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Diesel Particulate Matter Exposure to Railroad Train Crews

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APPLIED STUDIES

Exposure assessments were conducted aboard diesel locomotives. Results were evaluated to determine variables that affect exposure to DPM (diesel particulate matter) and to assess use of EC (elemental carbon) and OC (organic carbon) as surrogates for DPM. National Institute for Occupational Safety and Health Method 5040 was used for collection and analysis of samples in locomotives and in nonrailroad settings. The level of EC, but not OC, in locomotives was found to be significantly affected by position of exhaust stacks and windows. EC ranged from <1 to 45 μg/m³ with a geometric mean (GM) of 3.7 μg/m³ and OC ranged from 4 to 4570 μg/m³ with a GM of 36.3 μg/m³. Background measurements of EC ranged from <1 to 8 μg/m³ and OC levels were 4 to 84 μg/m³. This study confirms that train crew exposure to DPM is much lower than exposures for miners, is comparable to background urban exposures, and is lower than but comparable to exposures for truck drivers. It also indicates that EC levels are highly predictive of diesel exhaust exposure whereas OC levels are not, and that open windows and exhaust stack(s) in front of the locomotive cab have a significant effect on EC.
Keywords: diesel exhaust, elemental carbon, organic carbon, railroad

Since the late 1950s essentially all locomotives in railroad freight service have been diesel powered. The current fleet consists of approximately 22,000 locomotives ranging in size from 1500 to 6000 horsepower that are manufactured principally by General Electric (GE) and the Electro-Motive Division (EMD) of General Motors. Historically, all EMD locomotives have used two 2-cycle engines, whereas GE used a four-cycle engine.[(1)] Both manufacturers use the diesel engine to power electric drive motors.

Diesel exhaust is a complex mixture of gases, vapors, and particulates. Constituents have been reported to include carbon monoxide; carbon dioxide; sulfur dioxide; nitrogen oxides; benzene; 1,3-butadiene; various aldehydes; and polynuclear aromatic hydrocarbons.[(2)] Diesel particulate (soot) consists of an elemental carbon (EC) core comprising 60–70% of the particle, onto which other material may be adsorbed. Diesel particulates are less than 1 μm aerodynamic diameter in size and tend to form chains or clusters.[(3,4)] Estimates of the number of different compounds generated by a diesel engine that can be adsorbed onto the EC core have ranged up to 18,000.[(5)] Because of the complexity of this mixture, it is not possible to measure whole diesel exhaust. Investigators have used various components as surrogates or markers of exposure to quantify diesel exhaust exposure. Early investigations focused on carbon monoxide and irritant gases such as aldehydes and oxides of nitrogen.[(6–8)] Later studies utilized various surrogates to quantify the particulate component of whole diesel exhaust.[(3,9–13)]

In an epidemiological study of railroad worker exposure to diesel exhaust, Woskie and coworkers sampled respirable dust as a surrogate for diesel particulate matter (DPM). Those samples were adjusted to account for the significant amount of particulate derived from tobacco smoke. After determining weight gain, each filter was composited and analyzed for nicotine. This allowed the fraction of particulate from cigarette smoke to be subtracted from the total respirable particulate yielding an adjusted respirable particulate (ARP) level. The authors recognized that the samples may have been contaminated with sand, dirt, fibers, and other particulate matter, but had no mechanism for accurately subtracting these materials. Based on this analytical methodology freight engineers had a geometric mean (GM) exposure to ARP of 73 μg/m³, and there was a GM exposure level to ARP of 49 μg/m³ for yard engineers.[(10,14)]

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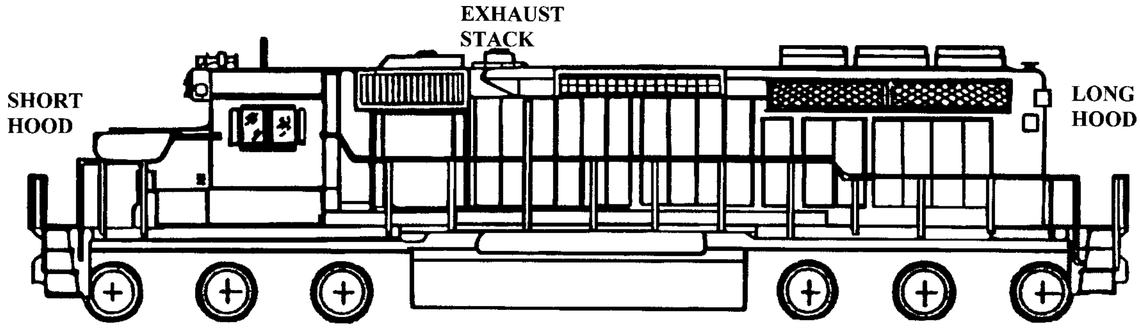

