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A Survey of Exposure to Diesel Engine Exhaust Emissions in the Workplace

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Forty sites were visited during a survey of exposures to diesel engine exhaust emissions. Personal and background exposure to gaseous components, respirable dust, elemental carbon, organic carbon and total carbon were measured and details of control systems were recorded. The results show a wide spread in exposure patterns reflecting the different work practices, job categories of employees and the control methods used. However, sites where fork-lift trucks were in use consistently produced the highest exposures. The survey results suggest that the measurement of elemental carbon could be used as an indicator of exposure to diesel engine exhaust emissions. Crown Copyright © 2000 Published by Elsevier Science Ltd on behalf of British Occupational Hygiene Society. All rights reserved.

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INTRODUCTION

Diesel engine exhaust is a complex mixture of gases and particulates. The principal gaseous components are carbon dioxide, carbon monoxide and nitrogen oxides while the particulate fraction mainly comprises fine carbon particles formed by incomplete combustion. The carbon particles are mixed with organic vapours and gases derived from oil, unburned fuel and products of combustion and, as the mixture issues from the engine, it cools and the higher boiling organic materials condense onto the carbon particles.

Diesel engine exhaust emissions (DEEEs) are classified by the International Agency for Research on Cancer as a Group 2A carcinogen, 'probably carcinogenic to humans' (IARC, 1989). But DEEEs are not considered to be carcinogens for the purposes of the Control of Substances Hazardous to Health (COSHH) Regulations 1999 (HSE, 1999a) because they are not considered to meet the criteria

for Category 1 or 2 carcinogens set out in the approved guide to classification and labelling supporting the Chemicals (Hazard Information and Packaging for Supply) Regulations 1994 (HSE, 1994). However, DEEEs are regarded as 'a substance hazardous to health' and for this reason are subject to the general provisions of the COSHH Regulations (HSE, 1999a) which require that exposure be prevented or, where this is not reasonably practicable, adequately controlled. Certain components of the DEEEs such as the individual gaseous components are covered by COSHH and have Occupational Exposure Limits listed in EH40 (HSE, 1999b).

The role of the various diesel exhaust fractions in causing ill health is not clear. The irritant effects of diesel exhaust are well known but much attention has also focused on the carbon particles and their adsorbed organics, particularly in Germany and the USA. In a search for an index of exposure to diesel exhaust, the Health and Safety Executive sponsored work (to be published) which resulted in a measurement method for carbon particles and adsorbed organics similar to that used in Germany (Dahmann *et al.*, 1996). This method was used to carry out a survey of industry with two objectives:

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to obtain quantitative information on workplace exposure to diesel engine exhaust, and to assess the range of measures used to control exposure to diesel engine exhausts. The outcome of that survey is reported in this paper. An alternative method for measuring elemental carbon derived from diesel exhaust was published (NIOSH, 1998) after this survey was carried out. This method uses a thermo-optical detector which is said to be able to correct for carbon formed pyrolytically during analysis. Recent studies have compared performance between different laboratories using the coulometric method under different operating conditions (Guillemin *et al.*, 1997) and laboratories using the coulometric and thermo-optical methods (Birch, 1998).

METHODS

Survey strategy

Sites were selected in the UK to provide a cross-

section of typical occupational exposures to diesel exhaust emissions. After preliminary enquiries, 40 premises were selected for inclusion in the survey and were classified, on the basis of similarity of operation, into the groups shown in Table 1. Groups 1-6 were reasonably well defined categories while group 7 comprised a miscellaneous collection of operations which did not fit neatly into the other six groups. Each site was visited to gather the following information: descriptions of the workplaces and the types of controls in operation (for example local exhaust, respiratory protective equipment); details of relevant work activities including range and timing of employee's work, and estimates of exposure to diesel exhaust mainly by personal sampling but also supported by background samples where appropriate.

Sampling and measurement

At the time of this survey, it was not clear which

Table 1. Sampling sites and job groups

Group	Site No.	Description of site
1 Ambulance depot	1	Regional ambulance depot
	2	Local hospital ambulance depot
2 Rò-ro ferry	3	Ro-ro ferry loading/unloading
	4	Ro-ro ferry loading/unloading
	5	Ro-ro ferry loading/unloading
3 Railway repair/stations	6	Repair and maintenance depot
	7	Repair and maintenance depot
	8	Repair and maintenance depot
	9	Repair and maintenance depot
	10	Repair and maintenance depot
	11	Railway station
	12	Repair and maintenance depot
	13	Repair and maintenance depot
	14	Repair and maintenance depot
	15	Railway station
4 Bus garage and/or bus repair	16	Repair and maintenance depot
	17	Repair and maintenance depot
	18	Repair and maintenance depot
	19	Repair and maintenance depot
	20	Bus garage run-in/run-out
	21	Bus garage run-in/run-out
	22	Bus garage run-in/run-out
	23	Bus garage run-in/run-out
	24	Bus garage run-in/run-out
	25	Repair and maintenance depot
5 Vehicle testing	26	Vehicle testing depot
	27	Vehicle testing depot
	28	Inspection/roller test (vehicle manufacture)
6 Fork-lift trucks	29	Warehouse
	30	Warehouse
	31	Truck loading depot
	32	Warehouse/assembly line
7 Toll booths, set-down area, tunnel repair sites	33	Toll booth
	34	Tunnel repair/maintenance
	35	Toll booth/tunnel repair
	36	Airport coach set-down area
	37	Airport cargo post
	38	Airport tunnel roadway
	39	Airport baggage handling area
	40	Ferry terminal gate cabin

