SHEET N° 02

GOBIERNO DE ESPAÑA
MINISTERIO DE TRABAJO Y ECONOMÍA SOCIAL
insst Instituto Nacional de Seguridad y Salud en el Trabajo

Diesel Engine Exhaust Emissions

CARCINOGENS AT WORK: Know to Prevent

Information about the substance and where it can be found

Diesel engine exhaust emissions are a complex mixture of particulates, liquid aerosols, gases and vapours generated as a combustion product during the operation of engines that use diesel fuel.

Solid particles, or soot, consist of a core of elemental carbon, also known as black carbon, organic carbon and other agents such as ash, metals and sulphates. The gaseous phase consists of carbon monoxide and dioxide and nitrogen oxides along with volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs), adsorbed on the surface of the particles.

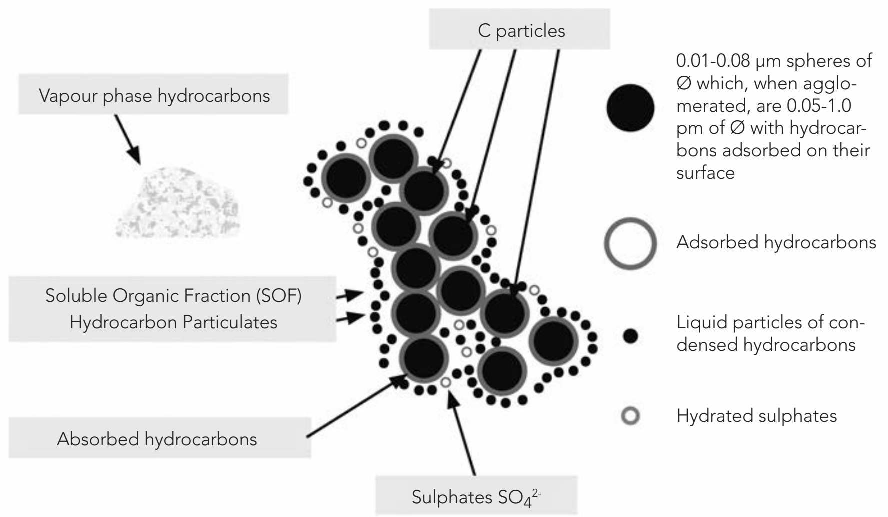

Diagram of diesel engine emission components and their relative size. Source: Revista Seguridad y Salud en el Trabajo, No. 73 - 2013.

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This mixture contains many substances recognised as carcinogenic, such as formaldehyde, benzene and polycyclic aromatic hydrocarbons (PAHs).

Some mixtures of polycyclic aromatic hydrocarbons, in particular those containing benzo(a)pyrene, meet the criteria to be classified as carcinogenic (category 1A or 1B according to the CLP Regulation) and must therefore be deemed to be carcinogens. These mixtures are often generated during combustion processes, such as those which take place in diesel engines, especially at very high temperatures.

Table 1 shows some of the components of combustion engine emissions classified as Group 1 and Group 2A carcinogens by the International Agency for Research on Cancer (IARC) (IARC, 2013).

Both the composition of these fumes and the quantity released into the environment is variable and depends on factors such as: the characteristics of the fuel and lubricating oils; the technology and age of the engine, including whether it has emission reduction systems; the operating speed of the engine, that is, whether it is idling, running with a low load or at full power; the temperature of the engine; and the engine maintenance conditions and settings.

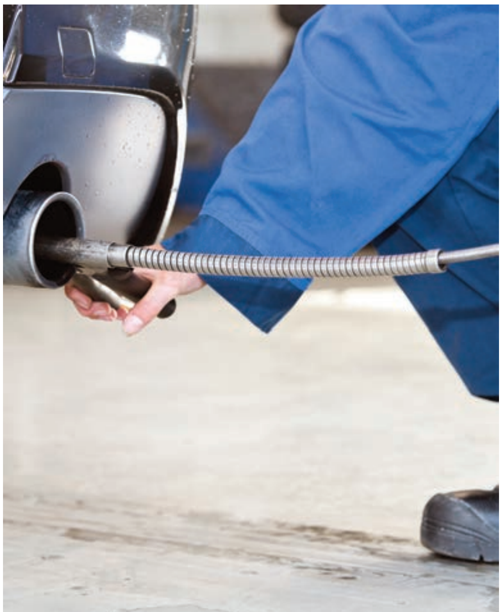
There is a background concentration of diesel engine exhaust emissions in the environment, which originates mainly from road traffic and which will be vary by the geographical area. Besides this background concentration, where machinery, whether mobile or stationary, using diesel as fuel, there will be an additional concentration.

