

## DIESEL AND GASOLINE ENGINE EXHAUSTS AND SOME NITROARENES

VOLUME 105

This publication represents the views and expert  
opinions of an IARC Working Group on the  
Evaluation of Carcinogenic Risks to Humans,  
which met in Lyon, 5-12 June 2012

LYON, FRANCE - 2014

IARC MONOGRAPHS  
ON THE EVALUATION  
OF CARCINOGENIC RISKS  
TO HUMANS

# CONTENTS

---

<b>NOTE TO THE READER.....</b>	<b>1</b>
<b>LIST OF PARTICIPANTS.....</b>	<b>3</b>
<b>PREAMBLE.....</b>	<b>9</b>
<b>A. GENERAL PRINCIPLES AND PROCEDURES .....</b>	<b>9</b>
1. Background.....	9
2. Objective and scope.....	10
3. Selection of agents for review .....	11
4. Data for the <i>Monographs</i> .....	11
5. Meeting participants .....	12
6. Working procedures.....	13
<b>B. SCIENTIFIC REVIEW AND EVALUATION .....</b>	<b>14</b>
1. Exposure data.....	15
2. Studies of cancer in humans.....	16
3. Studies of cancer in experimental animals.....	20
4. Mechanistic and other relevant data.....	23
5. Summary .....	26
6. Evaluation and rationale.....	27
References.....	31
<b>GENERAL REMARKS .....</b>	<b>33</b>

## **DIESEL AND GASOLINE ENGINE EXHAUSTS**

<b>1. EXPOSURE DATA.....</b>	<b>39</b>
1.1 Diesel and gasoline engines and the chemical composition of their exhausts.....	39
1.1.1 Diesel engine technology .....	40
1.1.2 Levels of diesel engine exhaust emissions .....	44
1.1.3 Biodiesel.....	55

1.1.4 Spark ignition (gasoline) engines	56
1.1.5 Levels of gasoline exhaust emissions	57
1.1.6 Comparison of levels of emissions from current technology	60
1.2 Sampling and analysis	65
1.2.1 Sampling	65
1.2.2 Analysis	66
1.2.3 Biomarkers of exposure	73
1.3 Regulations and guidelines	75
1.3.1 Structure and progression of emission standards	75
1.3.2 Representative emission standards worldwide	76
1.3.3 Availability of engines with new emission control technologies	77
1.3.4 In-use emission verification programmes	78
1.4 Occurrence and exposure	79
1.4.1 Occupational exposure of workers predominantly exposed to diesel exhaust	79
1.4.2 Occupational exposure of workers predominantly exposed to gasoline engine exhaust	95
1.4.3 Exposure of the general population	118
References	134
<b>2. CANCER IN HUMANS</b>	<b>147</b>
2.1 Introduction	147
2.1.1 General aspects	147
2.1.2 Aspects of exposure assessment methods	148
2.1.3 Studies of environmental air pollution	149
2.2 Cohort studies	149
2.2.1 Railroad workers	149
2.2.2 Bus garage workers	174
2.2.3 Professional drivers	174
2.2.4 Miners	181
2.2.5 Other groups exposed to vehicle exhausts	184
2.3 Case-control studies	188
2.3.1 Cancer of the lung	188
2.3.2 Cancer of the urinary bladder	199
2.3.3 Cancer at other and multiple sites	231
2.4 Meta-analyses	245
2.4.1 Cancer of the lung	245
2.4.2 Cancer of the urinary bladder	249
2.4.3 Cancer of the pancreas	250
2.4.4 Summary of meta-analyses	251
2.5 Studies of childhood cancer	251
References	260
<b>3. CANCER IN EXPERIMENTAL ANIMALS</b>	<b>267</b>
3.1 Diesel engine exhaust	267
3.1.1 Mouse	267
3.1.2 Rat	275
3.1.3 Hamster	291
3.1.4 Monkey	293

---

3.2 Gasoline engine exhaust.....	293
3.2.1 Mouse.....	293
3.2.2 Rat.....	301
3.2.3 Hamster.....	305
3.2.4 Dog.....	308
References.....	309
<b>4. MECHANISTIC AND OTHER RELEVANT DATA.....</b>	<b>313</b>
4.1 Overview of the mechanisms of carcinogenesis of polycyclic aromatic hydrocarbons.....	313
4.1.1 Mechanistic data to support the role of benzo[ <i>a</i> ]pyrene as a human carcinogen.....	313
4.2 Deposition, clearance, retention and metabolism.....	323
4.2.1 Humans.....	323
4.2.2 Experimental systems.....	327
4.3 Genetic and related effects.....	338
4.3.1 Humans.....	338
4.3.2 Experimental systems.....	345
4.4 Other data relevant to carcinogenicity.....	410
4.4.1 Diesel engine exhaust.....	410
4.4.2 Gasoline engine exhaust.....	415
4.5 Susceptibility in humans.....	416
4.5.1 Genetic polymorphisms.....	416
4.5.2 Vulnerable populations.....	418
4.5.3 Underlying lung disease.....	418
4.5.4 Respiratory tract microbiome.....	418
4.6 Mechanistic considerations.....	418
4.6.1 Diesel engine exhaust.....	418
4.6.2 Gasoline engine exhaust.....	423
References.....	423
<b>5. SUMMARY OF DATA REPORTED.....</b>	<b>451</b>
5.1 Exposure data.....	451
5.2 Human carcinogenicity data.....	453
5.2.1 Diesel engine exhaust.....	453
5.2.2 Gasoline engine exhaust.....	457
5.3 Animal carcinogenicity data.....	457
5.3.1 Diesel engine exhaust.....	457
5.3.2 Gasoline engine exhaust.....	459
5.4 Mechanistic and other relevant data.....	460
5.4.1 Diesel engine exhaust.....	460
5.4.2 Gasoline engine exhaust.....	464
<b>6. EVALUATION.....</b>	<b>467</b>
6.1 Cancer in humans.....	467
6.2 Cancer in experimental animals.....	467
6.3 Overall evaluation.....	467

