a review of european gasoline exposure data for the period 1993-1998

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ABSTRACT

This report presents data on over 5000 personal gasoline exposure measurements taken in European countries in the period 1993-1998. The majority of the data were generated by CONCAWE member companies as part of routine occupational hygiene programmes, but relevant literature data are also included. The exposure measurements covered both airborne breathing zone concentrations and biological monitoring of gasoline components. The data are presented as arithmetic means and ranges for full work shift and short-term (< 1 hour) exposures for a range of jobs in the production, distribution, retail and use of gasoline. Changes in exposures over time are evaluated.

This report updates information provided in CONCAWE Report 4/87.

KEYWORDS

Gasoline (CAS 86290-81-5); gasoline vapour (CAS 68514-15-8); occupational exposure; exposure monitoring; biological monitoring; benzene.

CONTENTS

SUMMARY

Under the European Existing Substances Regulation 793/93/EEC, the risk assessment of existing substances having wide dispersive use may be required. Although the risk assessment of gasoline has not yet been scheduled, CONCAWE has undertaken a programme of work to generate comprehensive data for use in the risk assessment. Data regarding the exposure to gasoline vapour have been published in the past, but continued changes to operating practices, vapour emission control and product composition highlighted the need for up-to-date data. Accordingly, a CONCAWE Special Task Force was formed:

- to gather, collate and review recent (1993-1998) European exposure data (including exposure data relating to individual gasoline components) for jobs associated with the production, distribution, retailing and use of gasoline;

- to carry out a programme of gasoline exposure measurements for those job groups for which there were either no data or too few data in number and/or scope to adequately reflect current (1999-2000) circumstances.

The present report contains the overview of exposure data from company files and published literature for the period 1993-1998. The data were subdivided according to exposure duration and standardised job categories, covering exposures in the production, distribution, retail and use of gasoline in Member States of the European Union, Norway and Switzerland. Both personal breathing zone air monitoring and biological monitoring data are presented. The available data indicated that, for all job categories, the average inhalation exposures were below occupational exposure limits currently existing in European countries.

A comparison was made with the data from the previously published survey (Report 4/87) in order to examine the exposure reductions resulting from a series of measures taken in the 1990's to reduce vapour emissions. It was concluded that since the 1984-1985 survey, exposures have either remained unchanged or have been reduced.

The results of the field monitoring work conducted in 1999-2000 will be the subject of a separate report.

1. INTRODUCTION AND BACKGROUND

Under the European Existing Substances Regulation 793/93/EEC, the risk assessment for existing substances having wide dispersive use may be required. Although the risk assessment for gasoline has not yet been scheduled, CONCAWE has undertaken a programme of work to complete the data base for gasoline for use in the risk assessment. Information regarding human exposure to a substance during production and use is part of the requirements in order to complete a comprehensive risk assessment report.

CONCAWE carried out a gasoline inhalation exposure survey in 13 European countries in 1984–1985. The survey involved the measurement of occupational exposures to airborne gasoline components arising from the production and distribution of gasoline. The exposure monitoring was accomplished using a standardised method of air sampling and the subsequent analysis of the gasoline components (CONCAWE, 1986). The results of the survey included exposure data for up to 150 individual components of gasoline as well as for total hydrocarbons (CONCAWE, 1987).

Since the publication of the results of that survey, there have been changes to the composition of gasoline as well as the introduction of measures, such as vapour recovery controls, in order to minimise evaporative losses of volatile hydrocarbons during the distribution and use of gasoline. The impact of these changes will have resulted in changes to the occupational exposures to gasoline components during production and distribution.

In view of the changes that have occurred, it was recognised that there is a need to update the 1984-1985 survey with current exposure data in order to provide a meaningful basis for the risk assessment of gasoline. In addition, a risk characterisation for benzene (EBSI, 1996) drew attention to specific activities involving gasoline for which further benzene exposure data were required. In the interim, new exposure assessment methods, notably biological monitoring, along with indices to aid interpretation, have been developed for a number of gasoline components and data of this type have been reported for activities involving gasoline which needed to be assessed.

This report summarises the results of exposure surveys that have been conducted by CONCAWE member companies during the period 1993 to 1998, as well as data retrieved from literature. Where available, data have been included for the use of gasoline, as well as for occupational activities during the production and distribution of gasoline.

2. METHODOLOGY

2.1. INTRODUCTION

2.1.1 This chapter addresses the collection and collation of available total hydrocarbon exposure data, obtained in the period 1993-1998, and information on changes in operating practices for activities involving gasolines and certain intermediates utilised in the production of gasolines, for example catalytic reformates. The range of exposure scenarios for which data were sought included:

- refinery, distribution (via road, rail and sea) and retail service station activities;
- other occupational activities involving contact with gasoline;
- consumer and end user activities.

These scenarios or job groups are identified and described briefly in **Appendix 1**. For some job groups, the potential for exposure to gasoline vapours is present over most if not all of the working day, whilst for other activities the main potential for exposure is over a relatively short period. As such, exposure data submitted for both full shift and short periods (less than one hour) are reported .

Corresponding exposure data for individual gasoline hydrocarbons, such as benzene, toluene, xylene and n-hexane, as well as any relevant biological monitoring exposure data are also reported .

2.1.2 The range of activities considered is considerably broader than those described in the 1984-1985 CONCAWE gasoline exposure survey, reflecting, in part, some of the operational changes that have occurred, such as the wider utilisation of vapour recovery/vapour control facilities, and in part the range of occupational and consumer/user activities that may be addressed in the EU risk assessment process (EU, 1996).

2.2. DATA COLLECTION

2.2.1 The survey sought two types of exposure data, namely those derived from:

- atmospheric monitoring in the breathing zone because these data are deemed to be representative of personal exposure to the airborne gasoline components present. Consequently this part of the data collection focused, almost exclusively, on obtaining exposure data derived from personal monitoring techniques. The static nature of work in retail service station kiosks does mean that suitably-located fixed position measurements can be indicative of the airborne concentrations of gasoline hydrocarbons to which the kiosk operators are exposed. Accordingly, the results from such measurements are included in the data base.
- biological monitoring (blood and urine analyses) to estimate the total uptake of gasoline hydrocarbons by all routes of exposure.

2.2.2 The Task Force contacted CONCAWE Member Companies to ascertain whether they had any relevant exposure data and carried out a literature search to identify any European exposure data published for the 5 year period of interest.

2.2.3 In view of the anticipated high number of data points available from Member Companies and the associated considerable work load in reporting, it was agreed that for each individual job group the Companies would submit their data in summary form, i.e. as an exposure range with the minimum and maximum stated together with the corresponding arithmetic mean, number of samples and any relevant explanatory notes.

2.2.4 Companies were invited to forward exposure data to CONCAWE in one of two formats, either by completing a standard computerised CONCAWE survey form **(Appendix 2)** or by submitting copies of reports of the field surveys that generated the data - with any proprietary information removed. Each set of company exposure data was allocated a code number so that its origin would remain confidential during the subsequent collation, analysis and reporting of the data.

2.2.5 Several requirements were specified:

- the breathing zone exposure data should have been obtained utilising the sampling and analytical methodology described in CONCAWE Report 8/86 - or by any other method which has been demonstrated to have the capability of providing reliable gasoline exposure data and / or reliable specific individual gasoline hydrocarbon exposure data;
- the biological monitoring data should have been obtained utilising valid methodologies, preferably as specified in connection with limit values;
- the atmospheric and biological exposure data should relate to European gasolines because of their relevance to the EU Existing Substances Regulation;
- the units of measurement relating to the exposure data should be clearly indicated.
- information should be provided relating to any unusual occurrences bearing in mind the intended aggregation and analysis of all the exposure data for each job group.

2.2.6 Information regarding changes in operating changes and product composition was also solicited from Companies via a questionnaire or derived from the published literature reports.

2.3. EXPOSURE DATA COLLATION

2.3.1 All the collected exposure data were grouped as a function of job group. For each job group the arithmetic mean exposure levels for both the full shift and short period data were calculated and the minimum and maximum readings were recorded separately for the data submitted by Member Companies and for the data derived from the literature search. The approach taken for the data submission (see 2.2.3) did not allow other descriptive statistics, such as the median and 90^{th} percentile values, to be accurately determined. A workbook containing the anonymised Company data sets is kept on file at the CONCAWE Secretariat. These data may be used, for instance to derive an estimate of 90^{th} or 95^{th} percentile values for use in a worst-case based risk assessment.