FIGURE 1. Diesel locomotive

In underground coal mines utilizing diesel equipment, particulate analysis exhibits bimodal distribution in which 90% of the coal dust is larger than 1.0 μm aerodynamic diameter and more than 90% of the DPM is smaller than 1.0 μm with a mass median aerodynamic diameter (MMAD) of 0.2 μm. The combination of DPM and coal dust led to the extensive use of a dichotomous sampler when sampling for DPM. The dichotomous sampler separates the particulate sample into mass fractions above and below 0.8 μm MMAD. The dichotomous sampler seems to be appropriate for sampling DPM in the presence of coal dust because there appears to be little relative interference in the small particle range to confound the DPM sample. However, this may not be true in other environments where other small particles may exist and DPM levels are lower and may confound the DPM sample.[3,15]

The most recent studies have used EC as a surrogate for evaluating the particulate component.[4,12,16] EC has been found to be the major component of DPM and has been described to be a "very sensitive and precise indicator" of DPM exposure that is not influenced by tobacco smoke, which is almost entirely OC.[4,17,18]

The American Conference of Governmental Industrial Hygienists (ACGIH) recently promulgated a proposed threshold limit value (TLV®) that specifies EC as the surrogate for DPM. The proposed TLV is 20 μg/m³ of EC.[19]

Industrial hygiene samples have been collected routinely to evaluate train crew exposure to diesel exhaust. As part of these ongoing evaluations, DPM levels have been measured under a variety of normal operating conditions using analytical techniques that determined both EC and OC levels in the sample. For comparison purposes the same sampling and analytical techniques were used to collect background samples in nonrailroad urban and rural settings.

METHODS AND MATERIALS

Sampling and Analytical Method Selection

ACGIH issued a proposed TLV of 150 μg/m³ for DPM in 1995, which was revised to a proposed 50 μg/m³ in 1999. This was further revised in 2001 to 20 μg/m³ measured as EC.[19] The Mine Safety and Health Administration (MSHA) also issued a regulation for DPM of 400 μg/m³ based on the measurement of total carbon (TC), which is EC plus OC. The 400 μg/m³ concentration limit is to be reduced to 160 μg/m³ in 2006. These MSHA limits are based on DPM being composed of approximately 80% TC.[20]

The National Institute for Occupational Safety and Health (NIOSH) Analytical Method 5040 for Elemental Carbon (Diesel Particulate) requires an open-faced quartz fiber filter (QFF) and thermo-optical analysis.[21] This method indicates that a size-selective impactor may be required in environments where coal dust may interfere positively with the analysis. There was no coal dust in the environments assessed in this study and thus, size selection was deemed to be unnecessary.

The collected QFF samples originally were submitted to the only commercial lab performing a thermal-optical method for EC. During the latter part of the study, samples also were submitted to an American Industrial Hygiene Association-accredited laboratory to expedite sample analysis. Both laboratories use the thermal-optical technique specified in NIOSH 5040 analytical method.[21]

Sampling Strategy

EC and OC levels were monitored on two major U.S. railroads in a variety of locations, terrains, weather conditions, types of trains, and models of locomotives. No air-conditioned locomotives were included in this study. The same sampling techniques were used to collect background samples in various nonrailroad locations throughout the United States including a national park, a beach, and major city locations. Many of the city locations were taken in downtown areas near the local courthouse.

