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## Diesel Exhaust

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Exposure to diesel exhaust continues to be widespread in industrialized and developing countries. Trucks, buses, trains, construction and farm equipment, generators, ships, and some cars have diesel engines. Exhaust from these engines brings a complex mixture of combustion particulates and gases to roadways, cities, farms, and other workplaces. Health concerns about diesel exhaust relate not only to cancer, but also to respiratory and heart diseases.

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## ▶ WHAT IS DIESEL EXHAUST?

Diesel engines function by using the heat of compressed air, rather than an electrical spark, to ignite fuel. In gasoline engines, a mixture of air and fuel is drawn into a combustion chamber, compressed, and ignited by an electric spark. In diesel engines, air alone is compressed in the combustion chamber. When fuel is then introduced into the chamber, the fuel ignites due to the heat of the compressed air.

- ▲ [TOP](#)
- [WHAT IS DIESEL EXHAUST?](#)
- ▼ [OCCUPATIONAL AND GENERAL...](#)
- ▼ [DOES DIESEL EXHAUST CAUSE...](#)
- ▼ [HOW SHOULD HEALTH PROFESSIONALS...](#)
- ▼ [REGULATORY INITIATIVES](#)
- ▼ [WHAT'S THE BOTTOM LINE?](#)
- ▼ [REFERENCES](#)

While diesel engines can operate with less highly refined fuel and consume less fuel per unit of work performed, they typically emit more particulate mass than catalytically equipped gasoline engines. Diesel engines are the predominant source of industrial power throughout the world for engines up to about 5,000 horsepower.<sup>1</sup> A much larger percentage of passenger vehicles in Europe are powered by diesel engines than in the US.<sup>2</sup>

The exhaust from diesel engines consists of both gas and particulate fractions, each of which is composed of thousands of different substances. The gas portion of diesel exhaust contains primarily carbon dioxide, carbon monoxide, nitric oxide, nitrogen dioxide, sulfur oxides, and hydrocarbons, including polycyclic aromatic hydrocarbons (PAHs). PAHs are produced as pyrolytic products during the combustion of any fossil fuel, including diesel fuel.<sup>3</sup>

The particulate portion of diesel exhaust, also known as soot, is mainly composed of elemental carbon, organic material (including PAHs), and traces of metallic compounds. Thus PAHs are found in both the gaseous and particulate fractions of diesel exhaust.<sup>4</sup>

Emissions of organic compounds from gasoline (both leaded and unleaded) and diesel engines are qualitatively similar, but there are quantitative differences. Older, light-duty diesel engines (automobile and light trucks), for instance, can emit 50 to 80 times more particulate mass, and heavy-duty diesel engines emit 100 to 200 times more particulate mass than catalytically equipped gasoline engines, although the difference has decreased substantially with newer models.<sup>5</sup> Gasoline engines without catalytic converters produce a similar quantity of PAHs compared with diesel engines.<sup>1</sup>

## ▶ OCCUPATIONAL AND GENERAL EXPOSURES

Exposures to diesel exhaust vary widely in intensity and duration. The highest exposures occur in occupational settings among workers such as truck drivers, bridge and tunnel workers, mineworkers, forklift drivers, railroad and dock workers, and garage workers. Farm workers and car, truck, and bus maintenance garage workers may also be subject to heavy exposures.<sup>1</sup> In all, approximately 1.35 million US workers are potentially exposed to diesel fuel combustion products on the job. The components of diesel exhaust most often quantified in occupational settings are particles, carbon monoxide, oxides of nitrogen, formaldehyde, and PAHs.

The general public is also exposed to diesel exhaust, although less frequently and at much lower concentrations than in the workplace. Exposures are highest where diesel traffic is heaviest, such as along highways and in cities.

Exposure to diesel exhaust occurs through inhalation rather than ingestion and skin absorption. It is difficult to quantify exposure, as diesel exhaust is chemically complex and its components—particulates, oxides of nitrogen, and others—may also derive from many other sources. This has been a challenge in epidemiologic studies.