2.3.2 The arithmetic mean exposure level for a job group is the average of the individual exposure measurements. Where these exposure data relate to the work shift, the arithmetic mean level is usually considered to be the best indicator of long term exposure - that is, over more than a week and up to the full duration of a working life (Rappaport, 1991). However, it should be noted that where the number of samples is small, the arithmetic mean can be subject to appreciable distortion if unusually low or high results are included.

2.3.3 The Task Force reviewed all the tabulated information and made a number of changes to ensure consistency between the various sets of exposure data that had been submitted, including an extension / modification to the initial list of job activities and a numerical adjustment to some of the exposure data so that they are all expressed in the same units of measurement (mg/m^3) for comparison purposes. Some basic 'rules' were defined to facilitate this quality check and these are summarised in **Appendix 3**.

2.4. OCCUPATIONAL EXPOSURE LIMITS

Occupational exposure limits have been set nationally and internationally for many hazardous substances. They refer to the airborne concentrations of the hazardous substances. The limits used in this report are the most recently published at the time of writing. There is no widely accepted occupational exposure limit for gasoline vapour in Europe, but both the Netherlands and Sweden have established an 8-hour time-weighted average (TWA) occupational exposure limit for gasoline vapour of 240 mg/m^3 and 200 mg/m^3, respectively. In addition, the American Conference of Governmental Industrial Hygienists (ACGIH) has adopted an 8-hour TWA limit of 890 mg/m^3 and a short-term limit of 1480 mg/m^3, based on the composition of gasolines in the United States.

Occupational exposure limits have also been published for a number of individual gasoline components by the European Commission's Directorate-General for Employment and Social Affairs, the ACGIH and various EU countries. These components include benzene, toluene, xylenes, butane, n-hexane and 1,3-butadiene, as well as methyl-tertiary-butyl ether (MTBE), which may be added to motor gasolines. 1999 limit values used in this report are shown in **Table 1** for gasoline and several of its components.

Table 1: Selected occupational exposure limits for gasoline and components in EU and US

Substance	**8-Hour TWA Occupational Exposure Limit (mg/m^3)**						
	European Commission [1]	**ACGIH**[3]	**France**	**Germany**	**NL**	**Sweden**	**UK**
Gasoline	-	890	-	-	240	200	-
Benzene	3.25(2)	1.6	16	3.2 - 8(4)	3.2	1.5	16(5)
1,3 Butadiene	-	4.4	-	11 - 34(4)	46	1	22
n-Butane	-	1950	1900	2400	-	-	-
n-Hexane	72	175	170	180	90	90	72
MTBE	-	150	-	-	180	-	92
Toluene	188	190	375	190	150	200	191
Xylene	221	440	435	440	210	200	441

Note 1: Values derived from EU (1998), EU (1999) and EU (2000)

Note 2: Value as of June 2003; interim value 9.75 mg/m^3 (EU, 1997)

Note 3: ACGIH states values for vapours in parts per million (ppm); conversion to mg/m^3 may lead to small variations, depending on the assumed pressure and temperature

Note 4: Depending on the nature of the operation

Note 5: Value applicable until June 2000

3. RESULTS

3.1. OVERVIEW OF AVAILABLE DATA

3.1.1 Airborne exposure data were submitted by 13 member companies for 29 of the gasoline job groups. Data were also derived from the literature for 6 job groups. In all a total of well over 4000 personal airborne exposure results were obtained for the period 1993-1998 and these are summarised in Tables A1 - A30, which form **Appendix 4**. Where available, the literature data have been included in the tables with an indication of their sources.

1467 individual biological exposure data were obtained. Of these, 1228 results related to benzene and its metabolites and are included in the report; the others were considered too sparse to be representative. All biological monitoring results were obtained from end of shift samples. The available data have also been included in the Tables of **Appendix 4**.

A number of the participating companies provided answers to the questionnaire relating to the changes in operating practices which may have resulted in different exposure levels. A short overview is provided in section 3.11.

3.1.2 A number of other atmospheric monitoring results were also submitted but are **not** included in this report. Most were excluded either because they were not directly associated with gasoline handling and/or because they were derived from fixed position measurements and were not considered to be indicative of personal exposures.

The excluded data mainly concerned refinery activities and data not relating to Europe or generated prior to 1993. Only those refinery results directly related to gasoline, or to streams (e.g. catalytic reformate) ultimately utilised in gasoline blending, have been included.

3.1.3 The only fixed position results included in this report are those which were obtained in service station kiosks, where the cashiers are located, because they were deemed to be indicative of the personal exposure of the cashiers.

3.1.4 Almost 91% of the results corresponded to full work shift (8 or 12 hours) measurements, or were derived from shorter period measurements considered to be typical of full shift exposures. The remaining data were representative of short period work activities (up to 1 hour).

3.1.5 Further analysis of the results indicated that 38% related to refinery activities, 37% corresponded to distribution tasks, 18% addressed service station activities and 6% covered a range of other work groups. Almost 75% of the monitored distribution tasks related to road transportation activities.

3.1.6 No exposure data were submitted by member companies or retrieved from literature for 13 identified job groups. For the following job groups, data generated before 1993 or for operations outside Europe can be found in the overviews prepared by DGMK (Jungen et al, 1994) and CONCAWE (CONCAWE, 1997):

- drum/barrel fillers (2.1.7)
- rail car operators engaged in bottom loading, without vapour recovery (2.2.3)

- deck crew during the closed loading of barges (2.3.3)
- bridge crew, e.g. during gas freeing/venting (2.3.4)
- airport yard staff (4.2)
- specified consumer activities (6.1-6.3)

There appeared to be a complete absence of data for the following job groups:

- rail car operators engaged in bottom loading, with vapour recovery (2.2.4)
- rail car maintenance (2.2.6)
- service station attendants, with stage 2 vapour recovery (3.1.2)
- service station mechanics (3.3)
- remediation workers (5.3)

This lack of exposure data may reflect either low perceived risk, the infrequent nature of the tasks, difficulties in scheduling monitoring surveys, or employment in sectors which have not conducted regular monitoring surveys.

3.1.7 Companies which submitted exposure data indicated that much of the monitoring had been carried out under 'typical worst case conditions' (to check compliance with exposure limits or to identify the need for targeted action) rather than being 'truly representative of all operating conditions'. As such it is likely that the overall results are higher than would be given by a monitoring strategy that aimed to characterise the precise nature of long term exposures. On the other hand the exposure data for many of the job groups do reflect the widespread geographic coverage and seasonal variations present in Europe.

3.1.8 None of the exposure information included the results for all 150 gasoline components identified in CONCAWE Report 8/86. However:

- benzene exposure data were reported for nearly all the measurements;
- in many instances exposure data were reported for some other individual gasoline components, such as toluene, the xylenes and n-hexane;
- total hydrocarbon exposure data were also often reported, although the actual extent to which 'total hydrocarbons' had been collected and subsequently analysed varied, dependent on the actual sampling and analytical methodology adopted within the companies which contributed the exposure data. Where the activity was limited to gasoline the measurement of 'total hydrocarbons' is considered adequate for assessment of exposure to gasoline.

3.1.9 The arithmetic mean full shift total hydrocarbon data for all the job groups were below the most stringent occupational exposure limit for gasoline (Sweden, 200 mg/m^3).

All the arithmetic mean exposure results for the individual gasoline components, including MTBE, were also within the appropriate prevailing occupational exposure limits.

However, some (1.7%) of the individual full shift total hydrocarbon results exceeded 200 mg/m^3. Similarly a small proportion (1.8%) of the individual full shift benzene results exceeded 3.2 mg/m^3 (1 ppm), with occasional (0.3%) exposures in excess of 16 mg/m^3.

3.2. REFINERY EXPOSURES (TABLES A1-A6)

Eleven companies provided refinery personal exposure data derived from over 1500 measurements for six job groups. These are summarised in Tables A1-A6. Almost 96% of the results related to full shift exposures.

