part final report on "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines," Contract No. EHS 70-108. It includes documentation and discussion on characterization of emissions from three locomotive diesel engines (sections III and IV), test data and computed mass emissions (Appendixes A, B, and C), estimation of emission factors and national impact for locomotive diesels (section V) and estimation of emission factors for their marine counterparts (section V). As a part of the final report on the characterization phase of EHS 70-108, this report does not contain information on aircraft turbine emissions, outboard motor crankcase drainage, or locomotive emissions control technology. As required by the contract, these three latter areas have been or will be reported separately.

Emissions tests on the three locomotive engines, each of which represented a widely-used type having distinctive design features, were conducted during April, 1972, at the San Antonio maintenance facility of the Southern Pacific Transportation Company. Southern Pacific personnel, both local and those in the corporate headquarters, were extremely cooperative, and the importance of this cooperation cannot be overstated. The emissions data gathered during this program are considered quite reliable, with the exception of particulate data which were acquired under less-than-ideal conditions. The data on hydrocarbons, CO, CO_2, NO and NO_x, oxygen, light hydrocarbons, aldehydes, and smoke were all quite repeatable, and where data from other investigations exist for comparison, agreement is reasonably good. As additional data is acquired in ongoing studies, it may be desirable to update the factors and impact estimates made in this report if the data on which these quantities are based is shown to be atypical for engines in service.

To measure smoke from the locomotive engines, special versions of the PHS smokemeter were fabricated with standard optical units mounted on 20-inch diameter and 40-inch diameter support rings to encompass the large locomotive exhaust stacks. These instruments were quite successful.

Expressing the results of this study in terms of national emissions impact of locomotive engines (after numerous assumptions regarding applicability of the subject results to the current locomotive population), figures were arrived at for locomotive emissions expressed as percentages of the (1970) national total. On this basis, locomotive emissions amounted to 0.467% of hydrocarbons from all sources and 0.831% of those from mobile sources, 0.146% of CO from all sources and 0.194% of that from mobile sources, 2.70% of NO_x from all sources and 5.24% of that from mobile sources, and 0.279% of SO_x from all sources and 9.60% of SO_x from mobile sources. Particulate data generated during this study are not considered reliable enough to be used in computing national impact. The other emissions measured are not relatable to available national source inventories.

In order to compile more comprehensive characterization data and make impact estimates more accurate, additional engines should be chosen to represent the locomotive population more fully, and they should be tested in a manner similar to the subject test program. An improvement could be made, however, by using a more highly-developed particulate sampling system. Regarding the class of diesel-powered vessels, the most notable need for further information is in the areas of population and usage. A separate study aimed at surveying the vessel population is really the answer to this problem, because the level of effort anticipated is too large to be accommodated by a study such as the subject effort.

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EXPLANATORY NOTES ON APPENDIX DATA

All emissions data in the Appendixes are on a wet basis, that is, corrected for removal of intake air humidity and water of combustion.

Emissions data in the Appendixes are considered to be accurate to 3 significant figures. Additional figures have been retained in those numbers which are considered to be intermediate, rather than final, results, to avoid unnecessary rounding errors.

APPENDIX A

Test Data and Computed Mass Emissions,
EMD 12-567 (S. P. Unit 1311)

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp		Fuel Rate, lbm/hr	Temperatures, °F		FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
			Net	Gross		Intake	Exhaust								
1	Idle	275	—	2.8	26.8	97	164	268	67	0.55	47	47	58	18.3	16
2	1	300	82.9	86.6	56.0	98	206	280	89	1.50	83	79	100	17.2	—
3	2	371	113.	120.	64.3	99	220	408	111	2.30	94	84	117	16.2	16
4	3	442	271.	283.	122.	101	290	448	122	1.88	226	199	219	16.1	—
5	4	513	423.	441.	181.	97	353	568	122	2.29	338	274	305	15.4	14
6	Idle	275	—	2.8	22.2	103	202	268	67	0.50	47	43	54	18.3	14
7	5	584	535.	562.	222.	97	380	619	165	3.48	629	505	541	13.3	—
8	6	655	733.	771.	302.	98	466	800	153	4.33	760	654	699	12.3	14
9	7	726	867.	919.	355.	100	518	938	185	4.64	845	770	796	11.8	—
10	8	800	1030.	1100.	421.	99	578	1250	363	5.10	989	845	890	11.0	24
11	Idle	275	—	2.8	22.0	104	275	475	112	0.73	83	65	83	17.3	28
~~12~~	~~Dyn. Brake~~														
~~13~~	~~Idle~~														
14	8	800	1015.	1085.	431.	99	548	1050	217	5.17	959	845	868	11.0	23
15	7	726	867.	919.	357.	106	547	900	218	4.65	920	806	828	11.4	—
16	6	655	750.	788.	305.	101	506	812	174	4.52	846	783	806	11.8	17
17	5	584	587.	614.	227.	106	454	700	153	3.90	706	593	621	12.5	—
~~18~~	~~Dyn. Brake~~		—												
19	Idle	275	—	2.8	22.2	109	252	288	55	0.64	70	47	63	17.9	17
20	4	513	443.	461.	174.	102	372	550	109	3.24	425	353	394	15.9	14
21	3	442	272.	284.	121.	102	350	412	110	2.57	261	232	273	16.1	—
22	2	371	195.	202.	73.0	103	290	388	111	2.03	164	141	175	17.5	14
23	1	300	100.	104.	54.0	105	250	262	77	1.52	117	90	118	17.1	—
24	Idle	275	—	2.8	22.3	108	193	138	45	0.73	58	50	66	17.9	16

LOCOMOTIVE S.P. UNIT 1311, EMD 12-567 SWITCH WET BULB TEMP., °F 76

RUN 1 DATE 4/12/72 BAROMETER 28.95 in Hg DRY BULB TEMP., °F 99

Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	Mass Rates, g/hr				Brake Specific, g/bhp hr				Fuel Specific, g/lbm fuel			
				HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
1	Idle	275	15.4	562	286	407	73.2	201.	102.	145.	26.1	21.0	10.7	15.2	2.73
2	1	300	5.0	462	299	360	—	5.34	3.45	4.16	—	8.25	5.34	6.43	—
3	2	371	2.5	683	378	656	58.4	5.70	3.15	5.46	0.49	10.6	5.88	10.2	0.91
4	3	442	2.0	1286	712	2104	—	4.50	2.51	7.43	—	10.5	5.84	17.2	—
5	4	513	1.0	1986	868	3570	107.	4.50	1.96	8.09	0.24	11.0	4.80	19.7	0.59
6	Idle	275	15.4	510	259	344	58.0	182.	92.5	123.	20.7	23.0	11.7	15.5	2.61
7	5	584	0.5	1752	951	5127	—	3.11	1.69	9.12	—	7.89	4.28	23.1	—
8	6	655	0.5	2481	965	7259	94.7	3.22	1.25	9.41	0.12	8.22	3.20	24.0	0.31
9	7	726	0.0	3182	1277	9042	—	3.46	1.38	9.39	—	8.96	3.60	25.5	—
10	8	800	0.0	4542	2684	10,827	190.	4.13	2.44	9.84	0.17	10.8	6.38	25.7	0.45
11	Idle	275	15.4	600	288	351	77.2	214.	103.	125.	27.6	27.3	13.1	16.0	3.51
~~12~~	~~Dyn. Brake~~														
~~13~~	~~Idle~~														
14	8	800	0.0	3884	1634	10,749	186.	3.57	1.50	9.91	0.17	9.01	3.79	24.9	0.43
15	7	726	0.0	3064	1511	9439	—	3.33	1.64	10.3	—	8.58	4.23	26.4	—
16	6	655	0.5	2434	1061	8088	111.	3.08	1.35	10.3	0.14	7.98	3.48	26.5	0.36
17	5	584	0.5	2212	984	6569	—	3.60	1.60	10.7	—	9.74	4.33	28.9	—
~~18~~	~~Dyn. Brake~~														
19	Idle	275	15.4	433	168	317	55.8	155.	60.0	113.	19.9	19.5	7.57	14.3	2.51
20	4	513	1.0	1316	531	3157	73.1	2.85	1.15	6.84	0.16	7.56	3.05	18.1	0.42
21	3	442	2.0	863	469	1916	—	3.04	1.65	6.75	—	7.13	3.88	15.8	—
22	2	371	2.5	618	360	933	48.6	3.05	1.78	4.62	0.24	8.47	4.93	12.8	0.67
23	1	300	5.0	414	253	625	—	3.98	2.43	6.01	—	7.67	4.69	11.6	—
24	Idle	275	15.4	186	124	298	47.1	66.7	44.3	106.	16.8	8.34	5.56	13.4	2.11

LOCOMOTIVE S.P. UNIT 1311, EMD 12-567 SWITCH

RUN 1 DATE 4/12/72

DUTY CYCLE SANTA FE SWITCH

Basis	Cycle Composite Emissions			
	HC	CO	NO_x	*RCHO
Mass, g/hr	550	277	636	63.4
Brake Specific, g/bhp hr	10.2	5.15	11.8	1.18
Fuel Specific, g/lbm fuel	13.6	6.85	15.7	1.57

*See note in text regarding RCHO computations

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp		Fuel Rate, lbm/hr	Temperatures, °F		FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
			Net	Gross		Intake	Exhaust								
1	Idle	275	—	2.8	22.2	91	175	268	45	0.92	94	74	96	19.0	16
2	1	300	85.8	89.5	56.4	91	198	320	89	1.78	141	114	148	17.9	—
3	2	371	180.	187.	71.3	89	224	536	122	2.19	164	152	196	16.7	16
4	3	442	254.	266.	116.	91	270	568	132	2.79	286	259	309	16.0	—
5	4	513	453.	471.	171.	89	334	756	110	3.61	451	395	445	15.4	13
6	Idle	275	—	2.8	22.0	95	226	328	45	0.83	70	72	91	19.5	14
7	5	584	535.	562.	224.	90	366	720	109	4.01	540	481	530	13.5	—
8	6	655	732.	770.	284.	90	443	944	109	4.47	706	629	670	12.8	11
9	7	726	855.	907	344.	95	503	952	129	4.96	826	726	757	12.0	—
10	8	800	1015.	1085.	436.	95	572	1070	274	5.66	960	855	891	11.2	18
11	Idle	275	—	2.8	22.0	102	270	352	45	0.83	119	65	79	19.0	18
~~12~~	~~Dyn. Brake~~														
~~13~~	~~Idle~~														
14	8	800	1015.	1085.	438.	92	552	1024	227	5.56	992	842	855	12.5	17
15	7	726	867.	919.	365.	101	534	832	140	5.10	870	774	783	13.1	—
16	6	655	733.	771.	280.	98	487	784	108	4.70	644	678	696	13.7	14
17	5	584	561.	588.	227.	99	446	676	108	4.32	620	573	600	14.1	—
~~18~~	~~Dyn. Brake~~														
19	Idle	275	—	2.8	22.2	102	294	280	45	0.83	83	63	80	19.3	17
20	4	513	453	471.	173.	100	370	560	110	3.80	520	446	496	15.3	14
21	3	442	271	283.	112.	99	329	444	110	3.01	322	300	344	16.2	—
22	2	371	166	173.	70.1	112	264	356	110	2.12	189	154	194	17.2	14
23	1	300	90.0	93.7	57.0	111	230	262	89	1.77	129	117	147	17.8	—
24	Idle	275	—	2.8	22.2	107	184	192	45	0.92	83	66	85	19.0	16

