NON-INDUSTRIAL PERSONAL BENZENE EXPOSURE IN A MEDITERRANEAN CLIMATE

THIS THESIS IS PRESENTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF MURDOCH UNIVERSITY

by

Anthony Michael Horton

BEnvSc (Hons)(Murdoch University, Western Australia)

SCHOOL OF ENVIRONMENTAL SCIENCE
DIVISION OF SCIENCE AND ENGINEERING,
MURDOCH UNIVERSITY,
WESTERN AUSTRALIA

I declare that this thesis is my own account of my research except where duly acknowledged, and contains as its main content work which has not been previously submitted for a degree at any tertiary education institution

Anthony Horton

TABLE OF CONTENTS

ABSTRACT

Benzene is a volatile organic air pollutant that is ubiquitous in the environment. It is frequently reported in urban airsheds, principally as a result of evaporative emissions from motor vehicles. Increasingly stringent fuel quality standards have resulted in lower mean benzene concentrations in many urban airsheds, however the concentrations reported indoors can be higher than those in urban airsheds. Mean indoor benzene concentrations can reach one order of magnitude higher than those reported in urban airsheds. Long term exposure to very high benzene concentrations can result in leukemia, however the health risks of long term non-industrial exposure in the general public are currently uncertain.

An important part of determining the risks of non-industrial benzene exposure is to first determine the influence of various activities on 24-hour personal benzene exposure. Previous research has identified commuting in a private motor vehicle and refuelling with low benzene fuel as statistically significant contributors to non-industrial benzene exposure in the Northern Hemisphere, however none has quantified the increase in benzene exposure as a result of these activities over a 24-hour period in the Mediterranean climate. The results of the 1987 TEAM study in the South Bay section of California reported that automobile exhaust was a significant contributor to non-industrial benzene exposure based on exhaled breath concentrations ($p<0.05$) and commuting in a private vehicle ($p=0.0003$) and refuelling (0.05) were important contributors based on personal benzene exposure concentrations (Wallace *et al*., 1988).

The aims of this thesis were to identify the roles and importance of selected activities in personal exposure to benzene, to determine the increase in 24-hour personal benzene exposure attributable to these activities and quantify the risk posed by these activities in a Mediterranean climate. In particular, the aim of this thesis was to investigate whether commuting in a private motor vehicle and refuelling are significant contributors to non-industrial personal benzene exposure in a Mediterranean climate, or whether lifestyle and climate interact.

This research was composed of a personal exposure study, a source monitoring study and a risk assessment. A cross-sectional personal exposure study was conducted for two reasons. Firstly, to quantify the mean personal benzene concentrations to which a representative sample of the general public of Perth was exposed as a result of their daily activities and behaviours. Secondly, to quantify the frequency of commuting by private motor vehicle and refuelling with low benzene fuel in Perth. Fifty participants were recruited for the personal exposure study, and asked to wear a monitor for 24-hour periods (including weekends) in summer and winter and record their activities and locations in a diary. Prior to the monitoring they were asked to complete a questionnaire seeking background information on their home, lifestyle and behaviours. The results of the research revealed that there was not a statistically significant difference between the personal benzene exposure concentrations in summer and winter. An analysis of the questionnaire and time activity diary data using a generalised linear mixed model revealed that the time spent commuting in a private motor vehicle (β= 0.281, p<0.0001) and refuelling with low benzene fuel (β = 0.194, p=0.033) were statistically significant contributors to non-industrial benzene exposure. Each hour spent commuting resulted in a mean increase in 24- hour

personal exposure of 0.74 μgm^{-3} (β= 0.729 μg m^{-3}, p< 0.0001). The mean increase in exposure per hour of commuting in a private motor vehicle was larger in winter (β= 0.8 μg m^{-3}, p=0.008) than summer (β= 0.67 μg m^{-3}, p=0.004). Refuelling increased personal exposure by 1.50 μg m^{-3} (1.49, p<0.0001) in each 24-period when refuelling was reported.

Benzene source monitoring was conducted at selected locations in Perth for two reasons. Firstly, data quantifying non-industrial personal benzene exposure during refuelling and commuting in a private vehicle in Perth was needed, and secondly, to make an assessment of risk attributable to these activities.

Benzene source measurements were conducted in two carparks in the Central Business District (CBD), in the vicinity of the northbound and southbound lanes of the Kwinana Freeway, and at a petrol station. The 7- day arithmetic mean benzene concentrations in the carparks were 4.49 μg m^{-3} and 1.23 μg m^{-3}. The 7- day mean benzene concentrations northbound on the Kwinana Freeway was 2.78 μg m^{-3}, and the mean benzene concentration southbound was 2.57 μg m^{-3}. Benzene emissions in the carpark and on the Kwinana Freeway were measured during vehicle idling, which is representative of vehicle speed during heavy vehicle traffic. Benzene emissions at the petrol station were monitored in the vicinity of the petrol bowser, which is representative of emissions during refuelling. The 24- hour mean benzene concentration at the petrol station bowser was 38.15 μg m^{-3}.