measurement would best represent exposure to diesel exhaust. Although there has been a trend towards the measurement of carbon particles, we did not want to exclude measurement of gases. The emphasis of this work was the measurement of personal exposure and as the measurement of exposure to carbon requires a pump for sample collection we needed to measure the gases diffusively to avoid overburdening operators with additional pumps. Consequently, long-term diffusive colorimetric gas detector tubes were used although we recognized that there was the potential for some interference from the gaseous components of the exhaust and that there may be detection limit problems. Carbon monoxide was measured with Draeger 50/a-D or Gastec Dosi No. 1 DL tubes (detection limit about 6 p.p.m. over 8 h); carbon dioxide was measured with Draeger 500/a-D or Gastec Dosi No. 2 D tubes (detection limit about 65 p.p.m. over 8 h for Draeger tube, 250 p.p.m. for Gastec tube); nitrogen dioxide was measured with Gastec Dosi No. 9 D tubes (detection limit about 0.1 p.p.m. over 8 h).

The respirable fraction of diesel exhaust particulate was collected onto pre-weighed 25 mm quartz filters using a cyclone sampling at 1.9 l. min^{-1} (the quartz filters were cleaned in a furnace at 550°C for 4.5 h before use to remove residual carbon). After sampling, the filters were re-weighed (appropriately blank corrected), treated with dilute hydrochloric acid (200 μl of 1.5% w/w) to remove carbonates, then analysed for elemental and organic carbon using a Ströhlein Coulomat. The Coulomat uses a two-stage analysis. In the first stage, the quartz filter is placed in an i.r. furnace and heated to about 800°C under a stream of nitrogen. The organics adsorbed onto the carbon particles are vaporized and catalytically converted to carbon dioxide. The carbon dioxide is adsorbed into barium perchlorate and quantified using a coulometer where the results appear as 'counts' each of which is equivalent to 0.02 μg carbon. The result is converted to the mass of carbon in the vaporized organic substances and is referred to as 'organic carbon' (OC). This represents the organic carbon adsorbed by the carbon particles in the exhaust without discriminating between the many substances that may be present. After the first stage of the analysis is complete, there should remain only carbon particles on the quartz filter. In the second stage, the furnace is again heated to 800°C but this time under oxygen. Under these conditions, carbon is converted to carbon dioxide and again quantified in the coulometer. This result is referred to as 'elemental carbon' (EC) and represents the carbon particles in the diesel exhaust. The OC and EC results can be added to provide a 'total carbon' (TC) figure. Field blank filters were analysed with each batch of samples and the sample results corrected appropriately. Pyrolytic formation of EC from diesel exhaust particulate

during the OC measurement stage has not been detected using the conditions of analysis reported here.

The measurement of aldehydes (acrolein, formaldehyde and acetaldehyde) was attempted at some background locations using glass fibre filters treated with 2,4-dinitrophenylhydrazine (DNPH) sampling at 200 ml min^{-1} . However, it became apparent that not only is DNPH unsuitable for the measurement of acrolein because of the formation of multiple reaction products but the DNPH itself was affected at some locations by other components of diesel exhaust. Consequently, this measurement was abandoned.

Personal samples were collected in the breathing zones of workers potentially exposed to diesel exhaust during their working shift. Static samples were placed in locations where personnel worked and occasionally in those areas where it was impractical to collect personal samples. Wherever possible, sampling times were at least 6 h duration to ensure collection of sufficient carbon for analysis but some processes inevitably resulted in shorter sampling periods. All results reported here are representative of 8 h time weighted exposures.

In summary, each set of personal and background samples provided results on: respirable particulate, elemental carbon, organic carbon, total carbon, carbon dioxide, carbon monoxide and nitrogen oxides.

DESCRIPTION OF WORKPLACES AND CONTROL STRATEGIES

Summary descriptions of typical premises in each workplace grouping are given in the following paragraphs.

Ambulance depots (group 1)

The ambulance engines are normally run only during engine testing or when the vehicles are moved on or off ramps so exposure to exhaust emissions is intermittent and of short duration. At one depot, the typical throughput with three mechanics was 5–10 vehicles per day. Flexible ducting was available to connect to the exhaust tailpipe but only occasionally used. Local exhaust ventilation (LEV) was available at four inlets adjacent to each inspection pit. General ventilation was provided by partially opening shuttered doors that run the full length of the workshop. No respiratory protection was worn.

Ro-ro ferries (group 2)

Ro-ro ferries are used to transport both freight and vehicles. When unloading the ferry, the freight is unlashd from the deck then taken by diesel-powered tugs or container lorries to the dock. When

loading the ferry, the vehicles are marshalled into position on the deck where the freight is unloaded and shackled to the deck. Unloading and subsequent loading can last for up to 3 h. Exhaust ventilation units are usually positioned at the stern end of the main deck but they are of limited use when the deck is filled to near capacity. General ventilation can be provided by opening the bow and stern doors when appropriate. Drivers are recommended not to start their engines until all freight loads are unlash.

Railway repair/stations (group 3)

The main activities at repair and maintenance sites include refuelling, watering, running repairs, servicing and examination of diesel-powered railway traction units. Night shifts tend to be busiest, as the rolling stock is required for service during the day. Operators may be exposed to diesel exhaust when the engine has to be running for certain repair and test operations but the time of exposure depends on the work undertaken. The depots vary in size and number of employees. At one large railway repair depot with 50 employees, general ventilation was achieved by opening the end doors of the building and there were roof mounted axial flow extractor fans fitted above the rails. No LEV was used during repair of the traction engines and respiratory protection was not used. At a smaller depot, general ventilation was provided by opening doorways in areas where visible fume was known to accumulate. Three timer controlled exhaust ventilation fans in the ceiling removed emissions at those times when exposure was at a maximum during the working day.

