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# TRAIN GENERATED AIR CONTAMINANTS IN THE TRAIN CREW'S WORKING ENVIRONMENT

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16. Abstract

This document contains data on the levels of air contaminants in the train crew's working environment. Measurements were made in locomotive cabs and cabooses of freight trains travelling through long tunnels and over mountainous terrain. In addition, measurements were performed in long-hood forward locomotives during through freight operations and in switchyard locomotives. The data from this study indicate that the breathing environment of railroad operating crews is acceptable within the guidelines of the published Occupational Safety and Health Administration (OSHA) standards. Appendix A covers the sources of air contaminants in the railroad environment and Appendix B gives a detailed description of the measurements in this study. A review of related studies is given in Appendix C.

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# PREFACE

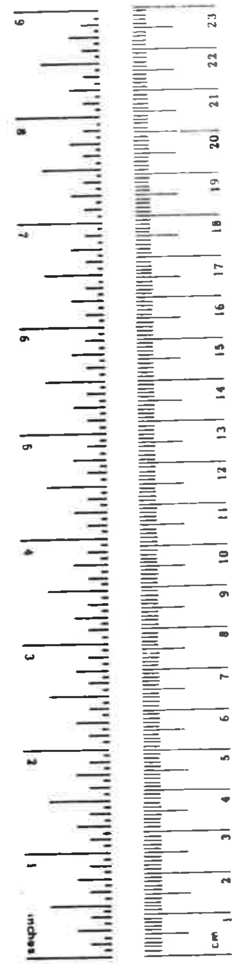
This report documents the results of measurements of air contaminants in the working environment of railroad train crews. The Biotechnology Division, DOT/Transportation Systems Center, performed the work under the auspices of The Federal Railroad Administration, Office of Research and Development; L.A. Peterson, director, Office of Rail Safety Research, and D. Levine, project officer.

Acknowledgement is given for the help of the Association of American Railroads; the Boston and Maine, Burlington Northern, Penn Central, and Southern railroads; and the United Transportation Union and the Brotherhood of Locomotive Engineers.

# METRIC CONVERSION FACTORS

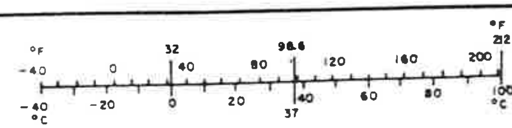
## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |




## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



## TABLE OF CONTENTS


| Section | | Page |
|---|---|---|
| 1. | INTRODUCTION | 1 |
| 2. | APPROACH | 2 |
| 3. | MEASUREMENT INSTRUMENTS | 5 |
| 4. | RESULTS | 7 |
| 5. | SUMMARY AND CONCLUSIONS | 13 |
| 6. | REFERENCES | 14 |
| APPENDIX A - | SOURCES OF AIR CONTAMINANTS IN THE TRAIN CREW ENVIRONMENT | 15 |
| APPENDIX B - | MEASUREMENT TRIP DESCRIPTIONS | 31 |
| APPENDIX C - | RELATED STUDIES | 36 |


## LIST OF ILLUSTRATIONS


| Figure | | Page |
|---|---|---|
| A-1. | ENGINE EXHAUST GAS CONCENTRATIONS AS A FUNCTION OF ENGINE LOAD | 19 |

## LIST OF TABLES


| Tables | | Page |
|---|---|---|
| 1. | SOURCE AND COMPONENTS OF FUMES IN THE TRAIN ENVIRONMENT | 3 |
| 2. | CHARACTERISTICS OF TUNNELS | 4 |
| 3. | MEASUREMENT INSTRUMENTATION AND TECHNIQUES (TSC) | 6 |
| 4. | MEASUREMENT INSTRUMENTATION AND TECHNIQUES (SCOTT) | 6 |
| 5. | SUMMARY OF AIR CONTAMINANT MEASUREMENTS IN TUNNELS | 9 |
| 6. | CALCULATED 8-HOUR TIME WEIGHTED AVERAGE AIR CONTAMINANT LEVELS FOR COMBINED TUNNEL AND THROUGH FREIGHT MEASUREMENTS | 10 |
| 7. | SUMMARY OF AIR CONTAMINANT LEVELS IN LONG-HOOD FORWARD LOCOMOTIVES | 11 |
| 8. | SUMMARY OF MAXIMUM AIR CONTAMINATION LEVELS DURING THROUGH FREIGHT OPERATIONS | 12 |
| A-1. | LOCOMOTIVE DUTY CYCLES | 17 |
| A-2. | AVERAGE EXHAUST CONCENTRATIONS AT IDLE & NOTCH 8 SELECTED TEST ENGINE/MEASURED IN THE STACK | 20 |
| A-3. | MASS EMISSION RATES FOR THREE LOCOMOTIVES AT IDLE AND NOTCH 8 MEASURED IN THE STACK | 21 |
| A-4. | EXHAUST FLOW RATE AND CONCENTRATIONS AT IDLE AND NOTCH 8 MEASURED IN THE STACK | 21 |
| A-5. | REQUIRED DILUTION RATIOS FOR RAW EXHAUST TO OBTAIN OSHA STANDARDS FOR EMD SD-45 | 22 |
| A-6. | EMISSIONS CONCENTRATIONS FROM COMMERCIAL OIL-HEATER | 27 |
| A-7. | EMISSION CONCENTRATIONS FROM A DOMESTIC WALLFLAME OIL-BURNER | 27 |
| B-1. | TRIP DESCRIPTIONS FOR TUNNEL MEASUREMENTS BY TSC | 32 |
| B-2. | TRIP DESCRIPTIONS AND MEASUREMENT INFORMATION FOR SCOTT ENVIRONMENTAL TECHNOLOGY INC | 35 |
| C-1. | PREVIOUS FIELD STUDIES | 37 |

# 1. INTRODUCTION

The Transportation Systems Center (TSC) has performed a study of air contaminants in the railroad crew's working environment to determine if the crews are exposed to contaminant levels harmful to health. Such contaminents are an unavoidable consequence of railroad operations. These contaminants may be gases or particulates. The Occupational Safety and Health Administration (OSHA) has determined the maximum permissible safe exposure levels for many air contaminents and has adopted these levels as standards; these standards served as the basis of comparison in the study reported here.

# 2. APPROACH

From a literature survey of air contaminants in railroad operations the sources of the contaminants are compiled in Table 1. In addition, applicable OSHA standards were examined. In an initial effort to limit the scope of the study, pilot measurements of air contaminant levels under selected worst case situations were made, namely freight trains in tunnels. This selection was based on information contained in publications of prior investigators who found the highest levels of air contaminants in tunnels. As explained in greater detail in Appendix A, the locomotives' diesel engine is the main source of crew space air contaminants and production of contaminants increases proportionally with engine size. Consequently, the primary objective was the measurement of air contaminants produced by the largest engines in the longest tunnels.

Measurements of air contaminant levels in locomotives and cabooses were made during 39 trips through tunnels that varied in length from 0.75 to 7.8 miles. These tunnels are listed in Table 2.

Measurement trips lasted from 30 minutes to 2 hours, with 20 to 30 minutes in a tunnel. The total trip distances range from 15 to 60 miles. The numbers of each type of locomotive sampled are as follows: EMD [SD-45 (1), SD-40-2 (5), SD-40 (2), GP-9 (4), GP-38 (2)] and GE [U-33 (3), U-30 (1)].

Additional measurements were performed in situations where either no previous data was available (long-hood forward locomotive and switchyard locomotives) or where it was thought desirable to check the accuracy of previously recorded data (locomotive and caboose in through freight service). These measurements were performed, under contract, by Scott Environmental Technology, Inc. (Scott).

The Scott measurements were comprised of eight through freight trips of distances from 130 to 240 miles. Sampled during these trips were cab-front locomotives, cabooses, long-hood forward locomotives, helper locomotives in tunnels, and switchyard locomotives.