Table 1. Some carcinogenic components of combustion engine emissions

Chemical Agents	IARC classification	CLP Classification
Chromium VI	1	Carc. 1A Muta. 1B Repr. 2
Inorganic lead compounds	2 A	Repr. 1 A
1,3-Butadiene	1	Carc. 1A Muta. 1 B
Benzene	1	Carc. 1A Muta. 1 B
Formaldehyde	1	Carc. 1B Muta. 2
Dioxins / dibenzofurans	1	Carc. 1 B
Benzo(a) pyrene	1	Carc. 1B Muta. 1B Repr. 1 B

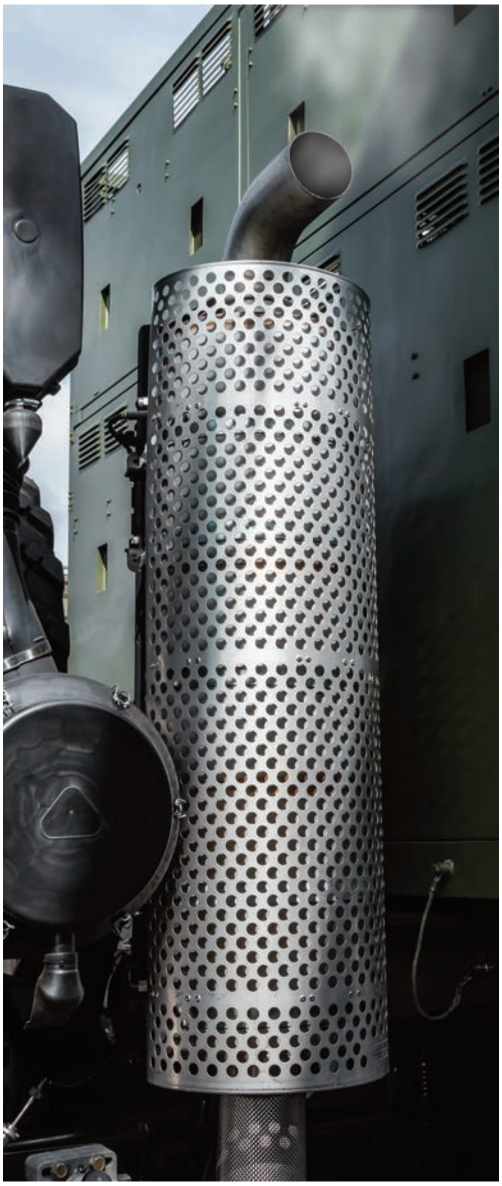
Source: IARC. Monographic 105

The IARC (iarc.who.int) is an autonomous agency of the World Health Organization of the United Nations. It seeks to promote international collaboration in cancer research. It runs studies that are widely recognised for their quality and independence.



The introduction of stringent emission regulations in the European Union and other countries triggered the development and application of new diesel engine technologies that have led to major changes in the composition of the particulate matter (PM) and gaseous components emitted, and to the development of new systems for treating emissions before they are released into the atmosphere. Thus, the age of the vehicles is a determining factor in the type and quantity of fumes they will emit.

It is important to note that this regulation does not apply to vehicles or equipment not intended for road transport, such as trains, ships, heavy machinery used in mining or construction, or stationary equipment for energy production, among others.



Health effects

Short-term (acute) exposure to high concentrations of diesel engine exhaust emissions may cause respiratory tract and eye irritation, headache, dizziness, nausea and symptoms of respiratory tract inflammation, which vary between individuals and are transient. When long-term (chronic) exposure occurs, more serious effects such as lung inflammation, exacerbation of allergic response, cardiovascular disease and lung cancer may occur (IARC, 2013). Exposure to this agent may also aggravate existing cardiovascular or respiratory pathologies.