During the assessment of occupational exposures, older locomotives, steeper grades, and tunnels were selected for sampling if available. A total of 19 different locomotive models manufactured between 1968 and 1997 by GE or EMD were included in this study. The terrain was categorized as flat, rolling, or mountainous, and it was noted whether the windows were open or closed. The crews positioned the windows for their own comfort, and the investigator had no input except when riding in an otherwise unoccupied trailing unit when the windows were opened to evaluate maximum possible exposures. Testing was conducted on both lead and trailing locomotives. Train crews are subject to the Hours of Service Regulation enforced by the Federal Railroad Administration. Their workday is determined by the length of run worked with a maximum of 12 hours prior to 8 hours of rest. During the tests the length of time the crew was on the locomotive ranged from 2 hours 4 min to 10 hours 29 min.

One or more locomotives are used to pull freight trains. Each can be operated facing in either direction and are referred to as "long-hood" or "short-hood" forward (Figure 1). The short-hood forward configuration is the more common, where the exhaust stack of the locomotive is approximately 5 m behind the

TABLE I. Summaries of Sampling Data

Date	Railroad	Loco. Mfg.	Loco. Type	Loco. Mfg. Date	Preceding Stacks	Run Type	Terrain	Windows
7/12/96	A	EMD	GP38-2	1978	0	local	flat	open
4/30/96	A	GE	CW40-8	1993	0	through	flat	closed
9/10/96	A	GE	CW40-8	1992	0	through	rolling	closed
9/10/96	A	EMD	SD40-2	1981	0	through	rolling	open
9/13/96	A	GE	CW40-8	1991	0	through	rolling	closed
9/23/96	A	GE	GP40-2	1975	0	through	flat	open
9/24/96	A	GE	C30-7	1979	0	through	flat	open
9/26/96	A	EMD	SD40-2	1980	0	through	flat	open
9/27/96	A	GE	CW40-8	1991	0	through	flat	open
7/11/96	A	EMD	GP38-2	1979	0	local	flat	open
9/12/96	A	GE	B36-7	1985	0	through	rolling	open
5/1/96	A	EMD	Road Slug	1991	0	through	rolling	open
5/2/96	A	EMD	SD40-2	1980	0	through	mountain	open
12/4/97	A	EMD	GP40-2	1981	0	through	mountain	closed
9/24/97	A	EMD	SD40	1968	0.5	yard	flat	open
9/25/97	A	EMD	MP15AC	1978	0.5	yard	flat	open
7/29/97	A	EMD	GP40-2	1972	0	yard	flat	open
7/30/97	A	EMD	SD40	1971	0.5	yard	flat	open
10/21/97	A	GE	CW44AC	1996	0	through	flat	closed
10/22/97	A	GE	CW44AC	1995	0	through	flat	closed
10/23/97	A	EMD	SD50	1984	0	through	flat	closed
7/15/97	A	GE	CW44-9	1994	0	through	rolling	closed
7/15/97	A	GE	C40-8	1990	2	through	rolling	open
7/15/97	A	GE	CW40-8	1992	0	through	rolling	open
7/15/97	A	GE	CW40-8	1992	2	through	rolling	open
7/16/97	A	GE	C40-8	1989	0	through	rolling	open
7/16/97	A	GE	C40-8	1989	2	through	rolling	open
7/17/97	A	GE	B36-7	1985	0	through	rolling	open
7/17/97	A	GE	B36-7	1985	2	through	rolling	open
7/18/97	A	GE	B36-7	1985	1	through	rolling	open
11/17/97	A	EMD	SD40-2	1980	0	through	flat	open
11/20/97	A	GE	C30-7	1981	0	through	flat	closed
11/20/97	A	GE	CW44-9	1994	0	through	flat	closed
8/26/97	A	GE	CW44AC	1996	1.5	pusher	mountain	closed
8/27/97	A	EMD	SD40-2	1989	0	local	mountain	open
6/3/97	B	EMD	SD60	1989	0	through	flat	open
6/3/97	B	GE	CW44-9	1994	1	through	flat	open
6/4/97	B	EMD	SD90MAC	1995	1	through	flat	open
6/4/97	B	GE	CW44-9	1994	2	through	flat	open
6/5/97	B	EMD	SD40M-2	1968	1	through	flat	open
6/6/97	B	GE	AC4400CW	1997	1	through	flat	open
6/7/97	B	GE	C40-8	1988	1	through	flat	open
11/6/97	A	EMD	SW1500	1971	0.5	yard	flat	open
6/26/98	A	GE	B23-7	1978	0	through	flat	open
6/28/98	A	GE	CW44-9	1994	0	through	flat	open
6/28/98	A	GE	CW40-8	1991	0	through	flat	open
7/7/98	A	GE	B36-7	1985	0	through	flat	open
7/8/98	A	GE	B36-7	1985	0	through	flat	open
6/27/98	A	GE	C40-8	1989	0	through	flat	open