TABLE 1.SOURCE AND COMPONENTS OF FUMES IN THE TRAIN ENVIRONMENT

| | GASES | | | | | | | PARTICULATES | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Carbon Monoxide | Oxides of Nitrogen | Total Hydrocarbons | Oxides of Sulfur | Ozone | Stibene | Sulfuric Acid | Carbon | Sand | Other | Odor |
| 1. Diesel Locomotive | | | | | | | | | | | |
| exhaust | x | x | x | x | | | | x | | | x |
| lube oil leaks | | | x | | | | | x | | | x |
| air compressor | | | x | | | | | x | | | x |
| toilet | | | x | | | | | x | | | x |
| batteries | | | | | x | x | | | | | |
| electrical | | | | x | | | | | | | |
| 2. Caboose | | | | | | | | | | | |
| oil fired heaters | x | x | x | x | | | | x | | | x |
| refrigerated cars | x | x | x | x | | | | x | | | x |
| toilets | | | x | | | | | x | | | x |
| 3. External | | | | | | | | | | | |
| track spillage | | | x | | | | | x | x | x | x |
| tobacco smoke | x | x | x | x | | | | x | | | x |
| brake shoes | | | | | | | | | | x | |
| 4. Miscellaneous | | | | | | | | | | | |
| fuel tanks | | | x | | | | | | | | x |
| engine blow-by | x | x | x | x | | | | x | | | x |
| oils, waxes, epoxy paints | | | x | | | | | | | | x |

TABLE 2. CHARACTERISTICS OF TUNNELS

| Tunnel | Length Miles | Ventilated | Railroad |
|---|---|---|---|
| Cascade | 7.8 | Yes | Burlington Northern |
| Hoosac | 5.0 | Yes | Boston and Maine |
| Flathead | 7.7 | Yes | BN |
| Blossburg | 0.7 | No | BN |
| Bozeman | 0.7 | No | BN |
| Stampede | 2.0 | No | BN |

These trips lasted from nine to twelve hours. The following locomotive types were sampled: SD-45 (2), GP-38-2 (2), SD-40 (2), SW-7 (1), SD-35 (1), and NW-2 (1). A compilation of all the trip information is given in Appendix B.

For all of the measurement trips the following contaminants were measured: carbon monoxide, nitric oxide, nitrogen dioxide, total particulates, total hydrocarbons, and total aldehydes. These contaminants were measured for the following reasons: (1) data can be compared with results of other investigators who have measured some or all of these contaminants; and (2) highly reliable and accurate instrumentation is available for measurement of these contaminants. Specific hydrocarbons, particulates, and aldehydes were not measured because continuous and fast responding techniques are not available for these contaminants. Sulfur dioxide was not measured because a sensitive, continuous technique was not available and the $SO_2$ level can be calculated from the sulfur content of the diesel fuel.

# 3. MEASUREMENT INSTRUMENTS

The measurement instruments utilized during the TSC studies were sensitive, highly reliable, battery operated, and portable. These characteristics were dictated by the low levels of air contaminants to be measured, the rough environment encountered in railroad operations, and the lack of space and power in locomotive cabs and cabooses. These instruments also permitted flexibility in measurement location with minimum set-up and break-down time. Table 3 lists the instruments used. This equipment was calibrated at the beginning and end of each day of measuring. Samples in the locomotive cab were taken at the brakeman's seat and at the console in front of the engineer. In the caboose, samples were taken at the rear conductor's desk.

Table 4 lists the measurement devices used by Scott. The Scott instruments were extremely sensitive, and featured continuous operation and fast response. The equipment was powered by a portable generator. Scott sampled from the sampling location to the instrumented test car through a teflon line. Measurements were taken in the same locomotive and caboose locations as the TSC measurements. Scott also sampled the air in the cupola of the caboose. Instrument calibrations were made at least every hour.

TABLE 3. MEASUREMENT INSTRUMENTATION AND TECHNIQUES (TSC)

| Gas | Techniques | Instrument |
|---|---|---|
| Carbon Monoxide (CO) | Electrochemical | Energetics Science, Inc., Model 2400 ECOlyzer |
| Oxides of Nitrogen ($NO_x$) | Electrochemical | Energetics Science, Inc., Model 2700 ENOlyzer |
| Total Hydrocarbons (HC) | Flame Ionization | Century Systems, Flame Ionization Organic Vapor Detector, Model OVS-98A |
| Particulates | Light Scattering and Filtration | NASA, In-Flight Aerosol Analyzer, Model T-003 |

TABLE 4. MEASUREMENT INSTRUMENTATION AND TECHNIQUES (SCOTT)

| Gas | Techniques | Instrument |
|---|---|---|
| Carbon Monoxide (CO) | Infra-red | Beckman Model 315A |
| | Electrochemical | Energetics Science, Inc. Model 2800, ECOlyzer |
| Oxides of Nitrogen ($NO_x$) | Chemiluminescence | Scott Model 125 |
| Total Hydrocarbons (HC) | Flame Ionization | Beckman 109A |
| Particulates | Anderson Impactor | Model No. 10-000 |
| | Bendix Personnel Monitor | Type C115 |
| Aldehydes | MBTH Method (1) | Precision Scientific sequential smapler Bausch & Lomb Spectronic 20 colorimeter |

## 4. RESULTS

Tables 5, 6, 7, and 8 summarize the results of the TSC and Scott measurements. In addition, the OSHA standards are presented. The values presented are the maximum levels measured over a time period in a particular sampling location. The reference measure of exposure (OSHA standard) for most substances is the "8-hour time weighted average" (TWA) in one 8-hour work shift for a 40 hour work week. Table 5 summarizes the peak levels measured by TSC and Scott in 39 separate measurements in locomotive cabs and caboose passing through the long railroad tunnels (20-30 minutes). Also summarized in Table 5, are the peak levels measured by prior investigators in locomotive cabs and cabooses in tunnels. A discussion of these other investigations is presented in Appendix C. The values shown in columns 3 and 4 for carbon monoxide and nitric oxide levels appear to exceed the OSHA standards, but this is not the case since the contaminants' concentration reached these levels for periods of only 20 and 30 minutes respectively while the trains were in a tunnel. Because the measurements were taken only during the time the trains were in the tunnels, an 8-hour time weighted average cannot be reported as such. However, if a crew member making a tunnel trip was exposed for the remainder of the 8-hour work shift to normal air contaminant levels, such as those summarized in Table 8, then an approximate 8-hour time weighted average can be calculated. Using this procedure the 8-hour TWA's for various numbers of tunnel trips were calculated and are presented in Table 6. The data used in these calculations were taken from Tables 5 and 8.

As can be seen from Table 6, the calculated 8-hour averages for a combined tunnel trip and normal working day yields an 8-hour time weighted average well within OSHA standards. Also shown in Table 6 are the 8-hour time weighted averages for five tunnel trips during a normal working day. These levels are within OSHA standards. Generally, helper locomotive crews make only three to four trips a day through these long tunnels and their exposure levels are within OSHA standards.

Table 7 presents the results of measurements in long-hood forward road-haul and switchyard locomotives. Comparison with Table 5 and 6 shows that the maximum levels measured are several orders of magnitude lower than those found in tunnel operations. In further comparison with Table 8, which presents the 8-hour time weighted averages measured in locomotives and cabooses during typical through freight operations, the long-hood forward locomotives were not found to differ significantly from cab forward locomotives. In fact, in all operations except tunnels, the maximum levels of some contaminants occurred when crew members smoked.

TABLE 5. SUMMARY OF AIR CONTAMINANT MEASUREMENTS IN TUNNELS

| Substance | OSHA Standard* | Peak level measured in helper locomotive in tunnel (single trip) | Peak level measured in caboose in tunnel (single trip) | Peak level in tunnels from the literature (single trip) | Reference |
|---|---|---|---|---|---|
| Carbon Monoxide (CO) | 50.0 ppm | 110 ppm (30 min) | 7 ppm (20 min) | 335 ppm (M) (L)<br>147 ppm (20 min) | (2) |
| Nitric Oxide (NO) | 25.0 | 70 ppm (30 min) | 39 ppm (20 min) | 100 ppm ($NO_x$)**<br>(1 min) | (3) |
| Nitrogen Dioxide ($NO_2$) | 5.0 ppm | 0.08 ppm (M) | 0.20 ppm (M) | 6 ppm (20 min)<br>(L) | (4) |
| Hydrocarbons--Total (HC) | No Standard | 6.0 ppm (30 min) | 25 ppm (20 min) | 50 ppm (20 min)<br>(L) | (5) |
| Particulates--Total | 15 $mg/m^3$ | 0.14 $mg/m^3$<br>(30 min) | 0.16 $mg/m^3$<br>(30 min) | 1.92 $mg/m^3$<br>(30 min) (C) | (6) |
| Aldehydes--Total | No Standard | 0.16 ppm (60 min) | 0.06 ppm (60 min) | 75 ppm (20 min)<br>(L) | (5) |

