environmental exposure to benzene

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Brussels
October 1999

ABSTRACT

A review is provided of the health risks from environmental exposure to benzene. Sources and levels of benzene exposure of the general public have been identified from literature. Model calculations are presented of the daily absorbed dose of benzene for different activity patterns. The possible influence of changing benzene levels due to legislative measures on the daily absorbed dose is estimated.

KEYWORDS

benzene, environmental, exposure, health, risk, leukaemia, source, dose, absorbed

CONTENTS

SUMMARY

This report provides a review of the health risks from environmental exposure to benzene. Various sources and levels of exposure to benzene of the general public have been identified from recent literature.

A method is described that allows the estimation of the daily absorbed dose of benzene for a range of individuals representative of different life-styles and working activities. The estimate of the daily absorbed dose is based on an individual's activities, their duration and associated exposure to benzene. The application of the method for some groups of individuals is discussed. The results may be used to evaluate, from a health perspective, the impact of changing ambient benzene levels, e.g. due to legislative measures. It also allows the possibility to use such health data in any subsequent health benefit/cost estimations.

The current understanding of the relationship between exposure to benzene and the occurrence of leukaemia is summarised.

This report is an update of a previous CONCAWE report (1/94).

1. INTRODUCTION

Previously, CONCAWE published a review of the available information on exposures to benzene from non-occupational sources and commented on the associated health risks (CONCAWE, 1994a). Since its publication, there have been two further significant reviews (EBSI, 1996; IEH, 1998) and these have provided additional data on ambient levels of benzene. The present report expands and updates the previous CONCAWE review in the light of newly published information and specifically addresses exposures of the general public to ambient levels of benzene.

The report identifies the various sources of benzene and the typical levels of benzene exposure associated with them. It then derives an estimate of a daily absorbed dose of benzene for a range of individuals engaged in various activities. These absorbed doses are compared with the doses of benzene that could be received by individuals exposed at levels of benzene equivalent to an Occupational Exposure Limit or Air Quality Limit Value (i.e. levels below which adverse health effects are considered negligible). The methodology is detailed in Section 2 of the report.

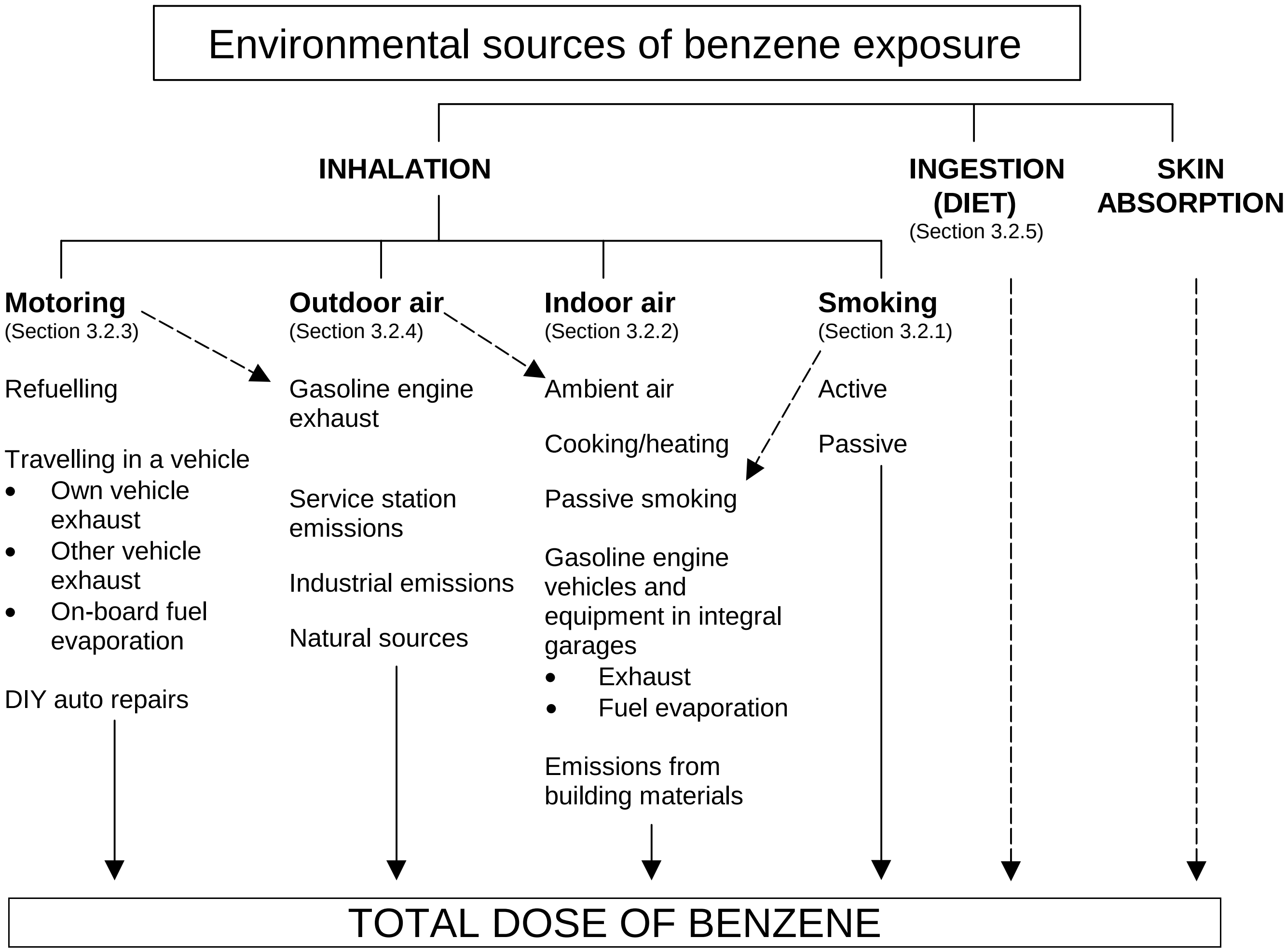
Sources of benzene exposure have been identified from the published literature and this information is summarised in Section 3 of the report, where the associated levels of exposure are also given. Section 4 of the report derives an estimated daily dose for a selection of various adult exposed populations using typical activity profiles. These data may be used further for an infinite range of activity/dose profiles. A summary of the current understanding of the relationship between exposure to benzene and the occurrence of leukaemia is given in section 5. In the discussion, section 6, the health risks for the hypothetical populations addressed earlier in the report are compared with those exposed to benzene at levels equivalent to the current EU Occupational exposure limit (OEL) for benzene. The conclusions of the review are summarised in Section 7.

2. METHOD AND PRESENTATION OF RESULTS

Although benzene intake may occur via the diet or through skin absorption, the inhalation route is the most important.

An overview of the various exposure routes and various environmental sources of benzene is shown in **Figure 1**. This highlights the inter-relationship between motoring, outdoor air, indoor air and smoking. The diagram also indicates those sections in the report, in which the various sources and resulting doses of benzene are discussed. It should be noted that an individual's total exposure to non-occupational benzene will result from a combination of these routes.

Figure 1 **Overview of the sources and routes of exposure to benzene**



2.1. METHODOLOGY FOR ESTIMATING THE ABSORBED DAILY DOSE OF BENZENE

There are several sources of exposure to benzene such as ambient air (both indoors and outdoors), smoking (active and passive), car refuelling, travelling in a vehicle, and diet. The total dose of benzene for a given individual depends on the levels of benzene to which exposure occurs and the duration of each of these. The total daily dose is the summation of that which arises from the various activities throughout a day. It follows that the overall daily dose of benzene for any individual is unique to that individual since it is dependent on his/her life-style and daily activities and the levels of benzene exposure associated with each of these.

In this report an estimation of a typical daily exposure of benzene is made for selected groups of adult individuals representing a variety of life-styles and activities. This is intended to reflect a range from lowest to highest exposure levels from non-occupational sources. Particular attention is given to exposures that arise from motoring-related activities. The data presented can be used to estimate the daily dose of benzene for almost any activity profile.

For comparative purposes in this report, the daily dose of benzene has also been calculated for occupationally exposed individuals.

2.1.1. Absorbed dose from inhalation

For benzene absorbed by inhalation, the following assumptions have been made:

- Only 50% of an inhaled dose is absorbed. The remaining 50% of the inhaled dose of benzene is exhaled unchanged (IPCS, 1993).