In 1988, the IARC classified diesel engine exhaust emissions as a probable human carcinogen in group 2A. In 2012, after reviewing the most recent studies, the same body concluded that this chemical agent is a human carcinogen, classifying it in group 1, due to sufficient evidence in humans, that is, in epidemiological studies, showing that exposure is associated with an increased risk of lung cancer. There is also limited evidence linking exposure to these emissions to an increased likelihood of developing urinary bladder cancer.

Epidemiological studies show a consistent positive association between exposure to diesel exhaust fumes and an increased risk of lung cancer. This increased risk has been estimated to be up to 40% more likely to develop this type of cancer (IARC, 2013).

The health effects due to exposure to particulate matter generally depend on the quantity that accumulates in the lungs, which in turn depends on the concentration of particulate matter in the air that is breathed and the size of the particles. Particles smaller than 10 μm, which are part of what is known in industrial hygiene as the respirable fraction, can be inhaled and enter the respiratory system until they reach the pulmonary alveoli and settle there, where they may produce their harmful effects.

Most of the particles in diesel engine exhaust emissions are smaller than 0.1 μm (100 nm), that is, they are nanoparticles or, as they are known in the public health and environmental field, "ultrafine particles" (UFP). Studies indicate that most of the particulate matter in diesel engine exhaust emissions is around 50 nm (Kittelson et al., 2008). Due to their very small size and high specific surface area, these particles are extremely reactive and can pass through the epithelium and vascular walls into the bloodstream (Sydbom et al., 2001).

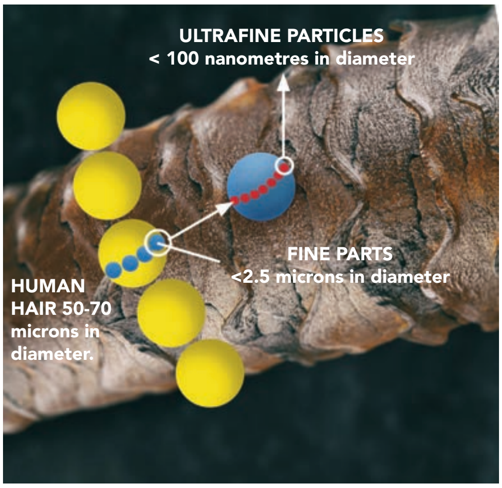
Where the exposure can take place

Occupational exposure to diesel engine exhaust emissions may occur in many different work environments including: mining, agriculture, construction and transport, whether by rail, road, air or sea, or in vehicle repair shops.

The main factors influencing exposure are the type and number of diesel engines in use, their power, the operating speed, whether operating outdoors or indoors and, in the latter case, the degree of ventilation available.

Regulatory references

Diesel engine exhaust emissions are not subject to classification as a hazardous chemical agent according to EC Regulation 1272/2008 (CLP), as they are not placed on the market but generated in a process; however, they are deemed to be a carcinogen under Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens, mutagens or reprotoxic substances at work, amended by Directive (EU) 2019/130 of 16 January 2019 to include work involving exposure to diesel engine exhaust emissions in Annex I to the Directive. This directive has been transposed into Spanish law by Royal Decree 427/2021 of 15 June, hence Royal Decree 665/1997 is already included in the scope of application.



Relative size of ultrafine particles. Source: @TuftsUniversity 2012 - Big Road Blues

Studies that have been conducted to characterise diesel exhaust exposure in various industries (Pronk, Coble, & Stewart, 2009) have found that the highest personal exposures occur in underground mining and tunnel construction, with average daily exposure levels measured as elemental carbon of 100 µg/m^3 (0.1 mg/m^3), followed by loading dock, mechanical and maintenance work with levels between 20 and 40 µg/m^3. This is followed by train crew, construction and aircraft baggage handlers, where average exposure is below 10 µg/m^3. Finally, professional drivers have an average daily exposure of around 2 µg/m^3 (see table 2).

Many of the studies characterising exposure to diesel engine exhaust emissions were conducted before various vehicle emission limiting standards came into force and the more widespread use of particulate filters and other integrated emission control systems (Pronk et al., 2009), so certain occupational settings exposure has changed both qualitatively and quantitatively as vehicles or equipment have been upgraded.