* = 8-hour time weighted average (TWA)
** = $NO_x$ = Oxides of nitrogen
ppm = Parts per million
M = Maximum momentary level
L = Locomotive
C = Caboose

TABLE 6. CALCULATED 8-HOUR TIME WEIGHTED AVERAGE AIR CONTAMINANT LEVELS FOR COMBINED TUNNEL AND THROUGH FREIGHT MEASUREMENTS (Calculated by Combining Data of Table 5 and 8)

| Substance | OSHA Standard* | 8-hr TWA locomotive single tunnel trip | 8-hr TWA locomotive five tunnel trips | 8-hr TWA caboose single tunnel trip |
|---|---|---|---|---|
| Carbon Monoxide (CO) | 50 ppm | 7.8 ppm | 35.1 ppm | 1.25 ppm |
| Nitric Oxide (NO) | 25 ppm | 4.6 ppm | 22.0 ppm | 1.93 ppm |
| Nitrogen Dioxide ($NO_2$) | 5 ppm | 0.02 ppm | 0.03 ppm | 0.01 ppm |
| Hydrocarbons--Total (HC) | No standard | 4.55 ppm | 4.94 ppm | 3.69 ppm |
| Particulates--as total inert dust | 15 $mg/m^3$ | 0.05 $mg/m^3$ | 0.07 $mg/m^3$ | 0.27 $mg/m^3$ |
| Aldehydes--Total as formaldehyde | No standard | 0.07 ppm | 0.09 ppm | 0.14 ppm |

* 8-hour time weighted average (TWA)

TABLE 7. SUMMARY OF AIR CONTAMINANT LEVELS IN LONG-HOOD FORWARD LOCOMOTIVES

| Substance | OSHA STANDARD* | Time weighted avg. in long-hood forward through freight (7 1/2 hr avg) | Time weighted avg. in long-hood forward switchyard locomotive (5 hr avg) |
|---|---|---|---|
| Carbon Monoxide (CO) | 50.0 ppm | 1.25 ppm | 0.26 ppm |
| Nitric Oxide (NO) | 25.0 ppm | 0.16 ppm | 0.07 ppm |
| Nitrogen Dioxide ($NO_2$) | 5.0 ppm | 0.02 ppm | 0.03 ppm |
| Hydrocarbons—Total (HC) | No standard | 2.89 ppm | 3.12 ppm |
| Particulates—as total inert dust | 15 $mg/m^3$ | 0.16 $mg/m^3$ | 0.01 $mg/m^3$ |
| Aldehydes—Total as formaldehyde | No standard | 0.05 ppm | 0.02 ppm |

* 8-hour time weighted average (TWA)

TABLE 8. SUMMARY OF MAXIMUM AIR CONTAMINATION LEVELS DURING THROUGH FREIGHT OPERATIONS

| Substance | OSHA Standard* | Time weighted average for locomotive (7 hr 10 min avg) | Time weighted average in caboose (8-hour avg) |
|---|---|---|---|
| Carbon Monoxide (CO) | 50.0 ppm | < 1.0 ppm | < 1.0 ppm |
| Nitric Oxide (NO) | 25.0 ppm | 0.11 ppm | 0.34 ppm |
| Nitrogen Dioxide ($NO_2$) | 5.0 ppm | 0.01 ppm | 0.05 ppm |
| Hydrocarbons--Total (HC) | No standard | 4.45 ppm | 2.78 ppm |
| Particulates--Total as inert dust | 15 $mg/m^3$ | 0.04 $mg/m^3$ | 0.16 $mg/m^3$ |
| Aldehydes--Total as formaldehyde | No standard | 0.06 ppm | 0.15 ppm |

* 8-hour time weighted average (TWA)

## 5. SUMMARY AND CONCLUSIONS

A survey of the literature has revealed that the highest levels of air contaminants in railroad operations occur when trains pass through long tunnels. In only one instance was the OSHA standard exceeded (5) and this was a deliberate attempt to determine the conditions that would occur if tunnel ventilation were faulty.

In the course of the present program, measurement of air contaminants levels were made during 39 trips through long railroad tunnels. In addition, 81 hours and 45 minutes of continuous measurements were performed in locomotive cabs and caboose in typical through freight operations during 15 measurement trips. Three different switchyard locomotives were continuously sampled for a total of 30 hours. The worst-case data from this study and the published work of others indicate that the breathing environment of railroad operating crews is acceptable within the guidelines of the published OSHA standards.

## 6. REFERENCES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# APPENDIX A. SOURCES OF AIR CONTAMINANTS IN THE TRAIN CREW ENVIRONMENT

## A.1 GENERAL

The purpose of this section is to identify the potential sources of gaseous and particulate emissions in the train crew environment and establish the nature and levels of emissions from these sources. Although this section primarily addresses the exhaust emissions from diesel engines, other potential sources of fumes such as batteries, oilfired heaters, air brake compressors and track sanding will also be discussed.

## A.2 DIESEL LOCOMOTIVES

The most obvious source of fumes for the train crew is the exhaust of diesel engines that are used to power the consist, either as lead, helper or pusher locomotives. Other sources of gases and particulates associated with the locomotive are vapor discharges from airbrake compressors, batteries used for starting, chemical and electrical toilets and oil and fuel leaks from the engines.

### A.2.1 Diesel Engine Exhaust

Diesel engine exhaust is composed of nitrogen ($N_2$), oxygen ($O_2$), carbon dioxide ($CO_2$), carbon monoxide (CO), oxides of nitrogen ($NO_x$), hydrocarbons (HC), oxides of sulfur ($SO_x$), water vapor, and particulate matter (smoke). Of these substances, CO, $NO_x$, some HC, $SO_x$, and some particulates are generally considered to be harmful to human health at sufficiently high levels. This fact has been recognized by the promulgation of OSHA and Clean Air Standards for these substances. CO, HC and particulate matter are products of incomplete combustion of the fuel in a diesel engine and the burnoff of lubricating oils. The particulate matter consists of carbon and hydrocarbon aerosols (black smoke) and, at times, unburned fuel droplets (white smoke). $NO_x$ is formed by the oxidation of atmospheric nitrogen at the high temperatures in the combustion process. $SO_x$ originates from the oxidation of the sulfur normally found in the diesel fuel (0.2% to 1%).

A.2.2 Levels of Substances in Diesel Engine Exhaust

Many measurements of the emission levels of diesel engine exhaust have been performed. Measurements of diesel engine locomotives in particular have been performed by Southwest Research Institute (SWRI) (1) for EPA and Scott Environmental Technology Laboratories (2) for the Southern Pacific R.R. In these studies a sample of the exhaust gas was extracted from the engine stack and measured with "real time" instrumentation while the engine was operated through its normal power cycle using an external resistive load bank for power absorption. The exhaust gas concentrations were measured on a parts per million (ppm) basis and subsequently converted to a mass basis as brake specific or fuel specific mass emission rates, i.e., grams per bhp per hour or grams per quantity of fuel consumed. Particulate matter was usually measured on a mass basis, that is milligrams per cubic foot of exhaust gas. For smoke measurements, EPA required the use of an opacity meter which measured the smoke density across the diameter of the stack.

Although for comparative reasons the most meaningful way of reporting the levels of the exhaust products from diesel engines is on a mass basis, it is more appropriate for the purpose of this study to examine these levels on a concentration basis, that is ppm or percent. OSHA and EPA standards for breathing air are given as ppm by volume.

Railroad locomotives generally operate in discrete engine power-speed levels called notches. Data collected on locomotive duty cycles (Table A-1) indicate that line haul locomotives spend approximately 40 percent of their time at the idle and 30 percent of their time in notch 8, while switcher locomotives spend 77 percent of their time in idle (3). Therefore, in order to simplify this discussion and to allow for the fact that the majority of the exposure of the crew to any fumes would be at idle and notch 8 operation, the comparison of measured concentrations that follows

TABLE A-1. LOCOMOTIVE DUTY CYCLES

| | % of Time/Notch | |
|---|---|---|
| Notch | Switch | Line Haul |
| Idle | 77 | 41 |
| Dynamic Brake | -- | 8 |
| 1 | 10 | 8 |
| 2 | 5 | 3 |
| 3 | 4 | 3 |
| 4 | 2 | 3 |
| 5 | 1 | 3 |
| 6 | 1 | 3 |
| 7 | 0 | 3 |
| 8 | 0 | 30 |

Reference 4

will only address itself to idle and notch 8 operation. However, Figure A-1 is included in order to present the general trends of emissions over the operating cycle of a diesel engine. (HC are not included as they depend more on injection parameters than engine performance characteristics.)