- Breathing rates for adults are:

  1 m^3/hr at rest/sedentary activity
  1.25 m^3/hr during active work
  2 m^3/hr during exercise/heavy work

Therefore, by inhalation for a particular activity:

dose absorbed (µg/hour) =

Benzene concentration in air (µg/m^3)	**X**	**Breathing rate (m^3/hour)**	**X**	**Fraction absorbed (0.5)**

2.1.2. Dose from ingestion

There have been several published reports that provide information on the levels of benzene in various foods (e.g. Wallace, 1996). Although the levels are generally very low, nevertheless, they have been taken into account in this report. Benzene intake through ingestion is assumed to be absorbed completely and for the purpose of this report is expressed as a daily dose of benzene (µg benzene/day).

2.1.3. Dose from skin absorption

For the general public, absorption of benzene through the skin may result as a consequence of accidental splashing of benzene containing fluids that might arise when pouring gasoline or when carrying out auto repairs at home. These exposures and the consequent absorbed doses of benzene are considered to be insignificant when compared to those from other sources and are not, therefore, considered further in this report.

2.1.4. Total daily absorbed dose

Using the calculation shown in section 2.1.1, the total absorbed doses of benzene via inhalation have been estimated for groups of adults with different life-styles and daily activities by adding the dose absorbed during the various activities undertaken throughout a 24-hour day. To this dose has been added the small contribution that might arise from the diet. These estimates are shown graphically and in tabular form in section 4 of the report.

By presenting the data in this way it is possible to estimate a total absorbed daily dose of benzene for any individual, provided that a time estimate is available for each of the activities performed by the individual.

Total absorbed dose (µg/24 hrs) =

Activity 1 **Absorbed dose/hr x No hrs**	+	**Activity 2** **Absorbed dose/hr x No hrs**	+ ….. +	**Diet** **µg/24 hrs**

3. SOURCES AND LEVELS OF EXPOSURE TO BENZENE

3.1. SOURCES OF ENVIRONMENTAL EXPOSURE

As shown in **Figure 1**, the primary non-occupational sources of exposure to benzene are:

- Smoking (including passive smoking)
- Indoor air
- Motoring related activities (i.e. travelling in a car, refuelling)
- Outdoor air
- Diet

3.2. EXPOSURE LEVELS

Typical levels of benzene associated with particular sources of exposure have been taken from a report issued previously (CONCAWE, 1994a) and more recent publications, where these have provided additional or more representative data. These data are shown in **Appendix 1**. The values selected for this report are considered to be representative. However, where data are sparse, to avoid under-estimation of exposure, upper range values have been chosen.

3.2.1. Smoking and Passive smoking

The smoke inhaled directly from a single cigarette is reported to contain between 6 and 100 µg of benzene, with an average value of 40 µg (data summarised in IEH, 1998). On the assumption that a typical smoker consumes 20 cigarettes daily, this would contribute 400 µg to the daily absorbed dose of benzene (i.e. 20 µg/cigarette).

In houses with one or more smokers, the average benzene concentration is increased by approximately 3.5 $\mu g/m^3$ (Wallace, 1989). Passive exposure for 15 hours would result in an increase of 25 µg to the daily benzene dose.

The importance of benzene in the assessment of health risks of smokers should be kept in perspective. In such an assessment it should be borne in mind that benzene is only one of a range of carcinogens or toxicants in cigarette smoke.

3.2.2. Indoor Air

Data have been described which typify urban/suburban and rural indoor levels. These indicate that benzene levels in rural homes are some 50% lower than those in urban/suburban homes. Data for city centre homes are sparse but a figure approximately twice that of suburban is considered representative (Krause, 1987a & b; CONCAWE, 1994a).

The benzene in indoor air arises from outdoor air and from indoor activities and sources. Excluding the significant contribution which can be made by tobacco smoke (3.2.1), other sources can be attributed to emissions from building materials, consumer products and from vehicles and gasoline driven equipment housed in attached garages.

Typical levels for indoor air in homes without smokers are:

Rural	3.5 $\mu g/m^3$
Urban	7.0 $\mu g/m^3$
City	14 $\mu g/m^3$

Based on the data reported for service station boundaries (CONCAWE, 1994c; CONCAWE, 1995) and summarised in section 3.2.4, it can be concluded that the benzene levels in a home immediately at the boundary of a service station could be increased by 6 $\mu g/m^3$, i.e. to 10, 13 and 20 $\mu g/m^3$ in rural, urban and city settings respectively. The contribution would rapidly decrease to background with increasing distance from the service station boundary.

Additionally, wood burning has also been identified as a source of indoor benzene (Zweidinger et al, 1988). The difference between homes with and without wood-burning stoves was reported as approximately 15 $\mu g/m^3$. Data regarding benzene exposure due to fuel burning in stoves and heaters in houses are sparse, however this may nonetheless be an important, under-recognised contribution to overall population exposure.

3.2.3. Exposures from Motoring Related Sources

Motoring related activities contribute to benzene exposure primarily as the result of

- evaporation from fuel at service stations, including during refuelling
- evaporation from gasoline on board vehicles during travel
- gasoline engine exhaust emissions contributing to ambient air levels and in vehicle exposure
- DIY auto repairs

Refuelling

Without any form of vapour recovery, the typical concentration of benzene measured in the breathing zone during refuelling with gasoline is approximately 3200 $\mu g/m^3$ (=1 ppm) (Bond et al, 1986; IPCS, 1993; Nicastro and Sperduto, 1993). It has also been estimated that installation of Stage II vapour recovery controls can reduce benzene levels in the breathing zone to approximately 640 $\mu g/m^3$ (Nicastro and Sperduto, 1993).

For the purpose of this report it is assumed that a typical motorist will refuel his/her car once each week amounting to 5 minutes total exposure.

A recent Finnish study concluded that average customer exposure during refuelling with gasoline containing less than 1% of benzene, was 0.9 mg/m^3 (Vainiotalo, 1999).

Travelling in a Vehicle

Benzene levels within a vehicle are dependent upon those in the external ambient air and for gasoline engine vehicles, evaporation from on-board gasoline as well as potential ingress of vehicle exhaust containing benzene. The type, age and maintenance of the vehicle significantly influence the latter. As a result a wide range of data have been reported, for example levels of benzene inside vehicles have been reported recently and ranged from 1.35 to 260 µg/m^3 (Crump et al, 1998). The assumed typical level is 40 µg/m^3.

DIY auto repairs, hobbies, and use of gasoline engined equipment

It is recognised that individuals involved in these activities will also be exposed to benzene, by inhalation and possibly also by skin absorption. However, there are inadequate data available to estimate exposure during these activities and therefore they are not considered further in this report.

3.2.4. Outdoor Air

Although industrial emissions and natural sources contribute to ambient benzene levels, these are not addressed because they are not considered to make a significant contribution to the overall personal intake of benzene for the general public. Gasoline motor vehicle exhausts are the major contributors to ambient benzene levels.

Ambient levels

Typical levels of benzene in ambient air have been summarised previously (IPCS, 1993, CONCAWE, 1994a). The levels selected in this report (**Appendix 1**) are typical of those reported. It should be noted that the difference between the benzene levels in the various locations have been ascribed to differences in traffic density.

- rural (country side/small village) 1.6 µg/m^3
- urban (town, city suburb) 6.0 µg/m^3
- city (residential area) 12 µg/m^3
- city centre (street-side “Hot Spot”) 40 µg/m^3

For comparison purposes, it is noted that the proposed EU Air Quality Limit Value for ambient benzene is 5 µg/m^3 as an annual average (EU, 1999).

Contribution of service station emissions

Additionally, CONCAWE reported on a study that identified the contribution that a service station (without any vapour recovery system) can make to benzene levels in ambient air in the immediate local area (CONCAWE, 1994c; CONCAWE, 1995).

Mean levels reported by CONCAWE were:

- Upwind of road and service station (i.e. background, free from any service station contributions) 8 µg/m^3
- Downwind of road (i.e. background and road) 14 µg/m^3

- Downwind of road and service station (i.e. background plus road plus service station) 20 µg/m^3

These data suggest that at the boundary line, a service station without any vapour recovery system contributes approximately 6 µg/m^3 benzene to local background ambient levels (See also section 3.2.2). As the distance from the boundary increases, the contribution made by the service station will diminish, eventually falling to background ambient levels.

3.2.5. Diet

The 1995-96 US Food and Drug Administration Total Diet Survey has identified that benzene is found in several foods with levels ranging from not detectable (less than 9 µg/kg) to 190 µg/kg. On the basis of calculated average intake the typical absorbed dose of benzene would be 5 µg daily (Diachenko, 1997).

