Int Arch Occup Environ Health (1994) 66:77–83 © Springer-Verlag 1994

ORIGINAL ARTICLE

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Evaluation of an exposure setup for studying effects of diesel exhaust in humans

Received: 4 November 1993 / Accepted: 24 March 1994

Abstract Diesel exhaust is a common air pollutant and work exposure has been reported to cause discomfort and affect lung function. The aim of this study was to develop an experimental setup which would allow investigation of acute effects on symptoms and lung function in humans exposed to diluted diesel exhaust. Diluted diesel exhaust was fed from an idling lorry through heated tubes into an exposure chamber. During evaluations of the setup we found the size and the shape of the exhaust particles to appear unchanged during the transport from the tail pipe to the exposure chamber. The composition of the diesel exhaust expressed as the ratios CO/NO, total hydrocarbons/NO, particles/NO, NO_2/NO, and formaldehyde/NO were almost constant at different dilutions. The concentrations of NO_2 and particles in the exposure chamber showed no obvious gradients. New steady state concentrations in the exposure chamber were obtained within 5–7 min. In a separate experiment eight healthy nonsmoking subjects were exposed to diluted exhaust at a median steady state concentration of 1.6 ppm NO_2 for the duration of 1 h in the exposure chamber. All subjects experienced unpleasant smell, eye irritation, and nasal irritation. Throat irritation, headache, dizziness, nausea, tiredness, and coughing were experienced by some subjects. Lung function was not found to be affected during the exposure. The experimental setup was found to be appropriate for creating different predetermined steady state concentrations in the exposure chamber of diluted exhaust from a continuously idling vehicle. The acute symptoms reported by the subjects were relatively similar to what patients reported at different workplaces.

Key words Diesel exhaust · Symptoms · Exposure chamber · Nitrogen dioxide · Particles

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Introduction

Diesel exhaust is generated from a wide variety of vehicles. Solid and liquid particles and gases are generated during the incomplete combustion of diesel fuel. The main gases are carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). Gases and hydrocarbons are absorbed or condensed on a carbonaceous core of submicron particles. The amounts of the components in the exhaust vary considerably from vehicle to vehicle. For instance, the emission of particles from heavy-duty diesels is 10–100 times greater than from gasoline-powered automobiles (Schuetzle 1983).

In studies of the effects on lung function, workers exposed to diesel and automotive exhaust have been found to have an increased airway resistance, increased closing volume (CV) and reversible reductions of forced expiratory volume in 1 s ($FEV_{1.0}$) and forced vital capacity (FVC) (Ayres et al. 1973; Ulfvarson et al. 1987, 1991; Ulfvarson and Alexandersson 1990).

Workers exposed to diesel exhaust have been reported to have an increased prevalence of such symptoms as burning eyes, headache, nausea, difficult or labored breathing, coughing, phlegm, and wheezing (Reger et al. 1982; Gamble et al. 1987a, b). Symptoms like these are in agreement with our clinical experience at the Department of Occupational Medicine with patients working in offices, garages, mines, and workshops. These patients were most commonly exposed to diesel exhaust from idling, rather than moving, vehicles.

The aim of this study was to develop and experimental setup which would adequately allow investigation of acute effects on symptoms and lung function in humans exposed to diluted diesel exhaust from an idling vehicle. This paper describes the basic experimental setup and investigates symptoms and lung function effects from concentrations of diesel exhaust encountered at workplaces (Attfield et al. 1982; Gamble et al. 1983). It also forms a basis for studies in our laboratory involving bronchoalveolar lavage (BAL) that are designed to investigate the inflammatory effects of diesel exhaust on the lungs of humans.

Materials and methods

Subjects

Eight healthy nonsmoking subjects participateted in the experiment, which included human exposure to diesel exhaust. All were free of any history of recent airway infection, asthma, and other lung disease.

Design of the study

Evaluation of exposure equipment

To enable us to administer adequate challenge tests in humans, to diluted diesel exhaust at predetermined concentrations in an exposure chamber, we found it essential to evaluate the experimental setup properly. We therefore conducted measurements in the experimental setup to evaluate whether it would meet the following demands:

1. The particles should not change in size and shape during their passage from the tail pipe of the vehicle into the exposure chamber in the experimental setup.
2. The composition of the exhaust should be equal at different dilutions, i.e. the ratio of the measured compounds should be constant or almost constant.
3. The concentration of the measured components of the exhaust should be distributed without gradients in the exposure chamber where the subjects and the inlet to the instruments are.
4. Steady state concentrations in the exposure chamber should be achieved in a short time, to enable further experiments with shifting concentrations during the time course of an exposure.

Evaluation of effects in humans

In a separate experiment the symptoms and lung function were examined in healthy subjects exposed to diluted diesel exhaust during 1 h at a steady state concentration by keeping NO_2 concentration at 1.6 ppm in the chamber. Symptoms were recorded before, during, and after exposure and lung function tests were performed before and after exposure. The study was approved by the local Ethics Committee

Experimental setup

An idling lorry (Scania Vabis AL 36: model 1968, 5 ton, direct injection, 4 cylinders, 5200 cm^3, SMMT 95 hP) was used to generate diluted diesel exhaust throughout the tests.