Table A-2 gives the exhaust concentrations in the stack at idle and notch 8 for some common railroad engines selected from the previously referenced studies. The variations in emission concentration can be attributed to engine design (two or four stroke cycle, turbocharged or blower-scavenged) and engine operating condition. Faulty or poorly maintained components can contribute to increased emission levels. The most critical components that effect emissions are fuel injectors and pumps, governors and turbochargers. It is of interest to note that the variations in the levels of emissions between identical engines (1, 2, and 5, 6), are possibly due to engine maintenance condition. It should be kept in mind that although Table A-2 indicates that the concentrations of emissions from large and small diesel engines are similar, the larger the engine the more pollutants are introduced into the air on a mass basis (g/hr). Table A-3 gives some mass emission rates in g/hr for three selected engines at idle and notch 8. As previously indicated, the mass emission rates increase with increasing engine horsepower.

Table A-4 gives the exhaust flow rates in cfm and the exhaust concentrations for two different engines. These rates are of particular importance in tunnels or other semiclosed areas where dilution of the exhaust is hindered and the helper and pusher locomotives are exposed to higher quantities of the hot exhaust of the other engines. Test performed by SWRI (2) have shown that with 30 percent hot exhaust gas recirculation, CO emissions were six to nine times higher on a brake specific basis (g/bhp/hr).

Table A-5 gives the dilution ratios necessary to lower the measured exhaust concentrations of an EMDSD-45 (Table A-2, 1 & 2) locomotive to the time-weighted eight-hour acceptable OSHA standard.

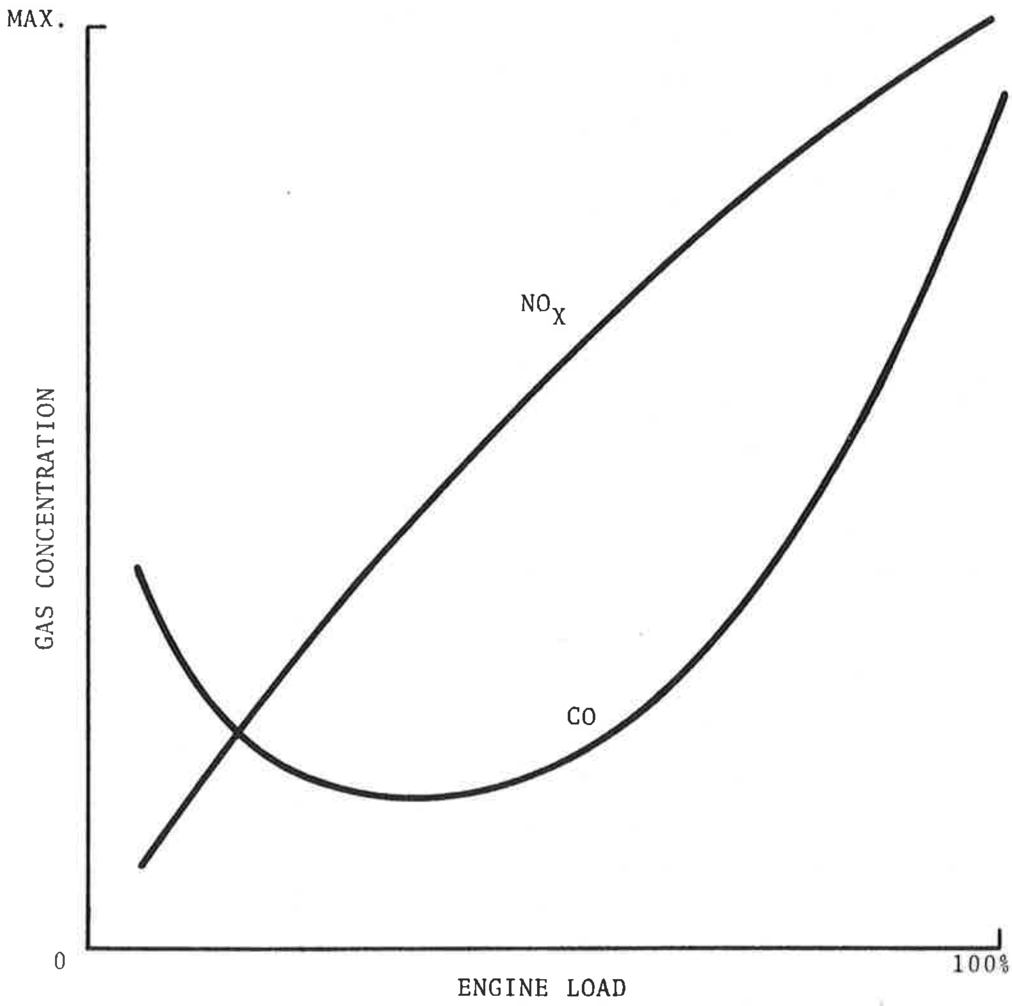


FIGURE A-1. ENGINE EXHAUST GAS CONCENTRATIONS AS A FUNCTION OF ENGINE LOAD

TABLE A-2. AVERAGE EXHAUST CONCENTRATIONS AT IDLE & NOTCH 8 SELECTED TEST ENGINE MEASURED IN THE STACK

| | SOURCE | ENG. MOD. | TYPE | USE | CO(ppm) IDLE | CO(ppm) 8 | $CO_2$(%) IDLE | $CO_2$(%) 8 | $NO_x$(ppm) IDLE | $NO_x$(ppm) 8 | THC(ppm) IDLE | THC(ppm) 8 | ALD(ppm) IDLE | ALD(ppm) 8 | SMOKE IDLE | SMOKE 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Scott | EMD SD-45 | 20-645 | Linehaul | 221 | 149 | NA | NA | 143 | 1400 | 98 | 110 | 1.65 | 1.05 | NA | NA |
| 2 | Scott | EMD SD-45 | 20-645 | Linehaul | 413 | 482 | NA | NA | 137 | 1353 | 374 | 190 | 11.2 | 4.9 | 0.6(1) | 0.83(1) |
| 3 | Scott | EMD GP-38 | 16-645 | Switch & Linehaul | 107 | 950 | NA | NA | 75 | 1588 | 121 | 294 | 2.7 | 6.1 | 0.1(1) | 0.65(1) |
| 4 | SWRI | EMD SD-40 | 16-645 | Linehaul | 104 | 567 | 0.73 | 6.13 | 118 | 899 | 103 | 238 | 15.0 | 11.6 | 1.7(2) | 6.4(2) |
| 5 | Scott | GE U33-C | FDL-16 | Linehaul | 476 | 372 | NA | NA | 404 | 1462 | 620 | 627 | 17.0 | 4.5 | 0.55(1) | 0.83(1) |
| 6 | SWRI | GE U33-C | 7FDL-16 | Linehaul | 424 | 499 | 1.50 | 5.39 | 318 | 1069 | 569 | 692 | 32.0 | 26 | 3.7(2) | 4.8(2) |
| 7 | SWRI | EMD | 12-567 | Switch | 56 | 252 | 0.72 | 5.4 | 74 | 857 | 282 | 1116 | 16.0 | 19.0 | 1.5(2) | 2.8(2) |

(1) Bosch Smoke number

(2) Opacity %

NOTE: All Scott data as measured; SWRI data corrected for removal of intake air humidity and water of combustion.

