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Diesel Engine Exhaust

Opinion from the
Scientific Committee on Occupational Exposure Limits

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OPINION FROM THE SCIENTIFIC COMMITTEE ON OCCUPATIONAL EXPOSURE LIMITS FOR DIESEL ENGINE EXHAUST EMISSIONS

Traditional Diesel Engine Exhaust Emissions DEEE

8-hour TWA:	to be derived
STEL:	not applicable
BLV:	not applicable
Additional categorisation:	Carcinogen Group B or Group C
Notation:	None

The present Opinion was adopted by SCOEL December 2016.

OPINION SUMMARY

1. Identification

The present Opinion adresses Diesel engine exhaust emissions. Thereby, "Traditional DEEE" in contrast to "New Technology DEEE" are understood to be identified by the following characteristics:

'Traditional Diesel Engine Exhaust Emissions (DEEE)': This category includes the exhaust emissions of all diesel vehicles the emissions of which comply, at best, with the Euro 2 emission standards referred in Table 1 and also specifically exhaust emissions of any other diesel engines which are not covered by the definition of 'new technology DEEE', such as exhaust emissions from diesel enginge powered heavy equipment.

'New technology Diesel Engine Exhaust Emissions (New technology DEEE)': This category includes the exhaust emissions of all diesel vehicles the emissions of which comply or exceed Euro 3 and Euro III standards referred in Table 1.

Outline description

Diesel engine exhaust emissions are mixtures of hundreds of chemical compounds, which are emitted partly in the gaseous phase, partly in the particulate phase (WHO 1996). Main gaseous combustions products are carbon dioxide and water vapour, oxygen and nitrogen (more than 99% of total mass). Products of incomplete combustion are carbon monoxide, sulfur compounds, nitrogen compounds (oxides), as well as low-molecular-weight hydrocarbons (alkanes, alkenes, carbonyls, carboxylic acids, aromatics) and their (nitrated) derivatives. Known to be of toxicological relevance are for example aldehydes like formaldehyde, acetaldehyde, or acrolein, benzene, 1,3-butadiene, toluene, and polycyclic aromatic hydrocarbons (PAH) and nitro-PAH and particles of different sizes.

Main particulate combustion product of traditional DEEE is the core of elemental carbon (EC) and absorbed organic compounds like PAH, oxidised PAH, and nitro-PAH (up to 1% of particulate mass), as well as small amounts of sulfates, nitrates, metals and other trace elements. This diesel particulate matter consists of fine particles with a diameter of < 2.5 μm, including also ultrafine particles with a diameter of < 0.1 μm.

Diesel engine exhaust emissions vary in their chemical composition and particle size distribution depending on engine types, engine operating conditions, fuel formulations, lubricating oil, additives, emission control systems. They also vary between on-road and non-road engines (IARC 2014; NEG 2016). The qualitative and quantitative composition of the diesel engine exhaust emissions has changed during the last years, beginning from the early 1990s, due to the introduction of stringent emission regulations in the EU. This triggered the development and application of new technology for diesel engines with changes in (the composition of) PM and gaseous constituents in the exhaust.

When using the new technology DEEE (especially those complying Euro IV-VI) engines, diesel engine exhaust emission composition differs substantially from traditional diesel engine exhaust emissions before 1995 (see Figure below). Especially the mass of diesel exhaust particles (DEP) emitted is reduced by more than 90% in the case of euro IV-VI engines when compared to Euro I and II engines. Elemental carbon, organic carbon, water-soluble carbon, aldehydes, PAHs, Nitro-PAHs, other aromatics, dioxins/furans, and metals are lower as well. However, sulphate and ammonium are increased (Hesterberg et al. 2012; Khalek et al. 2011). Also, even if the total amounts of nitrogen oxide emissions are decreased, too, the percentage of NO_x is substantially higher and may account for up to 50%, which is much more than in older engines (max. 10%) (McDonald et al. 2012). Typical compositions of "Traditional DEEE" and "New Technology DEEE" are shown in Table 2.

2. Chemical Agent and Scope of Legislation

Traditional Diesel Engine Exhaust Emissions (DEEE) are process-generated substances that are hazardous chemical agents in accordance with Article 2 (b) of Directive 98/24/EC and falls within the scope of this legislation.