LOCOMOTIVE S.P. UNIT 1311, EMD 12-567 SWITCH   WET BULB TEMP., °F 75

RUN 3   DATE 4/13/72   BAROMETER 28.86 in Hg   DRY BULB TEMP., °F 92

Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	Mass Rates, g/hr HC	CO	NO_x	RCHO	Brake Specific, g/bhp hr HC	CO	NO_x	RCHO	Fuel Specific, g/lbm fuel HC	CO	NO_x	RCHO
1	Idle	275	15.4	284	97	341	37.0	101.	34.6	122.	13.2	12.8	4.37	15.4	1.67
2	1	300	5.0	447	253	693	—	4.98	2.82	7.74	—	7.93	4.49	12.3	—
3	2	371	2.5	771	357	944	50.2	4.12	4.12	5.04	0.27	10.8	5.01	13.2	0.70
4	3	442	2.0	1046	495	1904	—	3.93	1.86	7.15	—	9.02	4.27	16.4	—
5	4	513	1.0	1586	470	3126	59.5	3.37	1.00	6.63	0.13	9.27	2.75	18.3	0.35
6	Idle	275	15.4	380	106	353	35.3	136.	37.8	126.	12.6	17.3	4.82	16.0	1.60
7	5	584	0.5	1790	552	4412	—	3.18	0.98	7.85	—	7.99	2.46	19.7	—
8	6	655	0.5	2663	626	6329	67.7	3.46	0.81	8.22	0.087	9.38	2.20	22.3	0.24
9	7	726	0.0	2938	810	7823	—	3.24	0.89	8.62	—	8.54	2.35	22.7	—
10	8	800	0.0	3658	1906	10,198	134.	3.37	1.56	9.39	0.12	8.39	4.37	23.4	0.31
11	Idle	275	15.4	404	105	304	45.1	144	37.5	109.	16.1	18.4	4.77	13.8	2.05
~~12~~	~~Dyn. Brake~~														
~~13~~	~~Idle~~														
14	8	800	0.0	3579	1615	10,004	130.	3.30	1.49	9.22	0.12	8.17	3.69	22.8	0.30
15	7	726	0.0	2656	910	8370	—	2.89	0.99	9.10	—	7.28	2.49	22.9	—
16	6	655	0.5	2085	585	6197	81.2	2.70	0.76	8.03	0.10	7.45	2.09	22.1	0.29
17	5	584	0.5	1583	515	4705	—	2.69	0.88	8.00	—	6.97	2.27	20.7	—
~~18~~	~~Dyn. Brake~~														
19	Idle	275	15.4	328	107	314	43.4	117.	38.2	112.	15.5	14.8	4.82	14.1	1.95
20	4	513	1.0	1139	456	3379	62.1	2.42	0.97	7.17	0.13	6.58	2.64	19.5	0.36
21	3	442	2.0	738	372	1914	—	2.61	1.31	6.73	—	6.59	3.32	17.1	—
22	2	371	2.5	522	328	953	44.8	3.01	1.89	5.50	0.26	7.45	4.68	13.6	0.64
23	1	300	5.0	377	260	708	—	4.02	2.77	7.56	—	6.61	4.56	12.4	—
24	Idle	275	15.4	204	97	302	37.0	72.8	34.6	108.	13.2	9.19	4.37	13.6	1.67

LOCOMOTIVE S.P. UNIT 1311, EMD 12-567 SWITCH

RUN 3 DATE 4/13/72

DUTY CYCLE SANTA FE SWITCH

Basis	Cycle Composite Emissions HC	CO	NO_x	*RCHO
Mass, g/hr	423	160	616	42.7
Brake Specific, g/bhp hr	7.82	2.95	11.4	0.79
Fuel Specific, g/lbm fuel	10.77	4.07	15.7	1.09

*See note in text regarding RCHO computations

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp Net	Gross	Fuel Rate, lbm/hr	Temperatures, °F Intake	Exhaust	FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
1	Idle	275	—	2.8	21.1	95	166	208	33	0.54	70	48	55	19.1	13
2	1	300	101.	104.	57.5	94	199	280	55	1.16	94	72	90	18.9	—
3	2	371	195.	202.	70.8	92	241	376	66	1.56	153	121	142	18.2	12
4	3	442	282.	294.	115.	91	282	431	66	1.82	201	168	189	17.9	—
5	4	513	421.	439.	172.	91	338	495	66	2.24	249	236	247	17.2	12
6	Idle	275	—	2.8	21.9	98	204	200	45	0.49	119	45	53	19.8	13
7	5	584	560.	587.	222.	90	382	767	109	4.08	499	489	520	14.6	—
8	6	655	691.	729.	290.	90	444	880	108	4.64	644	621	642	13.9	9
9	7	726	836.	888.	341.	92	492	1000	129	4.95	725	707	728	12.8	—
10	8	800	1000.	1070.	429.	91	552	1250	216	5.48	850	817	822	12.0	16
11	Idle	275	—	2.8	22.0	100	300	472	55	0.82	82	72	76	18.8	19
~~12~~	~~Dyn. Brake~~														
~~13~~	~~Idle~~														
14	8	800	1000.	1070.	438.	93	520	1055	228	5.29	868	799	816	12.0	16
15	7	726	867.	919.	351.	94	522	887	152	4.82	812	739	744	12.9	—
16	6	655	703.	741.	288.	94	484	767	129	4.44	729	656	669	13.0	10
17	5	584	564.	590.	225.	92	426	705	130	3.94	606	537	547	14.4	—
~~18~~	~~Dyn. Brake~~														
19	Idle	275	—	2.8	21.9	101	250	320	67	0.73	95	69	79	19.3	11
20	4	513	421.	439.	169.	92	356	552	132	3.51	454	419	455	15.3	10
21	3	442	282.	294.	112.	101	317	448	132	2.90	374	303	336	16.2	—
22	2	371	201.	208.	72.5	101	270	368	132	2.47	274	213	246	16.7	11
23	1	300	101.	104.	56.4	102	227	272	111	1.71	165	120	145	17.8	—
24	Idle	275	—	2.8	22.1	103	180	176	67	0.82	106	76	99	19.0	12

LOCOMOTIVE S.P. UNIT 1311, EMD 12-567 SWITCH WET BULB TEMP., °F 74

RUN 4 DATE 4/13/72 BAROMETER 28.86 in Hg DRY BULB TEMP., °F 87

Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	Mass Rates, g/hr				Brake Specific, g/bhp hr				Fuel Specific, g/lbm fuel			
				HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
1	Idle	275	15.4	355	115	315	48.5	127.	41.0	112.	17.3	16.8	5.45	14.9	2.30
2	1	300	5.0	614	245	661	—	5.90	2.35	6.35	—	10.7	4.26	11.5	—
3	2	371	2.5	755	270	955	52.6	3.73	1.34	4.28	0.26	10.7	3.81	13.5	0.74
4	3	442	2.0	1203	375	1767	—	4.09	1.27	6.10	—	10.5	3.26	15.4	—
5	4	513	1.0	1680	456	2808	88.8	3.83	1.04	6.39	0.20	9.77	2.65	16.3	0.52
6	Idle	275	15.4	390	178	346	55.3	139.	63.6	124.	19.7	17.8	8.13	15.8	2.53
7	5	584	0.5	1854	536	4208	—	3.16	0.91	7.17	—	8.35	2.41	19.0	—
8	6	655	0.5	2444	610	5970	54.5	3.35	0.84	8.19	0.075	8.43	2.10	20.6	0.19
9	7	726	0.0	3046	803	7457	—	3.43	0.90	8.40	—	8.93	2.35	21.9	—
10	8	800	0.0	4324	1521	9520	121.	4.04	1.42	8.90	0.11	10.1	3.55	22.2	0.28
11	Idle	275	15.4	542	128	292	47.6	194.	45.7	104.	17.0	24.6	5.82	13.3	2.16
~~12~~	~~Dyn. Brake~~														
~~13~~	~~Idle~~														
14	8	800	0.0	3871	1702	10,023	128.	3.62	1.59	9.37	0.12	8.84	3.89	22.9	0.29
15	7	726	0.0	2873	1002	8068	—	3.13	1.09	8.78	—	8.19	2.85	23.0	—
16	6	655	0.5	2214	758	6465	62.9	2.99	1.02	8.72	0.084	7.69	2.63	22.4	0.22
17	5	584	0.5	1791	672	4653	—	3.03	1.14	7.88	—	7.96	2.99	20.7	—
~~18~~	~~Dyn. Brake~~														
19	Idle	275	15.4	413	176	341	31.0	148.	62.8	122.	11.1	18.9	8.04	15.6	1.42
20	4	513	1.0	1183	576	3265	46.7	2.69	1.31	7.44	0.11	7.00	3.41	19.3	0.28
21	3	442	2.0	770	461	2411	—	2.62	1.57	8.20	—	6.88	4.12	21.5	—
22	2	371	2.5	481	351	1076	31.3	2.31	1.69	5.17	0.15	6.63	4.84	14.8	0.43
23	1	300	5.0	398	330	710	—	3.83	3.17	6.83	—	7.06	5.85	12.6	—
24	Idle	275	15.4	210	163	396	31.2	75.0	58.2	141.	11.2	9.50	7.38	17.9	1.41

LOCOMOTIVE S.P. UNIT 1311, EMD 12-567 SWITCH

RUN 4 DATE 4/13/72

DUTY CYCLE SANTA FE SWITCH

Basis	Cycle Composite Emissions			
	HC	CO	NO_x	*RCHO
Mass, g/hr	485	201	630	44.4
Brake Specific, g/bhp hr	8.58	3.56	11.1	0.79
Fuel Specific, g/lbm fuel	12.4	5.14	16.1	1.14