The chemical composition of the standard diesel fuel (C_{10}–C_{28}) was 65–95 vol% paraffins/naphthenes, 0–10 vol% olefins, 5–30 vol% aromatics, < 0.05 weight % sulfur and fuel additives.

The experimental setup is presented in Fig. 1. It included a continuously idling vehicle parked outdoors, a flexible metallic tube (length = 0.8 m, diameter = 100 mm) with an inflatable sleeve, a shunt/dilutor (l = 0.9 m, d = 100 mm) in mild steel, a shunt tube

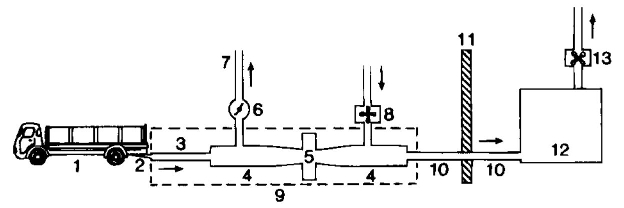

Fig. 1 The experimental setup: *1* an idling vehicle – outdoors, *2* exhaust pipe, *3* flexible metallic tube with an inflatable sleeve, *4* metallic shunt/dilutor, *5* adjustable diaphragm, *6* valve in the tube with undiluted diesel exhaust, *7* tube for shunting the undiluted diesel exhaust, *8* fan for air dilution, *9* electric heating (200°C) area, *10* tube for diluted diesel exhaust, *11* wall to the experimental hall, *12* exposure chamber (3 × 3 × 2.3 m), *13* waste fan

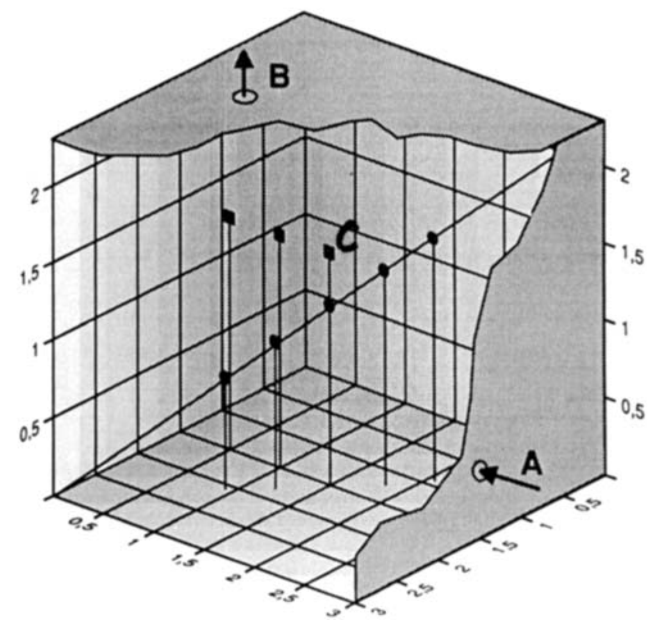

Fig. 2 The inlet *(arrow A)* and the outlet *(arrow B)* of the diesel exhaust to the exposure chamber (3 × 3 × 2.3 m). The breathing zone of the subjects is marked *C*. Three measuring points are placed 1.5 m above the floor, and five measuring points are placed along the space diagonal

(l = 6 m, d = 100 mm) with an adjustable valve, an external air dilution fan with a constant flow, and a tube for feeding diluted diesel exhaust (l = 6 m, d = 100 mm) into the exposure chamber (3 × 3 × 2.3 m) with a waste tube and fan at the roof of the exposure chamber. The diluted diesel exhaust was fed into the exposure chamber in the middle of one wall 45 cm above the floor. The waste tube with the fan was located above the roof, 65 cm from the middle of the wall opposite to the inlet for the diluted diesel exhaust (Fig. 2). The air in the chamber was changed every 2.3 min. The metallic frame of the exposure chamber was covered with a thin plastic foil of 0.15 mm polyethene. The diesel exhaust flowed continuously through the shunt/dilutor, the tubes, and the exposure chamber.

The flexible tube and the shunt/dilutor were heated to 200°C by an electric wire to avoid condensation. After the shunt tube the diameter of the shunt/dilutor was conically decreased to 30 mm and then successively increased to 100 mm. At the waist (smallest diameter 30 mm), there was a diaphragm adjustable from 3 to 30 mm.

The majority (more than 90%) of the primary diesel exhaust was shunted away through a valve opening in the shunt tube. The shunt flow was also dependent on the actual diameter of the diaphragm opening. The minor part of the diesel exhaust that passed through the diaphragm was diluted with air at a constant flow of 1.5 m^3/min, before it was fed into the exposure chamber.