3.3. COMPARATIVE DATA

3.3.1. Environmental AQS for benzene

There are several proposals and actual Air Quality Standards for benzene. For example, the proposed EU Air Quality Limit Value of 5 µg/m^3 (1.6 ppb as an annual average), to be achieved by year 2010 is representative of these (EU, 1999). The current standards in Italy, The Netherlands and the UK are 10, 10 and 16 µg/m^3, respectively.

3.3.2. Occupational Exposures

Occupational exposures to benzene have been surveyed and summarised previously (CONCAWE, 1994b; CONCAWE, 1997).

Typical 8 hour average occupational exposures in the downstream oil industry are:

Service Station Kiosk Attendant 160 µg/m^3

Refuelling Forecourt Attendant 600 µg/m^3

Petroleum Tanker Driver 800 µg/m^3

The proposed EU Occupational Exposure Limit for benzene as an 8-hour time-weighted average is 3200 µg/m^3. The OEL is to be achieved by year 2003 (EU, 1997).

4. CALCULATION AND COMPARISON OF ABSORBED DAILY DOSE FOR A RANGE OF ACTIVITY PROFILES

4.1. CALCULATION OF ABSORBED DAILY DOSE

The approach used to estimate a total absorbed daily dose of benzene for any given individual was described in section 2.1.

The daily dose of benzene will depend on the time an individual spends in a particular environment, and on the activities he/she undertakes. The potential range of scenarios is, therefore, infinite.

Examples of the time profiles that have been constructed for a variety of individuals are shown in **Table 1**. Profiles are included for occupationally and non-occupationally exposed individuals. A distinction is also shown between individuals working in the petroleum industry and other occupationally exposed groups. It should be noted that different time profiles could be constructed to suit the activities for any individual. The time profile estimates for urban office workers shown in **Table 1** are consistent with those that have been reported recently (Crump et al, 1998).

Table 1: Time profiles for individuals exposed to benzene

Individual type	Hours spent per day					
	Indoors		Outdoors		Driving	
	Rural	Urban/City	Rural	Urban/City	Rural	Urban/City
Non-occupationally exposed individuals						
Rural resident (non working, non driver)	18		6			
Rural resident (non working, driver)	18		5		1	
Urban/city resident (office worker, non driver)		20		4		
Urban/city resident (office worker, driver)		20		3		1
Rural outdoors worker (driver)	13		10		1	
Occupationally exposed (non petroleum industry)						
Bicycle courier		12		12		
Professional driver (gasoline car)		12		3		9
Traffic warden		12		11		1
Occupationally exposed (petroleum industry)						
Service station forecourt attendant		12		11		1
Service station kiosk attendant		12		11		1
Tanker driver		12		3		9

In this report, exposure scenarios have been constructed for each of the time profiles outlined in **Table 1**, to take account of the following factors:

- The area in which an individual lives
  - Rural
  - Urban
  - City
- A dwelling adjacent to a service station in rural urban and city locations
- The time spent indoors/outdoors
- Time spent driving a gasoline engine vehicle
- Diet
- Time spent refuelling a gasoline engine vehicle
- Occupation
  - Downstream Oil Industry
  - Non Oil Industry

Estimates of hourly absorbed doses of benzene for those individuals who are occupationally exposed are shown in **Table 2** and, for comparison purposes, estimates for those not occupationally exposed are given in **Table 3**.

Table 2: Estimates of hourly absorbed dose of benzene (μg/hour) for an adult through occupational activities

Situation	Benzene level in air (μg/m^3)	Ventilation rate (m^3/hour)	Absorbed dose (μg/hour)	Reference
Petroleum tanker driver	800	1.25	500	CONCAWE, 1994b
City driver (gasoline car)	200	1.25	125	Nordlinder & Ramnas, 1987
Traffic warden	40	1.25	25	UK DoE, 1994 *
Service station forecourt attendant	600	1	300	CONCAWE, 1994b
Service station kiosk attendant	160	1	80	CONCAWE, 1994b
Bicycle courier	40	2	40	UK DoE, 1994 *
Exposure at future EU OEL	3200	1.25	2000	EU, 1997
Exposure at ½ future EU OEL	1600	1.25	1000	EU, 1997

* The concentrations are those reported by UK DoE, 1994 as maximum values recorded

Table 3: Estimates of hourly absorbed dose of benzene (Non-occupational activities)

Situation	Benzene level in air (µg/m³)	Ventilation rate (m³/hour)	Absorbed dose (µg/hour)
Outdoor air			
Rural	1.6	1.25	1
Urban	6 (5)	1.25	3.8
City	12 (5)	1.25	7.6
City (streetside)	40	1.25	25
Indoor air (non smokers)			
Rural	3.5	1	1.75
Urban	7 (6)	1	3.5 (3)
City	14 (6)	1	7 (3)
Indoor air (Smokers)			
Rural	7	1	3.5
Urban	10 (9.5)	1	5 (4.75)
City	17.5 (9.5)	1	8.75 (4.75)
Indoor air at service station boundary			
Rural	10	1	5
Urban	13	1	6.5
City	20	1	10
Driving a car			
Rural	40 (20)	1	20 (10)
Rural/city	60 (30)	1	30 (15)
Refuelling			
With stage II	550	1	3.5/day
Without stage II	3200	1	20/day
Other			
Diet			5/day
Active smoking	800/day		400/day
Proposed EU limit value 5 µg/m³	5	1	2.5

( ) - Figures in parentheses are estimates of values after year 2010 when Auto oil changes have been implemented

Using the time profiles (**Table 1**) and the estimated hourly doses that are shown in **Tables 2 & 3**, the total daily absorbed doses have been derived. These are shown in **Tables 4 & 5**, which also include the various components that make up the total daily dose. The information is also shown diagrammatically in **Figures 2 & 3.**

Table 4: Estimates of daily absorbed dose of benzene (individuals occupationally exposed)

Residence:		City		City		Urban		Urban		Urban		Urban	
Worker:		Courier		Driver		Tanker driver		Forecourt attendant		Kiosk attendant		Traffic warden	
Driver:		No		Yes		Yes		Yes		Yes		Yes	
Situation/Activity	Hourly absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose
Occupational													
Petrol tanker driver	500					8	4000						
Professional driver (city)	125			8	1000								
Traffic warden	25											8	200
Service station forecourt attendant	300							8	2400				
Service station kiosk attendant	80									8	640		
Cycle courier	40	8	320										
Non-occupational													
Driving car (rural)	20												
Driving car (rural/city)	30			1	30	1	30	1	30	1	30	1	30
Refuelling (with Stage II)	3.5/day												
Refuelling (without Stage II)	20/day				20		20		20		20		20
Outdoor rural	1												
Outdoor urban	3.8	4	15.2			3	11.4	3	11.4	3	11.4	3	11.4
Outdoor city	7.5												
Outdoor city (streetside)	25			3	75								
Indoor rural	1.75												
Indoor urban	3.5	12	84	12	84	12	42	12	42	12	42	12	42
Indoor city	7												
Resident at service station boundary (rural)	5												
Resident at service station boundary (urban)	6.5												
Resident at service station boundary (city)	10												
Diet (dose/day)	5		5		0		5		5		5		5
TOTAL DOSE (μg/day)			424		1209		4108		2508		748		308

Table 5: Estimates of daily absorbed dose of benzene (individuals not occupationally exposed)

Residence:		Rural		Rural		Urban		Urban service station		Urban		Urban service station	
Worker:		No		No		Yes		Yes		Yes		Yes	
Driver:		No		Yes		No		No		Yes		Yes	
Situation/Activity	Hourly absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose
Non-occupational													
Driving car (rural)	20												
Driving car (rural/city)	30			1	30					1	30	2	60
Refuelling (with Stage II)	3.5/day												
Refuelling (without Stage II)	20/day				20						20		20
Outdoor rural	1	6	6	5	5								
Outdoor urban	3.8					4	15.2	4	15.2	3	11.4	2	7.6
Outdoor city	7.5												
Outdoor city (streetside)	25												
Indoor rural	1.75	18	31.5	18	31.5								
Indoor urban	3.5					20	70	8	28	20	70	8	28
Indoor city	7												
Resident at service station boundary (rural)	5												
Resident at service station boundary (urban)	6.5							12	78			12	78
Resident at service station boundary (city)	10												
Diet (dose/day)	5		5		5		5		5		5		5
TOTAL DOSE (µg/day)			42		91		90		126		136		199

Table 5 (continued)