TABLE A-3. MASS EMISSION RATES FOR THREE LOCOMOTIVES AT IDLE AND NOTCH 8 MEASURED IN THE STACK

| UNIT | RATED hp | CO g/hr IDLE | CO g/hr 8 | $NO_X$ g/hr IDLE | $NO_X$ g/hr 8 | THC g/hr IDLE | THC g/hr 8 | ALD g/hr IDLE | ALD g/hr 8 |
|---|---|---|---|---|---|---|---|---|---|
| EMD 12-567 | 1200 | 160 | 1840 | 335 | 10200 | 387 | 3980 | 48.2 | 148 |
| EMD 16-645 | 3000 | 523 | 9740 | 978 | 25500 | 254 | 2010 | 76.8 | 224 |
| GE FDL-16 | 3300 | 828 | 9630 | 1030 | 33200 | 551 | 6630 | 67.5 | 538 |

TABLE A-4. EXHAUST FLOW RATE AND CONCENTRATIONS AT IDLE AND NOTCH 8 MEASURED IN THE STACK

| UNIT | RATED hp | EXHAUST cfm Idle | EXHAUST cfm 8 | CO ppm Idle | CO ppm 8 | $NO_X$ ppm Idle | $NO_X$ ppm 8 | THC ppm Idle | THC ppm 8 | ALD ppm Idle | ALD ppm 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| EMD 20-645 | 3600 | 3700 | 25000 | 413 | 482 | 137 | 1353 | 374 | 190 | 11.2 | 4.9 |
| EMD 16-645 | 2500 | 2850 | 17100 | 107 | 950 | 75 | 1588 | 121 | 294 | 2.7 | 6.1 |

TABLE A-5. REQUIRED DILUTION RATIOS FOR RAW EXHAUST TO OBTAIN OSHA STANDARDS FOR EMD SD-45

| CO | | | $NO_X$ | | | ALD (as formaldehyde) | | |
|---|---|---|---|---|---|---|---|---|
| Weighted 8 hr avg. | Dilution Idle | Dilution Notch 8 | Weighted 8 hr avg. | Dilution Idle | Dilution Notch 8 | Weighted 8 hr avg. | Dilution Idle | Dilution Notch 8 |
| 50ppm | 8:1 | 10:1 | 25ppm(NO) | 5.5:1 | 54:1 | 3ppm | 3.7:1 | 1.6:1 |
| | | | 5ppm($NO_2$) | 27:1 | 271:1 | | | |

| Particulates* | |
|---|---|
| Weighted 8 hr avg. | Dilution |
| 5mg/m$^3$+ | 98:1 * |

*Based on 625mg/m$^3$ at 80% power on a 3600 hp CG engine ref (5)

+Based on Time Weighted Average (TWA) of Carbon Black

As no standard exists for aldehydes in general, the OSHA standard for formaldehyde was used in the table. Except for the $NO_x$ and particulate concentrations, all dilution ratios are below 10:1. An EMD-SD-45 locomotive with a frontal area of 140 $ft^2$ would displace 367,500 $ft^3$/min of air at 30 mph. Although an aerodynamic analysis is not within the scope of this report, is unlikely that emissions from a moving locomotive (CO, HC and $SO_x$) would not be diluted below OSHA levels, especially in the cab-forward configuration that most railroads have adopted. Although there are no published data on locomotives, measurements performed by SWRI (5) indicated that the exhaust dilution from a vertical stack on truck-tractors and buses ranged from 700:1 to 1000:1. Accordingly, it could be safely assumed that the dilution ratios for locomotives are at least of this order of magnitude. These dilution factors do not hold for idling engines (especially multiple engines in a switchyard or tunnel), or trailing helper locomotives (usually unoccupied). In regard to $NO_x$, approximately 90 percent of this contiminant in the raw exhaust is NO, while 10 percent is $NO_2$ (the most toxic oxide). There are also trace amounts of higher oxides of nitrogen. NO converts to $NO_2$ in the presence of oxygen with a reaction rate dependent on temperature and concentrations of the reacting substances. In ambient air, the reaction rates are long compared to the normal air flow and air exchange rated experienced by a train crew in their normal working environment. An exception to this condition could again occur in poorly ventilated tunnels where the residence time of air is longer than the time required to convert NO to $NO_2$.

No reference has yet been made to diesel engine odors, a common public complaint. Studies have been reported of diesel engine odors (6,7). The diesel odors are variously described as burnt, smoky kerosene or sweet aromatic smells. Odor is generally attributable to unburned fuel or oil compounds and oxygenated compounds produced by incomplete combustion and has yet to be quantitively measured.

### A.2.3 Fuel and Lube Oil Leakage in Diesel Engines

It is generally conceded by diesel engine manufacturers that large-bore diesel engines, because of their mass and associated thermal stresses, are more susceptible to leaks of seals and fittings than other smaller types of internal combustion engines. Leaking substances could be fuel or lubricating oils. Some of these may contact hot surfaces and produce vapors and odors. Others may collect under the engines and, by evaporation, produce odors which may be transported through bulkhead fittings to the crew compartment. These vapors would consist primarily of hydrocarbons. No measurements have been performed to quantify the extent of these vapors.

### A.2.4 Vapors from Air Compressors

Vapors in air compressors may originate in the engine compartment and be drawn into the compressor or be due to lubricating oil of the compressor itself. In many locomotive cabs compressed air is vented into the cab upon brake application to serve as an audible indication of braking action; also released in the cab are any vapors present in this air. The vapors may be minimized by draining of compressed air tanks and proper compressor maintenance. As with fuel and lube oil leakage, no measurements have been made of the contributory effect of these vapors. (However, if the problem were deemed significant, it would be eliminated completely by venting part or all of the compressed air outside the cab.)

### A.2.5 Toilets

Most line-haul locomotives are equipped with toilets for the crew. In newer locomotives these toilets are located in the short hood ahead of the crew compartment. These toilets either electrically incinerate the waste products or chemically treat them in holding tanks. With an electrical incinerator, a certain amount of odorous vapors are present. Holding tanks and chemical treatment produce little if any irritating fumes. In both cases, maintenance is of utmost importance. If holding tanks are not drained and chemicals refilled, overflow and improper treatment can occur with resultant irritating odors.

### A.2.6 Batteries

Modern diesel engines generally use lead-acid batteries with antimony-lead or calcium-lead electrodes for starting. Batteries are usually located directly ahead of the crew compartment in the short hood of the locomotive. An auxiliary generator keeps these batteries charged. Failures of equipment in the charging circuit, such as the voltage regulator, can cause battery overcharging with a subsequent release of hydrogen ($H_2$), stibine ($SbH_3$), and sulfuric acid ($H_2SO_4$) fumes. Hydrogen is not considered toxic at low levels but may be an explosion hazard. Sulfuric acid fumes are an extremely strong respiratory and eye irritant with an OSHA 8 hr time-weighted average (TWA) allowable exposure of 1 $mg/m^3$. Stibine has an 8 hr TWA of 0.5 $mg/m^3$. To avoid these problems, good maintenance practices should be utilized to minimize the risk of battery overcharging.

### A.2.7 Ozone Production from Electrical Discharges

Whenever heavy electrical equipment is used, a potential exists for the production of ozone ($O_3$) by the ionization of atmospheric oxygen. The propulsion system of a diesel-electric locomotive includes the main generator, traction motors and power contactors. Arcing with subsequent ozone production is possible at the motor and generator brushes, switches, relays, and contactors. Again, good maintenance minimizes this potential for ozone production. The characteristic odor of ozone can be detected at very low concentrations (approximately 0.02 ppm). Although the TWA for ozone is 0.1 ppm, any detection of an ozone odor requires appropriate steps to determine its source.

## A.3 CABOOSES

In locations such as tunnels, the caboose may be exposed to the exhaust fumes of the diesel locomotives. Oil-fired stoves, diesel fumes from refrigerator cars in front of the caboose, and oil spills on the caboose floor are other sources of air contamination in the caboose.

### A.3.1 Oil-Fired Heaters

Many cabooses are equipped with oil-fired stoves that provide heat for the comfort of the crew. Faulty maintenance of these heaters could vent potentially toxic fumes into the caboose from leaking combustion chambers and exhaust systems; fuel-oil fumes could be formed by evaporation of leaking fuel-supply systems. (The latter could also be a safety hazard by making floors slippery).

The oil-fired stove produces the same exhaust as a diesel engine, but with significantly different concentration levels. Table A-6 gives the measured emission concentrations from a commercial (5.2 gph) oil-heater burning #2 fuel oil. As can be seen, the emission concentrations from a properly maintained oil-fired heater are generally lower than from a locomotive diesel engine, especially the levels of $NO_x$. However, oilfired boilers can be out of adjustment (usually indicated by high levels of odor and smoke) and emissions can increase considerably. Table A-7 compares the emission concentrations from a 10,000 kcal/h domestic burner in good and bad condition. The CO concentrations were approximately a factor of 100 higher for the bad burner.