The predetermined concentration of diluted diesel exhaust in the exposure chamber was achieved by varying the diaphragm diameter in the shunt/dilutor and/or the valve opening in the shunt tube. In order to have a sufficiently low concentration in the exposure chamber, a secondary dilution was essential. The waste fan produced a higher air flow than the incoming primary diluted diesel exhaust. The air for the secondary dilution came from the experimental hall (17 × 10 × 7 m) and entered the exposure chamber via openings at the corners.

Chemical analysis

A Miran 1-A, an IR instrument (Foxboro Co, East Bridgewater, Mass., USA), was used for continuous analysis of CO. NO and NO_2 were continuously analyzed with a chemiluminescence instrument, CSI 1600 Oxides of nitrogen analyzer (Columbia Scientific Industries Corp., Austin, Texas, USA). The total hydrocarbons (THC) were analyzed continuously with the FID instrument, model 3-300 (J.U.M. Engineering GmbH, München, Germany), with a heated prefilter (180° C) and calibrated with propane. Continuous registration of the number of particles/cm^3 was obtained with a condensation particle counter (laser), model 3022 (TSI Inc., St. Paul, Minn., USA). X-y recorders were used. Formaldehyde was collected on glass fiber filters (diameter = 13 mm) impregnated with 2,4-dinitrofenylhydrazine (Levin et al. 1986) and analyzed with high-performance liquid chromatography (HPLC), model WISP 712 (Millipore Co, Milford, Mass., USA).

Evaluation of exposure equipment

Particles in the flexible tube at the tail pipe and inside the exposure chamber were collected isokinetically on Nucleopore filters (porous diameter = 0.8 μm, filter diameter = 25 mm) and analyzed with scanning electron microscopy (SEM).

The filters were mounted on aluminum stubs and coated with approximately 20 nm of gold in a modified vacuum coating system equipped with an automatic tilting and rotation device (Edwards E14 Vacuum Coating Unit, Edwards High Vacuum, Crawley, UK). The specimens were examined in a Cambridge Steroscan 350 iXP scanning electron microscope (Leica Cambridge Ltd, Cambridge, UK), operated at 20 kV, with a tilt angle of 0° and a 20 μm final aperture. Micrographs were taken randomly at 3000, 5250, 10500, and 26500 times magnification and were later used for assessment of particle morphology.

NO, NO_2, CO, THC, formaldehyde, and the number of particles were estimated at three different steady state dilutions of diesel exhaust in the exposure chamber. The duration of each steady state was 1 h. In order to evaluate the *composition* of the diesel exhaust, the ratios of the measured compounds were calculated.

In order to exclude *concentrations gradients* in the exposure chamber, NO_2 and particles were measured at the breathing zone of the subjects (point C in Fig. 2) and the inlet to the analyzing instruments. The instruments for gas analysis were placed outside the exposure chamber with measuring probes in the exposure chamber. The instrument for particle analysis and the formaldehyde filter were placed inside the chamber. The measuring probes, the inlet to the particle instrument, and the formaldehyde filter were close together in the exposure chamber adjacent to the breathing zone when humans were exposed.

The concentration was measured at different locations, in the middle 1.5 m above the floor and along the space diagonal, in the exposure chamber on two different occasions (Fig. 2).

On one occasion, every 5th minute during a period of 45 min the measuring probes for NO_2 and particles were alternated at 0.5, 1.0, and 1.5 m from the wall opposite to the inlet of diluted diesel exhaust in the middle of the chamber 1.5 m above the floor where the filters, measuring probes, and subjects were placed during exposures.

The concentrations of NO_2 were also measured on another occasion along the space diagonal in the exposure chamber, at five points for 5 min at each point. The concentrations were estimated at the middle of the exposure chamber 1.15 m above the floor and at 0.45 and 0.90 m above and below the midpoint along the space diagonal. The measuring points were at the heights of 0.75, 0.94, 1.15, 1.36, and 1.57 m above the floor.

NO, NO_2 and NO_x (NO + NO_2) were registered during a period of 50 min in the exposure chamber in order to show the time needed to obtain three different dilutions of diesel exhaust.

Evaluation of effects in humans

In a separate experiment eight healthy nonsmoking subjects, aged 19–27 years (mean 23 years), were exposed to a median steady state concentration of 1.6 ppm NO_2 for 1 h in the chamber. During exposure they performed light work, riding an ergonometer-bicycle at 75 W. Rest and work on the ergometer-bicycle were alternated every 10 min.

Before exposure, every 10 min during exposure, and 30 min after exposure the subjects were interviewed by a technician who registered the subjective symptoms according to a questionnaire. The symptoms were: headache, dizziness, nausea, tiredness, tightness of the chest, coughing difficult breathing, eye irritation, nasal irritation, an unpleasant smell, throat irritation, and a bad taste in the mouth. The symptoms were scored in 13 steps, from "no symptoms" (ranked 0) to "maximal symptoms" (ranked*) according to the Borg scale (Borg 1982).