- ▲ [TOP](#)
- ▲ [WHAT IS DIESEL EXHAUST?](#)
- [OCCUPATIONAL AND GENERAL...](#)
- ▼ [DOES DIESEL EXHAUST CAUSE...](#)
- ▼ [HOW SHOULD HEALTH PROFESSIONALS...](#)
- ▼ [REGULATORY INITIATIVES](#)
- ▼ [WHAT'S THE BOTTOM LINE?](#)
- ▼ [REFERENCES](#)

## ▶ DOES DIESEL EXHAUST CAUSE CANCER?

Two kinds of evidence are informative about the potential carcinogenicity of diesel exhaust: Studies of the components of diesel exhaust such as soot and PAHs, and studies of diesel exhaust itself. A full discussion of the evidence concerning substances and chemicals such as soot and PAHs is beyond the scope of this article, although these have been classified as carcinogenic. There is also evidence about diesel exhaust itself, which is presented below.

- ▲ [TOP](#)
- ▲ [WHAT IS DIESEL EXHAUST?](#)
- ▲ [OCCUPATIONAL AND GENERAL...](#)
- [DOES DIESEL EXHAUST CAUSE...](#)
- ▼ [HOW SHOULD HEALTH PROFESSIONALS...](#)
- ▼ [REGULATORY INITIATIVES](#)
- ▼ [WHAT'S THE BOTTOM LINE?](#)
- ▼ [REFERENCES](#)

### What Do Epidemiologic Studies Suggest?

The major cancer suspected of being linked to diesel exhaust is lung cancer. Epidemiologic studies of lung cancer risk in diesel-exposed workers are affected by the usual challenges of epidemiologic studies, especially the difficulty of correctly defining and quantifying occupational exposure, and confounding by other exposures such as smoking and concurrent workplace exposures.<sup>1</sup>

Epidemiologic studies of workers exposed to diesel exhaust have shown small but significant elevations in risk of lung cancer. A case-control study found that railroad workers with at least 20 years of service were significantly more likely to die from lung cancer than were members of the general population.<sup>6</sup> A cohort study of over 55,000 railroad workers by the same researchers found that lung cancer risk increased with duration of exposure to diesel exhaust; the relative risk was 1.72 among workers with the longest exposure (as much as 22 years).<sup>7</sup>

Several studies of teamsters also linked diesel exhaust exposure with lung cancer.<sup>8-10</sup> Still another study analyzed the lung cancer incidence of almost half a million American males in relation to their occupational exposure to diesel exhaust; men with the heaviest and most prolonged exposures, such as railroad workers, heavy equipment operators, miners, and truck drivers, had higher lung cancer mortality than unexposed workers.<sup>11</sup>

While most cohort and case-control studies have found an association between diesel exhaust exposure and lung cancer, several have not. Two recent meta-analyses quantitatively combined data from available epidemiologic studies to estimate the relative risk of lung cancer in workers exposed to diesel exhaust compared either to the general population or to unexposed workers after controlling for smoking. They reached very similar conclusions—a relative risk of 1.47 in one<sup>12</sup> and 1.35 in the other.<sup>13</sup>

By way of comparison, the relative risk of lung cancer for a typical male cigarette smoker is approximately 20, an increase in risk that is 40 times higher for smoking than for diesel exhaust. Nevertheless, with more than one million exposed workers, diesel exhaust may have a substantial health impact. The re-relationship between lung cancer and diesel fumes in the general environment has been studied much less than occupational exposures.

### **What Do Animal and Laboratory Studies Suggest?**

In laboratory studies, diesel exhaust (as particles or chemical extracts) is mutagenic. Several animal studies also provide evidence for the carcinogenicity of diesel exhaust. For example, a long-term inhalation study in mice, rats, and hamsters exposed to diesel exhaust demonstrated a statistically significant excess of lung cancer among exposed animals.<sup>14</sup> However, it has been observed that the carcinogenic effects of diesel exhaust in animals may relate to particle overload in the airways. If true, this would suggest that the overwhelming of lung defenses may be required for diesel exhaust carcinogenesis.<sup>15</sup>

### **What Do the Experts Say?**

Based on such animal and human evidence, expert agencies have evaluated the carcinogenicity of diesel exhaust.