operating cab. In the long-hood forward configuration the exhaust stack is approximately 5 m in front of the operating cab. Therefore, a sample collected in a short- hood forward leading locomotive would have no preceding stacks. A leading locomotive with long-hood forward would have one exhaust stack preceding the sampled cab.

Freight train runs can be categorized as "road" (from point A to point B with little or no intermediate work), "local" (from point A to point B or back to point A with intermediate stops to pick up or drop off rail cars), or "yard" (moving rail cars within a rail yard or industry). A typical freight train crew consists of an engineer and a conductor, which can be supplemented with a brakeman/switchman for local runs or yard jobs. The crew typically occupies the cab of the first (lead) locomotive except when the brakeman/switchman and/or conductor dismount for switching activities, including coupling and uncoupling freight cars. The engineer may be the only cab occupant during switching and coupling activities. Before the use of a caboose was largely discontinued in the mid−1980s, road train crews consisted of up to five people, two of whom occupied the caboose. Currently, there are occasions when a nonworking crew might "deadhead" (travel to another location to begin an assignment or return home) by riding

TABLE I. Extended

Sample Time (Min)	Elemental Carbon µg/m³	Organic Carbon µg/m³	Elemental to Total Carbon Ratio %
309	4	84	5
474	3	39	7
291	<4	26	13
624	3	40	7
268	<4	26	13
605	<2	32	6
539	4	53	7
546	<2	35	5
593	<2	31	6
312	<3	4570	<1
622	4	47	8
608	3	8	27
518	4	42	9
430	2	41	5
335	3	12	19
214	5	84	5
577	2	30	7
275	<2	37	6
455	<2	40	5
350	<2	31	6
400	2	32	6
315	<2	37	5
313	20	46	30
272	<3	33	8
278	12	69	15
344	<2	13	13
340	37	72	34
394	4	47	8
395	45	87	34
444	22	42	34
627	<1	33	3
175	<4	71	5
567	<1	36	3
629	2	5	24
529	6	35	14
450	<2	21	7
454	28	57	33
237	36	<12	75
383	4	4	53
575	11	46	20
603	12	29	29
424	23	61	27
394	2	31	7
380	<2	45	4
124	<6	50	11
235	<3	40	7
366	4	59	6
265	5	70	7
420	<2	29	6

in one of the trailing locomotives. In some mountainous terrain, and with certain types of trains, one or more pusher or helper locomotives may be added to the middle or rear of the train. These locomotives may or may not be occupied by train crew members.

The samples were collected on the engineer's operating console in each locomotive. This position is within an arm's length of the engineer and was selected as being representative of a breathing zone sample, yet not obtrusive to the engineer. A previous study in this type of railroad setting demonstrated that there was no significant difference between fixed location samples and personal samples.[10] A flow rate of approximately 2 L/min was maintained, and the samples were collected for the entire work period except for time spent away from the locomotives at the beginning and end of the shift. Any samples with flow rate variations exceeding 5% during the sampling period were discarded as were samples taken with tobacco smokers in the cab.

Data Analysis

GMs, based on log transformation of the data, were determined for all samples and for a number of subgroups. Prior studies of EC found the data to be lognormally distributed.[4,22] For samples reported as below the laboratory limit of detection (LOD), the LOD of the method was used to calculate the EC or OC level. All exposure estimates are expressed as the work period time-weighted average (TWA). The data were analyzed for significant effects of exhaust stack location, railroad, locomotive manufacturer, window position (open or closed), run type, and terrain using Statistical Analysis System (SAS®) software.[23] Analysis was done using the General Linear Model Procedure on the log-transformed data. Differences between means were evaluated with the Duncan's mean test. GM values were calculated by the following equation.

$$GM = \exp\left(\frac{\sum_{i=1}^{n} \ln x_i}{n}\right)$$

where x_i = untransformed EC or OC concentration.