Table 2
Levels of personal exposure to elemental carbon in different sectors of activity

Sector of activity	Daily exposure levels (µg/m^3)
Underground mining and tunnel construction	100
Loading dock, mechanics and maintenance	20-40
Train crew, construction, ground crew in aviation	10
Professional drivers	2

Source: Pronk et al., 2009

Table 3
Non-exhaustive list of occupations in which there may be exposure to diesel engine exhaust emissions

Main occupations where exposure may occur	
Miners	Traffic control personnel: police, civil guard, etc.
Tunnel construction workers	Heavy machinery operators
Professional drivers, including passenger transport, freight and courier services	Ferry loaders and dock workers on ferries
Firefighters	Sea workers
Diesel vehicle or equipment repair and maintenance workers	Operators of load handling equipment
Construction workers	Oil industry workers
Warehouse and logistics workers	Railway workers, both drivers and crew of diesel engines
Farmers	Refuse collection workers
Toll booth operators	Airport ground staff
Customs workers	Foresters and loggers

Other occupations that may be affected by occupational exposure to this agent include: firefighters, during their work at the station and in firefighting; toll booth workers and car park workers; forklift operators; oil industry workers; and any workplace near compressors, generators and other equipment using diesel as an energy source. A non-exhaustive list of occupations that may be exposed to emissions from diesel engines is given in table 3.

Exposure assessment

Where vehicles or other diesel-powered machinery are found in the workplace, there may be a risk of exposure to this agent. The first step in determining whether risk exists is to identify possible sources of emissions. To do so, there are several aspects that should be determined:

- Diesel engines or equipment used on the job. The higher the number, the higher the level of potential exposure.
- The site where diesel engine exhaust emissions are released. Whether it is an indoor or outdoor environment. The most unfavourable situation is that which would result from using diesel combustion engines indoors. The position and distance of workers from emission sources is also important.
- Ventilation grilles or openings through which fumes generated outdoors or in other locations can be filtered into areas where workers are present.
- Confined spaces or poorly ventilated areas where high concentrations of the agent may occur.
- Visible soot deposits on surfaces. It is an indication that the concentration of fumes in the air is too high.
- Symptoms or discomfort experienced by workers: eye or respiratory tract irritation, headache, dizziness or nausea. In this case, it is best to ask them directly and, in parallel, to check the company's accident and sick leave records.

In any of these circumstances, workers may be exposed to high concentrations of diesel engine exhaust emissions.

The information gathered in this preliminary study of the installation will help us to correctly approach the quantitative exposure assessment, that is, measurements of the concentration of this chemical agent for comparison with a reference criterion or limit value.

Royal Decree 427/2021, amending the regulations on carcinogens or mutagens at work, established a binding daily exposure limit value of 0.05 mg/m^3 measured as elemental carbon, mandatory as of 21 February 2023 or 21 February 2026, in the mining and tunnel construction sector, depending on the transitional periods set out in the directive it transposes.

For the quantitative assessment of exposure, reference can be taken from the NIOSH Method 5040 (National Institute for Occupational Safety and Health, USA), although a different thermal transmittance protocol, called EUSAAR_2, is currently used for laboratory analysis in the European Union.

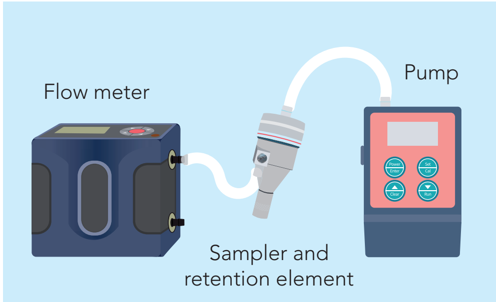
NIOSH Method 5040 proposes using a 37 mm quartz fibre filter on an open cassette as a sampler (except in mining environments with high levels of carbonaceous dust, where the use of an impactor is recommended), checking that the sample is deposited evenly on the filter. The proposed sampling flow rate is 2 to 4 l/min.