*See note in text regarding RCHO computations

APPENDIX B

Test Data and Computed Mass Emissions,
EMD 16-645E-3 (S. P. Unit 8447)

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp Net	Observed Power, hp Gross	Fuel Rate, lbm/hr	Temperatures, °F Intake	Temperatures, °F Exhaust	FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
1	Idle	307	—	5.6	40.8	77	168	108	158	0.73	83	81	103	19.4	22
2	1	307	89.2	94.8	66.9	75	186	102	67	1.16	203	198	216	19.1	—
3	2	360	495.	504.	204.	77	285	108	54	2.96	491	449	476	16.2	11
4	3	490	1055.	1084.	417.	77	500	140	599	4.57	701	639	642	13.6	12
5	4	546	1460.	1508.	580.	81	629	139	1297	5.50	794	718	731	11.7	13
6	Idle	307	—	8.6	41.2	82	325	98	100	0.73	94	102	116	20.5	9
7	5	627	1772.	1833.	697.	81	616	145	1401	5.70	835	738	764	11.2	—
8	6	728	2165.	2279.	847.	82	706	177	1249	6.19	919	810	823	10.8	13
9	7	812	2610.	2769.	993.	83	679	216	663	5.77	968	872	884	11.6	—
10	8	900	3070.	3323.	1179.	82	681	210	463	6.06	951	882	904	11.5	14
11	Idle	307	—	10.0	41.9	82	325	94	90	0.73	119	111	127	19.4	14
12	Dyn. Brake	546	—	40.0	114.	83	244	72	67	1.11	141	130	151	18.9	13
13	Idle	307	—	7.1	41.1	83	207	88	112	0.73	119	101	117	19.4	12
14	8	900	3045.	3224.	1168.	82	640	208	578	6.20	847	869	882	11.0	10
15	7	812	2550.	2736.	983.	84	684	192	662	6.06	863	860	882	11.1	—
16	6	728	2122.	2256.	865.	83	715	167	1288	6.34	831	809	813	10.6	8
17	5	627	1710.	1796.	697.	82	692	148	1492	6.05	776	758	762	11.1	—
18	Dyn. Brake	546	—	56.0	118.	85	329	78	67	1.11	130	129	143	18.8	13
19	Idle	307	—	7.1	42.0	84	215	102	112	0.73	119	99	117	19.3	13
20	4	546	1458.	1498.	580.	85	570	123	1469	5.77	791	729	742	11.6	5
21	3	490	1091.	1126.	431.	87	602	122	1572	5.36	752	696	709	12.1	—
22	2	360	515.	529.	212.	87	448	107	54	3.25	517	493	493	15.7	7
23	1	307	96.5	105.	67.0	86	282	90	45	1.27	240	226	235	18.5	—
24	Idle	307	—	8.6	41.2	88	237	97	134	0.73	119	97	114	19.2	7

LOCOMOTIVE S.P. UNIT 8447, EMD SD-40 (16-645E-3) WET BULB TEMP., °F 67

RUN 1 DATE 4/18/72 BAROMETER 29.10 in Hg DRY BULB TEMP., °F 74

Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	Mass Rates, g/hr				Brake Specific, g/bhp hr				Fuel Specific, g/lbm fuel			
				HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
1	Idle	307	6.833	263	785	840	117.	46.9	140.	150.	20.9	6.45	19.2	20.6	2.87
2	1	307	1.5	262	351	1861	—	2.76	3.70	19.6	—	3.92	5.25	27.8	—
3	2	360	1.5	336	342	6680	74.6	0.67	0.68	13.2	0.15	1.65	1.68	32.7	0.37
4	3	490	1.5	571	4979	8770	107.	0.53	4.59	8.09	0.099	1.37	11.9	21.0	0.26
5	4	546	1.5	649	12,338	11,426	133.	0.43	8.18	7.58	0.088	1.12	21.3	19.7	0.23
6	Idle	307	6.833	244	508	969	49.0	28.4	59.1	113.	5.70	5.92	12.3	23.5	1.19
7	5	627	1.5	784	15,440	13,836	—	0.43	8.42	7.55	—	1.12	22.2	19.9	—
8	6	728	1.5	1075	15,459	16,739	172.	0.47	6.78	7.34	0.076	1.27	18.3	19.8	0.20
9	7	812	1.5	1662	7022	22,769	—	0.60	2.53	8.22	—	1.67	7.07	22.9	—
10	8	900	15.0	1834	8237	26,428	267.	0.55	2.48	7.95	0.080	1.56	6.99	22.4	0.23
11	Idle	307	6.833	238	465	1078	77.5	23.8	46.5	108.	7.75	5.68	11.1	25.7	1.85
12	Dyn. Brake	546	4.0	330	625	1511	130.	8.25	15.6	37.8	3.25	2.89	5.48	13.2	1.14
13	Idle	307	6.833	219	568	975	65.2	30.8	80.0	137.	9.18	5.33	13.8	23.7	1.59
14	8	900	15.0	1757	9946	24,940	185.	0.49	2.77	6.93	0.051	1.35	7.64	19.2	0.14
15	7	812	1.5	1395	9804	21,463	—	50.5	3.55	7.84	—	1.42	9.97	21.8	—
16	6	728	1.5	1012	15,904	16,496	106.	0.45	7.05	7.31	0.047	1.17	18.4	19.1	0.12
17	5	627	1.5	754	15,490	13,000	—	0.42	8.62	7.24	—	1.08	22.2	18.7	—
18	Dyn. Brake	546	4.0	373	653	2290	136.	6.66	11.7	40.9	2.42	3.16	5.53	19.4	1.15
19	Idle	307	6.833	259	580	996	72.2	36.5	81.7	140.	10.2	6.17	13.8	23.7	1.72
20	4	546	1.5	546	13,290	11,031	48.5	0.36	8.87	7.36	0.032	0.94	22.9	19.0	0.084
21	3	490	1.5	432	11,333	8399	—	0.38	10.1	7.46	—	1.00	26.3	19.5	—
22	2	360	1.5	315	324	4858	45.0	5.95	0.61	9.18	0.085	1.49	1.53	22.9	0.21
23	1	307	1.5	214	218	1870	—	2.04	2.08	17.8	—	3.19	3.25	27.9	—
24	Idle	307	6.833	242	681	952	38.1	28.1	79.2	111.	4.43	5.88	16.5	23.1	0.92

LOCOMOTIVE S.P. UNIT 8447, EMD SD-40 (16-645E-3)

RUN 1 DATE 4/18/72

DUTY CYCLE EMD LINE-HAUL

Basis	Cycle Composite Emissions			
	HC	CO	NO_x	*RCHO
Mass, g/hr	817	4858	10,643	128
Brake Specific, g/bhp hr	0.635	3.78	8.25	0.107
Fuel Specific, g/lbm fuel	1.66	9.90	21.6	0.264

*see note in text regarding RCHO computations

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp Net	Observed Power, hp Gross	Fuel Rate, lbm/hr	Temperatures, °F Intake	Temperatures, °F Exhaust	FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
1	Idle	307	—	8.6	40.7	89	264	93	56	0.73	119	101	119	19.9	22
2	1	307	92.3	99.4	67.5	89	238	78	45	1.32	265	231	240	19.0	—
3	2	360	475.	486.	203.	90	353	97	44	3.19	545	458	481	16.3	13
4	3	490	1115.	1144.	443.	89	573	126	1346	5.57	823	718	723	12.4	—
5	4	546	1433.	1473.	577.	89	666	140	1428	6.06	864	746	760	11.6	18
6	Idle	307	—	8.6	41.0	87	347	107	78	0.73	131	109	122	19.7	15
7	5	627	1755.	1816.	690.	88	664	150	1492	6.20	906	789	802	11.3	—
8	6	728	2150.	2264.	865.	87	735	170	1366	6.63	962	839	839	10.7	18
9	7	812	2550.	2736.	974.	88	725	204	674	6.21	951	882	893	11.3	—
10	8	900	2960.	3213.	1168.	89	721	256	509	6.28	907	926	926	11.5	12
11	Idle	307	—	10.0	41.3	91	312	102	67	0.78	130	124	135	19.6	17
12	Dyn. Brake	546	—	40.0	114.	90	215	85	78	1.22	142	143	160	19.3	16
13	Idle	307	—	7.1	41.5	90	201	100	124	0.83	106	94	122	19.9	18
14	8	900	2960.	3139.	1158.	92	703	244	623	6.63	917	889	909	11.1	14
15	7	812	2540.	2726.	993.	92	725	200	733	6.35	950	891	903	11.2	—
16	6	728	2110.	2244.	838.	92	754	166	1378	6.71	902	829	829	10.7	8
17	5	627	1742.	1826.	697.	90	681	144	1588	6.34	861	783	788	10.6	—
18	Dyn. Brake	546	—	56.0	118.	90	322	78	67	1.16	154	148	154	18.3	13
19	Idle	307	—	7.1	41.3	87	211	94	112	0.73	106	106	118	19.6	12
20	4	546	1460.	1500.	577.	88	579	130	1442	5.92	806	747	747	11.8	8
21	3	490	1103.	1138.	435.	87	624	124	1640	5.63	780	718	722	12.2	—
22	2	360	524.	538.	204.	88	458	104	54	3.36	558	471	494	15.8	8
23	1	307	108.	116.	67.8	88	302	88	55	1.16	252	235	245	18.8	—
24	Idle	307	—	8.6	40.4	87	207	98	134	0.73	119	112	113	19.5	12

