

# **Air Pollution and Health**

## AIR POLLUTION REVIEWS

**Series Editor:** Robert L. Maynard

*(Department of Health, Skipton House, London, U.K.)*

---

Vol. 1: The Urban Atmosphere and Its Effects

*Peter Brimblecombe & Robert L. Maynard*

Vol. 2: The Effects of Air Pollution on the Built Environment

*(Peter Brimblecombe)*

Vol. 3: Air Pollution and Health

*(Jon Ayres, Robert L. Maynard & Roy Richards)*

Vol. 4: Air Pollution Impacts on Crops and Forests: A Global Assessment

*(Marisa Domingos, Mike Ashmore, Lisa Emberson & Frank Murray)*

*Forthcoming:*

Vol. 5: Indoor Air Pollution

*(Robert L. Maynard, Mike Ashmore & Peter Brimblecombe)*

Air Pollution Reviews – Vol. 3

---

# Air Pollution and Health

Jon Ayres

*University of Aberdeen, UK*

Robert Maynard

*UK Department of Health, UK*

Roy Richards

*University of Cardiff, UK*

*Published by*

Imperial College Press  
57 Shelton Street  
Covent Garden  
London WC2H 9HE

*Distributed by*

World Scientific Publishing Co. Pte. Ltd.

5 Toh Tuck Link, Singapore 596224

*USA office:* 27 Warren Street, Suite 401-402, Hackensack, NJ 07601

*UK office:* 57 Shelton Street, Covent Garden, London WC2H 9HE

**British Library Cataloguing-in-Publication Data**

A catalogue record for this book is available from the British Library.

The image on the front cover courtesy of Peter M. Ayres

**AIR POLLUTION AND HEALTH**

**Air Pollution Reviews — Vol. 3**

Copyright © 2006 by Imperial College Press

*All rights reserved. This book, or parts thereof, may not be reproduced in any form or by any means, electronic or mechanical, including photocopying, recording or any information storage and retrieval system now known or to be invented, without written permission from the Publisher.*

For photocopying of material in this volume, please pay a copying fee through the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, USA. In this case permission to photocopy is not required from the publisher.

ISBN 1-86094-191-5

Printed in Singapore by B & JO Enterprise

## CONTRIBUTORS

### **Jon G Ayres**

Environmental & Occupational  
Medicine  
Liberty Safe Work Research  
Centre  
University of Aberdeen  
Foresterhill Road  
Aberdeen AB25 2ZP

### **Dominique Balharry**

School of Biosciences  
Cardiff University  
Museum Avenue  
Cardiff CF10 3US  
Wales

### **Kelly A Bérubé PhD FRMS**

Cardiff School of Biosciences  
Biomedical Building  
Museum Avenue  
PO Box 911  
Cardiff CF10 3US

### **Lung Chi Chen**

Department of Environmental  
Medicine  
New York University School  
of Medicine  
57 old Forge Road  
Tuxedo  
NY 10987  
USA

### **Ken Donaldson**

MRC/University of Edinburgh  
Centre for Inflammation  
Research  
The Queen's Medical  
Research Institute  
47 Little France Crescent  
Edinburgh, EH16 4TJ

**Ron Eccles**

Director  
Common Cold Centre  
Cardiff School of Biosciences  
Biomedical Building  
Museum Avenue  
Cardiff CF10 3US, UK

**Paul Elliott**

Imperial College School  
of Medicine  
Department of Epidemiology  
& Public Health  
St. Mary's Campus  
Norfolk Place  
London W2 1PG

**Steven Faux**

MRC Toxicology Unit  
Hodgkin Building  
University of Leicester  
Leicester LE1 9HN

**Patrick Hayden**

MatTek Corporation  
200 Homer Avenue  
Ashland  
Massachusetts  
01721 USA

**Martina Hicks**

School of Biosciences  
Cardiff University  
Museum Avenue  
Cardiff CF10 3US  
Wales