The lung function test were performed before and after exposure. Dynamic spirometry was measured with a dry rolling seal spirometer (Ohio Medical Products, Pointe Claire, Quebec, Canada). Spriometer gas distribution and closing volume were recorded with the single breath nitrogen washout method using an Ohio nitrogen analyzer 720 (Ohio Medical Products, Pointe Claire, Quebec, Canada). All volumes are given at body temperature, pressure saturated (BTPS).

The following variables were determined: FVC, $FEV_{1.0}$, forced expiratory flow rate between 25% and 75% of FVC (FEF_{25-75}), mean transit time in seconds (MTT), and CV/VC%; in addition the alveolar plateau (phase III, % change in N_2/l) was calculated.

Results

Evaluation of experimental setup

The particles from the flexible tube close to the tail pipe were collected on Nucleopore filters for a period of 10 s. In the exposure chamber the collection time was 10 min. The reason for the extremely short collection time in the flexible tube was high concentration and the risk of overloading the filter. The particles at the tail pipe and in the exposure chamber are shown in Fig. 3 and 4. The size and the shape of the particles appear similar, indicating no or minimal change in the particles throughout the tubes of the experimental setup.

In order to estimate the composition and relationship between NO, NO_2, CO, THC, formaldehyde, and particles in the exposure chamber, the concentrations of these substances were measured at three different steady state dilutions of diesel exhaust. The ratios of the concentrations in the exposure chamber – CO/NO, THC/NO, particles/NO, NO_2/NO, and formaldehyde/NO – as a function of the diaphragm diameter are shown in Fig. 5. The ratios of

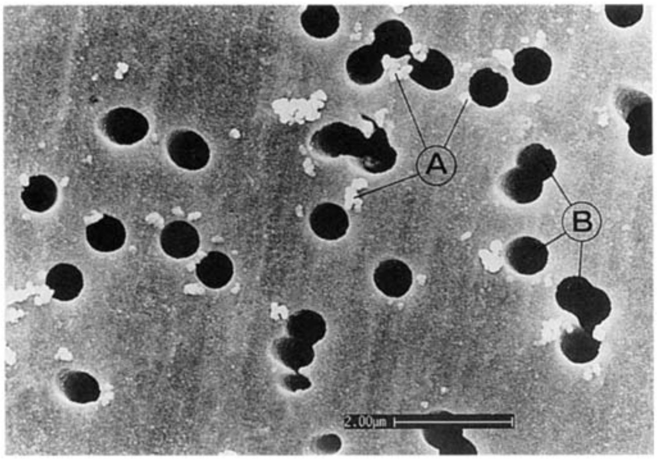

Fig. 3 SEM micrograph of the particles collected isokinetically on a Nucleopore filter at the tail pipe. *A* Diesel exhaust particles, *B* pores in the Nucleopore filter

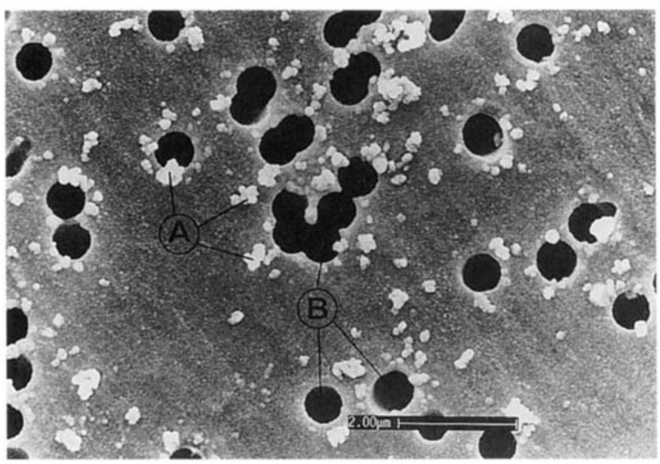

Fig. 4 SEM micrograph of the particles collected on a Nucleopore filter inside the exposure chamber. *A* Diesel exhaust particles, *B* pores in the Nucleopore filter

NO_2/NO and particles/NO were almost constant while CO/NO and formaldehyde/NO decreased and increased, respectively.

The concentrations of NO_2 and particles were measured in the exposure chamber during one steady state concentration of diluted diesel exhaust from the continuously idling lorry. The average concentrations were measured 0.5, 1.0, and 1.5 m from the opposite wall to the inlet of diesel exhaust 1.5 m above the floor during periods of 5 min. The concentrations of NO_2 were 1.25, 1.25, and 1.24 ppm, while the concentrations of paritcles were 2.40, 2.35, and 2.30 × 10^6/cm^3. The minimum and maximum concentrations of NO_2 and particles during these 45 min were 1.15 an 2.24 ppm and 1.8 × 10^6 and 3.2 × 10^6/cm^3, respectively.