The National Toxicology Program evaluates exposures that may be carcinogenic. Exposures that are thought to be carcinogenic are included in the *Reports on Carcinogens*, which is published every two years. Each exposure is assigned to one of two categories: "Known to be human carcinogens," and "reasonably anticipated to be human carcinogens." The first category includes substances for which human studies (epidemiologic and/or experimental studies) provide "sufficient evidence" of carcinogenicity in humans. The second category includes substances for which there is limited evidence of carcinogenicity in humans and/or sufficient evidence of carcinogenicity in experimental animals. The National Toxicology Program has classified diesel exhaust particulates as reasonably anticipated to be human carcinogens.<sup>16</sup>

***Prolonged exposure to diesel exhaust probably increases the risk of lung and perhaps other cancers.***

The International Agency for Research on Cancer (IARC) also evaluates exposures that may be carcinogenic. IARC classifies exposures into one of four categories: Group-1 exposures are those "known to be carcinogenic to humans," usually based on "sufficient" human evidence, but sometimes based on "sufficient" evidence in experimental animals and "strong" human evidence. Group-2 exposures are divided into two categories. Group-2A ("probably carcinogenic to humans") has stronger evidence, and Group-2B ("possibly carcinogenic to humans") has weaker evidence. Group-3 exposures are not considered classifiable because the available evidence is limited or inadequate. Finally, Group-4 exposures are "probably not carcinogenic to humans" based on evidence suggesting lack of carcinogenicity in humans and in experimental animals. IARC rated diesel exhaust as "probably carcinogenic to humans" (Group-2A).<sup>4</sup>

***People who are concerned about occasional short-term exposure to diesel exhaust can be reassured that this exposure is very unlikely to significantly affect their individual risk of developing lung cancer.***

The Environmental Protection Agency (EPA) uses a classification system very similar to that of the IARC. EPA considers diesel exhaust "likely to be carcinogenic to humans by inhalation at any exposure condition."<sup>17</sup>

The National Institute for Occupational Safety and Health (NIOSH) recommends that "whole diesel exhaust be regarded as a potential occupational carcinogen as defined in the Cancer Policy of the Occupational Safety and Health Administration (OSHA)."<sup>1</sup>

### **Does Diesel Exhaust Cause Any Other Health Problems?**

While lung cancer is the principal cancer to have been linked to diesel exhaust, there is also suspicion that other cancers, especially those of the larynx, pancreas, bladder, and kidney, may be associated with diesel exhaust.<sup>18</sup> The best evaluated of these is bladder cancer.

A recent meta-analysis concluded that diesel exhaust is associated with a slightly increased risk of bladder cancer, with a relative risk on the order of 1.1 to 1.13. This relative risk reached 1.44 among workers thought to have had the highest diesel exhaust exposures, and a dose-response relationship was seen in most studies. However, the authors could not rule out misclassification, bias, and confounding as explanations for the small observed increase in risk.<sup>19</sup>

Diesel exhaust contributes significantly to outdoor air pollution. Accordingly, diesel exhaust may play a role in other health problems associated with air pollution, such as eye irritation; headache; asthma and other lung diseases; cardiovascular diseases; and possibly, immune dysfunction.

## HOW SHOULD HEALTH PROFESSIONALS ADVISE PATIENTS WHO ARE OR HAVE BEEN EXPOSED TO DIESEL EXHAUST?

Patients may be counseled about exposure to diesel exhaust, as follows:

*If you are or have been heavily exposed to diesel fumes, your risk of lung cancer may be increased. If you have been exposed to diesel fumes in the general environment, the increase in your risk is likely to be very small. If you have had prolonged exposure to high concentrations at work, your risk is higher. However, because it is very difficult to translate epidemiologic and animal data to individuals, the exact amount of risk an exposed person has is difficult to quantify.*

*If your workplace potentially exposes you to diesel exhaust, there are many ways to reduce or prevent exposures. Some of these measures will also provide protection from other exposures that are likely to occur in the workplace.*

*Engineering changes, such as enclosing a process that generates diesel exhaust, or ventilating a source away from workers' breathing zones, are important. Good work practices, such as changing clothes after work, washing hands regularly, and keeping food out of the work area, are also essential. Finally, personal protective equipment such as respirators may be an important part of a workplace protective program.*

*You should work with your employer to assure that sufficient protection is in place. For more information on preventing or reducing occupational exposures in your current job, consult your company's safety and health manager. Additional technical assistance is available from the National Institute for Occupational Safety and Health (NIOSH).*