Table 4
Occupational exposure limit values to consider

Agent	8 hours-OEL		Short-term OEL	
	ppm	mg/m^3	ppm	mg/m^3
CE		0,05		
NO	2	2,2	-	-
NO_2	0,5	0,96	1	1,91

Representativeness of the samples

Whenever a quantitative assessment of inhalation exposure to a hazardous chemical agent, a sampling strategy must be adopted to ensure the representativeness of the data obtained. This can be obtained by following the standard UNE-EN 689:2019+AC:2019 "Workplace exposure Measurement of exposure by inhalation to chemical agents - Strategy for testing compliance with occupational exposure limit values"



In any case, the laboratory to which the samples are to be submitted for analysis can answer any questions about the most suitable requirements and materials to obtain adequate samples.

Elemental carbon is considered the best indicator of exposure to diesel engine exhaust emissions; however, diesel engines also emit significant quantities of nitrogen oxides (NO and NO_2). These gases have their own environmental limit value and exposure to these agents also needs to be assessed.

To determine quantitatively exposure to these gases the reference method can be either the NIOSH 6014 method, with active sampling and which is suitable for both gases, or the NIOSH 6700 method, which makes it possible to sample nitrogen dioxide using passive samplers.

Controlling exposure

Exposure control or prevention measures should be prioritised according to their effectiveness. The first option should always be substitution; when this is not possible, the option of working in a closed system should be considered; when this is not possible either, all measures to reduce exposure to as low a level as technically possible should be used; and finally, when the above measures are not sufficient, personal protective equipment (PPE) should be used.

1. Substitution

The priority measure, and mandatory whenever it is possible, when working with carcinogens or mutagens, is always substitution with another agent or process not dangerous or is less dangerous. This measure is the most difficult to implement, especially when a production process is already in place, and many variables must be taken into account, but it must be planned and implemented whenever feasible, even if it is more costly, and it is necessary to keep up to date with technological advances in each sector.

Prioritisation of preventive measures for carcinogens:

1. Substitution
2. Closed system
3. Reduction of exposure to a level as low as technically possible
4. Personal protective equipment

Resources for substitution:

More practical experiences of risk substitution or elimination can be found in the following links:

- Solutions, examples of substitution and good practice for carcinogens, from the Roadmap on carcinogens initiative.

- https://roadmaponcarcinogens.eu/solutions/good-practices/

- SUBSPORT Substitution Support Portal.

https://www.subsportplus.eu/

- OECD Substitution Toolkit Portal.

http://www.oecdsaatoolbox.org/

- INRS Substitution Fact Sheets.

http://www.inrs.fr/actualites/nouvelles-far-fas.html

In the case of diesel engine exhaust emissions, substitution may be based on using other types of energy technologies, for example, using electric forklift trucks in warehouses instead of combustion engines. A study characterising exposure to exhaust fumes in the logistics sector showed that 80% of workers' exposure could be attributed to forklift trucks and the remainder to vehicles in which goods were placed for further transport (Tharr, 1992).

Electric motors generate no emissions into the environment, produce less noise and do not increase the temperature in the workplace. Substitution with such engines would eliminate the risk (100% reduction). It can also be quite effective to replace engines with hybrid technology, which, while not eliminating risk, would reduce emissions significantly (Center, 2017).

2. Closed system

It consists of preventing the dispersion of the agent into the air breathed by the worker by placing the process within a closed system with air evacuation, and a system of treatment and evacuation to a safe environment to prevent the agents from harming the environment or public health.

In the case of diesel engine exhaust emissions, it could be applied in workplaces where equipment or machinery is stationary, for example, compressors, generators or other static machines. In this case, it is important to design the enclosure and the smoke exhaust system correctly so that smoke does not re-enter the workplace through openings or vents.

3. Reduction of exposure to as low a level as is technically possible

The aim is to implement technical and organizational measures so that exposure is reduced as much as technically possible. This obligation implies that it is not sufficient to achieve exposure levels below the established occupational exposure limit, but rather that it is necessary to go beyond it by applying all available measures.

Royal Decree 665/1997 establishes the obligation to adopt all necessary measures as set out in article 5.5. In general, these requirements are along the same lines as what should already be applied to comply with the Royal Decree 374/2001, on the protection of the health and safety of workers against risks related to chemical agents at work, adding the express mention of installing devices that detect and alert in the event of situations that could generate abnormally high exposures, such as a failure in a local exhaust ventilation system.