Traditional Diesel Engine Exhaust Emissions (DEEE) are process-generated substances that are carcinogens or mutagens for humans in accordance with Article 2(a) and (b) of Directive 2004/37/EC.

Traditional Diesel Engine Exhaust Emissions (DEEE) are carcinogenic SCOEL Group B or C, although a mode of action-based threshold may be applicable.

3. Limit Values, Mode of Action, notations

General Considerations

The critical effect of traditional Diesel Engine Exhaust Emissions (DEEE) in rats is pulmonary cancer, which is considered to be the consequence of inflammation and genotoxicity being primarily induced by particulate matter. Lung toxicity of newest technology diesel engine exhaust however results primarily from NO_2 exposure. Consequently, for traditional DEEE the OEL requires control of particulate matter emissions, for new type of engines it requires control of NO_2. Typical DEEE compositions are presented in tables 1 and 2. The changes in composition are additionally presented in figure 1.

3.1. Mode of action

Traditional DEEE contains genotoxic components like PAHs or nitro-PAHs, but the amount of PAH alone cannot explain the observed tumours (Heinrich et al. 1986). There is evidence for the direct genotoxic activity of DEEE and therefore, direct genotoxicity cannot be fully excluded. In animal studies chronic inflammation resulting in oxidative stress and reactive oxygen species has been observed at doses resulting in tumour formation in rats, and therefore secondary genotoxicity together with increased cell proliferation seem to be predominant in rats. Based on this mode of action, a non-linear dose-response relationship and a threshold mechanism for carcinogenicity could be anticipated. Considering this mechanism, traditional diesel engine exhaust would be classified as SCOEL carcinogen Cat. C (genotoxic carcinogens with a mode of action-based threshold). Considering that the genotoxic activity cannot be fully excluded and the epidemiological studies show a gradually increasing exposure response relation already starting at exposure levels close to background level and are not indicative of a clear exposure threshold, SCOEL carcinogen Cat. B would also apply.

Toxicological and pathobiological information from animal studies supports a mode of action, for which possibly a threshold could be established. However, the epidemiological evidence does not allow to identify a critical threshold that could serve for derivation of an OEL, and direct genotoxicity cannot be excluded. Thus, traditional DEEE are carcinogenic within SCOEL groups B or group C. Further scientific-technical analysis shall follow up on this issue.

In new-technology diesel engine exhaust (especially DEEE corresponding to Euro IV-VI) particulate matter and adsorbed mutagenic compounds are much lower than in traditional diesel engine exhausts. Accordingly, in a 1-year mouse and a 2-year rat study with the US 2007 compliant diesel engine exhaust (corresponding to Euro VI) did not show tumours or genotoxicity in vivo (HEI 2015). The toxic effects in the lung have been attributed to NO_2 exposure so that exhausts of these new technology diesel engines may not be considered carcinogenic.

3.2. Genotoxicity and Carcinogenicity:

The epidemiological studies which describe quantitative exposure response relations have been used by Vermeulen et al (2014) to conduct a meta-regression of lung cancer mortality and cumulative exposure to elemental carbon (EC), based on relative risk (RR) estimates reported of the three large occupational cohort studies (Steenland et al 1998, Garshick et al 2012, Silverman et al 2012). Based on the derived overall risk function, excess lifetime risks were calculated for several lifetime occupational exposure scenarios. Estimated numbers of excess lung cancer deaths through 80 years of age for lifetime occupational exposures of 1, 10, and 25 µg/m3 EC were 17, 200, and 689 per 10,000, respectively (Vermeulen et al 2014).

Thus, although toxicological data supports a threshold (possibly at 0.02 mg DEP/m^3 or below, corresponding 0.015 mg EC/m^3), epidemiological data suggests significant cancer risks already at and below these exposure levels. Therefore, an occupational exposure limit that would be adaequately protective for workers cannot be established on the basis of the current available data and analysis. However, both toxicological and human epidemiological data are further gathered and evaluated.

3.3. Short-term exposure limit (STEL)

For DEEE the pathobiological effect is the lung toxicity, which results from inflammation. Due to the long clearance half-life time of diesel engine exhaust particles (alveolar clearance for insoluble, non-toxic particles is 60-100 days in rats (WHO 1996), and several hundred days in humans (US-EPA 2002), it is not considered necessary to derive an acute 15 minutes short-term exposure limit (STEL).