Good maintenance practice minimizes the emissions from boilers and assure that no fumes from leaking flue pipes, combustion chambers and fuel supply systems enter the caboose environment.

### A.3.2 Diesel Powered Refrigerator Cars

It is common practice on railroads to power refrigerator cars with diesel engines. Though significantly smaller than those used for powering the consist, these engines emit concentration levels of pollutants comparable to those found on diesel locomotive engines. (See Table A-2.) However, as the exhaust flow rates on these engines are considerably less than those of larger engines, the exhaust emissions on a mass basis (g/hr) are much less. These engines are GM2-71, or equivalent, rated at 53 hp at 1800 rpm, and

TABLE A-6. EMISSIONS CONCENTRATIONS FROM COMMERCIAL OIL-HEATER

| $SO_2$ ppm | CO ppm | ALD ppm | NO ppm | Particles $mg/m^3$ |
|---|---|---|---|---|
| 138 | 2 | 11 | 34 | 167 |

Reference 8

TABLE A-7. EMISSION CONCENTRATIONS FROM A DOMESTIC WALLFLAME OIL-BURNER

| Condition | $CO_2$ % | CO ppm | THC ppm | ALD ppm | $NO_2$ ppm |
|---|---|---|---|---|---|
| Good | 13.6 | 60 | 15 | 3 | <20 |
| Bad | 13.9 | 8000 | 55 | 25 | <20 |

Reference 9

in this use operate continuously at constant speed; (usually 1200-1400 rpm), and at two power levels, idle, and loaded (50 to 80% max power). They consume approximately 20 gallons of #2 diesel fuel per day (avg 15 hp-hr) compared to the 1100 gallons per day consummed by the average line-haul locomotive. Fruit Growers Express indicated these small engines are completely overhauled every four months. If these units are located directly ahead of a caboose, under certain circumstances, some of the odors and fumes may be detected by the train crew. No measurements have been performed on the levels of these pollutants in the crew environment.

## A.4 EXTERNAL SOURCES

This section enumerates other possible sources of contamination of the train crew environment, not directly related to the operation of the locomotive and caboose, including smoking by the train crew.

### A.4.1 Leakage

Greases, oils, and fuels drip from the undercarriages of locomotives and cars. Other liquids can be accidentally spilled or leaked from tank cars. These liquids can accumulate in heavy traffic areas such as switchyards and contribute to environmental contamination through evaporation.

### A.4.2 Tobacco Smoke

Smoke from tobacco contrains CO, $NO_x$, various hydrocarbons and particulates. This smoke can be irritating to nonsmoking crew members in the confines of a locomotive cab or caboose.

### A.4.3 Brake Shoes

Brake shoes used on locomotives and cars may be a potential source of particulate matter, especially composite-type shoes using asbestos. No measurements have been made of the particulates from these shoes. The amounts produced, the shapes of the particles, and their size distribution should be determined so that the potential hazard may be evaluated.

### A.4.4 Miscellaneous Sources

Other sources of fumes that are considered to be of a potentially less serious nature, enumerated here without further explanation, are evaporative losses from fuel tanks on locomotives, cabooses and refrigerator cars, diesel engine crankcase blowby, and other oils, waxes, expoxies and paints used in railroad operations.

A.5 REFERENCES


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# APPENDIX B

# MEASUREMENT TRIP DESCRIPTIONS

## TABLE B-1. TRIP DESCRIPTIONS FOR TUNNEL MEASUREMENTS BY TSC

(All Data for Through Freight Terrain Operating Over Mountainous Terrain)

| Date | Tunnel | Tunnel Length | Ventilation | Time in Tunnel | Equipment Sampled | Length of Run | Duration of Run |
|---|---|---|---|---|---|---|---|
| 10/28/74 | Cascade | 7.8 miles | Yes | 20 min. | Lead Locomotive SD-40-2 | 61 miles | 2 hours |
| 10/30/74 | Cascade | 7.8 miles | Yes | 35 min. | Lead Locomotive SD-40-2 | 74 miles | 2 hrs. 45 min. |
| 10/31/74 | Cascade | 7.8 miles | Yes | 25 min. | Rear Helper Locomotive SD-40-2 | 62 miles | 2 hours |
| 11/1/74 | Cascade | 7.8 miles | Yes | 35 min. | Caboose | 125 miles | 5 hours |
| 12/9/74 | Hoosac | 5.5 miles | Yes | 9 min. | Caboose | 18 miles | 1 hour |
| 12/9/74 | Hoosac | 5.5 miles | Yes | 9 min. | Lead Locomotive GE-U33C | 18 miles | 1 hour |
| 12/9/74 | Hoosac | 5.5 miles | Yes | 9 min. | Caboose | 35 miles | 2 hrs. 7 min. |
| 12/9/74 | Hoosac | 5.5 miles | Yes | 9 min. | Lead Locomotive GE-U33C | 35 miles | 2 hrs. 7 min. |
| 12/10/74 | Hoosac | 5.5 miles | Yes | 9 min. | Caboose | 30 miles | 2 hrs. 14 min. |
| 12/10/74 | Hoosac | 5.5 miles | Yes | 9 min. | Lead Locomotive GE-U23C | 30 miles | 2 hrs. 15 min. |
| 12/10/74 | Hoosac | 5.5 miles | Yes | 9 min. | Lead Locomotive GE-U23C | 24 miles | 2 hrs. 45 min. |
| 12/10/74 | Hoosac | 5.5 miles | Yes | 9 min. | Caboose | 24 miles | 2 hrs. 45 min. |
| 4/1/75 | Hoosac | 5.5 miles | Yes | 9 min. | Lead Locomotive | 49 miles | 2 hrs. 20 min. |
| 4/1/75 | Hoosac | 5.5 miles | Yes | 9 min. | Caboose | 49 miles | 2 hrs. 20 min. |

TABLE B-1. TRIP DESCRIPTIONS FOR TUNNEL MEASUREMENTS BY TSC (CONTINUED)

(All Data for Through Freight Terrain Operating Over Mountainous Terrain)

| Date | Tunnel | Tunnel Length | Ventilation | Time in Tunnel | Equipment Sampled | Length of Run | Duration of Run |
|---|---|---|---|---|---|---|---|
| 4/2/75 | Hoosac | 5.5 miles | Yes | 9 min. | Lead Locomotive | 55 miles | 2 hrs. 42 min. |
| 4/2/75 | Hoosac | 5.5 miles | Yes | 9 min. | Caboose | 55 miles | 2 hrs. 42 min. |
| 5/20/75 | Cascade | 7.8 miles | Yes | 20 min. | Lead Locomotive SD-40-2 | 30 miles | 1 hr. 30 min. |
| 5/20/75 | Cascade | 7.8 miles | Yes | 20 min. | Helper Locomotive F-7 | 30 miles | 1 hr. 30 min. |
| 5/20/75 | Cascade | 7.8 miles | Yes | 26 min. | Helper Locomotive F-7 | 32 miles | 2 hrs. 20 min. |
| 5/20/75 | Cascade | 7.8 miles | Yes | 26 min. | Lead Locomotive SD-40-2 | 32 miles | 2 hrs. 20 min. |
| 5/21/75 | Cascade | 7.8 miles | Yes | 32 min. | Rear Helper F-7 | 32 miles | 2 hours |
| 5/21/75 | Cascade | 7.8 miles | Yes | 32 min. | Caboose | 30 miles | 1 hr. 17 min. |
| 5/21/75 | Cascade | 7.8 miles | Yes | 32 min. | Lead Locomotive SD-40-2 | 30 miles | 1 hr. 17 min. |
| 5/22/75 | Cascade | 7.8 miles | Yes | 30 min. | Caboose | 10 miles | 40 min. |
| 5/22/75 | Flathead | 7.7 miles | Yes | 12 min. | Caboose | 10 miles | 15 min. |
| 5/23/75 | Flathead | 7.7 miles | Yes | 16 min. | Caboose | 10 miles | 18 min. |
| 5/23/75 | Flathead | 7.7 miles | Yes | 15 min. | Caboose | 10 miles | 19 min. |
| 5/24/75 | Blossberg | 0.7 miles | No | 4 min. | Caboose | 5 miles | 15 min. |