Bus garage and/or bus repair (group 4)

There are two distinct groups of employees within a bus garage; the operations staff and the engineering staff. Operations staff such as drivers and conductors typically only spend short periods of time within the garage whereas engineering staff may spend their full working day within the garage. The buses are usually stationed overnight in the garage and are driven out at the start of the day during a period known as the 'run-out'. The majority return to the depot/garage ('run-in') in the early and late evening.

The diesel engines may be running while the buses are being cleaned, maintained and repaired within the garage and also when the buses are started prior to leaving the depot. There is a tendency for some drivers to start a vehicle and leave it running to allow the engine to warm up before 'run-out'. At several garages it is local policy that engines should not be left running or, where necessary, should not be left running for more than 15 min. One large garage included in the survey

employed 14 mechanics, 2 semi-skilled operators, 4 labourers and 3 cleaners all of whom were potentially exposed to diesel exhaust. Exposure occurs in the body repair shop when vehicles are driven into and out of the work area. General ventilation was by exhaust fans, ductwork and by keeping doors open at all times during the working day. Flexible ducting attached to the tailpipe was available at some sites. Respiratory protective equipment is not worn unless specifically requested by operators.

Vehicle testing (group 5)

Exposure to diesel exhaust occurs when vehicles are run into the inspection booths. There was little evidence of control measures at the sites visited although an electric portable air mover was in use at one station to control exposure to diesel exhaust during vehicle testing. One vehicle manufacturer had attempted to control exposure by fitting exhaust filters to vehicle tailpipes during testing but the filters were frequently not retrieved after the test and eventually lost.

Fork-lift trucks (group 6)

Fork-lift trucks, many of which are diesel powered, are widely used to load and unload goods from lorries and to move goods around warehouses. Where numerous fork-lift trucks are in use, there can be an accumulation of diesel exhaust. At one haulage firm where six fork-lift trucks were in operation, a number of employees complained of breathing problems allegedly linked to exposure to engine exhaust. During the busiest periods of the day shift, small amounts of fume were seen in the roof space of the warehouse. General ventilation was provided through open roller shutter doors in the warehouse.

Toll booths, set-down areas, tunnel repair sites (group 7)

Exposure at toll booths arises from passing vehicles and depends on the weather conditions and prevailing winds. Strong winds help to disperse the exhaust while it tends to linger and enter the booth in calm conditions. There is no mechanical ventilation in the majority of booths and general ventilation is provided by opening windows. The operators do not generally wear respiratory protection. Unusually, at one location, the toll booth operators work in heated pressurized booths with a supply of air passed in at roof level and out through the vehicle communication window to the sides of the booth at bench height.

Cargo ports at airports are generally temporary buildings where drivers have to present various documents. Queues of vehicles build up at these security checks and engines are often left idling while the driver enters the building.

Exhaust ventilation systems in tunnels usually consist of a series of fans at each end of the tube. Air is drawn in from outside the tunnel at several ventilation shafts on each side of the tunnel and the air is exhausted through extraction ducts in the roof at either end of the tunnel and then expelled into the atmosphere through exhaust tunnels.

RESULTS

A total of 691 respirable dust samples were collected. One personal sample was omitted from analysis because of pump failure. A further 5 personals and 29 background samples were declared invalid because of filter damage (producing negative weight gains) leaving a total of 656 respirable dust samples split between 215 personals and 441 background samples. Close examination of the respirable dust results required the elimination of a further 65 samples (26 personal, 39 background) because the sum of the elemental carbon and organic carbon analyses exceeded the respirable particulate on the filter. This probably reflects the difficulties in handling quartz filters which are prone to shed fibres during handling. All respirable dust masses in the survey were corrected by weighing blank filters in the usual way. A total of 189 personal and 402 background respirable dust results were accepted as valid.

Estimates of the limit of detection for weighing quartz filters (based on three times the standard deviation of the blanks) ranged during the survey from about 21 up to 120 μg for a random selection of 10 batches of samples. The median value of 45 μg was adopted as representative of the overall limit of detection. The median air volume sampled was 714 litres. Combining this with the limit of detection for weighing gives 63 $\mu\text{g m}^{-3}$ as the detection limit for airborne concentration of respirable dust. Any values reported below this concentration were assigned a value equal to half the detection limit as is the usual convention. The estimated detection limit for both EC and OC was 10 μg . Using the median volume of air given above, this equates to an airborne detection limit of 14 $\mu\text{g m}^{-3}$ for both EC and OC. Values reported below this concentration were allocated a value of half the detection limit. Total carbon is simply the sum of elemental and organic carbon.

Of the respirable dust samples collected, 220 personals and 244 backgrounds were analysed for EC and OC (these included some samples which produced invalid respirable dust results but which were nevertheless analysed for carbon content). During analysis, nine EC and one OC analysis failed. Consequently, results are reported for 217 personal and 237 background EC analyses and 220 personal and 243 background OC analyses.