The NO_2 concentration at five different points along the space diagonal of the exposure chamber was measured. The concentration in the middle of the exposure chamber was 0.87 ppm NO_2. The concentrations at the

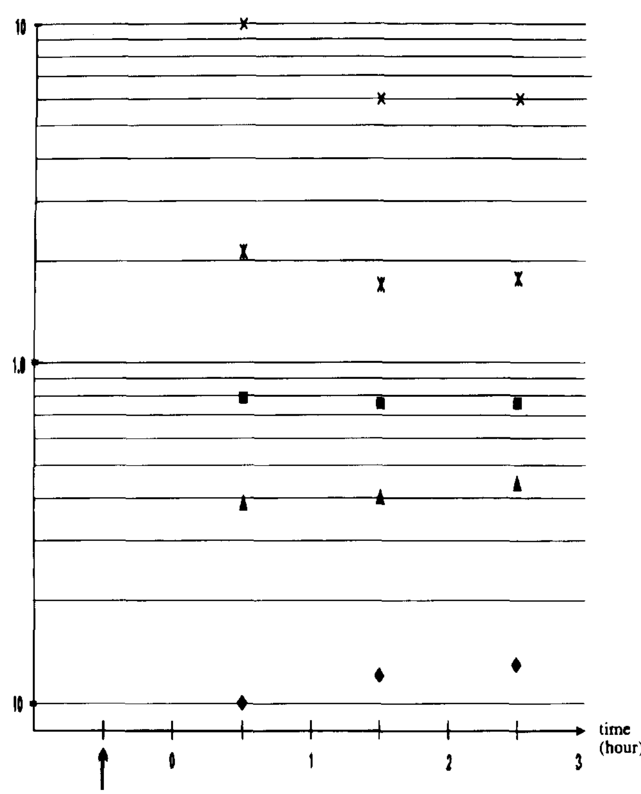

Fig. 5 The composition of the diesel exhaust in the exposure chamber expressed as the ratios CO/NO, THC/NO, particles × 10^6/NO, NO_2/NO, and formaldehyde (HCHO)/NO at three different dilutions. The diaphragm diameter was 10 mm from 0 to 1 h, 15 mm from 1 to 2 h, and 20 mm from 2 to 3 h. The engine of the vehicle was idling 0.5 h (*arrow*, engine starts) before concentrations were measured during 1 h at each diaphragm diameter, starting with the small diameter. × CO/NO; ⁎ THC/NO; ■ particles - 10^6/NO; ▲ NO_2/NO; ◆ HCHO/NO

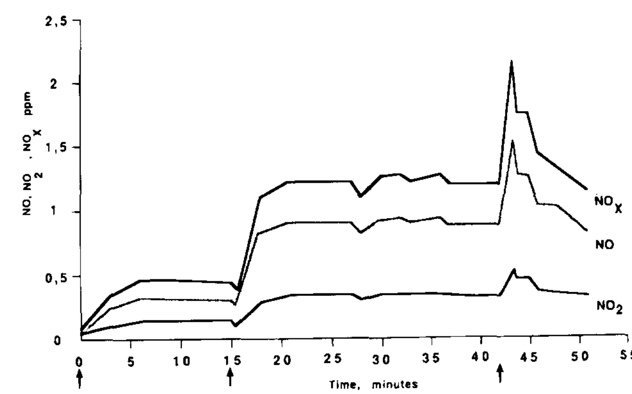

Fig. 6 The concentrations of NO, NO_2 and NO_x in diluted diesel exhaust in the exposure chamber at two different steady state concentrations and one peak concentration. The concentration in the exposure chamber was changed by increasing the diameter of the diaphragm on the shunt/dilutor. *Arrows* indicate the time point of diaphragm operation. The predetermined concentrations were reached in 5–7 min

Table 1 The median steady state concentrations of NO, NO_2, CO, formaldehyde, and particles during 1 h exposure of healthy subjects to diluted diesel exhaust in the exposure chamber. (*TLV* threshold limit value, *TWA* time-weighted average, *C* ceiling, *STEL* short-term exposure limit, – no occupational exposure limit value)

	NO (ppm)	NO_2 (ppm)	CO (ppm)	Formaldehyde (mg/m^3)	Particles ($\times 10^6/cm^3$)
Median	3.7	1.6	27	0.5	4.3
Interquartile range	3.3–>5	1.5–1.8	21–33	0.3–0.8	2.4–5.0
TLV-TWA[a]	25	1[b]	20[b]	0.6	–
TLV-C[a]	–	5	–	1.2	–
TLV-STEL[a]	50	–	100	–	–

[a] Swedish occupational exposure limits
[b] For exhaust

other four points along diagonal varied by ± 0.06 ppm compared to the midpoint.

NO, NO_2, and NO_x were estimated in the exposure chamber at different steady state concentrations by changing the diameter of the diaphragm in the shunt/dilutor. Figure 6 shows the concentrations of NO, NO_2, and NO_x at two different steady state concentrations and one peak concentration. The shunt/dilutor made it possible to have new and stable steady state concentrations within approximately 5 min. This possibility of varying the concentration will be valuable for challenge tests where different concentrations are desired during the same exposure period.