**A E M De Hollander**

Dept of Chronic Disease &  
Environmental Epidemiology  
National Institute of Public  
Health & the Environment  
PO Box 1  
3720 B A Bilthoven  
The Netherlands

**Timothy Jones**

School of Earth, Ocean and  
Planetary Sciences  
Cardiff University  
Park Place  
Cardiff CF10 3YE, Wales

**Johan M Melse**

Dept of Chronic Disease &  
Environmental Epidemiology  
National Institute of Public  
Health & the Environment  
PO Box 1  
3720 B A Bilthoven  
The Netherlands

**Luciano Merolla**

School of Biosciences  
Cardiff University  
Museum Avenue  
Cardiff CF10 3US  
Wales

**Teresa Moreno**

Instituto de Ciencias de la  
Tierra “Jaume Almera”  
Consejo Superior de  
Investigaciones Cientificas  
C/Lluis Sole I Sabaris s/n  
08028 Barcelona  
Spain

**William NcNee**

Centre for Inflammation  
Research  
University of Edinburgh  
The Queen’s Medical  
Research Institute  
47 Little France Crescent  
Edinburgh, EH16 4TJ

**Helen C. Routledge**

Specialist Registrar  
Department of Cardiology  
Birmingham Heartlands  
NHS Trust  
Birmingham B9 5ST

**Richard B. Schlesinger**

Department of Biological  
Sciences and Environmental  
Science Program  
Pace University  
1 Pace Plaza  
New York, NY 10038  
USA

**Keith Sexton**

School of Biosciences  
Cardiff University  
Museum Avenue  
Cardiff CF10 3US  
Wales

**Vicki Stone**

Biomedicine Research Group  
Napier University  
10 Colinton Road  
Edinburgh

**Cynthia Timblin**

Arti Shukla  
Brooke Mossman  
Department of Pathology  
University of Vermont  
Burlington  
Vermont 05045 USA

This page is intentionally left blank



## PREFACE

The literature on air pollution and its effect on health has burgeoned over the last 15 to 20 years, triggered by the development of time-series methods and the seminal Six Cities Study in the United States, which prompted realisation that despite Clean Air Acts aimed at controlling industrial and domestic emissions, pollution was having an impact on health. Since then, the field has expanded and the increasing complexity of the issues raised has become apparent. Today, many robust criticisms of the science to date have been greeted with equally robust rebuttals and modifications of methodology, but the message remains the same. Air pollution affects populations throughout the world, having a significant impact on public health. An important source of these pollutants is the motor vehicle.

In our attempt to address some of the issues within the field in this volume, it is clear that there is sufficient material to fill many volumes. In this context, we decided to address a number of issues which have either been neglected or which pose important critical questions.

We begin with the role of the nose of modulating or initiating responses to air pollutants, move through the epidemiological and experimental evidence that cardiac function is disturbed by pollution, and then address the question of point sources as opposed to area sources when trying to apportion exposure sources with respect to specific health effects. New work on the structure of particles and their toxicology then leads to a chapter addressing how best we might determine particle toxicity in the future. This is of particular relevance at present in view of the increasing concerns regarding manufactured nano-materials. The volume concludes with a new approach

to an assessment of the health impacts of air pollution — an area where policy developers keenly feel the need, when determining how best to address air pollution control. We hope that you will find some of these areas useful.

We are very grateful to the patience and tolerance of authors in putting together this volume. We take complete responsibility of any typographical errors that there may be within the text.