Analytical results were divided into personal and

Table 2. Respirable dust summary ($\mu\text{g m}^{-3}$)

Job group	Sampling site	Personal							Background						
		No.	Mean	Median	GM	GSD	Min	Max	No.	Mean	Median	GM	GSD	Min	Max
1	Ambulance depot	3	127	130	118	1.6	70	180	22	252	160	163	2.7	32	740
2	Ro-ro ferry	16	295	225	198	2.7	32	920	27	217	160	150	2.4	32	1090
3	Railway repair	55	250	190	203	1.9	32	902	107	163	126	109	2.4	32	1530
4	Bus garage/repair	41	267	237	224	1.8	70	980	106	211	180	159	2.2	32	1410
5	Vehicle testing	10	156	160	149	1.4	90	220	29	90	80	71	2.0	32	370
6	Fork-lift trucks	25	442	380	369	1.9	79	1356	47	381	370	301	2.2	32	801
7	Toll booths, tunnels, etc.	39	191	150	161	1.9	32	520	64	372	130	125	2.8	32	8184
	Totals	189	264	200	208	2.0	32	1356	402	237	150	140	2.5	32	8184

Table 3. Elemental carbon summary ($\mu\text{g m}^{-3}$)

Job group	Sampling site	Personal							Background						
		No.	Mean	Median	GM	GSD	Min	Max	No.	Mean	Median	GM	GSD	Min	Max
1	Ambulance depot	3	31	33	29	1.6	18	42	18	82	28	35	4.0	7	288
2	Ro-ro ferry	20	49	49	37	2.5	7	111	17	39	26	25	2.9	7	101
3	Railway repair	64	21	18	17	1.9	7	50	72	26	17	17	2.5	7	110
4	Bus garage/repair	53	39	31	31	2.1	7	217	61	43	35	32	2.2	7	298
5	Vehicle testing	11	13	7	11	1.8	7	31	15	15	7	10	2.2	7	77
6	Fork-lift trucks	27	122	75	66	3.3	7	403	22	155	92	84	3.8	7	425
7	Toll booths, tunnels, etc.	39	23	17	17	2.3	7	71	32	21	17	15	2.2	7	85
	Totals	217	41	25	25	2.6	7	403	237	46	24	24	3.0	7	425

Table 4. Organic carbon summary ($\mu\text{g m}^{-3}$)

Job group	Sampling site	Personal							Background						
		No.	Mean	Median	GM	GSD	Min	Max	No.	Mean	Median	GM	GSD	Min	Max
1	Ambulance depot	3	52	45	46	1.8	27	83	18	94	64	56	3.1	7	321
2	Ro-ro ferry	20	83	46	43	3.2	7	610	19	70	58	47	2.6	7	317
3	Railway repair	65	125	89	91	2.2	20	606	72	59	40	35	2.9	7	713
4	Bus garage/repair	53	109	90	90	1.9	21	297	61	90	66	69	2.2	7	383
5	Vehicle testing	11	46	44	36	2.4	7	91	16	33	19	22	2.4	7	171
6	Fork-lift trucks	28	119	99	99	1.9	17	358	24	93	90	70	2.6	7	216
7	Toll booths, tunnels, etc.	40	60	40	42	2.4	7	210	33	33	20	23	2.4	7	121
	Totals	220	100	76	70	2.4	7	610	243	69	51	43	2.8	7	713

background samples and various statistics calculated for each workgroup as shown in Tables 2-5.

Probability plots for respirable dust, elemental carbon, organic carbon and total carbon suggest that the data distributions are approximately log-normal.

Respirable dust

Table 2 shows that the geometric mean (GM) for 189 personal exposures to respirable dust was $208 \mu\text{g m}^{-3}$. Ambulance depots recorded the lowest exposures ($118 \mu\text{g m}^{-3}$) but exposures where fork-lift trucks were in use were nearly twice those of the other groups ($369 \mu\text{g m}^{-3}$). The fork-lift truck category also recorded the maximum respirable dust value. Except for the ambulance category, the exposures for background samples are all lower than the corresponding personal samples. The geometric standard deviations (GSD) for the personal samples are around two for each workgroup except for the ro-ro ferries with a value of 2.7 which perhaps reflects the non-repetitive nature of the work. Two background samples at site 34 (group 7) produced respirable masses of about 8 mg m^{-3} which are clearly unusually high.

Elemental carbon

The GM concentration for 217 personal exposures to elemental carbon was $25 \mu\text{g m}^{-3}$ (Table 3). Fork-lift trucks provided the highest GM exposure ($66 \mu\text{g m}^{-3}$), ro-ro ferries were ranked second ($37 \mu\text{g m}^{-3}$) and the lowest exposures were at vehicle testing stations ($11 \mu\text{g m}^{-3}$). Background exposures to elemental carbon within the work categories were very similar to the personal exposures with an overall background exposure of $24 \mu\text{g m}^{-3}$. Within the groups, fork-lift trucks were an exception since the geometric mean background was about 30% higher than the corresponding personal exposure. Ro-ro ferries were the only category where personal exposures exceeded background exposures to any degree. The close equivalence of personal and background exposures suggests that the elemental carbon is relatively homogeneously dispersed in the measured atmospheres. This might indicate that those people in the same work area but not directly involved in the process generating diesel exhaust might also be significantly exposed.