Residence:		City		City service station		City		City service station	
Worker:		Yes		Yes		Yes		Yes	
Driver:		No		No		Yes		Yes	
Situation/Activity	Hourly absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose	Hours	Daily absorbed dose
Non-occupational									
Driving car (rural)	20								
Driving car (rural/city)	30					1	30	2	60
Refuelling (with Stage II)	3.5/day								
Refuelling (without Stage II)	20/day						20		20
Outdoor rural	1								
Outdoor urban	3.8								
Outdoor city	7.5								
Outdoor city (streetside)	25	4	100	4	100	3	75	2	50
Indoor rural	1.75								
Indoor urban	3.5						0		
Indoor city	7	20	140	8	56	20	140	8	56
Resident at service station boundary (rural)	5								
Resident at service station boundary (urban)	6.5								
Resident at service station boundary (city)	10			12	120			12	120
Diet (dose/day)	5		5		5		5		5
TOTAL DOSE (μg/day)			245		281		270		311

Figure 2 Estimated total daily absorbed dose of benzene for a range of activity profiles for smokers and non-smokers

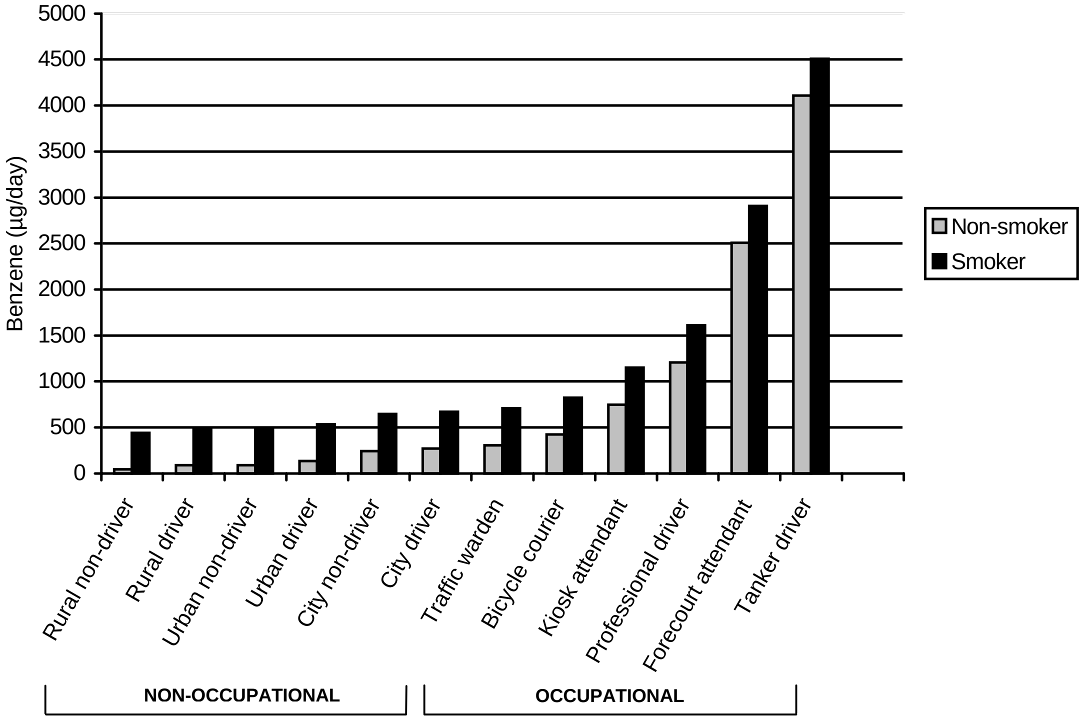
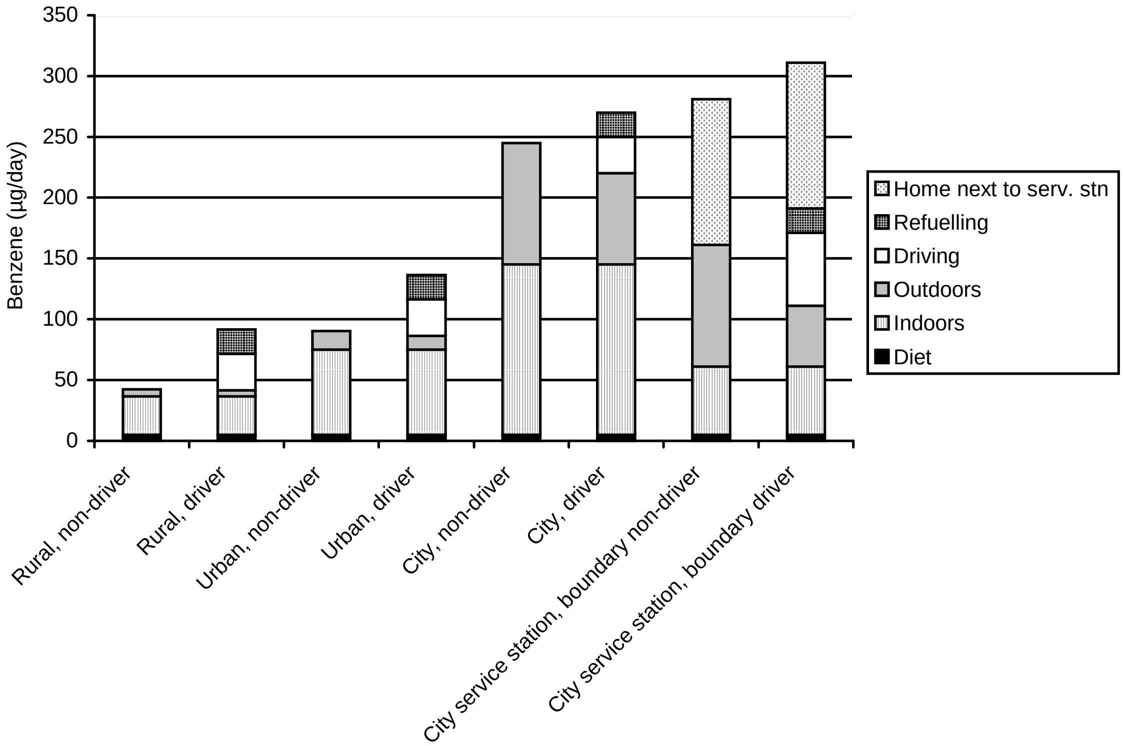


Figure 3 Estimated total daily absorbed dose of benzene for non-smoking individuals, not occupationally exposed (broken down by source)



4.2. COMPARISON OF ABSORBED DAILY DOSE FOR OCCUPATIONALLY EXPOSED WORKERS

Individuals whose occupational exposure to benzene arises from motoring-related benzene emissions include those working in city centres where vehicle exhaust emissions make a maximum contribution to the ambient air.

This report gives an estimate of the contribution of 8 hours continuous work at levels typically found at city street-sides for a traffic warden and bicycle courier. For the estimation, it is assumed that there is 8 hours of exposure to 40 $\mu g/m^3$ but differing breathing rates are used to represent different levels of physical activity. The exposure for the driver of a gasoline engine vehicle is also estimated, assuming an 8 hours exposure to 200 $\mu g/m^3$ (i.e. 5 times outside ambient street-side level).

For comparative purposes, on the assumption of 8 hours exposure to future OEL and ½OEL levels, daily doses for 3200 $\mu g/m^3$ and 1600 $\mu g/m^3$ respectively are included. Data are presented in **Figure 4** and **Table 6**.

NB: Although smoking makes a significant contribution to the daily dose for a smoker (400 µg) and non-smoker living with a smoker (25 µg/day), in order to limit the number of scenarios, smoking has not been included as a specific variable. The effects of its contribution can be easily calculated by the addition of 400 µg for smokers and 25 µg for passive smokers to the total calculated dose from all other sources.

Figure 4 Comparison of the estimated total daily dose of absorbed benzene for selected occupations with that arising from exposure to benzene at the level of the future EU OEL. (Figures given for OEL and half OEL assume 8 hour exposures and no other exposure to benzene.)