3.4. Reproduction

Reproductive and developmental toxicity are considered unlikely to be critical end-points for diesel engine exhaust, neither from old nor from new-technology engines.

3.5. Sensitization

No study investigating sensitization potential of diesel engine exhausts according to current guidelines is available in animals or humans. Several studies show effects of diesel engine exhausts on the immune system in humans and animals. Diesel engine exhausts react as an adjuvant in sensitization tests in humans and animals and can cause exacerbation of allergic responses and asthma-like symptoms. However, diesel engine exhaust itself is not an allergen. Therefore, a notation for sensitization is not recommended.

3.6. Skin notation

Due to the composition and the nature of the critical effect of DEEE and also new-technology diesel engine exhaust, a substantial dermal absorption is not anticipated. Therefore, a skin notation is not recommended.

3.7. Biological Monitoring

From the available data it is not possible to recommend a biological limit value nor biological guidance value for diesel exhausts. There is thus no BLV or BGV recommended for DEEE.

Table 1: Euro 2 and Euro 3 Emission standards for diesel vehicles1 in the EU

PASSENGER CARS AND LIGHT COMMERCIAL VEHICLES

Tier	Date	CO	THC	NMHC	NOx	HC+NOx	PM	P [#/km]
European emission standards for passenger cars (Category M), g/km**								
Euro 2	January 1996	1	-	-	-	0.7	0.08	-
Euro 3	January 2000	0.64	-	-	0.5	0.56	0.05	-
European emission standards for light commercial vehicles ≤1305 kg (Category N1-I), g/km								
Euro 2	January 1998	1	-	-	-	0.7	0.08	-
Euro 3	January 2000	0.64	-	-	0.5	0.56	0.05	-
European emission standards for light commercial vehicles 1305–1760 kg (Category N1-II), g/km								
Euro 2	January 1998	1.25	-	-	-	1	0.12	-
Euro 3	January 2001	0.8	-	-	0.65	0.72	0.07	-
European emission standards for light commercial vehicles >1760 kg max 3500 kg. (Category N1-III & N2), g/km								
Euro 2	January 1998	1.5	-	-	-	1.2	0.17	-
Euro 3	January 2001	0.95	-	-	0.78	0.86	0.1	-

TRUCKS AND BUSES

EU Emission Standards for HD Diesel Engines, g/kWh (smoke in m^{-1})

Standard	Date		CO (g/kWh)	HC (g/kWh)	NOx (g/kWh)	PM (g/kWh)	Smoke	
Euro II	October 1996	ECE R-49	4	1.1	7	0.25		
Euro II	October 1998	ECE R-49	4	1.1	7	0.15		
Euro III	*October 1999 EEVs only*	*ESC & ELR*	*1*	*0.25*	*2*	*0.02*	*0.15*	*Non-binding*
Euro III	October 2000	ESC & ELR	2.1	0.66	5	0.1	0.8	
						0.13 *		

* for engines of less than 0.75 dm3 swept volume per cylinder and a rated power speed of more than 3,000 per minute. EEV is "Enhanced environmentally friendly vehicle".

Euro norm emissions for category N3, EDC, (2000 and up)

Euro II	1995-1999	4	1.1	7	0.15
Euro III	1999-2005	2.1	0.66	5	0.1

Euro norm emissions for (older) ECE R49 cycle

Euro II	1995-99	4	1.1	7	0.15

[1] the table covers the categories of diesel vehicles that are explicitly specified. Other diesel engines, e.g. generators, train locomotives, if not following into one of the categories mentioned above, may reasonably be assumed to generate exhaust emissions comparable to Euro 2 / Euro II, unless otherwise proven or specified.