LOCOMOTIVE S.P. UNIT 8447, EMD SD-40 (16-645E-3) WET BULB TEMP., °F 65

RUN 2 DATE 4/18/72 BAROMETER 29.01 in Hg DRY BULB TEMP., °F 77

Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	Mass Rates, g/hr				Brake Specific, g/bhp hr				Fuel Specific, g/lbm fuel			
				HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
1	Idle	307	6.833	231	283	989	119.	26.8	32.9	115.	13.8	5.68	6.95	24.3	2.92
2	1	307	1.5	180	211	1851	—	1.81	2.12	18.6	—	2.67	3.13	27.4	—
3	2	360	1.5	279	258	4638	81.8	0.57	0.53	9.54	0.17	1.37	1.27	22.8	0.40
4	3	490	1.5	444	9659	8526	—	0.39	8.44	7.45	—	1.00	21.8	19.2	—
5	4	546	1.5	591	12,273	10,734	166.	0.40	8.33	7.29	0.11	1.02	21.3	18.6	0.29
6	Idle	307	6.833	266	395	1016	81.5	30.9	45.9	118.	9.47	6.49	9.63	24.8	1.99
7	5	627	1.5	739	14,973	13,225	—	0.41	8.24	7.28	—	1.07	21.7	19.2	—
8	6	728	1.5	985	16,121	16,270	228.	0.44	7.12	7.19	0.10	1.14	18.6	18.8	0.26
9	7	812	1.5	1434	9654	21,019	—	0.52	3.52	7.68	—	1.47	9.91	21.6	—
10	8	900	15.0	2138	8660	25,890	219.	0.66	2.69	8.06	0.068	1.83	7.41	22.2	0.19
11	Idle	307	6.833	240	322	1064	87.4	24.0	32.2	106.	8.74	5.81	7.80	25.8	2.12
12	Dyn. Brake	546	4.0	358	669	2254	147.	8.95	16.7	56.4	3.67	3.14	5.87	19.8	1.29
13	Idle	307	6.833	221	559	903	87.0	31.1	78.7	127.	12.2	5.33	13.5	21.8	2.10
14	8	900	15.0	1912	9945	23,845	240.	0.61	3.16	7.60	0.076	1.65	8.59	20.6	0.21
15	7	812	1.5	1400	10,454	21,164	—	0.51	3.83	7.76	—	1.41	10.5	21.3	—
16	6	728	1.5	921	15,571	15,393	96.9	0.41	6.93	6.86	0.043	1.10	18.6	18.4	0.12
17	5	627	1.5	700	15,727	12,824	—	0.38	8.61	7.02	—	1.00	22.6	18.4	—
18	Dyn. Brake	546	4.0	357	625	2361	130.	6.37	11.2	42.2	2.32	3.03	5.30	20.0	1.10
19	Idle	307	6.833	235	570	986	65.5	33.1	80.2	139.	9.23	5.69	13.8	23.9	1.59
20	4	546	1.5	561	12,679	10,793	75.4	0.37	8.45	7.20	0.050	0.97	22.0	18.7	0.13
21	3	490	1.5	421	11,358	8217	—	0.37	9.98	7.22	—	0.97	26.1	18.9	—
22	2	360	1.5	285	301	4532	47.9	0.53	0.56	8.42	0.089	1.40	1.48	22.2	0.23
23	1	307	1.5	232	295	2158	—	2.20	2.54	18.6	—	3.42	4.35	31.8	—
24	Idle	307	6.833	239	665	922	63.9	27.7	77.3	107.	7.44	5.92	16.5	22.8	1.58

LOCOMOTIVE S.P. UNIT 8447, EMD SD-40 (16-645E-3)

RUN 2 DATE 4/18/72

DUTY CYCLE EMD LINE-HAUL

Basis	Cycle Composite Emissions			
	HC	CO	NO_x	*RCHO
Mass, g/hr	872	4976	10,317	140
Brake Specific, g/bhp hr	0.691	3.94	8.18	0.111
Fuel Specific, g/lbm fuel	1.78	10.2	21.1	0.286

*see note in text regarding RCHO computations

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp		Fuel Rate, lbm/hr	Temperatures, °F		FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
			Net	Gross		Intake	Exhaust								
1	Idle	307	—	5.6	42.8	78	160	170	100	0.79	105	79	89	19.5	16
2	1	307	87.4	93.0	69.0	78	178	106	76	1.26	239	200	214	18.8	—
3	2	360	476.	485.	198.	78	315	124	88	3.12	491	416	431	15.9	13
4	3	490	973.	996.	433.	79	467	150	286	4.45	716	626	631	13.6	—
5	4	546	1410.	1458.	552.	81	609	138	774	5.43	809	718	723	12.3	11
6	Idle	307	—	8.6	41.3	79	305	80	90	0.73	142	102	113	19.5	15
7	5	627	1770.	1831.	696.	82	622	173	1492	5.90	804	741	744	11.3	—
8	6	728	2185.	2299.	856.	82	729	204	1224	6.12	905	819	829	10.7	16
9	7	812	2620.	2779.	993.	81	705	240	663	5.77	968	857	867	11.3	—
10	8	900	3020	3273.	1179.	83	703	270	498	5.84	998	884	884	11.2	14
11	Idle	307	—	10.0	41.5	85	374	114	78	0.73	167	122	126	19.0	13
12	Dyn. Brake	546	—	40.0	113.	83	237	90	78	1.11	178	134	146	18.6	13
13	Idle	307	—	7.1	40.7	84	426	95	112	0.78	166	102	115	19.1	14
14	8	900	3000.	3179.	1158.	84	678	234	626	6.13	950	859	859	10.8	12
15	7	812	2550	2736.	1002.	84	711	191	711	5.91	997	839	839	11.0	—
16	6	728	2146.	2280.	856.	84	735	181	1313	6.33	918	783	787	10.7	14
17	5	627	1722.	1808.	703.	88	726	146	1548	6.05	862	741	741	10.8	—
18	Dyn. Brake	546	—	56.0	112	86	334	86	67	1.07	191	134	142	18.4	13
19	Idle	307	—	7.1	40.4	88	238	94	100	0.73	178	109	116	18.9	13
20	4	546	1420.	1460.	557.	88	594	148	1522	5.91	863	710	724	11.1	12
21	3	490	1090.	1125.	433.	88	620	131	1815	5.36	781	674	688	11.7	—
22	2	360	513.	527.	206.	89	534	116	66	3.24	571	480	485	13.3	18
23	1	307	99.7	105.	67.3	90	327	92	55	1.31	289	226	230	18.0	—
24	Idle	307	—	8.6	41.6	90	211	106	134	0.73	142	102	113	18.9	18

LOCOMOTIVE S.P. UNIT 8447, EMD SD-40 (16-645E-3) WET BULB TEMP., °F 74

RUN 3 DATE 4/19/72 BAROMETER 29.09 in Hg DRY BULB TEMP., °F 87

Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	Mass Rates, g/hr HC	CO	NO_x	RCHO	Brake Specific, g/bhp hr HC	CO	NO_x	RCHO	Fuel Specific, g/lbm fuel HC	CO	NO_x	RCHO
1	Idle	307	6.833	404	485	709	83.1	72.4	86.6	127.	14.8	9.44	11.3	16.6	1.94
2	1	307	1.5	261	382	1767	—	2.81	4.10	19.0	—	3.78	5.54	25.6	—
3	2	360	1.5	355	513	3958	81.3	0.73	1.06	8.16	0.17	1.79	2.59	20.0	0.41
4	3	490	1.5	657	2551	9249	—	0.66	2.56	9.28	—	1.52	5.89	21.4	—
5	4	546	1.5	627	7159	10,990	109.	0.43	4.91	7.53	0.075	1.14	13.0	19.9	0.20
6	Idle	307	6.833	201	460	950	82.3	23.4	53.5	110.	9.57	4.87	11.1	23.0	1.99
7	5	627	1.5	902	15,850	12,988	—	0.49	8.66	7.09	—	1.30	22.8	18.7	—
8	6	728	1.5	1266	15,482	17,230	217.	0.55	6.73	7.49	0.94	1.48	18.1	20.1	0.25
9	7	812	1.5	1846	10,392	22,331	—	0.66	3.74	8.03	—	1.86	10.5	22.5	—
10	8	900	15.0	2441	9174	26,760	277.	0.74	2.80	8.17	0.085	2.07	7.78	22.7	0.23
11	Idle	307	6.833	287	400	1061	71.5	28.7	40.0	106.	7.15	6.92	9.64	25.6	1.72
12	Dyn. Brake	546	4.0	409	721	2219	129.	10.2	18.0	55.4	3.22	3.62	6.38	19.6	1.14
13	Idle	307	6.833	220	528	892	70.8	30.9	74.4	126.	9.98	5.41	13.0	21.9	1.74
14	8	900	15.0	1978	10,780	24,308	222.	0.62	3.39	7.64	0.70	1.71	9.31	21.0	0.19
15	7	812	1.5	1448	10,983	21,297	—	0.53	4.01	7.78	—	1.45	11.0	21.3	—
16	6	728	1.5	1085	16,044	15,802	183.	0.48	7.03	6.93	0.80	1.27	18.7	18.5	0.21
17	5	627	1.5	750	16,210	12,750	—	0.41	8.96	7.05	—	1.07	23.1	18.1	—
18	Dyn. Brake	546	4.0	405	643	2238	134.	7.23	11.5	39.9	2.39	3.62	5.74	20.0	1.20
19	Idle	307	6.833	230	499	951	69.6	32.4	70.3	134.	9.80	5.69	12.4	23.5	1.72
20	4	546	1.5	617	12,918	10,098	109.	0.42	8.85	6.92	0.075	1.11	23.2	18.1	0.20
21	3	490	1.5	464	13,098	8159	—	0.41	11.6	7.25	—	1.07	30.2	18.8	—
22	2	360	1.5	333	386	4658	113.	0.63	0.73	8.83	0.21	1.62	1.87	22.6	0.55
23	1	307	1.5	213	259	1782	—	2.02	2.46	16.9	—	3.16	3.85	26.5	—
24	Idle	307	6.833	266	684	948	98.5	30.9	79.5	110.	11.5	6.39	16.4	22.8	2.37

LOCOMOTIVE S.P. UNIT 8447, EMD SD-40 (16-645E-3)

RUN 3 DATE 4/19/72

DUTY CYCLE EMD LINE-HAUL

Basis	Cycle Composite Emissions HC	CO	NO_x	*RCHO
Mass, g/hr	968	5090	10,511	148
Brake Specific, g/bhp hr	0.759	3.99	8.25	0.116
Fuel Specific, g/lbm fuel	1.97	10.4	21.4	0.302