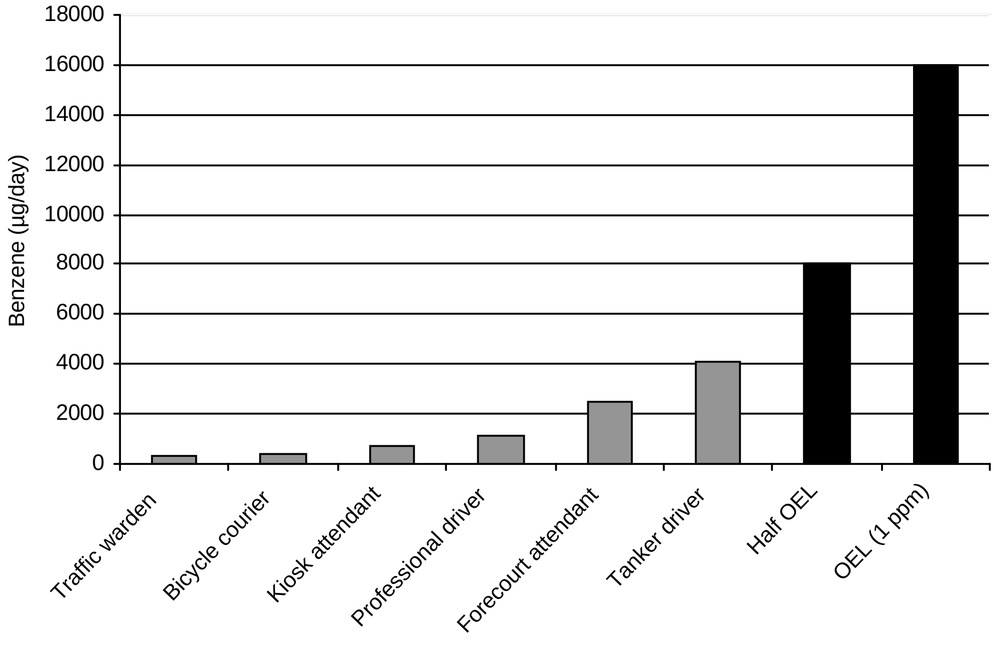


Table 6 provides a comparison in percentage terms of total absorbed daily dose (with and without smoking) with the future OEL for all the activity profiles.

Table 6: Comparisons (expressed as %age) of estimated total daily absorbed benzene doses with OEL 3200 µg/m^3

	dose (µg)	**% OEL**	**% OEL with smoking**
OEL (1 ppm)	**16000**	**100%**	**100%**
Petroleum Tanker Driver	4108	25.7	28.2
Forecourt Attendant	2508	15.7	18.2
Professional Driver	1209	7.6	10.1
Kiosk Attendant	748	4.7	7.2
Cycle Courier	424	2.7	5.2
Traffic Warden	308	1.9	4.4
City Dweller – Driver Service Station	311	1.9	4.4
City Dweller – Non-Driver	261	1.6	4.1
City Driver	270	1.7	4.2
City Non-Driver	245	1.5	4.0
Urban Dweller Driver Service Station	199	1.2	3.7
Urban Dweller Non-Driver	126	0.8	3.3
Urban Driver	136	0.9	3.4
Urban Non-Driver	90	0.6	3.1
Rural Driver	91	0.6	3.1
Rural Non-Driver	43	0.3	2.8

5. BENZENE AND LEUKAEMIA – CURRENT UNDERSTANDING

The key health concern related to benzene exposure is that of leukaemia. On the basis of numerous reviews including the most recent by CONCAWE (CONCAWE, 1996) the following conclusions can be drawn.

- Benzene is a weak genotoxic agent and carcinogen, but associated only with the occurrence of one kind of leukaemia (ANLL) in humans (ANLL - Acute Non Lymphocytic Leukaemia).
- ANLL is the most common form of leukaemia in adults and the second most common form in children. However, the incidence rate of this disease is very low. A published ecological study was not supportive of an association between increased gasoline conumption and reported leukaemia incidence (Swaen, 1995).
- The most common type of leukaemia in children is not benzene related. Children's blood cells divide more rapidly and theoretically could be more susceptible to any environmental agent causing leukaemia. Available data do not support a link between exposure of children to benzene and the occurrence of leukaemia.
- Previously it was assumed that there was no safe level of exposure. However, based upon research into its mode of action, there is now good support for the view that the overall risk of benzene-related ANLL involves a threshold of exposure and a non-linear dose response relationship.
- Based on available information from prolonged and repeated occupational exposure to benzene there is
  - no evidence of a risk of ANLL below 1 ppm 8 hour average exposures (equivalent to an absorbed dose of 16,000 μg of benzene in 8 hours)
  - an identified increased risk associated with prolonged exposures to 20 ppm and above
  - the likelihood of a threshold of effect lying between 1 and 20 ppm but there are insufficient data to identify this threshold level more precisely
  - an Occupational Exposure Limit (OEL) of 1 ppm has been identified as providing protection to all employees (including those who could potentially be more susceptible).
- There are no data relating to exposure to ambient environmental levels of benzene which demonstrate or support any adverse human health effects at current levels.
- Because they are founded upon previously held assumptions, many current (1999) occupational and environmental exposure limits are based on a no-threshold, linear dose response model. This results in an over estimate of risk and there is no evidence of any measurable human health risk occurring at these levels of exposure.

6. DISCUSSION

The report has identified the typical levels of exposure associated with the significant non-occupational sources of benzene. These exposure data have been taken from the open published literature and are considered to be representative of current day values. The report has also given some estimates of time profiles for a variety of individuals that represent a variety of different life-styles. The pragmatic estimates given in this report are consistent with those reported elsewhere (IEH, 1998; Crump et al, 1998).

Using these data, estimates have been made of the daily doses of benzene that would be absorbed for a selection of individuals representative of different life-styles and working activities. It is possible to estimate the daily-absorbed dose of benzene for any individual, provided that appropriate information is available on daily activities, their duration and the levels of benzene to which the individual is exposed for each of these activities.

Validation for the assumptions used in this report is provided by the EU programme MACBETH (Monitoring of Atmospheric Concentrations of Benzene in European Towns and Homes). This studied the relationship between ambient levels, indoor levels and personal exposures for five European cities. Ambient levels were measured on a grid of about 100 stationary sample points per city. Indoor levels and personal exposure data were generated with groups of volunteers, representing a cross section of the cities' populations. Preliminary results indicate higher levels and exposures in southern parts of Europe than in northern parts. Average personal exposures range from 6 $\mu g.m^{-3}$ in northern cities to 25 $\mu g.m^{-3}$ in southern cities which correspond to total daily absorbed doses of 72 and 300 µg. In general, personal exposures were higher than the corresponding indoor levels, which, in turn, were higher than outdoor levels, indicating that other sources contribute to personal exposure (Cocheo, 1998).

The estimates of daily benzene doses have been made for an average adult. Similar calculations could also be made for other subjects, by appropriately modifying activity/exposure profiles and breathing rates.

Children are more difficult to address because there is a wider range of size and breathing rates and dose expressed in terms of body weight may be more relevant. Since there is no evidence of an increased risk or susceptibility to benzene in children, children have not been considered in this report.

Use of the estimates that have been made in this report allows an assessment of the possible influence of life-style activities and occupational activities on the dose of benzene that is likely to be absorbed. It also allows an assessment of the importance of some of the sources of benzene and the impact of regulations, agreed and proposed, on the total daily dose of absorbed benzene. A limited number of these considerations are described in the following sections.

6.1. CONTRIBUTIONS FROM INDOOR AND OUTDOOR AIR AND DIET

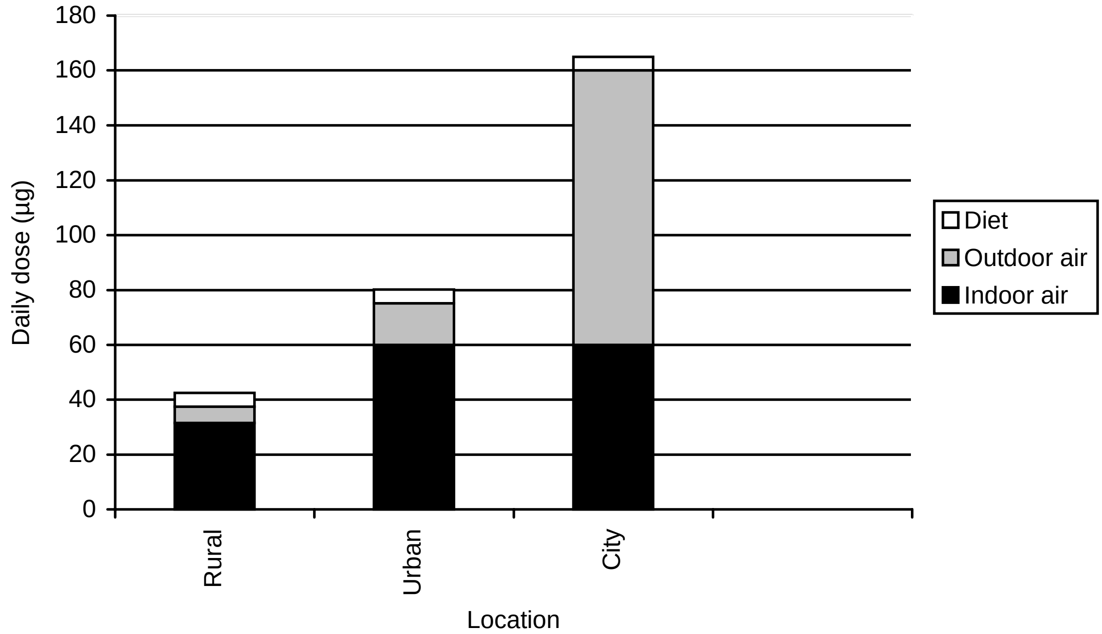
Figure 5 shows the relative contributions made by indoor air, outdoor air and the diet for non smoking, non driving individuals residing in rural, urban and city locations respectively. The data for the figure have been taken from **Tables 3** and **5**.