The highest number of full shift monitoring results was reported for laboratory technicians (628 samples, Table A4), maintenance workers (373 samples, Table A3) and off-site operators (321 samples, Table A2). Exposure data were also provided for on-site operators (Table A1), tank cleaners (Table A5) and for bund area work (Table A6).

Most of the results included exposure information for several individual gasoline components, including benzene, toluene, xylene and n-hexane. A summary of the full shift arithmetic mean exposures for these components and for the total hydrocarbon (THCs) exposure data submitted for six refinery job groups is given in **Table 2**.

Table 2: Full Shift Arithmetic Mean Exposures (mg/m^3) for Selected Gasoline Hydrocarbons for refinery workers

	Benzene	Toluene	Xylene	n-Hexane	THCs
1.1 On-Site Operators	0.22	0.87	1.24	1.15	9.06
1.2 Off-Site Operators	0.32	0.80	0.38	1.13	16.11
1.3 Maintenance Workers	0.41	0.94	0.85	1.46	22.35
1.4 Laboratory Technicians	0.30	1.28	0.93	0.56	13.36
1.5 Tank Cleaners	2.10*	-	-	-	2.37*
1.6 Miscellaneous	1.12	4.53	-	1.14	-

* the benzene and THC results corresponded to different sets of monitoring data

The arithmetic mean total hydrocarbon exposures were less than 25 mg/m^3 for all six job groups, with the corresponding benzene, toluene, xylene and n-hexane results all below 5 mg/m^3 and mainly less than 2 mg/m^3. However, occasional, relatively high full shift individual exposures have been reported, for example 335 mg/m^3 total hydrocarbons for an off-site operator (Table A2) and 410 mg/m^3 for a maintenance worker (Table A3).

The highest full shift result for any individual component was recorded for pentanes (121.6 mg/m^3 for an off-site operator, Table A2).

3.3. ROAD TANKER DISTRIBUTION EXPOSURES (TABLES A7-A14)

Ten companies provided full shift and short period personal exposure data derived from over 1000 breathing zone measurements during gasoline road tanker distribution activities. Over 70% were related to full shift exposures. Also included are literature data from a comparative study of top and bottom loading (Hakkola,

1996). Most of the data corresponded to tanker drivers (745 samples, Tables A7-A10), supervisors/terminal operators (159 samples, Table A12) and rack operators (126 samples, Table A11), but exposure data were also provided in connection with maintenance activities (Table A13) and some miscellaneous category or unspecified work (Table A14). No data were submitted for drum/barrel fillers.

Most of the results included exposure information for several individual gasoline components, including benzene, toluene, xylene and n-hexane. A summary of the full shift arithmetic mean exposures for these components and for the total hydrocarbons exposure data submitted for seven road tanker terminal job groups is given in **Table 3**. For a comparison of exposure levels associated with the various loading techniques the total hydrocarbon data are considered more appropriate than the individual gasoline components for which the differences may in part be due to gasoline compositional variations.

Table 3: Full Shift Arithmetic Mean Exposures (mg/m^3) for Selected Gasoline Hydrocarbons for road distribution workers

		Benzene	Toluene	Xylene	n-Hexane	THCs
2.1.1	**Drivers: Top Loading**	2.07	0.84	0.96	8.45	98.07
2.1.2	**Drivers: Bottom Loading (no VR)**	0.82	0.95	2.30	-	55.38
2.1.3	**Drivers: Bottom Loading (with VR)**	0.37	0.87	0.43	0.37	19.47
2.1.4	**Drivers: Other Category/Unspecified**	1.26	2.41	1.08	1.31	53.76
2.1.5	**Rack Operators**	0.64	3.50	1.75	0.51	32.05
2.1.6	**Supervisors / Terminal Operators**	0.36	1.37	1.03	0.39	19.78
2.1.8	**Maintenance**	0.52	1.75	1.64	0.67	9.29

The arithmetic mean total hydrocarbon exposures were less than 100 mg/m^3 for all the job groups, with the corresponding benzene, toluene, xylene and n-hexane results all below 10 mg/m^3. However, occasional, relatively high individual full shift exposures have been reported, for example up to 843 mg/m^3 total hydrocarbons for a road tanker driver engaged in the top filling of motor gasolines (Table A7).

The highest full shift result for any individual hydrocarbon component was recorded for benzene (48.16 mg/m^3 for a top loading road tanker driver, Table A7: without that single high result the arithmetic mean decreases from 2.07 mg/m^3 to 1.39 mg/m^3).

The road tanker driver bottom loading exposure data (Tables A8/A9) provide an indication of the impact on occupational exposure levels of vapour recovery facilities for product filling at a distribution terminal. Both the full shift and short period total hydrocarbon exposures were approximately a factor of three lower where vapour recovery had been utilised.

3.4. RAIL CAR TERMINAL EXPOSURES (TABLES A15-A18)

Six companies provided full shift and short period personal exposure data for operators engaged in the top filling of rail cars. These were derived from 78 breathing zone measurements (Table A15). A further 8 full shift results were obtained at top filling facilities equipped with vapour recovery (Table A16) and another 47 were obtained for the unloading of gasoline from rail cars (Table A17). The remaining 35 essentially related to the work of the rack operator and to off-site activities (Table A18).

No data were submitted for the bottom loading of rail cars or for maintenance activities.

Most of the results included exposure data for several individual gasoline components, such as benzene, toluene, xylene and n-hexane. A summary of the full shift arithmetic mean exposures for these components and for total hydrocarbons for four rail car terminal job groups is given in **Table 4**.

Table 4: Full Shift Arithmetic Mean Exposures (mg/m^3) for Selected Gasoline Hydrocarbons for rail distribution workers

	Benzene	Toluene	Xylene	n-Hexane	THCs
2.2.1 Operators: Top Loading	1.34	2.69	1.11	21.57	33.81
2.2.2 Operators: Top Loading (with VR)	0.23	3.0	3.0	0.30	7.5
2.2.5 Operators: Off-Loading (no VR)	1.29	2.71	0.80	1.77	37.74
2.2.7 Miscellaneous	1.19	1.83	0.51	0.21	130

For three main job groups the arithmetic mean total hydrocarbon exposures were less than 50 mg/m^3 and, with the exception of the n-hexane mean exposure level for the top loading operators, all the benzene, toluene, xylene and n-hexane results were below 5 mg/m^3. However, occasional, relatively high individual full shift exposures have been reported, for example 1708 mg/m^3 total hydrocarbons for a 'miscellaneous' activity (Table A18) and 309.5 mg/m^3 for a top loading operator (Table A15), which heavily influence the calculated arithmetic means.

The highest full shift result for any individual component was recorded for n-hexane (289 mg/m^3 for a top loading operator, Table A15).

Where top loading vapour recovery facilities had been installed, all the arithmetic mean exposure data were low, with the total hydrocarbon results up to only 10 mg/m^3 and the individual hydrocarbon results less than or equal to 3 mg/m^3. These findings are, however, based on a small number of samples (Table A16).

Very few short period exposure data were submitted.

3.5. SHIPPING / JETTIES EXPOSURES (TABLES A19-A23)

Four companies provided exposure results relating to the distribution of gasoline by ship and these are summarised in Tables A19-A23. The data were largely derived from measurements on deck crew and jetty staff during both gasoline loading and unloading activities (Tables A19-A22). Both full shift and short period air sampling were undertaken. It should be noted that in two individual studies, including ship discharging, the work period exceeded 12 hours.

Most of the results included exposure data for several individual gasoline components, such as benzene, toluene, xylene and n-hexane. A summary of the full shift arithmetic mean exposures for these components and for total hydrocarbons for four shipping job groups is given in **Table 4**.

Table 4: Full Shift Arithmetic Mean Exposures (mg/m^3) for Selected Gasoline Hydrocarbons for marine distribution workers

	Benzene	Toluene	Xylene	n-Hexane	THCs
2.3.1.1 Deck Crew: Open Loading	0.56	2.80	2.73	7.48	77.80
2.3.1.2 Deck Crew: Unloading	0.51	0.98	0.76	0.17	7.50
2.3.2 Deck Crew: Closed Loading	0.56	3.51	0.83	1.90	-
2.3.5 Jetty Staff	0.37	1.13	0.93	0.48	10.86

The arithmetic mean total hydrocarbon exposures were less than 100 mg/m^3, with the corresponding benzene, toluene, xylene and n-hexane results all below 10 mg/m^3 and mainly less than 3 mg/m^3.