TABLE B-1. TRIP DESCRIPTIONS FOR TUNNEL MEASUREMENTS BY TSC (CONTINUED)

(All Data for Through Freight Terrain Operating Over Mountainous Terrain)

| Date | Tunnel | Tunnel Length | Ventilation | Time in Tunnel | Equipment Sampled | Length of Run | Duration of Run |
|---|---|---|---|---|---|---|---|
| 5/24/75 | Bozeman | 0.7 miles | No | 3 min. | Caboose | 10 miles | 38 min. |
| 5/24/75 | Bozeman | 0.7 miles | No | 2.5 min. | Caboose | 15 miles | 1 hour |
| 5/25/75 | Bozeman | 0.7 miles | No | 8 min. | Caboose | 13 miles | 45 min. |
| 5/26/75 | Blossberg | 0.7 miles | No | 4 min. | Caboose | 20 miles | 1 hr. 15 min. |
| 5/28/75 | Stampede | 2.0 miles | No | 8 min. | Lead Locomotive | 25 miles | 1 hr. 30 min. |
| 5/28/76 | Stampede | 2.0 miles | No | 8 min. | Caboose | 25 miles | 1 hr. 30 min. |

TABLE B-2. TRIP DESCRIPTIONS AND MEASUREMENT INFORMATION FOR SCOTT ENVIRONMENTAL TECHNOLOGY INC.

| Railroad | Data | Trip Length (miles) | Trip Duration | Sampling Area | Route |
|---|---|---|---|---|---|
| Penn Central | 2/11/76 | 266 | 9 hr. 20 min. | Cab Ahead Locomotive GP-38-2 | Harrisburg to Conway, PA |
| Penn Central | 2/12/76 | 283 | 12 hr. 54 min. | Caboose | Conway to Harrisburg, PA |
| Penn Central | 2/14/76 | 266 | 9 hr. 28 min. | Caboose | Harrisburg to Conway, PA |
| Penn Central | 2/15/76 | 150 | 7 hr. 7 min. | Locomotive SD-40 | Conway to Altoona, PA |
| Penn Central | 2/16/76 | 102 | 7 hr. 52 min. | Helper Locomotive Through Tunnel SD-40 | Altoona to Southport |
| Penn Central | 2/18/76 | --- | 7 hr. 10 min. | Yard Switcher SW7 | Altoona Freight Yard |
| Penn Central | 2/19/76 | --- | 6 hr. 46 min. | Yard Switcher SW7 | Altoona Freight Yard |
| Penn Central | 2/20/76 | 124 | 5 hr. 22 min. | Locomotive GP-38-2 | Altoona to Harrisburg |
| Southern | 5/4/76 | 129 | 7 hr. 47 min. | Locomotive Long-Hood Forward EMD-SD-35 | Ashville, NC to Knoxville, TN |
| Southern | 5/5/76 | 129 | 7 hr. 34 min. | Locomotive Long-Hood Forward SD-45 | Knoxville, TN to Ashville, NC |
| Southern | 5/6/75 | 87 | 4 hr. 26 min. | Caboose | Ashville, NC to Morristown, TN |
| Southern | 5/6/76 | 87 | 7 hr. 32 min. | Locomotive, Long-Hood Forward SD-45 | Morristown, TN to Ashville, TN |
| Southern | 5/7/76 | --- | 4 hr. 55 min. | Switchyard Locomotive EMD-NW2 | Ashville Freight Yard |

## APPENDIX C. RELATED STUDIES

### C.1 PREVIOUS FIELD STUDIES

Since the Second World War, when diesel locomotives became available for railroad freight operations, there have been several studies of air pollution in railroad tunnels. The published reports resulting from those studies are summarized in Table C-1.

In the discussions that follow, peak pollutant concentrations are repeatedly compared with workplace eight-hour average limits, the latter being the only available standards.

Study A(1) was required because the Great Northern Railroad wanted to supplement existing electric traction, for which the Cascade Tunnel had been designed, with diesel helper locomotives near the middle of freight trains. During upgrade (eastbound) runs with trains thus equipped, CO concentrations in excess of 100 ppm and $NO_x$ concentrations in excess of 50 ppm were observed, both in the caboose and at trackside in the tunnel. Although the technique was not specified, the measurements appear to be derived from laboratory analysis of grab samples. Although these concentrations exceeded the workplace limits existing for these gases at that time (100 ppm CO and 25 ppm $NO_x$), the typical exposures were less than 1/2 hour and therefore did not represent a recognized hazard. Since then, the CO limit has been reduced to 50 ppm (8-hour time-weighted average) but again, due to the low exposure time, no recognized hazard existed.

Study B (2) was initiated as a result of a complaint of the Railroad Brotherhoods to the California Railroad Commission about hazards to the health and safety of railroad employees in the operation of trains through tunnels. These hazards were thought to have increased as freight hauling involved greater locomotive power and train tonnage. Trains powered by oil-fired superheated steam (and occassionally diesel) locomotives were tested in the tunnels of three railroads (WP, SP, and ATSF). The high temperature and humidity produced by steam locomotives were judged to be a far more serious hazard than gas concentrations. The observed

TABLE C-1. PREVIOUS FIELD STUDIES

| Study | Reference | Year of Publication | Test Location | Testing Organization | Requesting Organization |
|---|---|---|---|---|---|
| A | (1) | 1946 | Cascade Tunnel | US Bureau of Mines | Great Nothern |
| B | (2) | 1946 | Tunnels in California | State of California | State of California |
| C | (3) | 1954 | Cascade Tunnel | State of Washington | State of Washington |
| D | (4)<br>(5)<br>(6) | 1958 | Tunnels in California | State of California | State of California |
| E | (7) | 1958 | St. Clair Tunnel | Canadian National | Canadian National |
| F | (8) | 1967 | Unidentified Tunnel | Univ. of Washington | Not Given |
| G | (9)<br>(10)<br>(11) | 1972<br>1973<br>1973 | Cascade Tunnel<br>Cascade Tunnel<br>Moffat Tunnel | FAA Oklahoma City<br>FAA Oklahoma City<br>FAA Oklahoma City | FRA<br>FRA<br>FRA |
| H | (12) | 1974 | Tunnels in California | Scott Research Labs. | Southern Pacific |
| I | (13) | 1974 | Flathead Tunnel | Pollution Curbs | Burlington Nothern |

concentrations of $SO_2$, CO, and $NO_x$ often exceeded "critical levels" as defined in the report. The $SO_2$ critical level of 20 ppm (four times the 1975 OSHA 8-hour average limit) was often exceeded, reaching 122 ppm in one case. $NO_x$ was measured less often than $SO_2$ or CO; its critical level being 25 ppm (equal to the 1975 eight-hour average limit for NO). In certain tunnels, $NO_x$ reached 41 ppm in the cab of the third locomotive of one all-steam train, and 122 ppm in the cab of one diesel lead locomotive.

The report of Study B (2) offered a clear description of procedures, an analysis of all factors that might affect the measured hazards, and presented data, conclusions, and recommendations. To alleviate the hazards, it recommended electrification or dieselization (though diesel $NO_x$ emission levels were recognized as dangerous), elimination of tunnels by daylighting or route changes, use a cab-ahead locomotives (as done on one SP tunnel route since 1909), ventilation of cabs, ventilation of tunnels, increased train speed, and reduced train tonnage.

Study C (3) included pollution measurements in the Cascade Tunnel, using electric lead locomotives and diesel helpers (as in Study A), and also using all-diesel traction. The length-of-stain measurement technique was used. CO was not found in any of the tests, indicating that the CO instrumentation probably was incapable of measuring low levels. $NO_x$ reached 35 ppm in the cab of the first helper locomotive of the all-diesel train. In both Studies A and C, the levels of $NO_x$ (high by present OSHA standards) were compared with a table of the levels required to produce immediately observable physiological responses. Study C noted, "If at any time the train becomes stalled in the tunnel, it would be necessary to stop the diesel motors in order not to build up a harmful concentration of gases". Subsequently, ventilating fans and a door were installed at the eastern portal of the Cascade Tunnel.