It is clear that diet accounts for an insignificant portion of an individual's daily absorbed dose of benzene.

For rural and urban dwellers, the largest contributor to the total daily absorbed dose of benzene is the indoor air. This is because individuals spend a larger proportion of their time indoors rather than outdoors and also the reported indoor concentration of benzene is greater than that outside. This results in indoor sources making the greatest contribution to the daily absorbed dose. In the case of individuals living in cities, the outdoor air makes a larger contribution because streetside ambient benzene levels are much higher than those in either rural or urban locations.

Based on the limited data available, the use of wood burning stoves may make a significant contribution to the daily absorbed dose of benzene for those individuals who live in homes with such appliances. An estimation of the additional absorbed dose for people living in homes with such stoves, on the basis of 6 hours of wood burning, is 15 µg/day.

Figure 5 Contribution of diet, indoor and outdoor air to the estimated daily dose of benzene



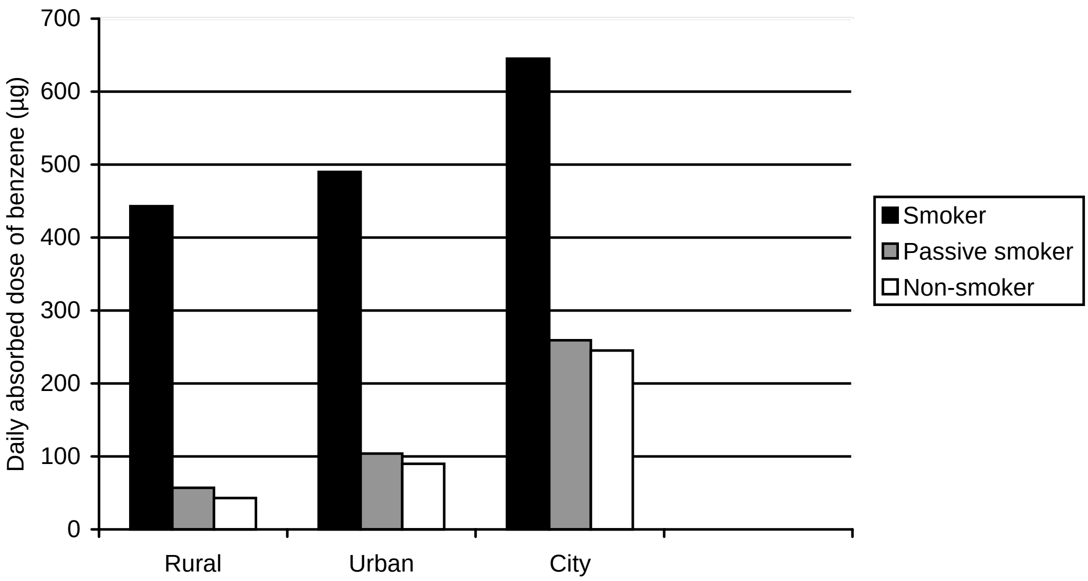
6.2. INFLUENCE OF SMOKING

An estimate has been made of the daily absorbed dose of benzene for an active and a passive smoker, using the levels reported for inside homes of smokers (Wallace, 1989). The data are also summarised in **Table 3**. The resulting estimates are compared with the values for rural, urban or city dwellers who neither drive nor smoke (**Table 5**). The comparisons are shown in **Figure 6.**

The comparisons demonstrate clearly the large contribution that active smoking can make to an individual's daily benzene intake. Smoking 20 cigarettes a day is estimated to contribute approximately 400 µg benzene per day. This dose is greater than the total daily absorbed dose of benzene that would be absorbed by a traffic warden (308 µg) and similar to the daily dose absorbed by a cycle courier (424 µg), even though both of these individuals would be exposed to traffic exhaust during an 8 hour working day.

Although passive smoking also increases an individual's daily benzene dose by 14 µg if exposed for 8 hours, its contribution is nevertheless relatively small.

Figure 6 Estimated daily absorbed doses of benzene for a smoker, passive smoker and non-smoker

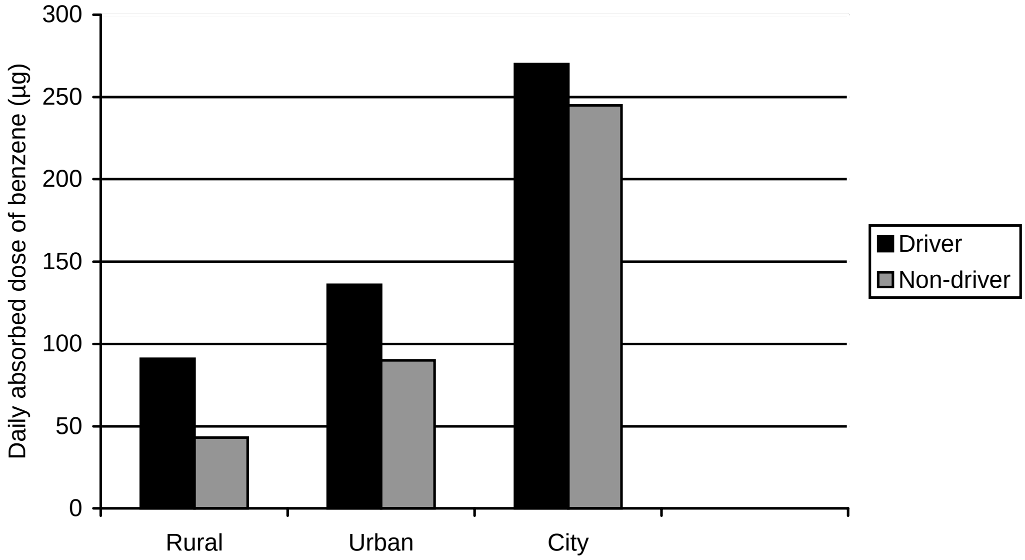


6.3. INFLUENCE OF DRIVING ON DOSE OF ABSORBED BENZENE

For individuals who are not occupationally exposed to benzene but who drive cars, there are extra sources of benzene which contribute to the daily absorbed dose. These include benzene inside the vehicle and the exposures that may occur during refuelling. For comparison the relative doses of absorbed benzene are shown in **Figure 7** for non-smoking rural, urban and city dwellers. The data that have been used for this comparison have been taken from **Table 5**.

Driving a car increases the absorbed dose by 40 µg to 50 µg per day. The highest increase in the contribution to the total daily dose is for those living in rural areas. Even so, the rural driver's daily dose of benzene is less than that for an urban non-driver.

Figure 7 Estimated typical daily absorbed dose of benzene for a driver and a non-driver

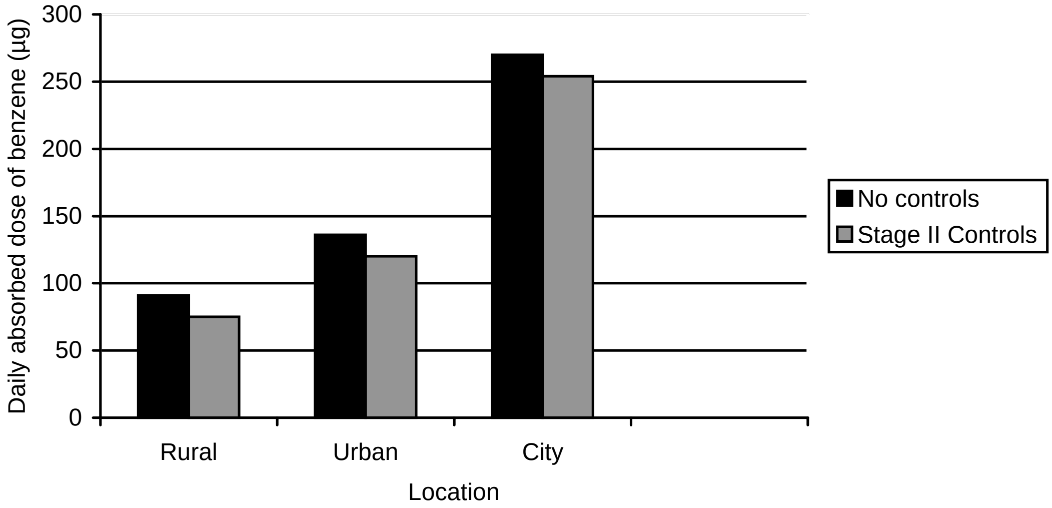


6.4. INFLUENCE OF VOC CONTROLS

There are many ongoing initiatives that are targeted at reducing and improving overall ambient air quality. These include the introduction of vehicle catalytic converters, changes in fuel specifications, vehicle fuel efficiency improvements, the introduction of VOC vapour recovery controls and also the introduction of air quality standards for various pollutants, including benzene. It is assumed that these initiatives will result in a reduction of benzene emissions and hence, an improvement in air quality and a consequent reduction in personal exposure. Since the data and scenarios used in this report are representative of current levels of benzene and do not take into account any new initiatives, the estimated daily absorbed doses of benzene can be considered as "worst case".