However, the nature of the open loading operation can lead to some considerably higher breathing zone results. For example, the highest full shift result for any individual component (pentanes) was 433 mg/m^3 for deck crew during the open loading of motor gasoline (Table A19) whilst the two highest total hydrocarbon exposures recorded - both for jetty staff - were 804 mg/m^3 over 85 minutes during discharging/hose disconnection and 585 mg/m^3 over 12 minutes whilst checking cargo tank filling (Table A22).

3.6. SERVICE STATION EXPOSURES (TABLES A24-A27)

Five companies provided results derived from almost 700 measurements at service stations, supplemented by additional data obtained from the published literature (Periago, 1997), and these are summarised in Tables A24-A27. Virtually all the results related to the exposure of service station attendants (459 samples, Table A24) or cashiers (270 samples, Table A25) to gasoline vapours. The service stations involved were not equipped with stage 2 vapour recovery facilities.

Limited exposure data were also provided in connection with petrol pump maintenance (Table A26) and car wash activities (Table A27), but no information was submitted regarding service station mechanics.

Most of the results included exposure data for several individual gasoline components, mainly benzene, toluene, xylene and n-hexane. A summary of the full shift arithmetic mean exposures for these components and for total hydrocarbons for two service station job groups, for which there were airborne exposure data, is given in **Table 5**.

Table 5: Full Shift Arithmetic Mean Exposures (mg/m^3) for Selected Gasoline Hydrocarbons for service station workers

	Benzene	Toluene	Xylene	n-Hexane	THCs
3.1.1 Service Station Attendants (no Stage 2 VR)	0.29	0.51	0.21	0.27	19.02
3.2 Service Station Cashiers	0.05	0.41	0.06	0.04	2.13

The arithmetic mean total hydrocarbon exposures were less than 20 mg/m^3, with the corresponding benzene, toluene, xylene and n-hexane results all below 1 mg/m^3. However, occasional, relatively high individual full shift exposures have been reported, for example 77.5 mg/m^3 total hydrocarbons for a service station attendant (Table A24). The highest equivalent result for the service station cashiers was 6.4 mg/m^3. The highest full shift result for any individual component was recorded for toluene (2.8 mg/m^3 for a service station attendant, Table A24).

3.7. AIRPORT EXPOSURES (TABLE A28)

One company provided information about its total hydrocarbon results for airfield operators, who, as part of their job, carry out the over-wing refuelling of light aircraft with aviation gasoline. The full shift total hydrocarbon exposures (Table A28) extended up to 31.3 mg/m^3, whilst short period exposures (up to 20 minutes) during the actual over-wing refuelling ranged from 3.4 - 526.6 mg/m^3 (arithmetic mean 107.2 mg/m^3). The limited exposure data received for this job activity reflected the fact that relatively little aviation gasoline is used at the larger European airports where Jet A1, which is similar to kerosine in composition, is the main fuel.

No exposure data were submitted regarding the activities of yard staff.

3.8. OTHER WORK GROUP EXPOSURES (TABLES A29-A30)

Some exposure data were retrieved from literature reports for agricultural and horticultural workers (LfU, 1994) (Table A29), and motor mechanics (Laitinen, 1994; Popp, 1994; Göen, 1997; Hotz, 1997) (Table A30). Benzene was the only airborne hydrocarbon determined in all cases.

The exposure data reported for forestry workers using gasoline-driven chain saws were all low, with the benzene results less than 0.6 mg/m^3 and the MTBE exposures at or below 0.8 mg/m^3. For motor mechanics the reported benzene exposures were less than 13 mg/m^3, with an arithmetic mean of 0.3 mg/m^3.

3.9. CONSUMER EXPOSURES

No results were submitted for the three job groups identified, namely consumers filling motor vehicles, vehicle drivers/passengers and non-professional users of petrol-driven machinery. Literature data for gasoline components have been retrieved, but relate primarily to Finland and focus on MTBE exposure (Vainiotalo et al., 1999). In view of the relatively high levels of MTBE blended into gasoline, these data are not considered representative for Europe during the period 1993-1998. However, these data are useful for the situation in Europe as of January 1, 2000, when the new content limit of 1% took effect for benzene. Reported average benzene exposure during car refuelling with gasoline with less than 1% benzene was 0.8-1.0 mg/m^3 for periods of less than 3 minutes. This study report does not provide whole gasoline vapour or total hydrocarbon results.

3.10. BIOLOGICAL MONITORING

There is currently no fully validated biological monitoring method to assess gasoline vapour exposure. There are methods for a number of gasoline components and these have been used by operating companies and researchers. The component of primary interest has been benzene and the available data have been included in the appropriate tables of Appendix 4.

The MAK Commission of the Deutsche Forschungsgemeinschaft (DFG) issued a comparison table between airborne exposure to benzene and three biological exposure parameters on end-of-shift samples, as shown in **Table 6**.

Table 6: Three biological exposure indices with corresponding airborne exposure levels from Deutsche Forschungsgemeinschaft (1999)

Airborne benzene (mg/m^3)	Benzene in blood (ng/l)	SPMA[1] (µg/g creatinine)	t,t-MA[2] (µg/l)
1.0	900	10	-
2.0	2400	25	1600
3.0	4400	40	-
3.2	5000	45	2000

Notes: 1: SPMA: *S-phenyl-mercapturic acid*
2: t,t-MA: *trans,trans-muconic acid*

A summary of the biological monitoring data submitted by CONCAWE member companies for benzene is provided in **Table 7**. For comparison, the inhalation exposure data for the same job groups have been included (taken from tables A1, A2, A3, A4 and A11). The biological and atmospheric monitoring data are from different operations and therefore this comparison is for illustrative purposes only. Moreover, smoking is known to increase the blood and urine levels of benzene and its metabolites, thereby making a direct comparison with airborne exposure very difficult.

A direct comparison between t,t-Muconic Acid expressed in ìg/l and in ìg/g creatinine is not possible.

Table 7: Summary of average biological exposure data with average ambient benzene concentrations

		Airborne benzene (mg/m^3)	Benzene in blood (ng/l)	Benzene in urine (ng/l)	t,t-MA (µg/g creatinine)
1.1	**On-Site Operators**	0.22	294	330	-
1.2	**Off-Site Operators**	0.32	515	320	-
1.3	**Maintenance Workers**	0.41	332	306	122
1.4	**Laboratory Technicians**	0.30	94	353	69
2.1.5	**Rack Operators**	0.64	353	1199	246

Notwithstanding the limitations of the data sets, it is interesting to note that the biological monitoring confirms that rack operators are more exposed, on average, than the other listed job groups. Discrepancies between the various indices may be explained by the fact that the various exposure measurements have not been taken simultaneously and may represent different exposure conditions. It is important to note that biological exposure indices also represent any dermal exposure, smoking, nutritional influences and the protective effect of personal protective equipment

For comparison purposes, biological monitoring data from the literature, for jobs where gasoline exposure and ambient benzene concentrations were identifiable, are shown in **Table 8**.

Table 8: Summary of average biological exposure indices with average ambient benzene concentrations from literature for gasoline-related activities

Job Class		Airborne benzene (mg/m^3)	Benzene in blood (ng/l)	Benzene in urine (ng/l)	t,t-MA (µg/g creatinine)	SPMA (µg/g creatinine)
	Unspecified (petrol station or refinery) (Brugnone et al, 1998)	0.186	420			
1.	**Refinery Workers (Boogaard and Van Sittert, 1995)**	0.77 (median)			550 (median)	12 (median)
1.	**Refinery Workers (Boogaard and Van Sittert, 1995)**	0.787			340	
2.1.1	**Road Tanker Drivers (Javelaud et al, 1998)**	1.88			309	
3.1.1	**Service Station Attendants (Brugnone et al, 1996)**	0.256	548			
5.2	**Motor Mechanics (Göen et al, 1997)**	< 0.40 (median)	450 (median)		590 (µg/l) (median)	7.6 (median)
5.2	**Motor Mechanics (Javelaud et al, 1998)**	0.48			148	

3.11. OVERVIEW OF REPORTED OPERATING CHANGES WHICH MAY AFFECT EXPOSURE LEVELS AND NUMBER OF EXPOSED WORKERS

It is, in general terms, not common practice in the oil industry to document specifically in occupational health records any changes in operating practices which may influence the levels of exposure to hazardous substances and the number of potentially exposed workers. Evidence of changes, e.g. engineering projects such as automation, re-organisation projects resulting in a re-distribution of work tasks, or product re-formulation to meet new specifications, can of course be found in dedicated project files, but often projects have served multiple purposes and the effect on the exposure level and number of exposed workers may not be obvious.