Fleet renewal

One of the most effective measures to reduce exposure is the renewal of old vehicle fleets. New technology vehicles can emit up to 99% less particulate matter than traditional vehicles thanks complex emission control systems (Hesterberg et al., 2011). This can be particularly useful in activities such as mining or tunnelling, where the use of heavy machinery is almost essential and ventilation is limited.

The National Institute of Silicosis conducted a multi-year characterisation study of diesel fume exposure in underground mining and found that there was a relationship between higher exposures and the average age of vehicle fleets (INS, 2018).

Switch off engines or keep them outside

A simple and effective measure is to minimise the number of engines running simultaneously in an environment. To this end, procedures can be put in place to provide instructions for shutting down engines that are not essential. For those engines that are, consideration may be given to the option of keeping them outdoors.

To prevent emissions from idling engines, automatic shutdown systems can be installed when engines are not used for a certain period. This measure is particularly effective for equipment that tends to idle for long periods of time.

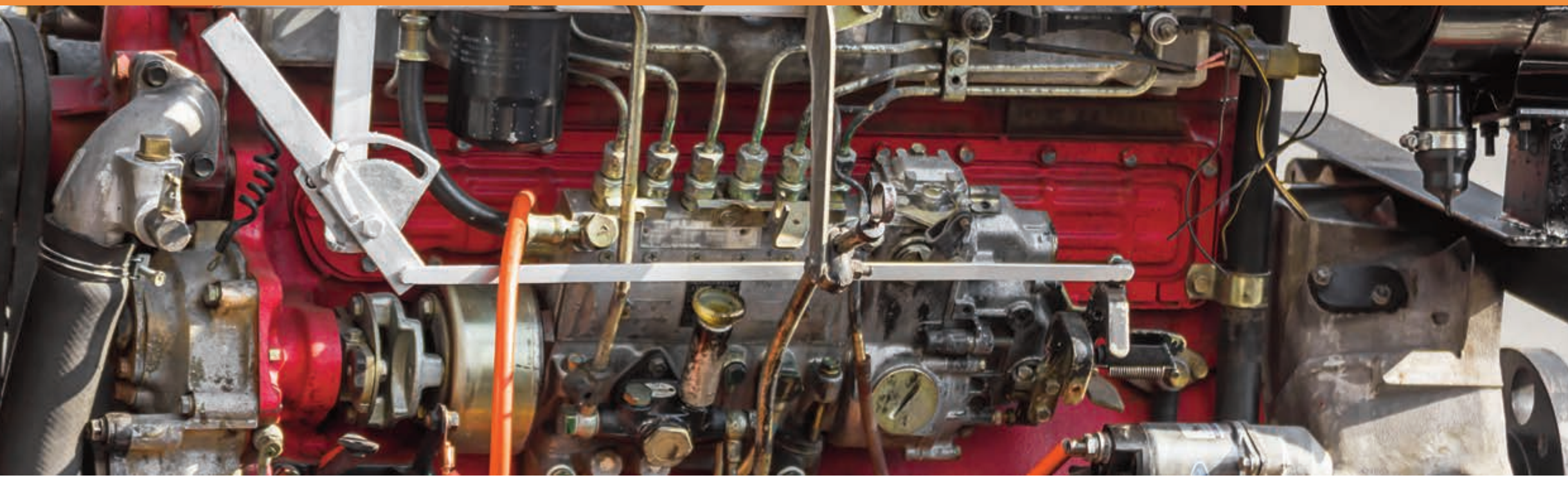
Another form of emission control is to warm up engines outdoors or in well-ventilated locations since cold engines are known to generate a higher quantity of unburned or partially burned hydrocarbons than those already at their optimum operating temperature.

Visible smoke

If you can see smoke from exhausts, it is likely that the exposure is too high. In these cases, the smoke itself may indicate the source of the problem:

- Bluish fumes: the presence of unburned oil and fuel. The engine needs to be checked and serviced as it may not be working properly.
- Black smoke: high levels of particulate matter and unburned oil and fuel. This could be due to a mechanical failure of the engine or it is running at high power.
- White fumes: water and unburned fuel. The engine is cold. If possible, it is advisable to warm up outdoors (HSE, 2012).

Portable exhaust filter. EHC Teknik, A. B. (https://ehcteknik.com/)



Engine maintenance

The implementation of a comprehensive engine maintenance programme is key to reducing emissions, especially for fuel supply systems, but also for other components of the engine and emission treatment systems. Maintenance can reduce particulate emissions by up to 55%.