Evaluation of effects in humans

In a separate experiment eight healthy volunteers were exposed to diluted diesel exhaust. The symptoms were evaluated before, during, and after exposure while the lung function tests were performed before and after exposure. The median steady state concentrations on NO, NO_2, CO, formaldehyde, and particles for this experiment are shown in Table 1.

An unpleasant small, eye irritation, and nasal irritation were the most frequent symptoms (Fig. 7). Unpleasant smell rose from the median score zero to 3 according to the Borg scale during the first 10 min. Eye irritation increased successively to the median score 3 during the exposure. The intensity of nasal irritation was milder than that of unpleasant smell and eye irritation.

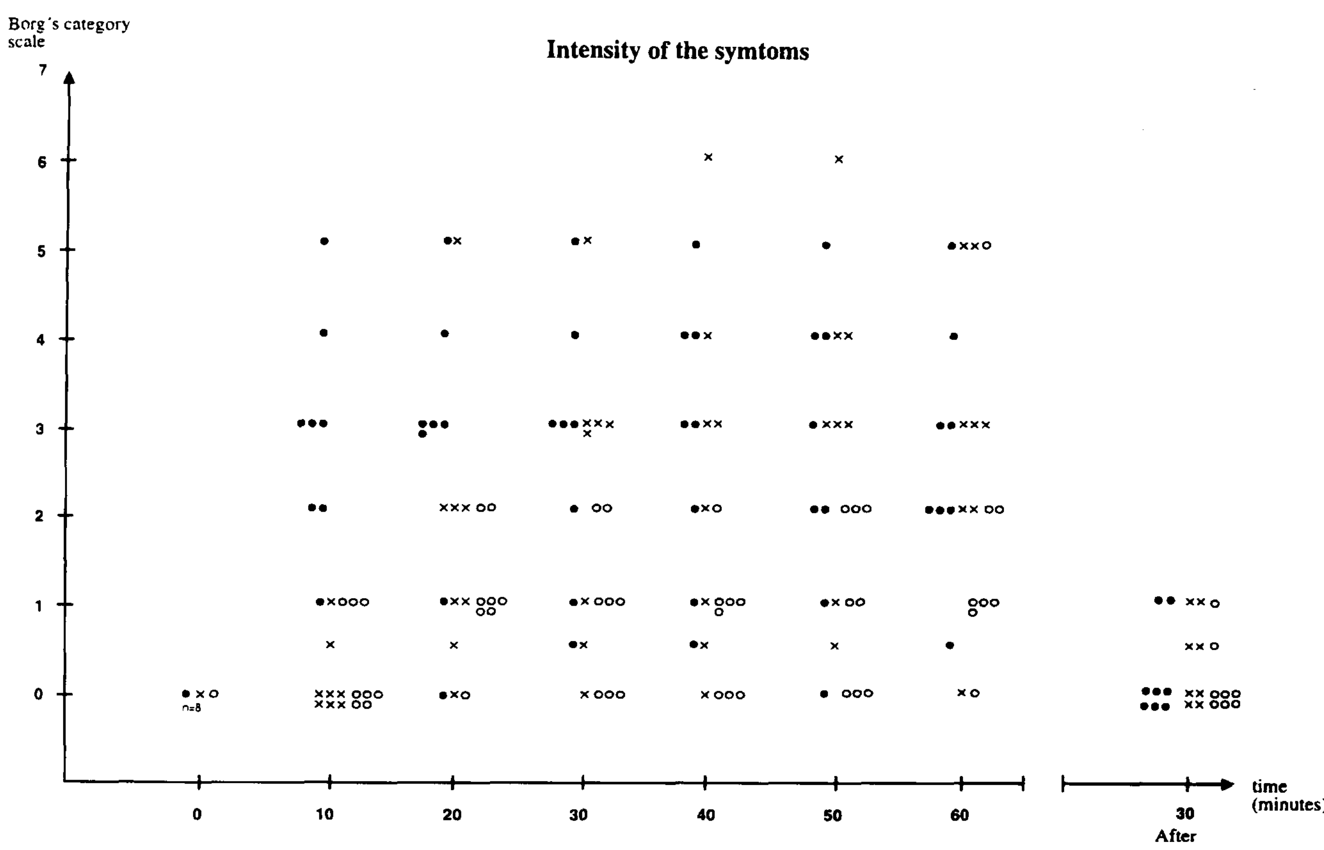

Fig. 7 The symptoms, unpleasant smell, eye irritation, and nasal irritation, experienced by the subjects (S1–S8) before, during, and after exposure to diluted diesel exhaust, 1.6 ppm NO_2 in the exposure chamber. The symptoms were recorded according to Borg's scale (*0* no symptom; *0.5* very, very weak symptom; *1* very weak symptom; *2* weak symptom; *3* moderate symptom; *4* somewhat strong symptom; *5* strong symptom, *7* very strong symptom) every 10 min during the exposure. ● Unpleasant smell; × eye irritation; ○ nasal irritation in nose