A potential source of information may be contained in reports of targeted occupational hygiene surveys before and after such changes take effect. However, no reports from those surveys were available to the Task Force from any of the Companies, although one such investigation was reported in literature and is included in the present report for tanker drivers involved in top and bottom loading (Hakkola, 1996).

A questionnaire was sent to Companies to solicit input that could provide supporting information about the time trends detected in the data set.

9 operating companies, based in 7 different countries, reported changes for a total of 23 of the job classes. The data have been summarised in **Table 9** below. A number of similar changes occurred at different points in time in the various countries. Overall, the type of changes suggests a decreasing potential for gasoline exposure with time.

Table 9: Aggregated changes in operating practices in the last 10-15 years reported by CONCAWE operating companies in European countries

Job class		Short description of Change
1.1	**On-site refinery operators**	Process sampling from open bottles to closed bottles in the Reformer and Isomerisation units
1.1 & 2	**Refinery operators**	Additional fixed tank roofs over internal floating roofs, reducing the need for rainwater drainage from tanks
1.1, 2 & 3	**Refinery operators**	Automation of blending of refinery streams, thus reducing the need for process sampling
1.1, 2 & 3	**Refinery operators**	From manual to automatic tank level gauging
2.1.1	**Tanker drivers: top loading**	Top loading discontinued
2.1.1	**Tanker drivers: top loading**	Drivers started filling own tankers, controlled loading rate to avoid splashes
2.1.1, 2 & 3	**Tanker drivers**	Conversion from top to bottom loading
2.1.1, 2 & 3	**Tanker drivers**	Installation of vapour recovery on loading facilities
2.1.4	**Tanker drivers**	Conversion from top to bottom loading
2.1.4	**Tanker drivers**	Vapour recovery on service stations with throughput over 1000 m^3 p.a.
2.1.5	**Loading rack operators**	Due to conversion to driver loading this job was discontinued
2.1.6, 8 & 9	**Terminal personnel**	Installation of closed draining and recycling system
2.2.1/2	**Top loading railcars**	Conversion from loading without vapour recovery to loading with vapour recovery
2.3.1 & 6	**Open ship loading**	Operation discontinued due to installation of VRU
2.3.3 & 6	**Closed ship loading**	Operation started due to installation of VRU
2.3.4 & 6	**Ship loading**	Doubling of the number of samples
3.	**Service station personnel**	Installation of vapour recovery facilities for stations with throughput of more than 1000 m^3 p.a.

4. COMPARISON OF 1993-1998 EXPOSURE DATA WITH 1984-1985 EXPOSURE DATA

4.1. INTRODUCTION

A comparison of the 1993-1998 gasoline total hydrocarbon exposure data with the total hydrocarbon exposure data collected and collated by CONCAWE in the 1984-1985 gasoline survey was done to ascertain:

- overall trends in the exposure data as a result of changes in operating practices;
- what variation in exposures has occurred, if any, for those jobs still nominally undertaken in a similar manner to previously.

In order to assist with these two analyses:

- the qualitative information about the prevailing operating practices that accompanied the submission of the 1993-98 exposure data has been reviewed, together with the responses to the questionnaire sent to all CONCAWE member companies in 1998. The latter expanded the scope of the initial information obtained with the exposure data submission about changes to operating practices;
- the comparative total hydrocarbon full shift arithmetic mean exposure data have been summarised in **Table 10** for eight job groups common to both CONCAWE gasoline exposure studies.

The potential difference in the basis for sampling between the 1984-85 CONCAWE survey and the 1993-98 member company surveys (i.e. representative for long-term exposure versus reasonable worst case) has been pointed out in section 3.1.7 and may partially hide any downward trend in the exposures.

4.2. EFFECT OF CHANGES IN OPERATING PRACTICES

Several major operating changes have been introduced over the past 10-15 years as described in 3.11 in relation to the production, distribution and retailing of motor gasolines. Most of the changes have contributed to a downward trend in exposures to gasoline. This has occurred particularly where increased gasoline vapour containment has been introduced, for example as a result of the utilisation of closed sampling systems and vapour recovery facilities.

In addition, road tanker vapour return facilities have been introduced for utilisation when delivering motor gasolines to retail service stations. This has led to less gasoline vapour emitted into service station environments during bulk gasoline deliveries and hence lower exposures for service station personnel and consumers.

Although the examples highlight the nature of recent trends in operating practices, they have certainly not been introduced in a consistent manner throughout the European oil industry. The changes commenced well over a decade ago, but the extent of their introduction has varied considerably.

The nature of the gasoline filling operation utilised by drivers for road tanker vehicles at distribution terminals and the resultant full shift gasoline total hydrocarbon exposures, as indicated by the arithmetic mean (AM) illustrates this point clearly. In 1984-85 much of the filling was via top loading (AM = 118 mg/m^3). Whilst some top loading is still carried out, it has ceased at other distribution terminals and is scheduled to be discontinued completely by 2004 according to European Parliament and Council directive 94/63/EC (EU, 1994). Consequently, there is an increasing number of bottom loading facilities (AM = 55 mg/m^3), some incorporating a vapour recovery system (AM = 19 mg/m^3), particularly at many of the larger distribution terminals. In other instances there is currently more than one type of gasoline filling system being utilised at some terminals as the operating changes are gradually being introduced and not all road tankers are equipped for bottom loading and/or vapour operation.

4.3. EXPOSURE DATA FOR COMPARATIVE JOBS

Some jobs are still nominally undertaken in the same way as in 1984-1985 in some areas of Europe, for example the road tanker top loading of motor gasolines. Nevertheless, by the mid-1990s even these jobs usually incorporated some variation in the specific manner in which they were carried out, possibly influencing the resultant exposures. Specific examples of the trends for road tanker loading have included:

- the utilisation of larger capacity road tanker vehicles;
- a reduction in the number of road tanker distribution terminals resulting in longer driving times;
- a longer daily working shift (12 hour v. 8 hour);
- higher gasoline filling and discharge rates;
- product composition changes, including a trend to lower benzene contents and an increased use of oxygenates (see 4.4).

The comparative total hydrocarbon full shift arithmetic mean exposure data, shown in **Table 10**, indicate that generally the 1990s exposure data are lower than the corresponding 1980s results, in some cases by a factor of at least two and a half. This is particularly evident for the refinery on-site and off-site operators and for rail car operators.

On the other hand, the extent of reduction for comparative road tanker activities and for service station attendants, is such that, for all practical purposes, the 1990s and the 1980s exposures are ‘similar’, possibly because of the counter-balancing effects of the job and product changes that have occurred.

Finally, it is difficult to draw any firm conclusions about the deck crew and jetty staff exposure data simply because of the relatively low number of air samples in one or other survey. However, a downward trend is suggested.

Table 10: Comparison of 1993-1998 v. 1984-1985 full shift arithmetic mean total hydrocarbon exposures for 8 job groups

Job Group		Total Hydrocarbons (mg/m^3)	
		1984-1985	**1993-1998**
1.1	**Refinery On-Site Operator**	53	9
1.2	**Refinery Off-Site Operator**	66	16
2.1.1	**Road Tanker Drivers, top loading**	118	98
2.1.2	**Road Tanker Drivers, bottom loading**	66	55
2.2.1	**Rail Car Operators, top loading**	85	34
2.3.1.1	**Deck Crew, open loading**	118*	78
2.3.5	**Jetty Staff**	120	11*
3.1.1	**Service Station Attendants**	29*	19

* Less than 20 results

4.4. TRENDS IN GASOLINE COMPOSITION

Since the last gasoline exposure survey in 1984-1985, a number of changes in the composition of gasolines blended in EU refineries have occurred:

- lead alkyl additives (not reported) have been progressively phased out and are now no longer present in gasolines in most EU countries;
- some gasolines are blended using higher levels of reformates and catalytically-cracked naphthas - in order to compensate for the absence of lead alkyls - thereby increasing both the aromatic hydrocarbon content (but not benzene) and the octane ratings; the maximum allowed content of benzene has been reduced from 5 to 1% by volume in some countries (this reduction has come into force in the entire EU as per 1 January 2000);
- the required octane ratings of gasolines have also been achieved in some instances via the use of oxygenated substances, notably MTBE and TAME (tertiary-amyl methyl ether).