*see note in text regarding RCHO computations

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp Net	Observed Power, hp Gross	Fuel Rate, lbm/hr	Temperatures, °F Intake	Temperatures, °F Exhaust	FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
1	Idle	307	—	8.6	41.4	93	244	116	45	0.73	142	113	124	19.0	17
2	1	307	96.5	104.	66.2	90	239	92	67	1.32	289	230	239	18.4	—
3	2	360	476.	487.	204.	91	312	113	76	3.24	571	480	493	15.7	9
4	3	490	1116.	1145.	440.	88	548	143	1459	5.50	822	713	718	12.1	—
5	4	546	1460.	1500.	557.	89	623	165	1562	6.05	862	741	749	11.3	8
6	Idle	307	—	8.6	41.8	90	392	125	95	0.70	159	110	120	18.1	9
7	5	627	1727.	1788.	689.	91	610	153	1548	6.13	876	771	776	11.1	—
8	6	728	2144.	2258.	846.	89	705	193	1380	6.48	947	826	830	10.4	9
9	7	812	2519.	2705.	993.	89	722	212	733	6.12	980	880	882	10.8	—
10	8	900	2935.	3188.	1169.	88	707	246	567	6.05	1042	917	926	10.8	9
11	Idle	307	—	10.0	41.9	89	377	104	90	0.78	178	129	135	18.9	12
12	Dyn. Brake	546	—	40.0	107.	91	260	84	100	1.11	203	146	157	18.4	12
13	Idle	307	—	7.1	41.1	90	205	90	134	0.72	155	112	123	19.0	13
14	8	900	2935.	3114.	1158.	90	708	234	672	6.33	948	901	901	10.4	12
15	7	812	2480.	2666.	993.	90	713	196	831	6.20	935	882	892	10.8	—
16	6	728	2109.	2243.	846.	90	745	188	1484	6.62	915	815	824	10.1	8
17	5	627	1709.	1795.	689.	91	726	151	1630	6.19	861	766	775	10.6	—
18	Dyn. Brake	546	—	56.0	113.	91	355	92	112	1.11	177	142	152	18.3	12
19	Idle	307	—	7.1	41.5	92	244	98	112	0.73	166	116	123	18.9	12
20	4	546	1443.	1483	571.	89	557	143	1635	5.84	819	733	751	11.1	14
21	3	490	1091.	1126.	435.	91	619	129	1755	5.49	808	708	718	11.2	—
22	2	360	524.	538.	212.	89	416	121	88	3.30	558	503	503	15.2	17
23	1	307	104.	113.	68.1	92	343	97	67	1.31	289	234	239	18.0	—
24	Idle	307	—	8.6	41.2	89	230	102	134	0.73	155	111	121	18.9	18

LOCOMOTIVE S.P. UNIT 8447, EMD SD-40 (16-645E-3) WET BULB TEMP., °F 75

RUN 4 DATE 4/19/72 BAROMETER 29.02 in Hg DRY BULB TEMP., °F 95

Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	Mass Rates, g/hr				Brake Specific, g/bhp hr				Fuel Specific, g/lbm fuel			
				HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
1	Idle	307	6.833	293	231	1047	93.7	34.1	26.8	122.	10.9	7.08	5.58	25.3	2.26
2	1	307	1.5	208	308	1808	—	2.00	2.96	17.3	—	3.14	4.65	27.3	—
3	2	360	1.5	321	440	4689	55.9	0.66	0.90	9.62	0.11	1.57	2.16	23.0	0.27
4	3	490	1.5	505	10,491	8484	—	0.44	9.16	7.40	—	1.15	23.8	19.3	—
5	4	546	1.5	671	12,938	10,195	71.1	0.45	8.62	6.79	0.047	1.20	23.2	18.3	0.13
6	Idle	307	6.833	331	512	1063	52.0	38.5	59.5	124.	6.05	7.92	12.2	25.4	1.24
7	5	627	1.5	760	15,660	12,900	—	0.42	8.75	7.21	—	1.10	22.7	18.7	—
8	6	728	1.5	1118	16,288	16,098	114.	0.50	7.21	7.12	0.050	1.32	19.3	19.0	0.13
9	7	812	1.5	1539	10,842	21,437	—	0.57	4.01	7.92	—	1.55	10.9	21.6	—
10	8	900	15.0	2130	10,002	26,842	170.	0.67	3.13	9.41	0.053	1.82	8.56	23.0	0.15
11	Idle	307	6.833	247	436	1075	62.3	24.7	43.6	108.	6.23	5.89	10.4	25.7	1.49
12	Dyn. Brake	546	4.0	364	884	2280	114.	9.10	22.1	57.0	2.85	3.40	8.26	21.3	1.07
13	Idle	307	6.833	226	687	1036	71.4	31.8	96.7	146.	10.1	5.50	16.7	25.2	1.74
14	8	900	15.0	1916	11,212	24,703	215.	0.62	3.60	7.93	0.069	1.65	9.68	21.3	0.19
15	7	812	1.5	1403	12,116	21,371	—	0.53	4.54	8.01	—	1.41	12.2	21.5	—
16	6	728	1.5	1065	17,128	15,628	99.0	0.47	7.64	6.96	0.044	1.26	20.2	18.5	0.12
17	5	627	1.5	743	16,334	12,762	—	0.41	9.10	7.10	—	1.08	23.7	18.5	—
18	Dyn. Brake	546	4.0	418	1036	2310	119.	7.46	18.5	41.2	2.12	3.70	9.17	20.4	1.05
19	Idle	307	6.833	246	573	1035	65.9	34.6	80.7	146.	9.28	5.93	13.8	24.9	1.59
20	4	546	1.5	617	14,369	10,845	132.	0.42	9.69	7.31	0.089	1.08	25.2	19.0	0.23
21	3	490	1.5	449	12,433	8358	—	0.40	11.0	7.42	—	1.03	28.6	19.2	—
22	2	360	1.5	351	520	4882	108.	0.65	0.97	9.07	0.20	1.66	2.45	23.0	0.51
23	1	307	1.5	227	320	1874	—	2.00	2.83	16.5	—	3.33	4.70	27.5	—
24	Idle	307	6.833	253	678	1006	97.7	29.4	78.8	117.	11.4	6.14	16.5	24.4	2.37

LOCOMOTIVE S.P. UNIT 8447, EMD SD-40 (16-645E-3)

RUN 4 DATE 4/19/72

DUTY CYCLE EMD LINE-HAUL

Basis	Cycle Composite Emissions			
	HC	CO	NO_x	*RCHO
Mass, g/hr	897	5575	10,613	118
Brake Specific, g/bhp hr	0.717	4.45	8.48	0.094
Fuel Specific, g/lbm fuel	1.83	11.4	21.7	0.241

*see note in text regarding RCHO computations

APPENDIX C

Test Data and Computed Mass Emissions,
G. E. 7FDL16 (S. P. Unit 8639)

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp Net	Gross	Fuel Rate, lbm/hr	Temperatures, °F Intake	Exhaust	FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
1	Idle	425	—	17.9	36.7	81	325	476	355	1.60	266	269	325	18.9	42
2	1	418	156	173.	84.9	81	393	574	321	4.08	1092	1033	1100	13.7	—
3	2	520	560	593.	224.	82	695	1260	2471	7.36	2197	2129	2172	9.6	26
4	3	601	805	856.	336.	82	793	910	2770	6.60	1968	1793	1836	10.6	—
5	4	689	1090	1166.	443.	82	843	644	2540	6.47	1633	1643	1689	10.8	20
6	Idle	425	—	17.9	35.5	84	470	532	556	1.51	264	276	322	18.6	23
7	5	783	1391	1503.	540.	80	819	658	2004	6.11	1343	1341	1362	11.4	—
8	6	878	1925	2083.	706.	84	845	672	1306	5.76	1265	1249	1280	12.0	24
9	7	996	2525	2755.	928.	84	792	755	654	5.36	1174	1153	1176	12.7	—
10	8	1077	3240	3531.	1172.	86	767	685	513	5.29	1049	1043	1079	12.8	24
11	Idle	425	—	17.9	34.6	86	489	532	341	1.47	277	295	341	18.5	29
12	Dyn. Brake	1077	—	291.	192.	87	490	902	405	3.19	585	561	616	16.0	26
13	Idle	425	—	17.9	33.8	88	347	518	345	1.54	255	280	331	18.7	30
14	8	1077	3240	3531.	1134.	88	760	700	553	5.27	1090	1031	1042	12.9	30
15	7	996	2525	2755.	943.	86	789	749	679	5.22	1176	1167	1189	12.7	—
16	6	878	1925	2083.	730.	91	845	727	1216	5.63	1284	1230	1249	12.3	29
17	5	783	1391	1503.	558.	90	870	644	1832	5.90	1379	1322	1353	10.6	—
18	Dyn. Brake	1077	—	291.	190.	92	552	888	417	3.12	599	576	616	16.0	27
19	Idle	425	—	17.9	34.0	89	361	552	376	1.52	264	276	331	18.0	40
20	4	689	1090	1166.	439.	91	822	720	2585	6.32	1671	1601	1643	10.6	35
21	3	601	805	856.	338.	88	824	979	2875	6.47	1894	1818	1907	10.2	—
22	2	520	560	593.	239.	88	778	1248	2388	6.83	2167	2184	2272	9.6	29
23	1	418	156	173.	84.5	87	567	678	786	3.83	1142	1102	1134	14.5	—
24	Idle	425	—	17.9	34.3	86	374	588	641	1.52	264	294	336	18.0	40