<b>ANNEX: EMISSION STANDARDS FOR LIGHT- AND HEAVY-DUTY VEHICLES</b> .....	<b>469</b>
1. Europe .....	469
2. USA .....	472
3. Other countries .....	484
<b>3,7-DINITROFLUORANTHENE</b> .....	<b>487</b>
1. Exposure Data .....	487
2. Cancer in Humans .....	488
3. Cancer in Experimental Animals .....	488
4. Mechanistic and Other Relevant Data .....	489
5. Summary of Data Reported .....	491
6. Evaluation .....	491
References .....	492
<b>3,9-DINITROFLUORANTHENE</b> .....	<b>493</b>
1. Exposure Data .....	493
2. Cancer in Humans .....	494
3. Cancer in Experimental Animals .....	494
4. Mechanistic and Other Relevant Data .....	496
5. Summary of Data Reported .....	498
6. Evaluation .....	498
References .....	499
<b>1,3-DINITROPYRENE</b> .....	<b>501</b>
1. Exposure Data .....	501
2. Cancer in Humans .....	510
3. Cancer in Experimental Animals .....	510
4. Mechanistic and Other Relevant Data .....	515
5. Summary of Data Reported .....	516
6. Evaluation .....	517
References .....	517
<b>1,6-DINITROPYRENE</b> .....	<b>521</b>
1. Exposure Data .....	521
2. Cancer in Humans .....	525
3. Cancer in Experimental Animals .....	525
4. Mechanistic and Other Relevant Data .....	531
5. Summary of Data Reported .....	533
6. Evaluation .....	534
References .....	534
<b>1,8-DINITROPYRENE</b> .....	<b>537</b>
1. Exposure Data .....	537
2. Cancer in Humans .....	541
3. Cancer in Experimental Animals .....	541
4. Mechanistic and Other Relevant Data .....	546
5. Summary of Data Reported .....	551
6. Evaluation .....	552
References .....	552

---

<b>3-NITROBENZANTHRONE</b> .....	<b>557</b>
1. Exposure Data .....	557
2. Cancer in Humans .....	561
3. Cancer in Experimental Animals .....	561
4. Mechanistic and Other Relevant Data .....	562
5. Summary of Data Reported .....	572
6. Evaluation.....	573
References.....	573
<b>6-NITROCHRYSENE</b> .....	<b>577</b>
1. Exposure Data .....	577
2. Cancer in Humans .....	580
3. Cancer in Experimental Animals .....	580
4. Mechanistic and Other Relevant Data .....	588
5. Summary of Data Reported .....	594
6. Evaluation.....	595
References.....	596
<b>2-NITROFLUORENE</b> .....	<b>601</b>
1. Exposure Data .....	601
2. Cancer in Humans .....	604
3. Cancer in Experimental Animals .....	604
4. Mechanistic and Other Relevant Data .....	607
5. Summary of Data Reported .....	615
6. Evaluation.....	616
References.....	616
<b>1-NITROPYRENE</b> .....	<b>621</b>
1. Exposure Data .....	621
2. Cancer in Humans .....	645
3. Cancer in Experimental Animals .....	645
4. Mechanistic and Other Relevant Data .....	657
5. Summary of Data Reported .....	674
6. Evaluation.....	677
References.....	677
<b>4-NITROPYRENE</b> .....	<b>689</b>
1. Exposure Data .....	689
2. Cancer in Humans .....	691
3. Cancer in Experimental Animals .....	691
4. Mechanistic and Other Relevant Data .....	694
5. Summary of Data Reported .....	697
6. Evaluation.....	697
References.....	698
<b>LIST OF ABBREVIATIONS</b> .....	<b>701</b>



## NOTE TO THE READER

---

The term ‘carcinogenic risk’ in the *IARC Monographs* series is taken to mean that an agent is capable of causing cancer. The *Monographs* evaluate cancer hazards, despite the historical presence of the word ‘risks’ in the title.

Inclusion of an agent in the *Monographs* does not imply that it is a carcinogen, only that the published data have been examined. Equally, the fact that an agent has not yet been evaluated in a *Monograph* does not mean that it is not carcinogenic. Similarly, identification of cancer sites with *sufficient evidence* or *limited evidence* in humans should not be viewed as precluding the possibility that an agent may cause cancer at other sites.

The evaluations of carcinogenic risk are made by international working groups of independent scientists and are qualitative in nature. No recommendation is given for regulation or legislation.

Anyone who is aware of published data that may alter the evaluation of the carcinogenic risk of an agent to humans is encouraged to make this information available to the Section of IARC Monographs, International Agency for Research on Cancer, 150 cours Albert Thomas, 69372 Lyon Cedex 08, France, in order that the agent may be considered for re-evaluation by a future Working Group.

Although every effort is made to prepare the *Monographs* as accurately as possible, mistakes may occur. Readers are requested to communicate any errors to the Section of IARC Monographs, so that corrections can be reported in future volumes.