The applicable EU Directives are:

Euro 2 (1996):
For passenger cars: Directives 94/12/EC[1] and 96/69/EC[2]
For motorcycles: Directives 2002/51/EC[3] (row A) and 2006/120/EC[4]
Euro 3 (2000):
For any vehicle: Directive 98/69/EC[5]
For motorcycle: Directives 2002/51/EC[6] (row B) and 2006/120/EC[7]

[1] OJ L 100,19.4.94, p.42–52
[2] OJ L 282, 1.11.1996, p. 64–67
[3] OJ L 252, 20.9.2002, p. 20–32
[4] OJ L 330, 28.11.2006, p. 16–17
[5] OJ L 350, 28.12.1998, p. 1–57
[6] OJ L 252, 20.9.2002, , p. 20–32
[7] OJ L 330, 28.11.2006, p. 16–17

Table 2: Typical composition of "Traditional DEEE" and "New Technology DEEE"

Constituents	"Traditional DEEE"	"New Technology DEEE"
PM*		
Elemental Carbon	75%	13%
Organic Carbon	19%	30%
Sulfates	1%	53%
Metals	2%	4%
Other	3%	
Gaseous constituents	6.8 g NOx/kg Fuel **	5.7 g NOx/kg Fuel***
	20.2 g HC/sec (Idle****)	7.6 g HC/sec (Idle****)
	1.2 g HC/mile (cruise****)	0.4 HC/mile (cruise****)

* Typical composition of diesel exhaust particles emitted by a 1990–2000 diesel engine ("Traditional DEEE"), and a post-2006 diesel engine ("New Technology DEEE") according to NEG/DECOS, 2016

** 1990 technology; Brian C. McDonald, 2012

*** 2010 technology; Brian C. McDonald, 2012

**** Clark et al. 2006

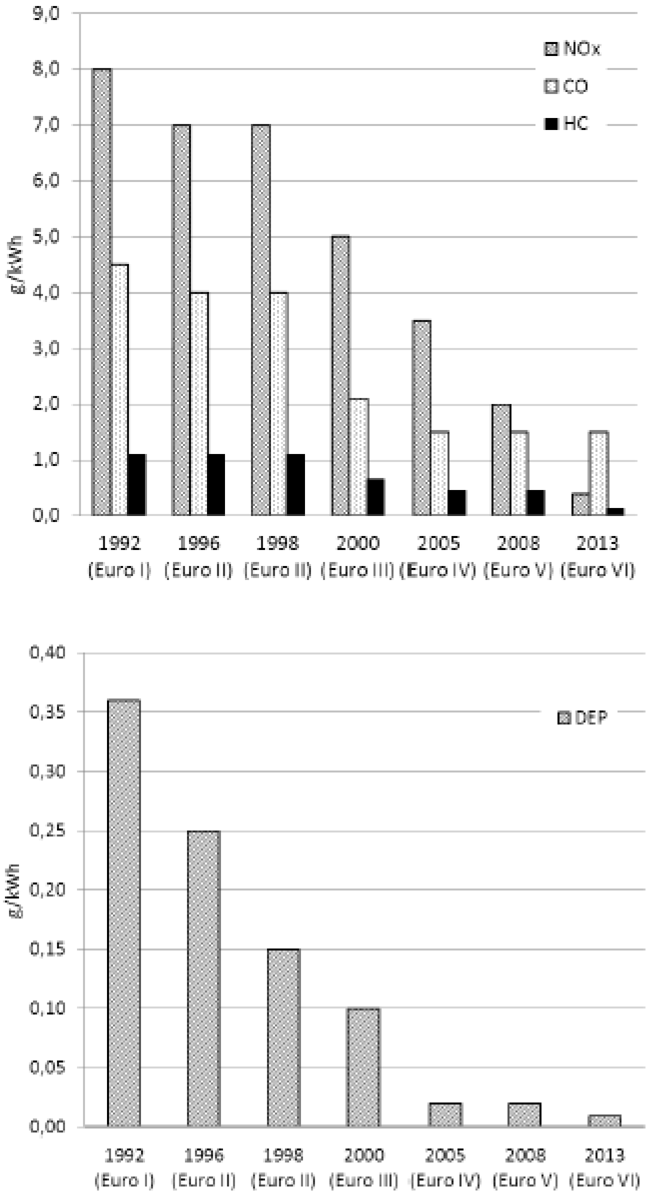

Figure 1: Development of emission standards for heavy-duty diesel engines in the EU. Euro I–VI refers to the European emission standards for heavy-duty diesel engines. NOX: nitrogen oxides, CO: carbon monoxide, DEP: diesel exhaust particles, HC: total hydrocarbons. Redrawn by NEG (2016) from the data presented in [Ecopoint. DieselNet. 2013 [cited 2013; Available from: https://www.dieselnet.com/.].

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