5. CONCLUSIONS

5.1. AVAILABILITY OF EXPOSURE DATA FOR RISK ASSESSMENT

This review has indicated that for a number of job classes involved in the production, distribution and use of gasoline there are adequate exposure data for gasoline vapour and components for use in risk assessment. However, there are no up-to-date fully characterised gasoline vapour data available. The vast majority of data relating to the production and distribution of gasoline are available via CONCAWE Member Companies, whilst data for exposure during use primarily stem from literature sources. There is, however, a number of jobs, including some for which elevated exposures have been reported in the past, for which there are no European data available within the specified time period. There is also a small group of jobs for which there appeared even to be a complete absence of data. Both these latter groups of jobs should be considered for future targeted data collection.

The available exposure data refer both to airborne exposures as measured in the breathing zone and to levels measured in biological specimens although the latter data set is limited to benzene. Similarly, many of the airborne exposure data were limited to selected gasoline components.

5.2. COMPARISON OF TOTAL HYDROCARBON EXPOSURE DATA WITH EUROPEAN GASOLINE OCCUPATIONAL EXPOSURE LIMITS

5.2.1. Airborne Exposure Data

Virtually all the full shift arithmetic mean total hydrocarbon exposures, for the job groups for which total hydrocarbon exposure data were submitted, were below 100 mg/m^3 and consequently well below all occupational exposure limits used in Europe, including the lowest ones (Sweden / the Netherlands) recommended for gasoline vapour (200 / 240 mg/m^3), although there were a few individual total hydrocarbon exposures in excess of 200 mg/m^3. The number of data available for the various identified categories of gasoline users was small, but the measured exposure levels generally appeared to be low.

5.2.2. Biological Monitoring Data

Biological monitoring data were only available in sufficient numbers to draw any conclusions for benzene. The measured levels appeared to be low in comparison with the published indices that would correspond to the future European exposure limit. The information generated in biological monitoring surveys appeared to be complementary to airborne exposure measurements, and to be particularly valuable where skin contact with gasoline may occur as e.g. with car mechanics. However, the confounding effect of non-occupational sources of benzene, notably cigarette smoking, has to be accounted for.

5.3. TREND IN GASOLINE EXPOSURES FOR SPECIFIC JOB GROUPS

The 1993-1998 gasoline exposures, taken in conjunction with the 1984-1985 data and the changes to operating practices, suggest the following:

5.3.1. Refinery On-site and Off-site Operators

The arithmetic mean total hydrocarbon exposures for refinery on-site and off-site operators have decreased significantly over the past 15 years, probably as a result of better operational and engineering practices, which prevent the release of gasoline vapour to the refinery environment.

5.3.2. Road Tanker Drivers

The trend within gasoline distribution away from top loading to the use of bottom loading road tanker facilities, and the further trend for the bottom loading facilities to be equipped with vapour recovery, continues. This has led to a significant reduction in occupational exposure to gasoline vapour. For those situations where operational practices are comparable to those of 15 years ago, the arithmetic mean total hydrocarbons exposures have remained similar.

5.3.3. Rail Car Operators

The arithmetic mean total hydrocarbon exposures for rail car operators have decreased over the past 15 years. Early findings, based on a limited number of measurements, point to a further reduction in gasoline exposures with the gradual introduction of vapour recovery for the loading operation.

5.3.4. Service Station Attendants

The arithmetic mean total hydrocarbon exposures for service station attendants are similar to those recorded 15 years ago where directly comparable operating practices are adopted.

The changeover from attended to self service retail stations is gradually eliminating the job of service station attendant.

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APPENDIX 1

TASKS OR JOB ACTIVITIES INVOLVING POTENTIAL FOR EXPOSURE TO GASOLINE VAPOUR

Activity Code	Job Group	Description of Tasks
1.	**REFINERY**	
1.1	On-site operators	Carry out tasks, such as valve operation, sample collection, and blowing down gauges, in process areas where gasoline or its components (eg catalytic reformate) are produced. In general the tasks are infrequent and of short duration (ie < 1 hr). The operators also spend part of the shift in a pressurised control room.
1.2	Off-site operators	Carry out tasks in areas such as tank farms (eg dipping / sampling / de-watering gasoline storage tanks) and water effluent treatment plants (eg API separators). In general the tasks are infrequent and of short duration (ie < 1 hr).
1.3	Maintenance workers	Carry out tasks, such as the draining, cleaning, opening and work on enclosed equipment for which there is potential for exposure to gasoline.
1.4	Laboratory technicians	Carry out gasoline analyses (for quality assurance purposes) plus research and octane rating tests.
1.5	Tank cleaners	Clean gasoline storage tanks, a specialist activity usually involving specialist contractors.
1.6	Miscellaneous	Includes multi-skilled refinery operator tasks.
2.	**DISTRIBUTION**	
2.1	Road Tanker Terminal	
2.1.1	Drivers: Top loading	Fill own vehicles with gasoline via top submerged loading and deliver to service stations; typically 2-3 loadings / deliveries per day.
2.1.2	Drivers: Bottom loading	Fill own vehicles with gasoline via bottom loading (without vapour recovery) and deliver to service stations; typically 2-3 loadings / deliveries per day.
2.1.3	Drivers: Bottom loading	Fill own vehicles with gasoline via bottom loading (with vapour recovery) and deliver to service stations; typically 2-3 loadings / deliveries per day.
2.1.4	Drivers: Other category	Incorporates delivery only, driving and delivery, or loading / driving / delivery where it is not known if the gasoline loading was by top or bottom filling.
2.1.5	Rack operators	Fill road tanker vehicles for drivers (normally via top submerged loading).
2.1.6	Supervisors / terminal operators	Includes general overseeing of road tanker gasoline filling.

2.1.7	Drum / barrel fillers	Fill 200 litre drums with gasoline; the extent of exposure to gasoline is largely dependent on whether good local ventilation is utilised.
2.1.8	Maintenance	Carry out tasks, such as the draining, cleaning, opening and work on enclosed equipment for which there is potential for exposure to gasoline.
2.1.9	Miscellaneous	Unspecified or mixture of all terminal operating duties.
2.2	Rail Car Location	
2.2.1	Operators: Top loading	Fill rail cars with gasoline via top submerged loading (without vapour recovery); includes opening and closing of hatches and valves. This task can extend over several hours per day.
2.2.2	Operators: Top loading	Fill rail cars with gasoline via top submerged loading (with vapour recovery); includes opening and closing of hatches and valves. This task can extend over several hours per day.
2.2.3	Operators: Bottom loading	Fill rail cars with gasoline via bottom loading (without vapour recovery); includes opening and closing of hatches and valves. This task can extend over several hours per day.
2.2.4	Operators: Bottom loading	Fill rail cars with gasoline via bottom loading (with vapour recovery); includes opening and closing of hatches and valves. This task can extend over several hours per day.
2.2.5	Operators: Off-loading	Off-load gasoline to storage (includes hose connection / disconnection and sampling).
2.2.6	Maintenance	Carry out tasks, such as the draining, cleaning, opening and work on enclosed equipment for which there is potential for exposure to gasoline.
2.2.7	Miscellaneous	Unspecified or mixture of duties.
2.3	By ship (product carrier, coastal craft, barge)	
2.3.1.1	Deck crew: Open loading	Fill ships with gasoline with the cargo hatches or ullage ports open. Displaced vapour is discharged close to deck level. Specific tasks include connection / disconnection of cargo lines, checking tank fill levels and tank dipping.
2.3.1.2	Deck crew: Unloading	Discharge gasoline cargoes. Specific tasks include connection / disconnection of cargo lines. Less opportunity for exposure to gasoline vapour than in 2.3.1.1.
2.3.2	Deck crew: Closed loading	Fill ships with gasoline with the cargo hatches and ullage ports closed. Displaced vapour is discharged remotely. Ullage measurements are read automatically. Specific tasks include connection / disconnection of cargo lines.
2.3.3	Deck crew: Closed loading of barges	Similar to 2.3.2; however, the decks of barges are generally flatter and vapour vents may be at a lower level.
2.3.4	Bridge crew	Exposure to gasoline vapour may arise as a result of gas-freeing / venting and the overseeing (un)loading activities.
2.3.5	Jetty staff	Supervise gasoline cargo loading and unloading operations. Specific tasks include gasoline sampling, tank dipping and the handling of hoses.
2.3.6	Miscellaneous	Unspecified or mixture of duties.