The results of this research revealed that refuelling and commuting in a private vehicle are the most significant contributors to non-industrial benzene exposure in

Perth, and that the contribution of these two activities in Perth is far greater than in previous published research, on the basis of the results obtained from the generalised linear model. The results of this research quantified the increase in non-industrial benzene exposure from refuelling and commuting in a private motor vehicle in a Mediterranean climate for the first time, and quantified the lifetime excess cancer risk attributable to these activities in a Mediterranean climate for the first time. The lifetime excess cancer unit risks of these two activities in a Mediterranean climate were 7.4×10^{-5} or 7.4 per 100000 population for commuting and 15.03×10^{-4} or 15 per 10000 for refuelling.

ACKNOWLEDGEMENTS

I would firstly like to acknowledge the extremely valuable and tireless encouragement, guidance, support and constructive criticism of my supervisor, Associate Professor Frank Murray. I would particularly like to thank him for his assistance in enabling the research to progress smoothly throughout its life, and for believing in me. In addition, I would also like to thank Kelvin Maybury for giving me the benefit of his considerable patience, encouragement and wealth of experience in the many highly technical aspects of this research and for his ability to explain the highly technical in simple ways. My thanks also to Professor Tom Lyons and Emeritus Professor Bill Scott and Jennifer Robinson, for their encouragement, employment, and most of all for engaging me to think and converse on their level.

The nature of the research on which this thesis is based is dependent on participation from the general public, and could not proceed without it. My sincere thanks must go to the members of the public who provided their time, efforts and patience in order for this research to be undertaken and for it to run smoothly. My thanks also to the owners of the petrol stations and the carparks for granting me access for the source monitoring, and to Main Roads for access to the Kwinana Freeway. I would like to acknowledge Ian Weeks, Rob Gillett, Jenny Powell and Sarah Lawson of the Division of Atmospheric Research at CSIRO Aspendale for their provision and analysis of the personal samplers. I would also like to acknowledge the Emergency Response team at the Chemistry Centre of WA, Steve Wilkinson, Lincoln Morton, Dave Fleming and Nigel West for their provision of the sampling equipment for the source monitoring

and for their patience in troubleshooting. Thanks also to Max Bulsara for his tireless statistical support.

A great deal of our work as scientists is done in collaboration. In that respect, we rely on the wise words of our friends to encourage and assist us along the path. My thanks must go to the Aquatic Ecosystems Research group for adopting me as an honorary member, and particularly Karin Strehlow for her friendship, encouragement, belief in my ability to get things done, for being there when I needed a word and for showing me the importance of challenging and questioning. Thanks also to my fellow residents of the "wind tunnel", Lucy Peters, Jason Fox, Joanne O'Connor and Otti Bajsa for their friendship, humour and encouragement throughout the journey that is a PhD. I hope you get your water cooler one day.

Technical support is also crucial to the success of the journey. My sincere thanks to Frank Salleo and Colin Ferguson for their tireless computer hardware and software support, and for giving me the benefits of their abilities with maps/photos and other images. I also wish to acknowledge the frequent document formatting support of Ross Lantzke during the construction of the thesis. Thanks also to Dan Hewitt, Steve Goynich and Phil Good for their assistance and abilities with equipment failures and construction. Thanks also to Catherine Baudains for her patience in lending me numerous computer power cords and thereby preventing the unthinkable.

The support and encouragement provided by my parents Margot and Richard must also be acknowledged. Their continued listening, wise word and counsel through the

life of this research are things for which I will be eternally grateful. I have been truly blessed.

Lastly, the availability of funding is crucial to any scientific research. I would like to express my gratitude for the funding provided by Environment Australia as part of the Living Cities Air Toxics Program, without which this research clearly would not have proceeded.

LIST OF TABLES

LIST OF FIGURES

LIST OF PUBLICATIONS

The research in this thesis has facilitated the following publications:

- "Personal Monitoring of Benzene in Perth, Western Australia: Results of a Pilot trial" A. Horton and F. Murray, presented at Indoor Air 2002, Proceedings of the 9th International Conference on Indoor Air Quality and Climate, Monterey California July 2002 Volume 1 pp. 221-225.

- "A review of the contribution of benzene hotspots to non-industrial personal exposure" A. Horton and F. Murray, presented at the 15th Conference for the International Society of Environmental Epidemiology, September 2003 (abstract published in Epidemiology Volume 14 number 5, September 2003.

- "On diffusive badges and VOC sampling in IAQ investigations" S Rastan, A Horton, F Murray, J-P Farant and F. Haghighat, presented at Healthy Buildings 2003, Proceedings of International Society of Indoor Air Quality and Climate, the 7th International Conference Singapore, Volume 1 pp. 337-342.

- "Personal Monitoring of benzene in Perth, Western Australia: The contribution of sources to non-industrial personal exposure" A. Horton, F. Murray, M. Bulsara, A. Hinwood and D. Farrar, Atmospheric Environment Volume 40 number 14, pp. 2596-2606.