Organic carbon

The pattern of exposure changed for organic carbon (Table 4). Fork-lift trucks again gave the highest GM personal exposure ($99 \mu\text{g m}^{-3}$) but not markedly different from railway repair ($91 \mu\text{g m}^{-3}$) and bus garage/repair ($90 \mu\text{g m}^{-3}$). This suggests that the latter two job groups are exposed to a higher proportion of organics adsorbed onto the

Table 5. Total carbon summary ($\mu\text{g m}^{-3}$)

Job group	Sampling site	Personal							Background						
		No.	Mean	Median	GM	GSD	Min	Max	No.	Mean	Median	GM	GSD	Min	Max
1	Ambulance depot	3	83	63	78	1.5	60	125	18	176	100	89	3.8	7	585
2	Ro-ro ferry	20	131	102	79	3.3	7	681	17	102	79	70	2.9	7	324
3	Railway repair	64	147	113	113	2.0	27	622	72	84	68	48	3.2	7	823
4	Bus garage/repair	53	148	133	124	1.9	28	416	61	133	101	100	2.2	7	681
5	Vehicle testing	11	59	65	48	2.2	7	104	15	48	28	29	2.7	7	248
6	Fork-lift trucks	27	243	184	188	2.2	24	748	22	253	205	176	2.9	7	609
7	Toll booths, tunnels, etc.	39	83	76	63	2.3	7	232	32	53	36	34	2.8	7	206
	Totals	217	141	108	102	2.3	7	748	237	114	82	65	3.2	7	823

carbon particles than the fork-lift trucks category. Whereas the overall means for personal and background exposure to elemental carbon were similar, they are different for organic carbon at $70 \mu\text{g m}^{-3}$ for personals and $43 \mu\text{g m}^{-3}$ for backgrounds (the ratio of these two results for organic carbon is similar to the ratio of the corresponding results for respirable dust). This suggests that those closest to the source of organic carbon receive a higher exposure to organic carbon than those more remote from the source.

Total carbon

In terms of total carbon (elemental + organic) shown in Table 5, fork-lift trucks provided the highest GM personal exposures ($188 \mu\text{g m}^{-3}$) followed by bus/garage repair ($124 \mu\text{g m}^{-3}$) and railway repair ($113 \mu\text{g m}^{-3}$). The overall mean of personals ($102 \mu\text{g m}^{-3}$) was greater than for the backgrounds ($65 \mu\text{g m}^{-3}$). It is interesting to note that total carbon accounts for 49% of the overall mean personal respirable concentration in mass terms for the personal exposures. The corresponding percentage for background samples is very similar at 46%. In both cases, the remaining 50% or so of the respirable mass will be made up of the elements burned off from adsorbed organics carbon during the measurement of organic carbon together with combustible and non-combustible general workplace dust.

Personals vs backgrounds

Generally, personal exposures will be expected to be higher than background exposures since the operator will usually be closer to the source of the pollutant. This is the case with respirable dust in this survey ($208 \mu\text{g m}^{-3}$ personal, $140 \mu\text{g m}^{-3}$ background), organic carbon ($70 \mu\text{g m}^{-3}$ personal, $43 \mu\text{g m}^{-3}$ background) and total carbon ($102 \mu\text{g m}^{-3}$ personal, $65 \mu\text{g m}^{-3}$ background). The ratio of personal to background concentration is

1.5 for respirable dust, 1.6 for organic carbon and 1.6 for total carbon. However, for reasons not yet understood, elemental carbon deviates from this trend and the personal and background overall geometric means are essentially the same ($25 \mu\text{g m}^{-3}$ personal, $24 \mu\text{g m}^{-3}$ background).

When the four sets of results (Tables 2-5) are ranked on the basis of highest personal exposure, fork-lift trucks rank first with bus/garage repair and railway repair consistently occupying second or third place. The ranking for ambulance depots on this basis is dubious as it is based on only three personal results.

Percentiles

Personal exposure percentiles are given in Table 6. Whereas the 95th percentile for most job groups is less than about $110 \mu\text{g m}^{-3}$ EC, the fork-lift truck group has a corresponding percentile of $390 \mu\text{g m}^{-3}$ indicating significantly higher exposures.

Relationship between elemental and organic carbon

Figure 1 shows the relationship between elemental carbon and organic carbon for personal samples. There is clearly no straightforward relationship between these two measurements. Other work in this laboratory (HSE, 1999c) has shown that the relative proportion of elemental and organic carbon in diesel exhaust varies depending on the load on the engine. For example, when idling at low revs, one particular engine produced elemental carbon which was about 30% of the total carbon emitted (i.e. organic carbon predominated). At higher revs and higher engine loads, the proportion of elemental carbon in the total carbon increased to as much as 80% of the total carbon. This information can help to interpret the results in Fig. 1 on the basis of the workloads on the engines. The percentage of EC was calculated as a proportion of TC for the GM personal concentrations at each site where the concentrations of EC were greater than the detec-

Table 6. Percentiles for personal samples

Analysis	Percentile (%)	Job group concentrations ($\mu\text{g m}^{-3}$)							
		All data	1	2	3	4	5	6	7
Respirable dust	90	520	180	730	540	430	215	805	450
	95	730	180	920	800	640	220	871	500
	99	980	180	920	902	980	220	1356	520
Elemental carbon	90	75	42	84	42	60	21	359	56
	95	107	42	98	46	78	31	390	60
	99	359	42	111	50	217	31	403	71
Organic carbon	90	196	83	148	254	189	80	257	140
	95	262	83	384	494	253	91	297	197
	99	528	83	610	606	297	91	358	210
Total carbon	90	281	125	244	302	249	100	524	190
	95	416	125	475	513	352	104	531	224
	99	622	125	681	622	416	104	748	232