3.	**SERVICE STATIONS**	
3.1.1	Service station attendants (without vapour recovery)	Fill customers vehicles with gasoline; exposed to gasoline vapour as a result of this task and the ambient concentration in and around the service station. Exposure may also arise during the bulk delivery of motor gasolines to the service station.
3.1.2	Service station attendants (with vapour recovery)	Fill customers' vehicles with gasoline. Little direct opportunity for exposure to gasoline vapour, although exposure arises from the ambient concentration in and around the service station and may also occur during the bulk delivery of motor gasolines to the service station.
3.2	Service station cashiers	Receipt of payment for gasoline and goods sold in the service station shop. Exposed to ambient concentrations of gasoline vapour in the service station shop.
3.3	Service station mechanics	Carry out general mechanical duties within service stations. Exposure arises from residual gasoline in vehicle's fuel tank and from background levels as a result of refuelling pumps on the forecourt.
3.4	Petrol pump maintenance	Carry out in-situ pump maintenance on the forecourt. Exposure to gasoline vapour may occur from residual gasoline in the pump or interventions on components of pump.
3.5	Miscellaneous	Work on service stations without duties involving direct contact with gasoline, e.g. car wash operator.
4.	**AIRPORTS (aviation gasoline)**	
4.1	Operators	Carry out the bottom loading of road tankers with gasoline and the over-wing filling of light aircraft, both with potential for exposure to gasoline.
4.2	Yard staff	Carry out a range of jobs including fuel testing for water, meter proving, filter cleaning and meter servicing, and tank ullaging.
5.	**OTHER WORK GROUPS**	
5.1	Agricultural & horticultural workers	Includes the filling and routine use of chainsaws, strimmers and other gasoline-powered equipment.
5.2	Motor mechanics	Includes normal motor industry tasks, such as car repairs. Exposure to gasoline vapour may occur from residual gasoline in the fuel tank or interventions on components of fuel supply system.
5.3	Remediation workers	Includes the excavation, soil handling and soil clean-up of sites (eg service stations) contaminated with petroleum products such as gasoline.
6.	**CONSUMERS**	
6.1	Vehicle drivers	Fill own vehicles with gasoline at service stations.
6.2	Vehicle drivers / passengers	Their presence within a driven vehicle gives rise to in-vehicle exposures to gasoline/gasoline components/exhaust emissions arising from that and other vehicles present.
6.3	Users of petrol-driven machinery in connection with home / leisure activities	Includes the filling / use of mowers and outboard motor jet skis with gasoline.

APPENDIX 2

CONCAWE SURVEY FORM FOR THE SUBMISSION OF GASOLINE EXPOSURE DATA (1993-98) FROM MEMBER COMPANIES

CONCAWE SURVEY OF GASOLINE EXPOSURE DATA
1993 - 1997

ACTIVITY CODE [(1)] **:**

COUNTRY [(2)] **:**

DATA TYPE [(3)] **:** personal / area / biological

(4) DATE	(5) JOB TYPE	(6) TASK DESCRIPTION	(7) NOS. OF WORKERS	(8) SUBSTANCE (gasoline components & metabolites)	(9) TOTAL NOS. OF SAMPLES	(10) SAMPLE PERIOD (hrs/mins)	(11) EXPOSURE RANGE (mg/m3)	(12) ARITHMETIC MEAN EXPOSURE (mg/m3)	(13) SAMPLE METHOD	(14) ANALYTICAL METHOD	(15) COMMENTS AND FURTHER INFORMATION

APPENDIX 3

BASIC RULES ADOPTED IN THE TABULATION OF GASOLINE EXPOSURE DATA (1993-98)

- The conversion factor used for converting *total hydrocarbon* exposure data from ppm to mg/m^3 is 890/300 = 2.97 (ACGIH). This is the conversion factor which normally applies to gasoline.

- Where not specified, the limit of detection for individual hydrocarbon data has been recorded as 0.01 mg/m^3.

- Where a Company has submitted 3 results for a job activity, but not indicated the arithmetic mean exposure level, the arithmetic mean has been calculated by taking the highest and the lowest results and dividing by two.

- Where two data points are required to be averaged and one of the data points is a '<' figure, for calculation purposes, the figure taken will be 75% of that '<' number.

  Example <0.01 will equate to 0.0075 for calculation purposes.

APPENDIX 4

GASOLINE EXPOSURE DATA (1993-98): TABLES A1-A30

Table A1 Refinery On-site Operators (1.1)
(incl. catalytic reformer, gasoline blending)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	97	0.008 - 7.88	0.22
Toluene	53	0.01 - 8.8	0.87
Xylenes	33	0.008 - 5.9	1.24
Pentanes	40	0.008 - 3.41	0.31
n-Hexane	28	0.01 - 3.0	1.15
Heptanes	16	0.01 - 2.2	0.54
1,3 Butadiene	30	<0.008	<0.01
Cyclohexane	-		
Ethylbenzene	7	0.008 - 0.53	0.15
MTBE	10	3.0 - 4.0	3.50
TAME	-		
THCs	34	0.08 - 126	9.06

Biomonitoring Data for Benzene			
Method	**No. of Samples**	**Range of Exposure Results (ng/l)**	**Mean Exposure (ng/l)**
Blood	132	0 - 1560	294
Urine	248	30 - 4450	330

Table A2 Refinery Off-site Operators (1.2)
(tank farm, e.g. dipping, sampling, valve operation, dewatering, loading rail cars)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	321	0.008 - 23.3	0.32
Toluene	291	0.008 - 21.6	0.80
Xylenes	281	0.008 - 19.5	0.38
Pentanes	24	0.01 - 121.6	5.73
n-Hexane	224	0.008 - 90.6	1.13
Heptanes	-	0.01 - 2.2	0.54
1,3 Butadiene	26	0.008 - 0.01	0.01
Cyclohexane	44	0.08 - 0.5	0.22
Ethylbenzene	8	0.0008 - 0.066	0.02
MTBE	29	0.08 - 3.0	1.09
TAME	-		
THCs	293	0.08 - 335.0	16.11

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	49	0.08 - 11.8	2.19
Toluene	47	0.49 - 32.0	7.42
Xylenes	46	0.09 - 23.9	4.06
Pentanes	-		
n-Hexane	46	0.08 - 18.0	3.27
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	29	3.0 - 61.0	7.41
TAME	-		
THCs	56	2.7 - 528	56.83

Biomonitoring Data for Benzene			
	No. of Samples	**Range of Exposure Results (ng/l)**	**Mean Exposure (ng/l)**
Blood	5	0 - 936	515
Urine	87	50 - 6990	320

Table A3 Refinery Maintenance Workers (1.3)
(e.g. pump maintenance, instrument calibration, enclosed equipment)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	373	0.008 - 18.1	0.41
Toluene	316	0.008 - 67.2	0.94
Xylenes	312	0.008 - 106	0.85
Pentanes	24	0.02 - 86.0	18.72
n-Hexane	264	0.008 - 32.0	1.46
Heptanes	16	0.8 - 16.0	2.40
1,3 Butadiene	18	0.008 - 0.03	0.01
Cyclohexane	65	0.08 - 11.4	0.28
Ethylbenzene	-		
MTBE	7	ND	3.0
TAME	-		
THCs	289	0.08 - 410	22.35

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	7	0.23 - 8.6	2.62
Toluene	5	3.0 - 22.0	8.0
Xylenes	5	3.0 - 11.0	3.0
Pentanes	-		
n-Hexane	5	3.0 - 4.0	3.20
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-	3.0 - 35.0	11.50
TAME	-		
THCs	5	7.5 - 145	35.0

Biomonitoring Data for Benzene			
	No. of Samples	**Range of Exposure Results**	**Mean Exposure**
Blood	8	23 – 797 (ng/l)	332 (ng/l)
Urine	207	30 – 2460 (ng/l)	306 (ng/l)
muconic acid	4	43 - 187 (µg/g creat.)	121.5 (µg/g creat.)