LOCOMOTIVE S.P. UNIT 8639, G.E. U-33C   WET BULB TEMP., °F 69

RUN 1   DATE 4/25/72   BAROMETER 29.20 in Hg   DRY BULB TEMP., °F 84

Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	Mass Rates, g/hr				Brake Specific, g/bhp hr				Fuel Specific, g/lbm fuel			
				HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
1	Idle	425	7.167	472	712	1072	90.3	26.4	39.8	59.8	5.04	12.9	19.4	29.2	2.46
2	1	418	1.5	533	601	3390	—	3.08	3.47	19.6	—	6.28	7.08	39.9	—
3	2	520	1.5	1658	6573	9504	74.1	2.80	11.1	16.0	0.12	7.40	29.3	42.4	0.33
4	3	601	1.5	2044	12,258	8034	—	2.39	14.3	9.38	—	6.08	36.5	23.9	—
5	4	689	1.5	1908	15,213	16,640	128.	1.64	13.0	14.3	0.11	4.31	34.3	37.6	0.29
6	Idle	425	7.167	529	1118	1065	46.3	29.6	62.5	59.5	2.58	14.9	31.5	30.0	1.30
7	5	783	1.5	2528	15,571	17,407	—	1.68	10.4	11.5	—	4.68	28.8	32.2	—
8	6	878	1.5	3614	14,202	22,895	280.	1.73	6.82	10.9	0.13	5.12	20.1	32.4	0.40
9	7	996	1.5	5783	10,130	29,962	—	2.10	3.68	10.8	—	6.23	10.9	32.3	—
10	8	1077	14.0	6737	10,202	35,296	512.	1.91	2.89	9.99	0.14	5.75	8.70	30.1	0.44
11	Idle	425	7.167	539	699	1149	63.7	30.1	39.0	64.1	3.56	15.6	20.2	33.2	1.84
12	Dyn. Brake	1077	4.0	2368	2150	5379	148.	8.14	7.39	18.4	0.51	12.3	11.2	28.0	0.77
13	Idle	425	7.167	488	657	1036	61.2	27.3	36.7	57.8	3.42	14.4	19.4	30.7	1.81
14	8	1077	14.0	6886	10,680	33,103	621.	1.95	3.02	9.37	0.18	6.07	9.42	29.2	0.55
15	7	996	1.5	5983	10,966	31,587	—	2.17	3.98	11.4	—	6.34	11.6	33.5	—
16	6	878	1.5	4140	14,001	23,653	358.	1.99	6.72	11.3	0.17	5.67	19.2	32.4	0.49
17	5	783	1.5	2657	15,284	18,567	—	1.77	10.2	12.3	—	4.76	27.4	33.3	—
18	Dyn. Brake	1077	4.0	2357	2238	5438	155.	8.09	7.69	18.6	0.53	12.4	11.8	28.6	0.82
19	Idle	425	7.167	529	729	1055	83.1	29.6	40.7	58.9	4.64	15.6	21.4	31.0	2.44
20	4	689	1.5	2158	15,666	16,378	227.	1.85	13.4	14.0	0.24	4.92	35.7	37.3	0.52
21	3	601	1.5	2193	13,023	14,209	—	2.56	15.2	16.5	—	6.49	38.5	42.0	—
22	2	520	1.5	1879	7287	11,404	94.8	3.17	12.3	19.2	0.16	7.86	30.5	47.7	0.40
23	1	418	1.5	655	1536	3645	—	3.79	8.88	21.0	—	7.75	18.2	43.1	—
24	Idle	425	7.167	558	1231	1061	82.3	31.2	68.8	59.2	4.59	16.3	35.9	30.9	2.40

LOCOMOTIVE S.P. UNIT 8639, G.E. U-33 C

RUN 1 DATE 4/25/72

DUTY CYCLE G.E. LINE-HAUL

Basis	Cycle Composite Emissions			
	HC	CO	NO_x	*RCHO
Mass, g/hr	2885	5752	13,879	246
Brake Specific, g/bhp hr	2.23	4.45	10.7	0.190
Fuel Specific, g/lbm fuel	6.38	12.7	30.7	0.544

* see note in text regarding RCHO computations

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp		Fuel Rate, lbm/hr	Temperatures, °F		FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
			Net	Gross		Intake	Exhaust								
1	Idle	425	—	17.9	35.0	88	395	581	318	1.57	328	272	327	18.9	28
2	1	418	156	173.	79.5	88	367	685	277	4.15	1127	1001	1103	14.8	—
3	2	520	536	569.	234.	92	699	1231	2072	7.62	2077	2087	2174	8.9	16
4	3	601	805	856.	334.	92	800	950	2718	7.07	1927	1766	1854	9.4	—
5	4	689	1090	1166.	446.	93	862	692	2460	6.77	1724	1566	1622	10.2	21
6	Idle	425	—	17.9	34.6	90	470	588	582	1.57	367	272	314	18.9	28
7	5	783	1392	1504.	523.	88	837	622	1786	6.41	1445	1309	1364	11.0	—
8	6	878	1922	2080.	692.	89	859	692	1176	6.07	1367	1202	1238	11.5	31
9	7	996	2530	2760.	900.	92	807	749	595	5.65	1272	1145	1177	12.1	—
10	8	1077	3240	3531.	1180.	91	775	672	467	5.51	1176	1031	1075	12.6	33
11	Idle	425	—	17.9	34.6	90	444	580	307	1.52	381	282	323	18.8	40
12	Dyn. Brake	1077	—	291.	194.	90	482	984	359	3.26	684	550	596	16.0	40
13	Idle	425	—	17.9	34.6	90	406	602	295	1.52	381	272	323	18.6	44
14	8	1077	3240	3531.	1130.	94	753	692	501	5.57	1159	1011	1054	13.1	35
15	7	996	2530	2760.	933.	92	798	763	606	5.65	1288	1154	1188	12.6	—
16	6	878	1922	2080.	733.	90	844	770	1086	5.93	1369	1205	1248	12.5	37
17	5	783	1392	1504.	546.	93	871	672	1597	6.30	1471	1316	1362	10.6	—
18	Dyn. Brake	1077	—	291.	192.	90	530	938	335	3.24	695	560	614	16.9	39
19	Idle	425	—	17.9	35.8	88	348	510	307	1.52	381	272	318	19.8	42
20	4	689	1012	1088.	454.	90	846	700	2240	6.77	1705	1520	1587	10.5	37
21	3	601	778	829.	345.	90	824	950	2300	6.85	1892	1729	1816	10.3	—
22	2	520	536	569.	242.	91	781	1244	2182	7.39	2204	2024	2136	9.8	37
23	1	418	172	188.	85.3	92	588	650	682	4.06	1263	1073	1138	15.2	—
24	Idle	425	—	17.9	35.5	90	454	587	545	1.52	381	282	323	19.5	49

LOCOMOTIVE S.P. UNIT 8639, G.E. U-33 C WET BULB TEMP., °F 68

RUN 2 DATE 4/25/72 BAROMETER 29.10 in Hg DRY BULB TEMP., °F 89

Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	Mass Rates, g/hr				Brake Specific, g/bhp hr				Fuel Specific, g/lbm fuel			
				HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
1	Idle	425	7.167	556	616	1041	58.1	31.1	34.4	58.2	3.24	15.9	17.6	29.7	1.66
2	1	418	1.5	583	477	3123	—	3.37	2.76	18.0	—	7.33	6.00	39.3	—
3	2	520	1.5	1645	5599	9662	46.3	2.89	9.84	16.9	0.81	7.03	23.9	41.3	0.20
4	3	601	1.5	1939	11,216	12,285	—	2.26	13.1	14.3	—	5.81	33.6	36.8	—
5	4	689	1.5	1979	14,226	15,429	130.	1.70	12.2	13.2	0.12	4.44	31.9	34.6	0.29
6	Idle	425	7.167	547	1094	971	56.4	30.6	61.1	54.2	3.15	15.8	31.6	28.1	1.63
7	5	783	1.5	2221	12,894	16,198	—	1.48	8.57	10.8	—	4.25	24.7	31.0	—
8	6	878	1.5	3478	11,953	20,698	338.	1.67	5.75	9.95	0.16	5.03	17.3	29.9	0.49
9	7	996	1.5	5295	8505	27,674	—	1.91	3.08	10.0	—	5.88	9.45	30.7	—
10	8	1077	14.0	6406	9001	34,082	682.	1.81	2.55	9.65	0.19	5.43	7.63	28.9	0.58
11	Idle	425	7.167	566	606	1048	84.6	31.6	33.8	58.5	4.72	16.4	17.5	30.3	2.44
12	Dyn. Brake	1077	4.0	2557	1886	5150	225.	8.79	6.48	17.6	0.77	13.2	9.72	26.5	1.16
13	Idle	425	7.167	587	582	1048	105.	32.8	32.5	58.5	5.86	17.0	16.8	30.3	3.03
14	8	1077	14.0	6239	9134	31,607	685.	1.77	2.59	8.95	0.19	5.52	8.08	28.0	0.61
15	7	996	1.5	5582	8964	28,907	—	2.02	3.25	10.4	—	5.98	9.61	31.0	—
16	6	878	1.5	4194	11,960	22,608	437.	2.01	5.75	10.8	0.21	5.72	16.3	30.8	0.60
17	5	783	1.5	2555	12,277	17,223	—	1.70	8.16	11.4	—	4.68	22.5	31.5	—
18	Dyn. Brake	1077	4.0	2228	1609	4850	201.	7.65	5.52	16.6	0.69	11.6	8.38	25.3	1.05
19	Idle	425	7.167	518	631	1074	92.5	28.9	35.2	60.0	5.17	14.5	17.6	30.0	2.58
20	4	689	1.5	2044	13,223	15,410	234.	1.88	12.2	14.1	0.22	4.50	29.1	33.9	0.52
21	3	601	1.5	2075	10,159	13,194	—	2.50	12.2	15.9	—	6.01	29.4	38.2	—
22	2	520	1.5	1768	6271	10,097	114.	3.11	11.0	17.7	0.20	7.31	25.9	41.7	0.47
23	1	418	1.5	601	1275	3498	—	3.20	6.78	18.6	—	7.05	14.9	41.0	—
24	Idle	425	7.167	580	1090	1062	103.	32.4	60.9	59.3	5.75	16.3	30.7	29.9	2.90

LOCOMOTIVE S.P. UNIT 8639, G.E. U-33 C

RUN 2 DATE 4/25/72

DUTY CYCLE G.E. LINE-HAUL

Basis	Cycle Composite Emissions			
	HC	CO	NO_x	*RCHO
Mass, g/hr	2741	4945	13,284	295
Brake Specific, g/bhp hr	2.12	3.83	10.3	0.228
Fuel Specific, g/lbm fuel	6.06	10.9	29.4	0.653

*see note in text regarding RCHO computations

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp		Fuel Rate, lbm/hr	Temperatures, °F		FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
			Net	Gross		Intake	Exhaust								
1	Idle	425	—	17.9	35.3	72	391	547	411	1.61	314	257	307	18.4	25
2	1	418	156	173.	82.4	72	368	567	343	4.13	1059	986	1086	14.3	—
3	2	520	571	604.	240.	71	638	1300	2232	7.27	2073	2040	2126	8.9	17
4	3	601	823	874.	339.	72	775	1010	2622	6.60	1793	1769	1869	9.8	—
5	4	689	1129	1205.	438.	72	832	790	2300	6.38	1631	1568	1620	10.3	19
6	Idle	425	—	17.9	33.6	72	470	672	566	1.56	314	267	303	18.2	22
7	5	783	1416	1528.	527.	75	805	770	1742	6.04	1360	1275	1327	10.8	—
8	6	878	2000	2158.	704.	74	819	790	1045	5.62	1249	1192	1247	11.6	21
9	7	996	2567	2797.	883.	76	748	776	570	5.29	1205	1131	1176	12.1	—
10	8	1077	3328	3619.	1189.	75	737	678	452	5.49	1076	983	1018	12.5	19
11	Idle	425	—	17.9	36.3	74	464	595	375	1.56	340	267	307	18.2	22
12	Dyn. Brake	1077	—	291.	193.	76	478	930	393	3.24	626	547	601	15.6	20
13	Idle	425	—	17.9	35.3	76	365	615	358	1.49	321	253	310	18.5	24
14	8	1077	3284	3575.	1130.	78	741	727	512	5.21	1064	976	1009	12.3	16
15	7	996	2567	2797.	926.	76	771	791	566	5.33	1213	1111	1146	12.5	—
16	6	878	2000	2158.	742.	76	823	791	984	5.49	1301	1228	1240	11.6	17
17	5	783	1416	1528.	555.	77	857	658	1618	5.83	1379	1322	1365	11.0	—
18	Dyn. Brake	1077	—	291.	194.	78	521	922	431	3.15	632	565	584	15.8	18
19	Idle	425	—	17.9	34.7	76	363	581	387	1.52	340	276	285	18.2	17
20	4	689	1129	1205.	445.	76	792	762	2287	6.31	1614	1544	1588	10.2	24
21	3	601	823	874.	344.	77	812	958	2522	6.38	1797	1751	1805	9.8	—
22	2	520	571	604.	240.	76	772	1225	2209	6.77	2093	2068	2125	9.4	19
23	1	418	156	173.	84.6	76	581	700	760	3.95	1156	1078	1112	14.2	—
24	Idle	425	—	17.9	33.3	77	363	600	580	1.52	353	280	304	18.2	29