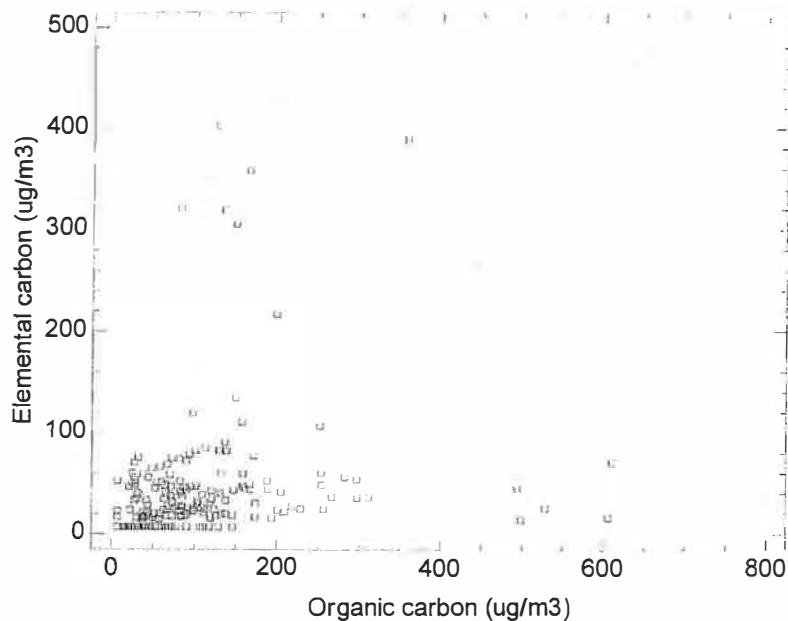


Fig. 1. Elemental carbon vs organic carbon.

tion limit. The results were ranked in ascending order of percentage EC.

Sites 3-5, 29-31 and 33 had percentages of EC above 40% (range 40-69%). These samples should originate mainly from engines that are working under some load and generating higher proportions of EC. Sites 3-5 are ro-ro ferries where there would be expected to be heavy loads on the engines during start-up and manoeuvring of vehicles on deck. Sites 29-31 are in the fork-lift truck category where there is likely to be much activity requiring frequent acceleration of the engine under load. Site 33 is a toll booth where vehicles will have to pull away from a standing start, again putting a heavy load on the engine.

At the other end of the scale, sites 6-9, 11, 14, 32, 36 and 39 have percentages of EC up to about 20% (range 5-21%). These samples would be expected to derive from lightly loaded engines. Sites 6-9 and 14 are railway repair and maintenance depots where it is likely that the engines are left idling for some time while adjustments are made and tests carried out. Site 11 is a railway station where engines may be left running while trains are standing at platforms. Site 32 is in the fork-lift truck category and stands apart from the three other fork-lift truck sites. However, this may not be surprising since the work activity included supplying an assembly line as well as warehouse duties. Site 36 is an airport coach set-down area and site 39 is in an airport baggage handling area. Between the two arbitrary percentages of 20% EC and 40% EC, there is a range of activities which would be

expected to be a mixture of heavy and lightly loaded engine duties.

The relevance of these findings depends on the risk to health associated with EC and OC since some operations will generate proportionately more of one than the other. Those operations that place heavy loads on the engine might be expected to present more problems if EC is regarded as a health risk. Lighter engine loadings, particularly with frequent idling, will be mainly associated with OC as the dominant feature.

Because the fork-lift truck category produced higher exposures than the other job categories, the four sites which make up this group were examined in more detail. Table 7 summarizes the geometric mean personal exposures at each site for the four measurements shown. All four measurements rank site 29 as producing significantly higher exposures than the other sites. The GM respirable dust at these four sites was significantly greater than the GM for all results (Table 2). The result for elemental carbon for sites 29-31 was also higher than for

Table 7. Personal results at fork-lift truck premises ($\mu\text{g m}^{-3}$)

Site No.	Respirable		EC		OC		TC	
	No.	GM	No.	GM	No.	GM	No.	GM
29	4	873	6	348	6	152	6	509
30	7	396	7	83	7	93	7	176
31	5	343	5	81	5	100	5	182
32	9	248	9	17	10	80	9	104
Total	25	369	27	66	28	99	27	188

the mean of all results (Table 3) but site 32 was lower. A similar pattern was repeated for organic and total carbon where site 32 produced results similar to the overall means. Thus, amongst the fork-lift truck category, sites 29–31 confirm the significantly higher exposures than in the other work categories but site 32 produced results which were more in line with the overall mean. It is interesting to note that the ratios of elemental carbon to organic carbon change significantly between the sites in Table 7. At site 29, elemental carbon predominates which could indicate that the engines are being worked under some load. At sites 30 and 31, organic carbon is present at a slightly higher proportion than elemental carbon, but at site 32, organic carbon predominates markedly perhaps indicating engine usage under light load.

Relationship between respirable dust and elemental/organic carbon

Figures 2 and 3 show the relationship between respirable dust and elemental carbon and organic carbon, respectively, for personal samples. There appears to be no direct relationship between respirable dust and elemental carbon (Fig. 2) so respirable dust could not be used as a surrogate for elemental carbon. Some structure may be present in Fig. 3, probably because organic carbon accounts for the bulk of the DEEE mass in most samples but even in this graph there is considerable scatter.

Gas detector tubes

Measurements with the gas detector tubes pro-

duced results of questionable value because the exposures were low and, for most samples, less than the detection limit of the tubes. To calculate the various statistics, gas detector tube results recorded as less than the limit of detection were assigned values equal to half the limit of detection as follows: carbon monoxide 3 p.p.m.; carbon dioxide 125 p.p.m.; nitrogen dioxide 0.1 p.p.m.