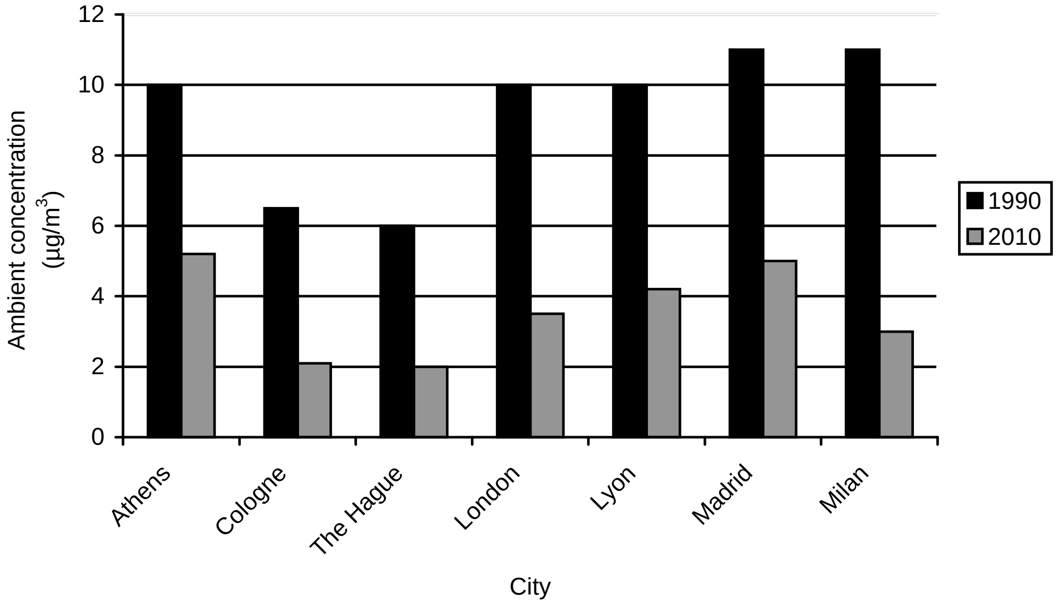
As an example, the possible influence that the introduction of stage II vapour recovery controls at service stations might have on the daily absorbed dose of benzene for drivers who are either rural, urban or city dwellers is shown in **Figure 8**. The estimate is made on the basis that Stage II recovery controls will reduce the daily absorbed dose by 16.5 µg (i.e. from 20 µg to 3.5 µg). Although this is a significant reduction, its impact on total daily absorbed dose is relatively small because refuelling is only a brief activity.

Figure 8 Influence of Stage II vapour recovery controls on the estimated daily absorbed dose of benzene for selected drivers



On the other hand, the predicted reductions in ambient levels of benzene between the years 1990 and 2010 as a consequence of implementing planned controls (EU, 1996) as shown in **Figure 9** will lower ambient benzene concentrations and therefore dose substantially.

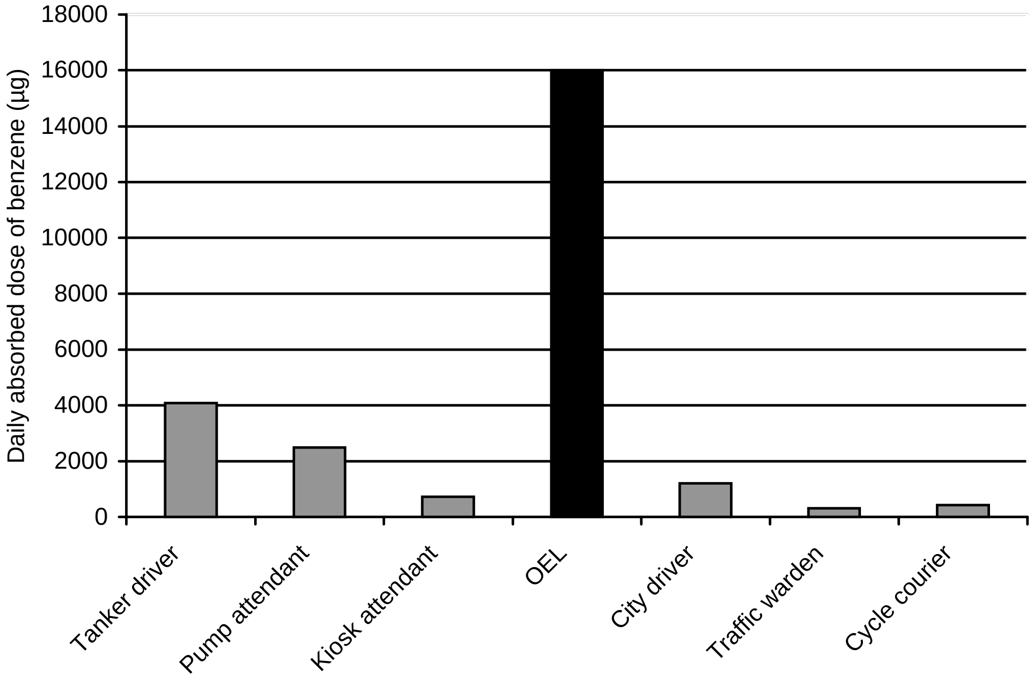
Figure 9 A comparison of predicted ambient levels of benzene in 7 European cities in year 2010 with those found in 1990



6.5. OCCUPATIONAL EXPOSURES TO BENZENE

The daily absorbed doses of benzene have been estimated for individuals who are occupationally exposed either within the oil industry or elsewhere (**Figure 10**). The estimated doses are compared with those that would arise from only an 8 hour exposure at a level equivalent to the EU OEL and no further exposure to benzene. This information has been included for comparison purposes, since the OEL is considered to be a level to which an individual may be occupationally exposed for 8 hours a day, five days a week for a working lifetime without adverse health effects.

Figure 10 Comparison of the estimated daily absorbed dose of benzene for those individuals working in the petroleum industry and those in unrelated industries



N.B. OEL value assumes no other exposure in addition to 8 hours at 1 ppm.

For all the occupationally related exposures, the calculations demonstrate that the daily benzene doses are significantly less than for an equivalent short exposure to the 1 ppm Occupational Exposure limit. As an example, for a typical Petroleum Distribution Tanker Driver, representative of the higher levels of occupational exposure currently found in the Oil Industry, the daily absorbed benzene dose is approximately one quarter of the equivalent OEL exposure i.e. approximately 4,000 µg compared to 16,000 µg.

Tanker drivers are an important occupational reference since as a group they have been subject to extensive epidemiological study where no relationship between current levels of actual benzene exposure and adverse health effects has been identified.

For the non oil industry occupationally exposed groups i.e. traffic wardens, cycle couriers and professional drivers working in city centres, the total daily benzene doses are significantly below the OEL equivalent (i.e. ranging from 308 to 1209 µg/day, compared to 16000 µg/day). With the exception of the professional drivers, other occupational exposures are similar to the typical higher levels of non-occupational exposures.