Prof. Jon G Ayres  
University of Aberdeen  
and

Dr. Robert Maynard  
UK Department of Health

# CONTENTS

*Contributors* v

*Preface* ix

## **1 The Role of the Nose in Health and Disease** 1

*Ron Eccles*

1	Introduction . . . . .	1
2	The Nose as a Defender of the Airway . . . . .	2
	2.1 Filtration of Suspended Particulate Matter . . .	2
	2.2 Humidification of Inspired Air . . . . .	4
	2.3 The Nose as a Heat Exchanger . . . . .	6
	2.4 Mucociliary Clearance . . . . .	6
	2.5 Innervation of the Nose and Nasal Reflexes . .	8
3	Effects of Pollutants on the Nose . . . . .	9
	3.1 Effects on Sensory Nerves . . . . .	10
	3.2 Effects on Mucociliary Clearance . . . . .	13
	3.3 Effects on Epithelial Cells . . . . .	13
	3.4 Effects on Immune System . . . . .	13
	3.5 Rhinitis and Air Pollution . . . . .	14
4	Summary . . . . .	15
	References . . . . .	15

## **2 Cardiovascular Effects of Particles** 19

*Helen C. Routledge and Jon G. Ayres*

1	Introduction . . . . .	19
2	Epidemiology . . . . .	20

- 2.1 Air Pollution and Mortality . . . . . 20
- 2.2 Air Pollution and Cardiovascular Mortality and Morbidity . . . . . 20
- 2.3 Pollutants Implicated in Cardiovascular Health Effects . . . . . 24
- 3 Potential Mechanisms . . . . . 27
  - 3.1 The Inflammatory Hypothesis . . . . . 27
  - 3.2 The Autonomic Hypothesis . . . . . 34
  - 3.3 Air Pollution and Coronary Vasoconstriction . . . . . 39
- 4 Future Experimental Research and Considerations in Exposure Studies . . . . . 40
- References . . . . . 42

**3 Point Sources of Air Pollution – Investigation of Possible Health Effects Using Small Area Methods 49**

*P. Elliott*

- 1 Introduction . . . . . 49
- 2 Data Sources . . . . . 50
  - 2.1 Health Data . . . . . 52
  - 2.2 Population Data . . . . . 54
  - 2.3 Exposure Assessment . . . . . 55
  - 2.4 Socioeconomic Confounding . . . . . 56
- 3 Assessing Effects of Factory Emissions on the Health of Local Populations . . . . . 59
  - 3.1 Example of a Point Source Investigation . . . . . 63
  - 3.2 Cluster Investigation . . . . . 64
- 4 Conclusions . . . . . 64
- References . . . . . 66

**4 Characterisation of Airborne Particulate Matter and Related Mechanisms of Toxicity: An Experimental Approach 69**

*Kelly Bérubé, Dominique Balharry, Timothy Jones, Teresa Moreno, Patrick Hayden, Keith Sexton, Martina Hicks, Luciano Merolla, Cynthia Timblin, Arti Shukla and Brooke Mossman*

1	Introduction . . . . .	69
1.1	Mechanisms of Inhaled Particle Toxicity . . . . .	71
2	Collection Methods for Airborne Particles . . . . .	72
2.1	Impaction Collection . . . . .	72
2.2	Filtration Collection . . . . .	74
2.3	Filter Selection . . . . .	75
3	Analysis Methods for Airborne Particles . . . . .	75
3.1	Electron Microscopy and Image Analysis . . . . .	75
3.2	Elemental Analysis . . . . .	77
3.3	<i>In Vitro</i> and <i>In Vivo</i> Characterisation . . . . .	78
3.4	Plasmid Assay . . . . .	80
3.5	<i>In Vivo</i> Techniques . . . . .	80
3.6	Case Study: Characterisation of PM in Port Talbot, South Wales . . . . .	81
3.7	SEM Characterisation . . . . .	83
3.8	ICP-MS Characterisation . . . . .	84
3.9	Case Study: <i>In Vitro</i> Effects of Water-soluble Metals Found in Particles Collected in London in 1958 . . . . .	85
4	<i>In Vitro</i> Human Airway Epithelial Models . . . . .	87
4.1	The EpiAirway™ <i>In Vitro</i> Human Tracheal/ Bronchial Epithelial Model . . . . .	88
5	Toxicogenomics and Gene Expression Studies . . . . .	90
5.1	Case Study: Bioreactivity of Metals in UK Particulate Matter . . . . .	91
6	Molecular Bioreactivity of Different Particles <i>In Vitro</i> . . . . .	93
6.1	Case Studies — Exposure of Pulmonary Epithelial Cell Lines to Ambient PM . . . . .	95
6.2	Molecular Mechanisms of Toxicity . . . . .	95
6.3	Proto-oncogenes . . . . .	96
6.4	NF-Kappa B . . . . .	97
7	Proteomics . . . . .	98
7.1	Two Dimensional SDS-PAGE . . . . .	99
7.2	Image Analysis . . . . .	100
7.3	Mass Spectrometry . . . . .	100
7.4	Proteomic Analysis and the Lung . . . . .	100