Of the 202 detector tubes used to measure personal exposure to carbon monoxide, 113 produced no response; 118 of the 216 background tubes deployed also produced no response. The result was an overall personal GM exposure of < 6 p.p.m. Only the ambulance depot category produced measurable exposures (38 p.p.m.) but this was based on only two results above the detection limit so they may not be representative.

Amongst the 202 personal measurements for carbon dioxide, 49 produced a response less than the detection limit. A total of 116 background results (out of 216) were less than the limit of detection. The highest GM personal exposure was in the fork-lift truck category (1200 p.p.m.) and the two results from the ambulance depot category produced an exposure of similar magnitude lending some weight to the carbon monoxide results for this job group. Contrary to findings using the other measurements, vehicle testing ranks third when using carbon dioxide as the index of exposure (900 p.p.m.). The overall background exposure (270 p.p.m.) is only just above the detection limit but is less than the corresponding personal exposure value (650 p.p.m.),

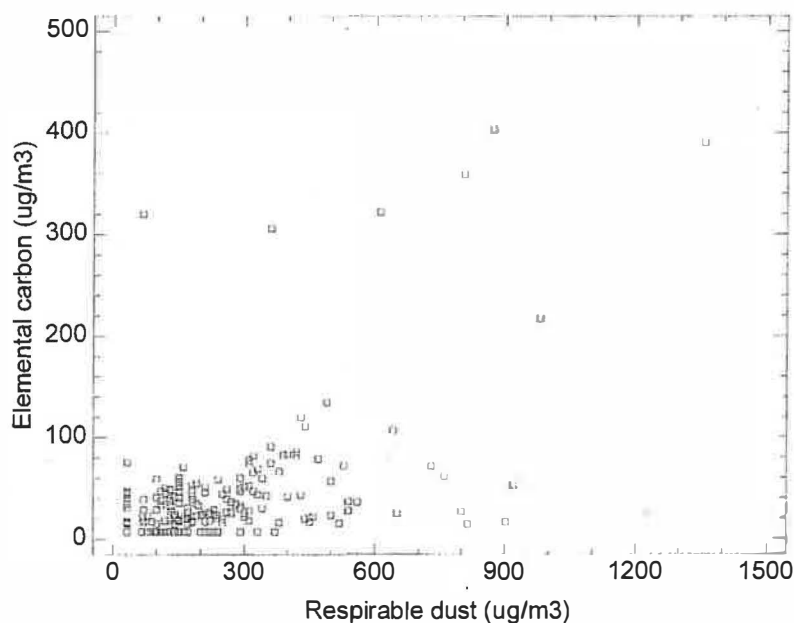


Fig. 2. Elemental carbon vs respirable dust.

possibly suggesting a job-related exposure. Atmospheric carbon dioxide will of course contribute to these results.

Of the 202 gas detector tubes used to measure personal exposure to nitrogen dioxide, 176 recorded values less than the limit of detection; 157 of the 216 background tubes produced responses less than the limit of detection. However, the measurements did again confirm the fork-lift truck category as providing the highest GM exposure (0.2 p.p.m.) supporting to some extent the conclusions drawn from other measurements.

The data suggest that time weighted average gas detector tubes are unlikely to have sufficient sensitivity to measure exposures to carbon monoxide, carbon dioxide or nitrogen dioxide resulting from diesel exhaust except where exposures are relatively high.

DISCUSSION AND CONCLUSIONS

Forty sites were visited during the survey. The results of personal exposure and background sampling concentrations for gaseous components, respirable dust, elemental carbon, organic carbon and total carbon varied between sites and between workgroups. The data analysis shows a wide spread in exposure patterns reflecting the different work practices, job categories of employees and the control methods used.

The 95th percentiles for personal exposure to EC, OC, TC and respirable dust were: EC $107 \mu\text{g m}^{-3}$;

OC $262 \mu\text{g m}^{-3}$; TC $416 \mu\text{g m}^{-3}$; respirable dust $730 \mu\text{g m}^{-3}$.

In a complex mixture such as diesel exhaust, it is difficult to identify one component which would be representative of exposure as a whole. However, this survey has demonstrated that elemental carbon could be used as an indicator of exposure. With some exceptions, such as the manufacture and use of carbon black and in coal mines, the diesel engine is likely to be the only significant source of elemental carbon in the workplace (elemental carbon is produced only in trace amounts by petrol engines).

Placing the various sites into seven workplace groups was a pragmatic approach to categorizing the data and the results obtained for each group should not be taken as an indication that all premises fall into one of these groups. However, exposures in premises using fork-lift trucks were consistently higher than at other workplaces. Poor working practices (e.g. failure to switch off the engine when not required for a substantial period of time or not driving the vehicle correctly), poorly maintained engines and inefficient general ventilation contributed to the high exposures at these premises.