In Study D, (4) (5) (6) toxic gas levels were measured on freight runs through numerous tunnels and physiological measures of the trainmen were taken before and after such trips. High CO concentrations were found in westbound trips through Tunnel #41, near Norden CA, when several diesel units were malfunctioning. The report recommended against burning high-sulfur fuel on westbound trips through Tunnel #41, because of the high $SO_2$ concentrations observed there. Peak $NO_2$ levels often exceeded acceptable eight-hour average limits in tunnel air, though never inside a well-closed caboose. Caboose crews were therefore advised to open all doors and windows between tunnels, and to close them upon approaching a tunnel; and stopping a train with its caboose still in the tunnel was discouraged. No significant difference between summer and winter pollution levels was found, but subjective response of trainmen were much stronger in summer, when caboose and cab temperatures was higher. The medical findings revealed increased physiological irritation in most trainmen after one or more trips, but less than one-half of the trainmen were irritated on any given trip. Both the observed physiological changes and subjective complaints were strongest in caboose crew members over 45 years old.

In Study E (7) was an investigation of the 1.1 mile, two-percent grade St. Clair Tunnel between Sarnia, Ontario and Port Huron, Michigan. The study revealed concentrations of CO, $NO_2$, $NO_x$, and formaldehyde in passenger train cars and locomotive cabs during six -minute traverses of the tunnel that were deemed acceptable by Canadian standards. However, serious exposures were observed in a stalled train. Maximum levels of $NO_x$ (36.5 ppm), and formaldehyde (6.4 ppm), were measured in a trailing locomotive at the head of a train.

In Study F (8), higher CO and $NO_2$ concentrations were found in a highway tunnel than in a railroad tunnel, neither of which was identified. In the latter case, a train was halted at the center of the tunnel, where its power was operated at half load for at least five minutes. This might have been achieved by apply air brakes and power simultaneously. The report concluded that "train crewmen working in engine cabs do not appear to be exposed to any significant amounts of diesel exhaust products"; however, insufficient data was presented to adequately determine the basis for this conclusion.

In Study G (9) (10), three reports were produced, derived from two series of tests in the Cascade Tunnel and one in the Moffat Tunnel. CO, $NO_2$, $SO_2$, and aldehydes were measured by length-of-stain methods, and particulates and hydrocarbons by personal integrating samplers. In one of the tests, a train was stopped in the Cascade Tunnel for one hour with one ventilating fan operating. Maximum $NO_2$ observed was 66 ppm in a caboose in the Cascade Tunnel; all other results in both tunnels were within present OSHA limits. Use of rail-road supplied respirators was recommended for pollution-sensitive trainmen.

In Study H (11), CO, $NO_x$, and total hydrocarbons were measured continuously, and particulates intermittently, along the same tunnel route as Study D, and on other routes. Instrumentation was mounted in a dynamometer car, with long sample lines to the train crew locations (lead locomotive cab, helper cab, and caboose, on separate trips). Unlike previous studies, it used the continuous records of entire trips to make "engineering estimates" of time-weighted averages. The measured results indicated that the levels were well within currently acceptable limits. However, a 20-minute caboose exposure to 147 ppm CO was reported during one trip through Tunnel #41. In a lead locomotive cab on a non-tunnel route between Bakersfield and Tehachapi CA, peak CO concentrations between 50 and 335 ppm were observed over a 40 minute period.

In Study I (12), $NO_x$, $SO_2$, aldehydes and CO were measured by length-of-stain methods, in the recently built Flathead Tunnel, particulates by filter weighing, and hydrocarbons by gas chromatography of grab samples. The highest contaminant concentration were found when a westbound (downgrade) train succeeded three eastbound trains without intervening ventilation by the tunnel fans. In this case, these concentrations were higher in the locomotive cab than in the caboose, as might be expected when the train is forcing polluted air out of the tunnel while adding some of its own. Under these conditions, a maximum $NO_x$ concentration of 35 ppm was found at trackside in a bay near the west portal, and a maximum total aldehyde concentration of 75 ppm was found in the locomotive cab. For comparison, OSHA 8-hour average limits for individual aldehydes include 3 ppm for formaldehyde, 200 ppm for acetaldehyde, and 0.1 ppm for acrolein, all of which occur in diesel exhaust. On the other hand, for a train stopped in the tunnel while the ventilating system was working, pollutant concentrations were well within OSHA 8-hour average limits.

## C.2 OTHER RELEVANT STUDIES

In 1972, Southern Pacific (13) reported tests of emissions of four stationary diesel-electric locomotives under electrical-resistive load, as a function of power setting and history of maintenance. The emissions measurements were conducted by Scott Research Laboratories, and the study was funded by the Association of American Railroads and three of its member railroads (ATSF, SP, and UP). The study was motivated by the possibility that California highway diesel emissions standards might be applied to the railroads. Stack emissions were aspirated through sample lines; CO and NO (by a non-dispersive infrared analyzer), and total hydrocarbons (by preheated flame-ionization detection), were continunously monitored. Water-soluble aliphatic aldehydes were cyclically monitored by the MBTH method (14). This study was largely exploratory, but some tentative conclusions were reached regarding the dependance of CO, $NO_x$, and hydrocarbons on engine type, method of air introduction, maintenance condition, and load. Absolute $NO_x$ emissions increased with increasing load, but when normalized (divided by the load), they decreased with increasing load. Hydrocarbons behaved similary, though the absolute increase with load was not as strong as that of $NO_x$. CO emissions, both absolute and normalized, showed two peaks, one at idle and the other in the medium-to-high load range. Reduction in air supply increased CO emissions. Engines with lower fuel consumption for a given load produced higher $NO_x$ emissions.

In 1971, Dravnieks (15), et al., of the IIT Research Institute reported on measurements of componants of exhaust from a small (non-railroad) diesel engine. Of the many hundreds of compounds that were separated, "over 80 odorants were inventoried. Many of these were identified. The odorous compund types include: aliphatic aldehydes and acids; aliphatic compounds with more than one position of unsaturation; alkyl derivatives of benzene, indane, tetralin, and naphthalene; aldehyde and ketone derivatives of benezene and alkylbenzenes; and sulfur-containing species." The columns had poor collection efficiency for higher volatile substances such as formaldehyde and acrolein which do occur in hydrocarbon combustion exhausts. Since this study addressed odorants, rather than toxic substances, the lit of observed compounds is incomplete from the health viewpoint.

In the 1942 article entitled "Piston Effect of Trains in Tunnels", R. L. Dougherty, (16) studied the ventilation of the Moffat Tunnel, and recommended the use of a low-pressure, high-capacity fan to clear smoke from the empty tunnel, in lieu of the then existing high-pressure, lower-capacity fan that provided air when a train was in the tunnel. Moreover, it was pointed out that blowing air in the direction of train movement would save energy at both the fan and the locomotive. Present ventilation of the Moffat, Cascade, and Flathead Tunnels follows the first recommendation, but violates the second, in an effort, possibly, to maximize visibility from the lead locomotive cab.

Battigelli (17) has studied the effects of diesel exhaust in railroad engine houses and found that "the exhaust discharged within a railroad engine house is immediately diluted to concentrations well below those commonly accepted as tolerable for an 8-hour per day exposure". His data were taken 6-12 feet from an idling locomotive in an engine house and the maximum levels obtained were:

| | |
|---|---|
| oxides of nitrogen | 6.4 ppm |
| total aldehydes | 1.8 ppm |
| formaldehyde | 0.11 ppm |
| acrolein | 0.015 ppm |
| sulfur dioxide | 0.34 ppm |

There was no measurement of carbon monoxide.

In another study, Battigelli (18) investigated environmental and clinical effects on workmean exposed to diesel exhaust in railroad engine houses. His literature review of related work showed that high concentrations of known toxic pollutants had not been found. He went on to note, "If one omits the occasional values which have exceeded the MAC (maximum allowable concentration) reference level, the great majority of single diesel pollutants determined in close environments have been well within acceptable limits." Battigelli also noted that most of the complaints registered by the railroad members participating in these tests came from those members that smoked.

Finally, Battigelli (19) investigated the effects of diesel exhaust on railroad employees in locomotive repair shops. In this study, exhaust gases from a single cylinder, four cycle, seven horsepower diesel engine was diluted and directed to subjects who inhaled the diluted gas or whose eyes were exposed to the gas. The only complaint by the subjects as they were exposed to mouth inhalation was a transitory, unpleasant taste which quickly disappeared after the exposure was terminated. However, the same concentrations in the eye test were all sooner or later objectionable to the point that several abandoned the tests.

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