Installation of portable exhaust filters

There are movable filters on the market that can be fitted in the exhaust pipes and may be useful for specific operations such as factory testing, inspections, loading of vehicles on ferries or any other operation that must be performed in environments without adequate ventilation and where other measures cannot be implemented.

Local exhaust ventilation

This measure is particularly useful when using equipment that produces emissions in indoor spaces such as workshops, garages, vehicle inspection centres and tunnels. Extraction systems, either portable or in the form of flexible pipes, can be used in vehicle exhaust pipes to prevent emissions from spreading around the workplace. If the diesel equipment is fixed, more conventional solutions can be adopted.

An example of the implementation of a portable local exhaust ventilation system in a vehicle inspection workshop in France can be found at this link (AESST, 2018).

Although it is one of the most effective measures, there may be situations or applications where its implementation is not possible, since it limits the mobility of equipment, which may be necessary in some situations, for example in construction.

General ventilation

General ventilation helps to dilute the concentration of diesel engine exhaust emissions. In enclosed and fixed workplaces, it is essential that the general ventilation system is properly designed and maintained. When air renewal is not sufficient naturally, forced or mixed ventilation systems can be used to guarantee it is renewed. Seasonal changes also need to be taken into account, since in the cold season there must be openings to ensure fresh air flow.

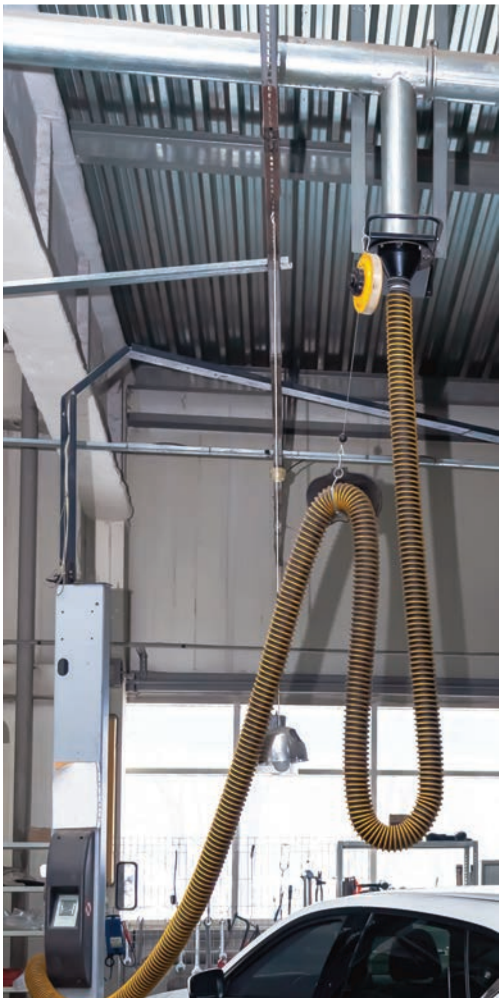
Adjustable and mobile local exhaust ventilation for exhaust pipes in a workshop where vehicles are tested in operation.

Enclosed cabins

The way to avoid or minimise exposure of workers driving vehicles or machinery is to put them in enclosed cabins with inlet air filtering systems and, if necessary, air-conditioning systems to avoid open windows. This must be accompanied by procedures and training to ensure that cabins are left only when absolutely necessary and after the engine has been switched off. The measure should also be accompanied by a ban on smoking in the cabins, to prevent windows from being opened.

It is important to note that this measure protects only the workers inside the cabins but not the workstations around the equipment or vehicle.

Properly functioning enclosed cabins can reduce exposure to dust and particulate matter from diesel emissions by 90% or more (Bugarski, Janisko, Cauda, Noll, & Mischler, 2011). However, if the cabins are not optimised, their efficiency may be less than 40%. Other factors influencing its proper functioning include recirculation filters, cabin integrity, open windows, etc.



When deciding to implement enclosed cabins, consideration must be given to space restrictions if the work is to be done in confined spaces. For example: space constraints in an inland mine may be a problem for adopting this measure.