Geometric standard deviation (GSD) was calculated by the following equation.

$$GSD = \exp(s_{lnx})$$

where s_{lnx} is the sample deviation of the log-transformed data.

RESULTS

The EC and OC levels under various conditions are summarized in Table I. EC and OC concentrations are reported to the nearest whole microgram. "Preceding stacks" refers to exhaust stacks in front of the sample in the direction of travel. Fractional stacks are the result of a change of direction during sample collection. The statistical analysis results are summarized in Table II.

Data analysis shows that exhaust stacks preceding the sample have a highly significant effect on EC ($p=0.0001$). Window position (open or closed) also has a highly significant effect on EC ($p=0.0001$). None of the other variables have a significant effect on EC levels. Both the type of run (road, yard, or local) ($p=0.004$) and railroad ($p=0.01$) had a significant effect on OC but not EC. All runs on one railroad were of the road type. Caution is advised in interpreting some of these OC results, as some variables had few data points. No other variables had a statistically significant effect on EC. The study was not well balanced in design in terms of run type, and more data may be necessary to fully evaluate some of the OC results. The one OC result that is orders of magnitude higher than the others was collected during industrial switching of a wood pulp mill and is believed to be the result of biogenic contamination.

DISCUSSION

Although EC has few sources other than diesel engines, OC may originate from a variety of sources including biogenic materials.[4,24,25] A study of the South Coast Air Basin of California

TABLE II. Results of Statistical Analysis

Conditions	Number of Samples	Elemental Carbon (μg/m³) GM	Elemental Carbon (μg/m³) GSD	Organic Carbon (μg/m³) GM	Organic Carbon (μg/m³) GSD
No Preceding Stacks	33	2.5	1.5	36.9	2.5
Preceding Stacks	16	10.1	1.9	31.6	2.6
Local Freight	3	4.1	1.4	236.6	13.5
Yard Engine	5	2.8	1.3	32.4	2.0
Road Freight[A]	40	4.5	2.7	37.1	1.8
4 Cycle Engine	31	4.9	2.7	36.6	2.0
2 Cycle Engine	18	3.2	2.2	44.2	3.4
Railroad A	42	3.6	2.2	42.8	2.5
Railroad B	7	10.9	3.1	23.6	2.8
Mountainous	4	2.9	1.8	23.3	2.8
Rolling	14	6.4	2.9	40.5	1.6
Flat	31	3.6	2.4	41.5	2.9
Windows Open	38	4.9	2.7	42.4	2.7
Windows Closed	11	2.3	1.5	30.3	1.9
All Samples	49	3.7	2.6	36.3	2.5

[A]Due to the unusual nature of pusher unit, it was left out of these calculations.

found that 65% of the EC was contributed by diesel engines, whereas only 21% of the TC (EC plus OC) particulate was from diesel engines. The remainder of the EC was primarily from other fuels such as gasoline and jet fuel. Other large OC sources included industrial processes, natural gas combustion, and fugitive emissions such as cigarette smoke, cooking food, and wood fires.[26] Preliminary data collected by the Environmental Protection Agency indicates that biogenic sources of volatile organic compounds exceed anthrogenic sources on a national basis.[27] OC also can be generated by many sources in the workplace and is often substantial if gasoline powered equipment is used in the area.[25]

The analyses indicate that EC is a better surrogate for diesel exhaust than TC or OC. This is because of its limited sources, and because variables more likely to effect exposure (e.g., preceding stacks and window position) are highly associated with EC and not associated with OC. Higher diesel exhaust levels are logically expected when windows are open and when the exhaust stack precedes the cab, and these expectations are confirmed by personal observation, such as more odor and visible smoke. These results show that the locomotive cab levels of EC with a GM of 3.7 μg/m³ and a GSD of 2.6 are near background urban levels of EC having a GM of 3.1 μg/m³. The EC level in an engine without exhaust stacks preceding the sampler was a GM of 2.5 μg/m³ compared to a GM of 10.1 μg/m³ with at least one stack preceding the sample. The overall GM for OC was 36.3 μg/m³. The OC GM was 36.9 μg/m³ when there were no preceding stacks and 31.6 μg/m³ with at least one preceding stack. These data indicate that the OC has sources other than diesel exhaust and little relevance in determining DPM exposure.