7. CONCLUSIONS

This report has updated the information given previously in CONCAWE report No. 1/94 by including more representative data than had been provided before. The following conclusions can be drawn:

- A model has been described that has allowed a simple comparison of the absorbed daily doses of benzene for a variety of individual types ranging from the rural dweller to the city resident.
- The model may be used by anybody who may modify it to be able to apply it to any given activity/situation. By so doing any likely impact of changes to air quality or work patterns/life-styles may be assessed.
- In the comparisons presented in this report the minimal impact of the introduction of Stage II vapour recovery controls is demonstrated (i.e. 16.5 µg reduction in daily absorbed dose).
- The importance of indoor exposures to benzene depends on where the individual resides. For a rural/urban dweller generally, an individual's greatest exposure to benzene arises from his/her indoor activities. For a city dweller outdoor activities become more important.
- Data regarding benzene exposure due to fuel burning in stoves and heaters in houses are sparse, however this may nonetheless be an important, under-estimated contribution to overall population exposure.
- The absorbed dose from active smoking dwarfs that of all other non-occupational exposure.
- Driving and refuelling adds to the total daily absorbed dose, but the relative contribution is greater for those in rural areas.
- The dietary contribution to the daily intake of benzene is insignificant.
- Occupational exposures to benzene are much lower than the future OEL in the EU for benzene of 1 ppm, 8-hour Time-Weighted Average. For those exposed in oil-industry activities daily absorbed doses of benzene range from 25% of the OEL for a tanker driver to 5% of the OEL for a service station kiosk attendant.
- For those occupationally exposed to benzene but who are not employed in the petroleum industry (traffic warden, cycle courier) the absorbed daily dose of benzene is less than 3% of that which would be absorbed from an exposure to benzene at the level of an OEL for 8 hours and without any further exposure to benzene.
- For the highest non-occupationally exposed profile the absorbed dose of benzene is only 2% of the OEL.
- Exposures and hence absorbed doses of benzene for all other individual profiles given as examples in this report are even lower than those described above.
- For the non-oil industry occupationally exposed and non-occupationally exposed individuals, given the measures being implemented, exposures and thus absorbed daily doses will be reduced in future.

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APPENDIX 1A SOME REPORTED CONCENTRATIONS OF BENZENE FOR SELECTED OUTDOOR LOCATIONS

Location/activity	Concentration (µg/m³)	Comment	Reference
OUTDOOR AIR			
Remote areas			
USA	0.51	Daily median for 42 states	US DHHS, 1993 Shah & Singh, 1988
Nepal	0.27-1.99	5050m height at foot of Mt. Everest	Ciccioli et al, 1993
Starkow (Former GDR)	0.54	Pine forest	Ciccioli et al, 1993
Italy	4.39	Forested site	Ciccioli et al, 1992
Rural/Suburban			
Europe	1-10	24 hour (rural)	Neumeier, 1991
Black Forest	2	Germany	Bruckmann et al, 1983
Germany	<1	Location unspecified	Enquête-Kommission, 1992
UK	1.6	Daily mean	UK DoE, 1994
UK	1.28-5.4	3 monthly average	UK DoE, 1994
UK other sites	2.88-3.2	Annual averages (1991)	UK DoE, 1994
Former FRG	1.0		BUA, 1988
Austria	1-1.8	Annual average (1992-3)	Hanus-Illnar & Hrabcik, 1994 cited in EBSI, 1996 Lanzerstorfer & Puxbaum, 1990
Italy	3.08	25 Km west of Rome	Ciccioli et al, 1993
Hamburg,Germany	9.3	Residential area	Bruckmann et al, 1983
Bilthoven NL	2.8	10.4 max	RIVM, 1988
Urban/City			
Seven German cities	6-45	Monthly averages (1992-1993)	LUEN, 1993 cited in EBSI, 1996
Baden-Wuerttemberg, Germany	15-28	Monthly averages (1992-1993)	UMEG, 1994 cited in EBSI, 1996
Baden-Wuerttemberg, Germany	20	Annual average (1992-1993)	UMEG, 1994 cited in EBSI, 1996
Hamburg, Germany	19.3	Annual mean (1986-1987)	Bruckmann et al, 1988
Hamburg tunnel	80.5-95.3		Dannecker et al, 1990
	28-31		Bailey & Schmidl, 1989
	147.7		Jonsson et al, 1985
Munich, Germany	15.63-24.89	24 hour average Heavy traffic street	TUEV, 1994 cited in EBSI, 1996 DEKRA, 1994 cited in EBSI, 1996
Vienna, Austria	8.8-15.5	High traffic density	Hanus-Illnar & Hrabcik, 1994 cited in EBSI, 1996 Lanzerstorfer & Puxbaum, 1990
Rome, Milano &Taranto, Italy	39-43.9	Averages over 15 days	Ciccioli et al, 1992
Tunnel, Goeteborg, Sweden	61 & 450	High value on day of slow traffic	Barrefors & Petersson, 1992
Europe	10-30	24 hour (urban)	Neumeier, 1991
Vlaardingen, NL	9		RIVM, 1988
Oslo, Norway	40		IPCS, 1993
London, UK	23	85 max.	Clark et al, 1984
London, UK	10-12		Bailey & Schmidl, 1989
Stockholm, Sween	7.7	Quiet street	Jonsson et al, 1985
London, UK	39	Max. daily mean	UK DoE, 1994
London & Middlesborough, UK	3.2-12.8	Monthly averages	UK DoE, 1994
London, Urban	3.2-43.5	Monthly average	UK DoE, 1994

APPENDIX 1B SOME REPORTED CONCENTRATIONS OF BENZENE FOR SELECTED INDOOR LOCATIONS, CIGARETTE SMOKE, DRINKING WATER AND FOOD

Location/activity	Concentration (µg/m³)	Comment	Reference
INDOOR AIR			
In classroom, Munich	9		BLFU, 1994 cited in EBSI, 1996
Frankfurt	15		Müller, 1991
Germany, homes without smokers	6.5		Enquête-Kommission, 1992
Germany, homes without smokers	6-8		Krause, 1987
Germany, homes with smokers	11		Enquête-Kommission, 1992
Germany, homes with smokers	10-12		Krause, 1987
Tobacco			
Cigarette smoke	150,000-204,000		Lauwerys, 1983
Passive smoking	3.5		Wallace, 1989
Smoking	10-30 µg/cig.		Fishbein, 1984
Smoking	6-73 µg/cig		Brunneman et al, 1989
Smoking	57 µg/cig		Wallace, 1989
Smoking	40 µg/cig		Hattemer-Frey et al, 1990
Smoking	10-30 µg/cig		Eikmann et al, 1992
Smoking	30-100 µg/cig		IARC, 1988
Sidestream smoke	345-653 µg/cig		Brunneman et al, 1990
Drinking water			
EU Commission (DG V)	<0.1-1 µg/l		Neumeier, 1991
Germany	0.018-0.045 µg/l		Eikmann et al, 1992
Germany	0.01-1 µg/l		IPCS, 1993
Spain	<0.005 µg/l		Guardiola et al, 1991
Netherlands	<0.005 µg/l		RIVM, 1988
Food			
UK	2.03 µg/kg	Total concentration in food	MAFF, 1995

APPENDIX 1C REPORTED EXPOSURES TO BENZENE AT AND IN THE VICINITY OF SERVICE STATIONS AND DURING REFUELLING.

Location/activity	Concentration (µg/m³)	Comment	Reference
Occupational exposures			
Various	90% <2940		Neumeier, 1991
Tanker driver	800	8 hour TWA	CONCAWE, 1994b
Forecourt attendant	600	8 hour TWA	CONCAWE 1994b
Kisok attendant	160	12 hour average	CONCAWE 1994b
At Service stations			
Vehicle refuelling	3200		Wallace,1989, Bond et al, 1986
Refuelling at 10-20m	10-26		Enquête-Kommission, 1992
Refuelling peak exposure	2940-27170	For approx 30 sec	Enquête-Kommission, 1992
Refuelling (no vapour recovery)	3709	For approx. 1 min.	Nicastro & Sperduto, 1993
Refuelling (no vapour recovery	<160-5216	2100 mean value	CONCAWE 1994b
Refuelling (with vapour recovery)	920	Predicted value	Nicastro & Sperduto, 1993
Inside vehicles during driving			
Driving	50-200	locality not specified	Enquête-Kommission, 1992
Parking in sunshine (windows closed)	Max 2700		
Sweden (high traffic)	100-200		Nordlinder & Ramnas, 1987
Sweden (high traffic + queues)	200-400		Nordlinder & Ramnas, 1987
Driving in rural area	5-10	Sweden	Nordlinder & Ramnas, 1987
Before starting engine	60-180		Eikmann et al, 1992
During driving	30-60		Eikmann et al, 1992
Average during commuting trips	40		Crump et al, 1998
Paris – inside vehicle	38-46	Average of 1.5hr trips	Dor et al, 1995
Inside stationary diesel engine	3.2-3.5		Dor et al, 1995
Inside stationary petrol engine	12-33		Dor et al, 1995
Inside taxi (highway)	3-8		Nordlinder & Ramnas, 1987
Inside taxi (city rush hour)	40-110		Nordlinder & Ramnas, 1987