Table 2 The lung function data in eight subjects (S1–S8) before and after exposure to diluted diesel exhaust in the exposure chamber at a median steady state concentration at 1.6 ppm NO_2 during 1 h

		$FEV_{1.0}$	FVC	FEF_{25-75}	MTT	VC/VC	$\Delta N_2/1$
S1	Before	5.06	7.19	3.85	0.86	7.87	0.78
	After	5.17	7.14	3.96	0.77	6.32	0.62
S2	Before	4.50	5.16	4.96	0.46	8.35	1.29
	After	4.59	5.26	5.15	0.54	8.30	1.13
S3	Before	4.18	5.69	2.87	0.84	12.42	0.80
	After	4.27	5.83	2.99	0.81	13.49	0.81
S4	Before	4.46	5.79	3.58	0.70	8.45	0.99
	After	4.44	5.59	3.82	0.61	0.35	0.62
S5	Before	5.48	6.63	5.41	0.59	6.17	0.59
	After	5.49	6.73	5.25	0.63	7.67	0.48
S6	Before	4.88	6.65	3.60	0.81	5.76	0.52
	After	4.82	6.74	3.79	0.85	7.02	0.38
S7	Before	6.71	7.39	9.38	0.46	5.55	0.46
	After	6.79	7.35	9.34	0.41	6.34	0.49
S8	Before	3.92	5.71	2.34	0.94	12.01	0.74
	After	3.95	5.77	2.41	0.92	12.35	0.68

Three subjects did not experience throat irritation, headache, dizziness, nausea, tiredness, and coughing. The other five subjects experienced one to three of these symptoms and the intensity of the symptoms were less compared to unpleasant smell, eye irritation, and nasal irritation. The symptoms normalized 30 min after exposure. A tight feeling in the chest, difficult breathing, and a bad taste in the mouth were not experienced.

The data regarding the lung function are shown in Table 2. We did not find that any of the lung function parameters we investigated in the eight subjects were significantly changed.

Discussion

In order to carry out realistic and controlled challenge tests with diluted diesel exhaust we found it essential to have the experimental setup carefully evaluated. Regarding the evaluation of the exposure equipment, the size and the shape of particles in the diesel exhaust in SEM micrographs at the opening of the tail pipe and in the exposure chamber did not appear to differ. No visible change in the size and the shape or further agglomeration of the submicron particles was found in the exposure chamber, in spite of the high concentration of particles.

The composition of the measured substances at different dilutions of diesel exhaust in the exposure chamber was almost constant during 3 h of idling. No gradients of NO_2 and particles were found between the breathing zone of the exposed volunteers and the inlet for the analyzing instruments in the exposure chamber. New predetermined concentrations measured as NO, NO_2, and NO_x in the exposure chamber were reached in 5–7 min and this made it possible to generate different concentrations during one exposure.

At workplaces where workers have been exposed to diesel exhaust, NO_2 is often measured as an indicator of exposure. Miners, for example, have been found to be exposed to diesel exhaust up to an average concentration of 3.3 ppm NO_2 during a full work shift (Attfield et al. 1982). Short-term exposure values of up to 8 ppm in miners have been reported (Gamble et al. 1983). Workers on Ro-Ro ships have been found to be exposed to an average concentration of 1.15 ppm NO_2 during a whole work shift (Ulfvarson et al. 1987) and drivers in a tunnel to an average concentration of 1.3 ppm NO_2 (Ulfvarson et al. 1991). The subjects in this study were exposed to diluted diesel exhaust at a median steady state concentration of 1.6 ppm NO_2 during 1 h, which is comparable to a relatively high concentration at workplaces during a part of the day.

The patients that we have clinical experience of at the Department of Occupational Medicine were mostly exposed to diesel exhaust from idling vehicles. This had occurred in garages, queues, and at stop lights in the streets. It also occurred when the power from the engine was used for additional work equipment, in order to have a sufficient pressure for the brakes and during the winter in order to maintain a comfortable temperature in the driver's cab. The device described in this article was therefore constructed in order to carry out challenge tests regarding diesel exhaust from idling vehicles, but it could also be used in other experimental situations.

The acute symptoms that our volunteers experienced while exposed to diluted diesel exhaust were in agreement with our experience from the diesel-exposed workers at the Department of Occupational Medicine. The symptoms were also in agreement with another chamber study with approximately 2 ppm NO_2 of diluted diesel exhaust from a running diesel-powered car in a chassis dynamometer during 3.5 h (Ulfvarson et al. 1985). The most frequent symptoms were an unpleasant smell and eye irritation.