7.5	Case Study — Proteomic Analysis of Bleomycin Induced Lung Injury . . . . .	101
7.6	Other Proteomic Studies Involving BALF . . . . .	102
8	Summary and Conclusions . . . . .	103
	References . . . . .	103
	Abbreviations . . . . .	109

**5 Acid Aerosols as a Health Hazard 111**

*Lung Chi Chen, George Thurston and Richard B. Schlesinger*

1	Introduction . . . . .	111
2	Formation of Atmospheric Acid Aerosols . . . . .	111
3	Exposure Levels . . . . .	112
4	Dosimetry and Fate . . . . .	113
5	Health Effects of Acidic Aerosols . . . . .	113
5.1	Epidemiological Evidence . . . . .	113
6	Toxicological Evidence . . . . .	135
7	Assessment of Health Risk from Ambient Acidic Particles . . . . .	148
8	Conclusion . . . . .	153
	References . . . . .	154

**6 Testing New Particles 163**

*K. Donaldson, V. Stone, S. Faux and W. MacNee*

1	Background to Particles and Lung Disease . . . . .	163
1.1	Which Particles Cause Lung Disease? . . . . .	164
1.2	Which Diseases are Caused by Particles? . . . . .	164
1.3	How Do Particles Cause Disease? . . . . .	165
1.4	Factors Affecting Particle Toxicity . . . . .	166
2	Approaches to Testing . . . . .	174
2.1	Characterising the Particles . . . . .	174
2.2	Assessment of Toxicity <i>In Vitro</i> . . . . .	175
2.3	Animal Studies . . . . .	185
3	Conclusion: A Tiered Approach to Testing of a New Particle . . . . .	189
	References . . . . .	190

<b>7</b>	<b>Valuing the Health Impact of Air Pollution: Deaths, DALYs or Dollars?</b>	<b>197</b>
	<i>A.E.M. de Hollander and J.M. Melse</i>	
1	Fifty Years on . . . . .	197
2	Problems for Policy Makers . . . . .	198
3	Putting Money where Public Health Profits Most . . . . .	200
	3.1 Numbers . . . . .	202
	3.2 Health Adjusted Life-Years (e.g. DALYs) . . . . .	203
	3.3 Monetary Value . . . . .	204
4	Healthy Time as a Metric . . . . .	205
5	Trading Health for Wealth or Wealth for Health . . . . .	209
6	Impact Assessment . . . . .	210
	6.1 Health Responses to Exposures . . . . .	210
	6.2 Long-term Versus Short-term Mortality . . . . .	214
	6.3 The Health Market . . . . .	215
	6.4 Uncertainty . . . . .	220
7	Deaths, DALYs and Dollars (Euro) . . . . .	220
8	Discussion . . . . .	226
	8.1 Health Impact Assessment . . . . .	226
	8.2 Environmental Health Impacts on a Scale . . . . .	227
	8.3 Worth the Money? . . . . .	229
	8.4 Equity and Efficiency . . . . .	231
	8.5 Conclusion . . . . .	231
	References . . . . .	233
	Index . . . . .	241