LOCOMOTIVE S.P. UNIT 8639, G.E. U-33 C WET BULB TEMP., °F 69

RUN 3 DATE 4/26/72 BAROMETER 29.06 in Hg DRY BULB TEMP., °F 75

Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	Mass Rates, g/hr				Brake Specific, g/bhp hr				Fuel Specific, g/lbm fuel			
				HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
1	Idle	425	7.167	516	783	963	51.1	28.8	43.7	53.7	2.85	14.6	22.2	27.3	1.45
2	1	418	1.5	503	615	3202	—	2.91	3.55	18.5	—	6.10	7.46	38.9	—
3	2	520	1.5	1859	6453	10,111	52.7	3.08	10.7	16.7	0.087	7.75	26.9	42.1	0.22
4	3	601	1.5	2233	11,724	13,746	—	2.55	13.4	15.7	—	6.59	34.6	40.5	—
5	4	689	1.5	2348	13,824	16,015	122.	1.95	11.5	13.2	0.10	5.36	31.6	36.6	0.28
6	Idle	425	7.167	610	1039	915	43.3	34.1	58.0	51.1	2.42	18.2	30.9	27.2	1.29
7	5	783	1.5	2929	13,398	16,788	—	1.92	8.77	10.9	—	5.56	25.4	31.9	—
8	6	878	1.5	4353	11,644	22,855	251.	2.02	5.39	10.5	0.12	6.18	16.5	32.4	0.36
9	7	996	1.5	5740	8525	28,930	—	2.05	3.05	10.3	—	6.50	9.65	32.8	—
10	8	1077	14.0	6535	8810	32,638	397.	1.81	2.43	9.01	0.11	5.50	7.41	27.4	0.33
11	Idle	425	7.167	591	753	1014	47.3	33.0	42.1	56.6	2.64	16.3	20.7	27.9	1.30
12	Dyn. Brake	1077	4.0	2418	2066	5197	113.	8.30	7.10	17.8	0.39	12.5	10.7	26.9	0.59
13	Idle	425	7.167	620	730	1039	52.4	34.6	40.8	58.0	2.93	11.6	13.7	19.5	0.98
14	8	1077	14.0	6997	9964	32,301	334.	1.96	2.79	9.03	0.093	6.19	8.82	28.6	0.30
15	7	996	1.5	6079	8796	29,294	—	2.17	3.14	10.4	—	6.56	9.50	31.6	—
16	6	878	1.5	4700	11,821	24,503	219.	2.18	5.48	11.3	0.10	6.33	15.9	33.0	0.30
17	5	783	1.5	2736	13,603	18,877	—	1.79	8.90	12.3	—	4.93	24.5	34.0	—
18	Dyn. Brake	1077	4.0	2476	2340	5216	105.	8.51	8.04	17.9	0.36	12.8	12.1	26.9	0.54
19	Idle	425	7.167	565	761	922	35.8	31.6	42.5	51.5	2.00	16.3	21.9	26.6	1.03
20	4	689	1.5	2329	14,134	16,143	159.	1.93	11.7	13.3	0.13	5.23	31.8	36.3	0.36
21	3	601	1.5	2223	11,834	13,931	—	2.54	13.5	15.9	—	6.46	34.4	40.5	—
22	2	520	1.5	1877	7337	10,831	63.1	3.11	12.1	17.9	0.10	7.82	30.6	45.1	0.26
23	1	418	1.5	656	1440	3465	—	3.79	8.32	20.0	—	7.75	17.0	41.0	—
24	Idle	425	7.167	553	1081	932	57.9	30.9	60.4	52.0	3.24	16.6	32.5	28.0	1.74

LOCOMOTIVE S.P. UNIT 8639, G.E. U-33 C

RUN 3 DATE 4/26/72

DUTY CYCLE G.E. LINE-HAUL

Basis	Cycle Composite Emissions			
	HC	CO	NO_x	*RCHO
Mass, g/hr	2946	5201	13,353	165
Brake Specific, g/bhp hr	2.23	3.95	10.1	0.125
Fuel Specific, g/lbm fuel	6.50	11.5	29.5	0.364

*see note in text regarding RCHO computations

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp		Fuel Rate, lbm/hr	Temperatures, °F		FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
			Net	Gross		Intake	Exhaust								
1	Idle	425	—	17.9	32.5	78	315	630	363	1.61	314	243	289	18.3	26
2	1	783	186	298.	142.	78	431	860	333	3.71	1425	1304	1358	15.1	—
3	2	783	625	737.	290.	77	629	1050	522	5.58	1401	1282	1335	12.3	19
4	3	783	867	979.	364.	77	721	930	745	5.90	1533	1408	1506	11.6	—
5	4	1077	1130	1421.	502.	78	709	867	340	5.15	1238	1131	1162	12.7	17
6	Idle	425	—	17.9	33.2	76	375	601	363	1.56	340	252	294	13.0	22
7	5	1077	1445	1736.	613.	73	712	895	362	5.21	1238	1162	1197	12.6	—
8	6	1077	2000	2291.	785.	72	730	895	385	5.21	1141	1075	1108	12.6	23
9	7	1077	2580	2871.	964.	73	739	888	384	5.49	1137	1039	1061	12.6	—
10	8	1077	3330	3621.	1189.	74	748	700	430	5.35	1107	983	1007	12.4	22
11	Idle	425	—	17.9	31.8	74	368	615	352	1.56	326	257	294	18.2	25
12	Dyn. Brake	1077	—	291.	192.	76	474	909	346	3.30	625	528	569	15.7	20
13	Idle	425	—	17.9	34.4	75	318	574	328	1.61	326	252	293	18.2	27
14	8	1077	3330	3621.	1189.	74	736	720	452	5.48	1091	983	1006	12.1	22
15	7	1077	2580	2871.	953.	72	739	810	362	5.21	1174	1065	1108	12.6	—
16	6	1077	2000	2291.	785.	72	738	832	351	5.21	1190	1075	1108	12.6	21
17	5	1077	1472	1763.	620.	72	731	790	328	5.15	1271	1153	1188	12.6	—
18	Dyn. Brake	1077	—	291.	190.	73	502	880	346	3.23	638	523	564	15.7	25
19	Idle	425	—	17.9	33.7	72	349	566	340	1.61	326	252	293	18.1	31
20	4	1077	1130	1421.	511.	75	686	867	340	5.21	1205	1108	1153	12.6	26
21	3	783	867	979.	336.	76	724	867	769	5.90	1480	1363	1431	11.5	—
22	2	783	632	744.	287.	74	678	915	511	5.35	1402	1305	1336	12.2	24
23	1	783	201	313.	142.	74	554	810	356	3.70	806	701	728	14.8	—
24	Idle	425	—	17.9	32.0	73	358	560	375	1.56	326	257	294	18.6	35

LOCOMOTIVE S.P. UNIT 8639, G.E. U-33 C   WET BULB TEMP., °F 70

RUN 4   DATE 4/26/72   BAROMETER 29.04 in Hg   DRY BULB TEMP., °F 78

NOTE: NOTCHES 1-7 RUN AT OFF-DESIGN SPEEDS

Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	Mass Rates, g/hr				Brake Specific, g/bhp hr				Fuel Specific, g/lbm fuel			
				HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
1	Idle	425	7.167	544	633	829	48.6	30.3	35.3	46.3	2.72	16.7	19.5	25.5	1.50
2	1	783	1.5	1448	1133	7603	—	4.86	3.80	25.5	—	10.2	7.98	53.5	—
3	2	783	1.5	2408	2421	10,185	94.5	3.26	3.28	13.8	0.13	8.30	8.35	35.1	0.33
4	3	783	1.5	2536	4108	13,659	—	2.59	4.19	13.9	—	6.97	11.3	37.5	—
5	4	1077	1.5	3749	2973	16,714	159	2.64	2.09	11.7	0.11	7.47	5.92	33.3	0.32
6	Idle	425	7.167	549	670	893	43.6	30.7	37.4	49.8	2.43	16.5	20.2	26.9	1.31
7	5	1077	1.5	4673	3822	20,788	—	2.69	2.20	11.9	—	7.62	6.23	33.9	—
8	6	1077	1.5	5984	5205	24,641	333	2.61	2.27	10.7	0.14	7.62	6.63	31.4	0.42
9	7	1077	1.5	6928	6057	27,530	—	2.41	2.11	9.58	—	7.19	6.28	28.6	—
10	8	1077	14.0	6921	8596	33,113	471	1.91	2.37	9.14	0.13	5.82	7.23	27.8	0.40
11	Idle	425	7.167	538	623	856	47.4	30.0	34.8	47.8	2.65	16.9	19.6	26.9	1.49
12	Dyn. Brake	1077	4.0	2317	1783	4824	110	7.96	6.12	16.5	0.38	12.1	9.29	25.1	0.57
13	Idle	425	7.167	527	609	895	53.8	29.4	34.0	50.0	3.00	15.3	17.7	26.0	1.56
14	8	1077	14.0	6940	8810	32,253	460	1.92	2.43	8.90	0.13	5.84	7.41	27.1	0.39
15	7	1077	1.5	6588	5953	29,971	—	2.29	2.07	10.4	—	6.91	6.25	31.4	—
16	6	1077	1.5	5574	4755	24,687	305	2.43	2.07	10.8	0.13	7.10	6.06	31.5	0.39
17	5	1077	1.5	4228	3549	21,145	—	2.40	2.01	11.9	—	6.82	5.72	34.1	—
18	Dyn. Brake	1077	4.0	2266	1801	4830	140	7.79	6.19	16.5	0.48	11.9	9.48	25.4	0.74
19	Idle	425	7.167	509	619	877	60.5	28.4	34.6	48.9	3.38	15.1	18.4	26.0	1.79
20	4	1077	1.5	3774	2992	16,692	245	2.66	2.11	11.7	0.17	7.39	5.86	32.7	0.48
21	3	783	1.5	2182	3914	11,981	—	2.23	4.00	12.2	—	6.49	11.6	35.7	—
22	2	783	1.5	2172	2452	10,546	123	2.92	3.30	14.1	0.16	7.57	8.54	36.7	0.43
23	1	783	1.5	1371	1218	4097	—	4.38	3.89	13.0	—	9.65	8.58	28.9	—
24	Idle	425	7.167	493	668	861	66.8	27.5	37.3	48.1	3.73	15.4	20.9	26.9	2.09