*If you are exposed to diesel exhaust fumes in the general environment, you can take some of the same precautions. For example, you can avoid spending time near large sources of diesel exhaust, such as behind trucks and buses. The EPA is now considering more stringent environmental exposure standards for diesel vehicles, which would decrease public exposure to diesel exhaust.*

*Cigarette smoking is a much more powerful risk factor for lung cancer than are diesel fumes. The two exposures combined, however, may increase risk. Therefore, if you have a history of diesel exhaust exposure, you should avoid contact with tobacco smoke, either through smoking or through second-hand exposure.*

- ▲ [TOP](#)
- ▲ [WHAT IS DIESEL EXHAUST?](#)
- ▲ [OCCUPATIONAL AND GENERAL...](#)
- ▲ [DOES DIESEL EXHAUST CAUSE...](#)
  - [HOW SHOULD HEALTH PROFESSIONALS...](#)
- ▼ [REGULATORY INITIATIVES](#)
- ▼ [WHAT'S THE BOTTOM LINE?](#)
- ▼ [REFERENCES](#)

## REGULATORY INITIATIVES

The EPA regulates diesel exhaust emissions from motor vehicles under the Clean Air Act. In the past, diesel vehicles were permitted to emit more pollutants than were gasoline vehicles. However, in late 2000, the EPA announced rules that will dramatically reduce diesel emissions from cars and trucks, by mandating changes in both engines and fuel. ([www.epa.gov/otaq/diesel.htm#documents](http://www.epa.gov/otaq/diesel.htm#documents)). The principal reductions in emissions will be in oxides of nitrogen and sulfur compounds, which contribute to particulate formation. These regulations will be phased in over approximately seven years.

- ▲ [TOP](#)
- ▲ [WHAT IS DIESEL EXHAUST?](#)
- ▲ [OCCUPATIONAL AND GENERAL...](#)
- ▲ [DOES DIESEL EXHAUST CAUSE...](#)
- ▲ [HOW SHOULD HEALTH PROFESSIONALS...](#)
- [REGULATORY INITIATIVES](#)
- ▼ [WHAT'S THE BOTTOM LINE?](#)
- ▼ [REFERENCES](#)

## ▶ **WHAT'S THE BOTTOM LINE?**

Prolonged exposure to diesel exhaust probably increases the risk of lung and perhaps of other cancers. In addition, components of diesel exhaust, such as soot and PAHs, have independently been shown to be carcinogenic. Accordingly, several government and research organizations have declared that diesel exhaust probably causes cancer in humans. Another reason for limiting exposure is that diesel exhaust, like many other air pollutants, is also a respiratory and cardiovascular hazard.

- ▲ [TOP](#)
- ▲ [WHAT IS DIESEL EXHAUST?](#)
- ▲ [OCCUPATIONAL AND GENERAL...](#)
- ▲ [DOES DIESEL EXHAUST CAUSE...](#)
- ▲ [HOW SHOULD HEALTH PROFESSIONALS...](#)
- ▲ [REGULATORY INITIATIVES](#)
- [WHAT'S THE BOTTOM LINE?](#)
- ▼ [REFERENCES](#)

People who are concerned about occasional short-term exposure to diesel exhaust can be reassured that this exposure is very unlikely to significantly affect their individual risk of developing lung cancer. However, it is appropriate that US regulatory agencies such as the EPA and OSHA continue to look for ways to limit exposures of the general public and of workers exposed to diesel exhaust, because diesel exposure is common and the combined risk for the population overall may be considerable.

### **FOR MORE INFORMATION**

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## ▶ **Footnotes**

This article is also available at <http://www.cancer.org/>.

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▲ [TOP](#)

▲ [WHAT IS DIESEL EXHAUST?](#)

▲ [OCCUPATIONAL AND GENERAL...](#)

▲ [DOES DIESEL EXHAUST CAUSE...](#)

▲ [HOW SHOULD HEALTH PROFESSIONALS...](#)

▲ [REGULATORY INITIATIVES](#)

▲ [WHAT'S THE BOTTOM LINE?](#)

■ [REFERENCES](#)

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- ▶ [Articles by Thun, M. J.](#)

---

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