Separation of workplaces

Places where running engines are located should be separated from other activities in the workplace so that workers who do not have to perform operations with the engine-driven equipment are not exposed to this agent. This separation can be achieved with physical elements and positive pressure ventilation systems in the workplaces to be protected.

In toll collection booths or car parks, openings should be minimised, booths should be fitted with positive pressure forced ventilation systems and filtered air intake, and workers should be trained to keep openings closed for as long as possible.

Remote control

This measure allows the worker to operate diesel equipment from a safer location, such as in a better ventilated area or in a cabin or control room isolated from emissions.

Remote control requires additional training for operators to ensure safe and effective use of remote equipment. Specialist equipment and technologies are also needed to implement them and these devices may require maintenance by qualified personnel.

Remote operation can be useful in excavation or tunnelling work, where diesel emissions can be high.

4. Personal protective equipment

PPE should only be used where adequate control of exposure cannot be achieved by other means. PPE is considered as a last resort within the hierarchy of control measures. The results of the risk assessment shall be the basis for determining the need for personal protective equipment and for selecting the most appropriate equipment. Moreover, when selecting equipment, the anatomy of the workers who will be using it must be taken into account and it is highly recommended that a fit test be carried out on each person.

In the event of exposure to diesel engine exhaust fumes, it should be noted that particulate filtering equipment does not protect against gases, in this case nitrogen oxides; therefore, particulate filters should be combined with gas filters.

Cleaning and maintenance procedures for this PPE are as important as their proper selection and use. Manufacturers' recommendations must be strictly followed and workers must be trained to know and apply them properly. A suitable storage place for PPE must be provided.

Regulatory references

The respiratory protective equipment facepieces must comply with the following legal and technical regulations:

1. Legal provision on design and manufacture:

   Regulation (EU) 2016/425 (Royal Decree 773/1997. article 5.3.)

2. Harmonised technical standards with applicable requirements:

   Full masks:

   UNE-EN 136:1998

   Half masks (face masks): UNE-EN 140:1999

   Gas and combined filters: UNE-EN 14387:2004+A1:2008

More information at https://www.insst.es/epi

Example of combined filters. www.draeger.com

Colour code	Filter type	Application
Blue	NO	Nitrous oxide and nitric oxide
White	P	Particles

Health surveillance

Carcinogens or mutagens are generally characterised by long-term effects or diseases with long latency periods. Thus, Royal Decree 665/1997 establishes a right for workers who have been exposed to these agents to the extension of health surveillance beyond the end of the exposure or of the employment relationship.

Where the cessation of exposure is due to the termination of the employment relationship, post-occupational health surveillance shall be performed through the national health system. However, where the cessation of exposure is due, for example, to a change of job, it will continue to be the responsibility of the employer.

Currently, there is no specific health surveillance protocol for workers exposed to diesel engine exhaust emissions. However, it may be useful to consult workers if they experience discomfort related to irritation of the eyes or mucous membranes, dizziness or coughing at work, and to observe possible signs of these conditions since these symptoms are indicative of possible exposure to high concentrations of diesel engine exhaust emissions at work.

Normative references on health surveillance

Health surveillance must be performed (Royal Decree 665/1997, art. 8):

- Before the beginning of the exposure.
- At regular intervals, as often as medical events dictate.
- When it is necessary because a disorder has been detected in one of the company's workers with similar exposure, which may be due to exposure to carcinogenic or mutagenic agents.

Other preventive measures

At works involving the risk of exposure to diesel engine exhaust emissions, other series of preventive measures established in Royal Decree 665/1997 must be complied with, such as the following:

- Personal hygiene measures (article 6).
- Measures to be taken in the event of accidental and non-regular exposures (article 7).
- Obligations with regard to documentation (article 9).
- Information for the competent authorities (article 10).
- Consultation, information and training of workers (articles 11 and 12).

Training

The training of workers operating diesel equipment or vehicles is particularly important since emissions will be highly dependent on the conditions under which the engines are used.

Training in efficient driving skills can greatly reduce emissions and also reduce engine wear, fuel consumption and maintenance needs.

Training to detect engine maintenance problems, effective use of enclosed cabins and use and maintenance of emission control technologies are also important.

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Author:
Instituto Nacional de Seguridad y Salud en el Trabajo (INSST), O.A., M.P.

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