LOCOMOTIVE S.P. UNIT 8639, G.E. U-33 C

RUN 4 DATE 4/26/72

DUTY CYCLE G.E. LINE-HAUL

Basis	Cycle Composite Emissions: HC	CO	NO_x	*RCHO
Mass, g/hr	3155	3612	13,507	211
Brake Specific, g/bhp hr	2.33	2.66	9.96	0.156
Fuel Specific, g/lbm fuel	6.69	7.66	28.6	0.447

*see note in text regarding RCHO computations

NOTE OFF-DESIGN SPEEDS, NOTCHES 1 — 7

Mode	Notch or Cond.	Engine Speed, Rpm	Observed Power, hp		Fuel Rate, lbm/hr	Temperatures, °F		FIA HC, ppmC	NDIR CO, ppm	NDIR CO_2, %	NDIR NO, ppm	C.L. NO, ppm	C.L. NO_x, ppm	O_2, %	RCHO, ppm
			Net	Gross		Intake	Exhaust								
1	Idle	425	—	17.9	33.7	68	247	518	410	1.51	301	238	266	18.3	
2	1	783	176	288.	81.0	69	399	868	356	3.59	763	639	698	14.9	
3	2	783	640	752.	285.	69	631	1070	607	5.59	1465	1433	1480	12.6	
4	3	783	877	989.	369.	69	706	936	880	5.76	1534	1365	1410	11.1	
5	4	1077	1172	1463.	513.	70	720	868	428	4.97	1263	1101	1146	12.5	
6	Idle	425	—	17.9	33.7	69	475	553	363	1.41	314	252	275	18.4	
7	5	1077	1475	1766.	608.	70	721	833	431	5.08	1271	1108	1153	12.3	
8	6	1077	2000	2291.	792.	78	773	881	453	5.14	1157	1063	1107	12.5	
9	7	1077	2605	2896.	954.	76	755	860	407	5.35	1155	1028	1062	12.7	
10	8	1077	3330	3621.	1167.	78	736	672	429	5.48	1074	981	993	12.5	
11	Idle	425	—	17.9	34.2	74	412	560	328	1.56	352	280	303	18.5	
12	Dyn. Brake	1077	—	291.	194.	77	487	930	357	3.35	610	528	568	15.8	
13	Idle	425	—	17.9	33.7	76	420	546	316	1.61	313	266	298	18.7	
14	8	1077	3290	3581.	1167.	76	723	672	463	5.48	1043	972	993	12.2	
15	7	1077	2605	2896.	958.	76	747	819	395	5.41	1106	1028	1061	12.6	
16	6	1077	2000	2291.	776.	78	746	832	372	5.35	1171	1062	1073	12.7	
17	5	1077	1475	1766.	613.	78	739	840	339	5.35	1235	1128	1173	12.7	
18	Dyn. Brake	1077	—	291.	189.	78	576	875	338	3.32	631	551	574	16.0	
19	Idle	425	—	17.9	33.7	74	419	532	316	1.61	313	266	303	18.4	
20	4	1077	1150	1441.	516.	76	677	818	350	5.35	1203	1097	1128	12.6	
21	3	783	868	980.	364.	74	721	860	767	6.03	1460	1353	1383	11.4	
22	2	783	625	737.	286.	76	695	951	486	5.48	1298	1280	1325	12.3	
23	1	783	180	292.	82.6	75	549	797	332	3.69	760	690	726	15.1	
24	Idle	425	—	17.9	33.9	75	428	539	362	1.61	288	270	303	18.4	

LOCOMOTIVE S.P. UNIT 8639, G.E. U-33 C   WET BULB TEMP., °F 70

RUN 5   DATE 4/26/72   BAROMETER 29.04 in Hg   DRY BULB TEMP., °F 76

NOTE: NOTCHES 1 — 7 RUN AT OFF-DESIGN SPEEDS

				Mass Rates, g/hr				Brake Specific, g/bhp hr				Fuel Specific, g/lbm fuel			
Mode	Notch or Cond.	Engine Speed, Rpm	Time-Based Mode Weights in Percent	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO	HC	CO	NO_x	RCHO
1	Idle	425	7.167	495	793	846		27.6	44.3	47.2		14.7	23.5	25.1	
2	1	783	1.5	860	714	2301		2.99	2.48	7.98		10.6	8.81	28.4	
3	2	783	1.5	2407	2762	11,077		3.20	3.67	14.7		8.45	9.69	38.9	
4	3	783	1.5	2640	5018	13,226		2.67	5.07	13.3		7.15	13.6	35.8	
5	4	1077	1.5	3964	3952	17,406		2.71	2.70	11.9		7.73	7.70	33.9	
6	Idle	425	7.167	564	749	933		31.5	41.8	52.1		16.7	22.2	27.7	
7	5	1077	1.5	4422	4626	20,357		2.50	2.62	11.5		7.27	7.61	33.5	
8	6	1077	1.5	6011	6250	25,121		2.62	2.73	10.9		7.59	7.89	31.7	
9	7	1077	1.5	6810	6516	27,968		2.35	2.25	9.65		7.14	6.83	29.3	
10	8	1077	14.0	6369	8222	31,303		1.76	2.27	8.64		5.46	7.05	26.8	
11	Idle	425	7.167	527	624	948		29.4	34.9	52.9		15.4	18.2	27.7	
12	Dyn. Brake	1077	4.0	2354	1827	4781		8.08	6.28	16.4		12.1	9.42	24.6	
13	Idle	425	7.167	491	575	892		27.4	32.1	49.8		14.6	17.1	26.5	
14	8	1077	14.0	6369	8873	31,303		1.78	2.48	8.74		5.46	7.60	26.8	
15	7	1077	1.5	6441	6262	27,754		2.22	2.16	9.58		6.72	6.54	29.0	
16	6	1077	1.5	5359	4845	22,985		2.34	2.11	10.0		6.91	6.24	29.6	
17	5	1077	1.5	4282	3494	19,886		2.42	1.98	11.2		6.99	5.70	32.4	
18	Dyn. Brake	1077	4.0	2183	1705	4762		7.50	5.86	16.3		11.6	9.02	25.2	
19	Idle	425	7.167	482	578	912		26.9	32.3	50.9		14.3	17.2	27.1	
20	4	1077	1.5	3510	3036	16,097		2.44	2.11	11.1		6.80	5.88	31.2	
21	3	783	1.5	2296	4140	12,280		2.34	4.22	12.5		6.30	11.4	33.7	
22	2	783	1.5	2197	2270	10,182		2.98	3.08	13.8		7.68	7.94	35.6	
23	1	783	1.5	787	662	2383		2.70	2.26	8.16		9.53	8.01	28.8	
24	Idle	425	7.167	488	663	912		27.3	37.0	50.9		14.4	19.6	26.9	

LOCOMOTIVE S.P. UNIT 8639, G.E. U-33 C

RUN 5 DATE 4/26/72

DUTY CYCLE G.E. LINE-HAUL

	Cycle Composite Emissions			
Basis	HC	CO	NO_x	RCHO
Mass, g/hr	2963	3638	12,972	
Brake Specific, g/bhp hr	2.19	2.69	9.59	
Fuel Specific, g/lbm fuel	6.38	7.83	27.9	

NOTE OFF-DESIGN SPEEDS, NOTCHES 1 — 7

APPENDIX D

Analysis of Fuels Used During Locomotive Emissions Tests

CHARACTERISTICS OF LOCOMOTIVE TEST FUELS

Locomotive Unit No.	SP-1311	SP-8447	SP-8639
Gravity, °API @60°F	33.5	30.8	34.2
H/C Mole Ratio	1.73	1.71	1.82
Sulfur, weight %	0.22	0.37	0.21
Fluorescence Indicator			
Analysis: % Aromatics	27.0	36.0	22.4
% Olefins	0.0	1.5	0.0
% Saturates	73.0	62.5	77.6
Cetane No. (calculated)	44.5	41.1	45.6
Distillation Temperatures, °F			
Initial Boiling Point	376	382	386
10%	435	430	439
20%	456	455	458
30%	472	479	474
40%	487	497	488
50%	501	516	501
60%	518	535	515
70%	534	555	530
80%	556	578	549
90%	582	608	575
95%	605	631	597
End Point	636	664	625
% Recovery	99.0	99.0	99.0
% Residue	1.0	1.0	1.0

APPENDIX E

Major Maintenance History of Test Locomotives

The maintenance information recorded here is that which was easily available at the San Antonio facility. The salient point is that when emissions measurements were taken, all the engines were judged to be in good operating condition. More detailed information could probably be obtained if the need arose.

Unit SP-1311 (EMD 12-567)

The date when this unit was placed in service was not on record, but the last engine overhaul date was listed as September 1971. No engine work had been performed since the overhaul. The engine was equipped with low-output 6-hole "N" injectors with 0.421 diameter plungers (not low sac type), EMD part no. 8276707.

Unit SP-8447 (EMD 16-645E-3)

This unit was placed in service in April 1966, and was last overhauled in December, 1968. Maintenance was also performed January 16, 1972, including renewal of all power assemblies, and no work had been performed since that time.

Unit SP-8639 (G. E. 7FDL-16)

Unit 8639 was placed in service in May, 1969, and had not been overhauled. It had undergone maintenance February 24, 1972, including L2, L7, R6, and R8 power assembly replacement. When it was tested prior to beginning emissions tests, the power level was low, so injector pumps and nozzles were replaced on L6, L7, and R7. The racks were also set to 21mm (static) and measured at 22.5mm running before the emissions tests were conducted.