The EC levels measured in lead locomotives (those without preceding stacks), with a GM of 2.5 μg/m³, are less than local truck drivers with a GM of 4.0 μg/m³ and road truckers with a GM of 3.8 μg/m³. The locomotive EC data was consistent with data collected inside locomotive cabs in a recent Canadian railroad study.[16] Highway background EC levels have been reported to have a GM of 4.0 μg/m³ with residential background levels (defined as at least 1 mile from any major highway) having a GM of 1.1 μg/m³. All of the above referenced samples were collected as submicrometer-sized particulates.[4] Other background EC levels reported include an annual average in Los Angeles of 4.78 μg/m³ and background levels of more than 10 μg/m³ in some areas.[26] NIOSH reported 14–78 μg/m³ EC in a fire station and 8–12 ug/m³ EC as background levels outside of the fire station. These building and fire station samples were collected with open-faced filter cassettes.[28] Railroad train crew EC exposures are well below those found in underground mines where EC levels of 400 μg/m³ have been exceeded.[12] Locomotive levels of OC were inconsistent.

Levels of EC do not correlate well with previously published ARP levels reported for railroad workers, most likely due to the fact that EC is more indicative of DPM, whereas ARP includes particulates from other than diesel emissions.[14]

TC is determined by adding EC to OC. In this study EC constituted a range of <1–75% of the TC in the locomotive cab. The GM of the percentage of EC to TC of samples collected in lead locomotives is 6.3% and in trailing locomotives is 22.2%. This demonstrates that increased diesel exhaust levels result in higher amounts of EC and indicates that TC and OC levels are associated with nondiesel sources. The low ratio of EC to TC in lead locomotives, where the exhaust stack was behind the sampler, compared with the higher ratio of EC to TC in trailing locomotives shows that TC is not indicative of diesel exhaust at low EC levels. The fact that OC levels are similar, whether measured in front of or behind the exhaust stacks, brings into question the relevancy of using OC or TC to determine diesel particulate levels. If diesel particulate contains 70% EC, other sources must be responsible for most of the OC found in these tests.

The background samples collected for comparison purposes are shown in Table III. Detectable background EC levels ranged from 2 to 8 μg/m³ and OC levels ranged from 8 to 62 μg/m³. The EC levels are in the same range as the background levels discussed earlier. The TC of the Denver, Chicago, and San Francisco areas' background sample data is above the proposed TLV for EC of 20 μg/m³. This supports the conclusion that TC has many nondiesel sources and is inappropriate for determining DPM levels. This data and previous research suggest that OC or TC should not be used to calculate whole diesel particulate. If TC data is desired, it may

TABLE III. Background Samples

Location	Date	Sample Time (min)	Sample Rate (L/min)	EC $\mu g/m^3$	OC $\mu g/m^3$	TC $\mu g/m^3$	Elemental to Total Carbon Ratio %
Chicago, IL	7/29/99	480	2.0	8	45	53	15
Crestview, FL	2/24/99	491	2.1	<2	39	39	5
Dade City, FL	2/11/99	332	2.0	4	15	19	21
Dallas, TX	9/21/99	422	2.2	4	39	43	13
Denver, CO	8/31/99	420	2.1	3	84	87	5
Elmhurst, IL	7/29/99	624	2.0	3	21	24	13
Houston, TX	5/1/99	280	2.0	4	30	34	12
Junction City, GA	4/8/99	323	2.1	<2	13	13	15
Kansas City, MO	9/29/99	480	2.5	<1	10	10	17
Kansas City, MO	9/29/99	480	2.6	2	4	6	33
Lakeland, FL	3/25/99	420	1.9	<2	14	14	14
Las Vegas, NV	11/22/99	491	2.2	<2	39	39	5
Los Angeles, CA	7/14/99	430	2.0	2	35	37	5
McCook, NE	7/14/99	360	2.5	<2	48	48	4
McKenzie, TN	4/20/99	335	2.0	<2	21	23	9
McKenzie, TN	4/21/99	413	2.0	<2	20	20	10
Salida Beach, CA	7/15/99	504	2.0	2	8	10	20
San Bernardino, CA	5/25/99	360	2.5	4	29	33	12
San Diego, CA	7/15/99	430	2.0	8	32	40	20
San Francisco, CA	9/30/99	472	2.0	3	59	62	6
San Jose, CA	8/21/99	550	2.5	1	24	25	7
Santa Ana, CA	7/14/99	563	2.0	<1	20	20	5
Sequoia National Forest, CA	7/13/99	480	2.0	3	30	33	9
Shelbiana, KY	6/14/98	267	2.0	3	10	13	75
Shelbiana, KY	10/11/99	77	4.1	5	20	25	20
St. Louis, MO	10/25/99	420	2.0	2	11	13	15
St. Paul, MN	7/14/99	509	1.9	3	25	28	11
Visalia, CA	7/13/99	540	2.0	2	12	14	14