Diesel exhaust contains many chemicals and some of them are known irritatives in the gas and particulate phase, such as NO_2 and hydrocarbons including aldehydes. Coughing, nasal irritation, and symptoms from the larynx (Hackney et al. 1978) have been described as being caused by 1 ppm NO_2. At workplaces formaldehyde was found to cause eye irritation at 0.16–0.54 mg/m^3 (Bourne and Seferian 1959). A dose-response relationship at concentration ≥ 0.36 mg/m^3 was reported, but in sensitive individuals symptoms appeared at lower concentrations (Schuck et al. 1966). The smell sensation may arise from oxygenated and aromatic compounds (Cernansky 1983).

Lung function measured as dynamic spirometry was not affected in our material. This is in agreement with other studies in normal individuals after exposure to such low doses of diesel exhaust (Ayres et al. 1973; Ulfvarson et al. 1987, 1991; Ulfvarson and Alexandersson 1990). Presently we are investigating the lung function using a more sensitive technique, body plethysmography, at the same dose range as in this study.

In conclusion, the experimental setup was found to be appropriate for creating different predetermined steady state concentrations in the exposure chamber. The particles did not change in shape or size and there were no concentrations gradients. The measured compounds showed a relatively constant composition. The time taken to reach a new steady state concentration was short. The acute symptoms reported by the exposed subjects were in our experience similar to those reported by workers exposed to exhaust from idling diesel vehicles. The described setup is currently used in studies with lung function and bronchoalveolar lavage to investigate the inflammatory effects of diesel exhaust on the lungs of humans.

Acknowledgements We wish to thank Kjell Englund, Per Gandal, Annika Hagenbjörk-Gustavsson, Kjell Hollström, Lennart Lawin, Karin Lindström, Anna Wenngren, and "Västerbotten Regiment and Defence Area" for technical assistance and the Volvo Research Foundation and Volvo Educational Foundation for financial support.

References

Attfield MD, Trabant GD, Wheeler RW (1982) Exposure to diesel fumes and dust at six potash mines. Ann Occup Hyg 26: 817–831

Ayres SM, Evans R, Licht D, Griesbach J (1973) Health effects of exposure to high concentrations of automotive emissions. Arch Environ Health 27: 168–178

Borg GAV (1982) Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14: 377–381

Bourne HG Jr, Seferian S (1959) Insufficiently polymerized resins, used for wrinkle-proofing clothing, may liberate toxic quantities of formaldehyde. Ind Med Surg 2: 232–233

Cernansky NP (1983) Diesel exhaust odor and irritants: a review. J Air Poll Contr Assoc 33: 97–104

Gamble J, Jones W, Hudak J (1983) An epidemiological study of salt miners in diesel and nondiesel mines. Am J Ind Med 4: 435–458

Gamble J, Jones W, Minshall S (1987a) Epidemiological-environmental study of diesel bus garage workers: acute effects of NO_2 and respirable particulate on respiratory system. Environ Res 42: 201–214

Gamble J, Jones W, Minshall S (1981b) Epidemiological-environmental study of bus garage workers: chronic effects of diesel exhaust on the respiratory system. Environ Res 44: 6–17

Hackney JD, Thiede FC, Linn WS, Pedersen EE, Spier CE, Law DC, Fischer DA (1978) Experimental studies on human health effects of air pollutants. IV. Short-term physiological and clinical effects of nitrogen dioxide exposure. Arch Environ Health 33: 176–181

Levin JO, Lindahl R, Andersson KA (1986) A passive sampler for formaldehyde in air using 2,4-dinitrophenylhydrazine-coated glass fiber filters. Environ Sci Technol 20: 1273–1276

Reger R, Hancock J, Hankinson J, Hearl F, Merchant J (1982) Coal miners exposed to diesel exhaust emissions. Ann Occup Hyg 26: 799–815

Schuck EA, Stephens ER, Middleton JT (1966) Eye irritation response at low concentrations of irritants. Arch Environ Health 13: 570–575

Schuetzle D (1983) Sampling of vehicle emissions for chemical analysis and biological testing. Environ Health Perspect 47: 65–80

Ulfvarson U, Alexandersson R (1990) Reduction in adverse effect on pulmonary function after exposure to filtered diesel exhaust. Am J Ind Med 17: 341–347

Ulfvarson U, Alexandersson R, Aringer L, Anshelm-Olson B, Ekholm U, Hedenstierna G, Hogstedt C, Holmberg B, Lindstedt G, Randma E, Rosén G, Sorsa M, Svensson E (1985) Hälsoeffekter vid exponering för motoravgaser (Health effects of exposure to motor exhaust gases) (in Swedish, English summary). Arbete och Hälsa 5: 1–83

Ulfvarson U, Alexandersson R, Aringer L, Svensson E, Hedenstierna G, Hogstedt C, Holmberg B, Rosén G, Sorsa M (1987) Effects of exposure to vehicle exhaust on health. Scand J Work Environ Health 13: 505–512

Ulfvarson U, Alexandersson R, Dahlqvist M, Ekholm U, Bergström B (1991) Pulmonary function in workers exposed to diesel exhausts: the effect of control measures. Am J Ind Med 19: 283–289