None of the measurements for carbon monoxide, carbon dioxide and nitrogen dioxide exceeded the relevant current UK 8 h time weighted average occupational exposure limits (50 p.p.m. for carbon monoxide, 3 p.p.m. for nitrogen dioxide, 5000 p.p.m. for carbon dioxide). Where exposure to carbon dioxide was over 1000 p.p.m. 8 h TWA, the control systems were generally faulty, poorly maintained or inadequately designed. While the measure-

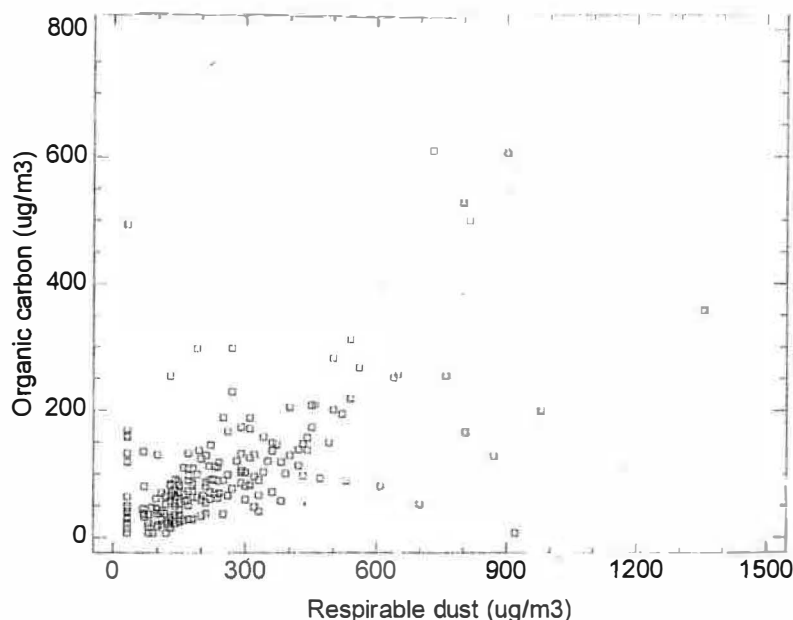


Fig. 3. Organic carbon vs respirable dust.

ment of carbon dioxide may not represent exposure to diesel exhaust as a whole, it may be an indicator of the overall adequacy of control measures, in particular LEV or roof extraction systems.

It is uncertain at present what would be a useful indicator of irritancy. Aldehydes (acrolein, formaldehyde and acetaldehyde) are a possibility but further research is required in this area. Measurement of exposure to the aldehydes and other gases such as nitrogen dioxide derived from diesel exhaust may be important in building up a database in a field where little information is available. However, the employer should look for better means of control where the workforce complain of irritancy.

Exposure to DEEEs should be prevented or where this is not reasonably practicable, adequately controlled, following a suitable risk assessment as required under COSHH regulation 6. In those situations where it is not reasonably practicable to prevent exposure to DEEEs, for example by changing the method of work, modifying the layout of the workplace or modifying the work operations, then a number of measures can be taken to control exposure. These include: the use of lower emission or more fuel efficient engines; the use of cleaner fuels such as low sulphur diesel fuels; the use of catalytic converters and catalysed and non-catalysed particulate traps; the use of tailpipe exhaust extraction systems and the provision of sufficient general ventilation. As exposure to DEEEs is best controlled at source, respiratory protective equipment (RPE) should be used only as a last resort. This survey revealed that the main means of controlling exposure to DEEEs were engineering controls (in particular engine exhaust filters and extraction fans) or work practices (e.g. regular engine maintenance, turning the engine off when not in use, job rotation, etc.) or a combination of these and that they varied between premises. Overall, poor working practices, poorly maintained engines and inefficient, inadequately maintained mechanical ventilation contributed to higher occupational exposure to DEEEs measured during this survey.

In warehouses where fork-lift trucks are used and where the highest personal exposures and background concentrations were measured, control is mainly by general ventilation. Improved general ventilation as well as regular servicing of the trucks would reduce exposure. Furthermore, where goods are being unloaded from delivery lorries, the delivery vehicles should not enter the warehouse. If this is not possible then engines should be switched off during loading and unloading.

At bus railway locomotive depots, control of exposure is mainly by a combination of general ventilation such as extraction fans in the roof and LEV. Many such sites rely on general ventilation only. Ideally the contaminated air should be exhausted to

the outside with make-up air flowing into the workplace through open doors or supply air openings. The major drawback to such control is the cost of heating the make-up air during cold weather and the failure to remove diesel emissions at source. In the winter months, these premises conserve heat by keeping the doors shut as much as possible so causing an accumulation of DEEEs.

At several sites, engine exhaust filters were attached to the tailpipe of the vehicle to remove particulate from the diesel fume at source. One vehicle manufacturer could not achieve control using this method because the drivers of the vehicles are responsible for fitting the filters to the exhaust and removing them. The filters are often misplaced as the drivers do not always retrieve them once they have been removed. There is also a high level of system damage to the filter units and the filter elements require high levels of maintenance.

A tailpipe exhaust hose, connected to a fan which discharges the diesel exhaust outside the building, was used as a means of control together with engine exhaust filters at vehicle repair premises and vehicle testing sites. The tailpipe exhaust hoses remove the gaseous emissions as well as the respirable particulate at source. Personal exposure and background concentrations to the respirable particulate tended to be lower at these sites compared with other sites in the survey. These engineering controls are, however, not common in the average motor vehicle repair and vehicle testing sites.

RPE was used to control exposure to DEEEs at only two sites and was only provided on request by employees.

Following an adequate risk assessment of workplace exposure to DEEEs to assess whether to prevent or control such exposure, consideration should be given, where appropriate, to the use of: alternative technologies where practicable such as battery powered vehicles; alternative fuels such as 'green diesel' or compressed natural gas; low emission or more fuel efficient engines; catalyst technology or particulate filters. Additional measures might include instigating a programme of regular engine maintenance, reviewing the engineering controls used, introducing worker job rotation and providing information, instruction and training of staff on the hazards associated with exposure to DEEEs where necessary. The chosen control measures will be based on the levels of risk and exposure, the type of workplace, present work practices and cost and benefit factors. Additional information on control of diesel exhaust emissions is given in an HSE publication (HSE, 1999d).

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