be advantageous to use a size selective sampler to eliminate some potential nondiesel OC sources.

CONCLUSIONS

EC is an appropriate surrogate for determining levels of DPM in the railroad and similar environments. OC and TC are not associated with conditions expected to result in higher levels of DPM, and the use of TC to compare DPM levels to the TLV will result in incorrect conclusions.

The level of DPM, as determined by EC, in lead locomotive cabs is well below the proposed TLV and in the range of background exposures regardless of variables such as railroad, locomotive manufacturer, geographic location, and age of locomotive. Levels of EC are higher if the cab is preceded by exhaust stacks and/or the windows are open. Railroad train crew exposures to EC are comparable with those of truck drivers and much lower than those of underground miners.

REFERENCES

1. **Marre, L.A., and J.A. Pinkepank:** *The Contemporary Diesel Spotter's Guide*. Waukesha, Wisc.: Kalmbach Publishing, 1989.
2. **National Institute for Occupational Safety and Health (NIOSH):** *Current Intelligence Bulletin 50: Carcinogenic Effects of Diesel Exhaust* (DHHS [NIOSH] Publication no. 88–116). Cincinnati, Ohio: NIOSH, 1988.
3. **Cantrell, B.K., and W.F. Watts, Jr.:** Diesel exhaust aerosol: Review of occupational exposure. *Appl. Occup. Environ. Hyg J. 12*:1019–1027 (1997).
4. **Zaebst, D.D., D.E. Clapp, L.M. Blade, et al.:** Quantitative determination of trucking industry workers' exposure to diesel exhaust particles. *Am. Ind. Hyg. Assoc. J. 52*:529–541 (1991).
5. **Weisenberger, B.:** Health effects of diesel emissions—an update. *J. Soc. Occup. Med. 34*:90–92 (1984).
6. **National Institute for Occupational Safety and Health (NIOSH):** *Health Hazard Evaluation/Toxicity Determination, Union Pacific Railroad, Pocatello, Idaho,* by A. A. Apol (NIOSH-TR-042-74). Cincinnati, Ohio: 1973.
7. **National Institute for Occupational Safety and Health (NIOSH):** *Health Hazard Evaluation/Toxicity Determination, White Pass and Yukon Railroad, Skagway, Alaska,* by A. A. Apol (NIOSH-TR-74-1-160). Cincinnati, Ohio: 1974.
8. **U.S. Department of Transportation (DOT):** *Train Generated Air Contaminants in the Train Crew's Working Environment,* by J.A. Hobbs, R.A. Walter, T. Hard, and D. Devoe (FRA/ORD-77/08). Cambridge, Mass.: U.S. Department of Transportation/Federal Railroad Administration, 1977.
9. **Garshick, E., M.B. Schenker, A. Munoz, et al.:** A case-control study of lung cancer and diesel exhaust exposure in railroad workers. *Am. Rev. Respir. Dis. 135*:1242–1248 (1987).
10. **Woskie, S.R., T.J. Smith, S.K. Hammond, M.B. Schenker, E. Garshik, and F.E. Speizer:** Estimation of the diesel exhaust exposures of railroad workers: I. Current exposures. *Am. J. Ind. Med. 13*: 381–394 (1988).
11. **Froines, J.R., W.C. Hinds, R.M. Duffy, W.J. Lafuente, and V. Wen-Chen:** Exposure of firefighters to diesel emissions in fire stations. *Am. Ind. Hyg. Assoc. J. 48*:202–207 (1987).
12. **Stanevich, R.S., P. Hintz., D. Yereb, M. Dosemecci, and D.T. Silverman:** Elemental carbon levels at a potash mine. *Appl. Occup. Environ. Hyg. 12*:1009–1012 (1997).
13. **Garshick, E., M.B. Schenker, A. Munoz, et al.:** A retrospective cohort study of lung cancer and diesel exhaust exposure in railroad workers. *Am. Rev. Respir. Dis. 137*:820–825 (1988).

14. **Hammond, S.K., T.J. Smith, S.R. Woskie, B.P. Lederer, and N. Bettinger:** Markers of exposure to diesel exhaust and cigarette smoke in railroad workers. *Am. Ind. Hyg. Assoc. J. 49*:516–522 (1988).
15. **McCartney, T.C., and B.K. Cantrell:** A cost-effective personal diesel exhaust aerosol sampler. In *Diesels in Underground Mines: Measurement and Control of Particulate Emissions* (IC 9324), pp. 24–30. Washington, D.C.: U.S. Department of the Interior/ Bureau of Mines, 1992.
16. **Verma, D.K., L. Shaw, J. Julian, K. Smolynec, C. Wood, and D. Shaw:** A comparison of sampling and analytical methods for assessing occupational exposure to diesel exhaust in a railroad work environment. *Appl. Occup. Environ. Hyg. 14*:701–714 (1999).
17. **Truex, T.J., J.M. Norbeck, and M.R. Smith:** *Evaluation of Factors That Affect Diesel Exhaust Toxicity.* Riverside, CA: California Air Resources Board,1998.
18. **Norbeck, J.M., T.D. Durbin, T.J. Truex, and M.R. Smith:** *Characterizing Particulate Emissions from Medium- and Light Heavy-Duty Diesel-Fueled Vehicles.* Diamond Bar, CA: South Coast Air Quality Management District,1998.
19. **American Conference of Governmental Industrial Hygienists (ACGIH):** *Documentation of the Threshold Limit Values and Biological Exposure Indices, Notice of Intended Changes.* Cincinnati, Ohio: ACGIH, 2001.
20. "Diesel Particulate Matter Exposure of Underground Coal Miners," *Federal Register 30*:72(19 January 2001).
21. **National Institute for Occupational Safety and Health (NIOSH):** *NIOSH Manual of Analytical Methods.4th ed.* Cincinnati, Ohio: NIOSH, 1996.
22. **Whittaker, L.S., L. MacIntosh, and P.L. Williams:** Employee exposure to diesel exhaust in the electric utility industry. *Am. Ind. Hyg. Assoc. J. 60*:635–640 (1999).
23. **SAS Institute Inc.:** Statistical Analysis Systems. [Computer software]. Cary, N.C.: SAS Institute Inc., 1998.
24. **U.S. Environmental Protection Agency (EPA):** *Implementation Plan $PM_{2.5}$ Monitoring Program.* Research Triangle Park, N.C.: EPA/ Monitoring and Quality Assurance Group, 1998.
25. **Birch, M.E., and R.A. Cary:** Elemental carbon-based method for monitoring occupational exposure to particulate diesel exhaust. *Aerosol Sci. Technol. 25*:221–241 (1996).
26. **Cass, G.R., and H.A. Gray:** Regional emissions and atmospheric concentrations of diesel engine particulate matter: Los Angeles as a case study. In *Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects,* pp. 127–137. Cambridge, Mass.: Health Effects Institute, 1975.
27. **U.S. Environmental Protection Agency (EPA):** *National Air Pollutant Emission Trends, 1900–1996* (EPA-454/R-97–011). Research Triangle Park, N.C.: EPA/Office of Air Quality, 1997.
28. **National Institute for Occupational Safety and Health (NIOSH):** *Health Hazard Evaluation, City of Lancaster, Division of Fire,* by A. Echt, L. Blade, and J. Sheey (HETA 92–0160–2360). Cincinnati, Ohio: 1993.