Table A4 Refinery Laboratory Technicians (1.4)
(incl. product analyses, octane rating testing)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	628	0.0015 - 5.0	0.30
Toluene	207	0.01 - 20.6	1.28
Xylenes	188	0.008 - 38.0	0.93
Pentanes	12	0.03 - 22.6	2.20
n-Hexane	112	0.008 - 9.0	0.56
Heptanes	22	0.05 - 1.5	0.20
1,3 Butadiene	63	0.008 - 6.2	0.28
Cyclohexane	12	0.6 - 2.8	1.50
Ethylbenzene	-		
MTBE	62	0.008 - 5.0	0.49
TAME	-		
THCs	238	0.08 - 316.2	13.36

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	5	0.28 - 4.6	1.93
Toluene	1		3.0
Xylenes	1		3.0
Pentanes	-		
n-Hexane	1		3.0
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	1		3.0
TAME	1		3.0
THCs	1		7.5

Biomonitoring Data for Benzene			
	No. of Samples	**Range of Exposure Results**	**Mean Exposure**
Blood	8	38 – 186 (ng/l)	94 (ng/l)
Urine	191	30 – 2910 (ng/l)	353 (ng/l)
muconic acid	6	10 - 117 (µg/g creat.)	69 (µg/g creat.)

Table A5 Tank Cleaners (1.5)
(incl. sludge cleaning)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	49	0.008 - 38.7	2.10*
Toluene	-		
Xylenes	-		
Pentanes	-		
n-Hexane	-		
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	39	0.1 - 11.0	2.37*

* the benzene and THC results correspond to different aspects of tank cleaning

Table A6 Refinery Workers – Miscellaneous/Unspecified (1.6) (bund area)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	10	0.24 - 1.8	1.12
Toluene	8	1.5 - 18.0	4.53
Xylenes	-		
Pentanes	-		
n-Hexane	8	0.24 - 2.8	1.14
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	-		

Table A7 Road Tanker Drivers, Top Loading (2.1.1)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	69	0.04 - 48.16	2.07
Toluene	22	0.1 - 2.5	0.84
Xylenes	22	0.1 - 3.8	0.96
Pentanes	10	16.0 - 32.0	20.0
n-Hexane	20	0.2 - 24.0	8.45
Heptanes	10	0.8 - 36.0	16.0
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	64	1.2 - 843	98.07

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	114	0.03 - 39.2	6.84
Benzene (Hakkola 1996)	4	3 - 43	18
Toluene	98	0.08 - 200	22.16
Xylenes	81	0.15 - 160.6	21.28
Pentanes	-		
n-Hexane	28	0.7 - 35.8	14.90
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
MTBE (Hakkola 1996)	4	20 - 226	91
TAME	-		
THCs	45	2.97 - 1602	478
THCs (Hakkola 1996)	4	121 - 1414	551

Table A8 Road Tanker Drivers, Bottom Loading (2.1.2) (without vapour recovery)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	223	0.008 - 15.0	0.82
Toluene	10	0.045 - 3.4	0.95
Xylenes	10	0.12 - 4.5	2.30
Pentanes	-		
n-Hexane	-		
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	42	0.12 - 49.6	8.18
TAME	-		
THCs	120	0.08 - 528	55.38

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	39	0.023 - 30.6	2.55
Benzene (Hakkola 1996)	6	0.2 - 3.5	1.1
Toluene	24	0.3 - 38	8.51
Xylenes	24	0.023 - 10.2	2.29
Pentanes	-		
n-Hexane	22	0.3 - 37.1	2.72
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
MTBE (Hakkola 1996)	6	2.8 - 42	13
TAME	-		
THCs	23	6.3 - 2121	261
THCs (Hakkola 1996)	6	7 - 140	44

Table A9 Road Tanker Drivers, Bottom Loading (2.1.3)
(with vapour recovery)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	137	0.03 - 1.99	0.37
Toluene	112	0.08 - 2.8	0.87
Xylenes	107	0.08 - 1.6	0.43
Pentanes	23	0.85 - 8.5	4.01
n-Hexane	107	0.1 - 0.9	0.37
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	25	0.01 - 1.0	0.17
MTBE	25	0.001 - 2.83	0.28
TAME	-		
THCs	28	3 - 113	19.47

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	72	0.08 - 17.5	1.40
Toluene	46	0.08 - 26.3	3.55
Xylenes	46	0.7 - 4.3	1.56
Pentanes	-		
n-Hexane	18	0.3 - 16.0	3.11
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	13	ND	3.0
MTBE	17	0.8 - 180	18.52
TAME	13	0.3 - 13	1.70
THCs	18	0.75 - 632	69.66

Table A10 Drivers, Other Category (or unspecified) (2.1.4)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	56	0.07 - 19.2	1.26
Toluene	56	0.08 - 28.6	2.41
Xylenes	56	0.08 - 7.0	1.08
Pentanes	-		
n-Hexane	56	0.08 - 22.9	1.31
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	56	0.08 - 596	53.76

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	25	0.06 - 14.4	2.01
Toluene	9	0.2 - 10.2	3.39
Xylenes	9	0.4 - 4.54	1.78
Pentanes	-		
n-Hexane	9	0.2 - 17.9	3.69
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	21	4.2 - 474	75.3
THCs (Hakkola 1996)	11	17 - 628	267

Table A11 Road Tanker Terminal Rack Operators (2.1.5)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	126	0.003 - 4.2	0.64
Toluene	39	0.001 - 36.16	3.5
Xylenes	35	0.001 - 19.51	1.75
Pentanes	26	0.03 -10.0	2.14
n-Hexane	30	0.04 - 2.1	0.51
Heptanes	-		
1,3 Butadiene	13	<0.008	<0.01
Cyclohexane	-		
Ethylbenzene	13	0.001 - 17.35	2.05
MTBE	6	3.3 - 16.3	8.77
TAME	-		
THCs	63	0.2 - 352.8	32.05

Biomonitoring Data for Benzene			
	No. of Samples	**Range of Exposure Results**	**Mean Exposure**
Blood	88	100 – 2808 (ng/l)	353 (ng/l)
Urine	26	114 – 9404 (ng/l)	1199 (ng/l)
muconic acid	18	72 – 591 (µg/g creat.)	246 (µg/g creat.)

Table A12 Road Tanker Terminal Supervisors / Operators (2.1.6)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	151	0.001 - 3.1	0.36
Toluene	94	0.003 - 7.7	1.37
Xylenes	87	0.08 - 6.7	1.03
Pentanes	22	0.066 - 6.0	1.21
n-Hexane	86	0.001 - 4.2	0.39
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	10	0.08 - 0.2	0.08
Ethylbenzene	14	ND	3.0
MTBE	53	0.001 - 9.2	1.31
TAME	14	0.3 - 0.8	0.40
THCs	126	0.1 - 120.6	19.78

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	8	0.23 - 11.2	2.20
Toluene	8	1.5 - 61.0	14.33
Xylenes	8	0.9 - 18.0	7.50
Pentanes	-		
n-Hexane	8	0.3 - 57.6	7.83
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	6	<3.0 - 4.0	3.0
MTBE	6	0.3 - 432	88.0
TAME	6	0.3 - 31.9	5.90
THCs	7	7.5 - 820	160.20

Table A13 Road Tanker Terminal Maintenance (2.1.8)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	52	0.001 - 7.9	0.52
Toluene	44	0.007 - 11.0	1.75
Xylenes	44	0.007 - 11.0	1.64
Pentanes	20	0.014 - 4.85	1.11
n-Hexane	44	0.001 - 8.0	0.67
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	34	0.001 - 3.0	1.28
MTBE	37	0.001 - 16.0	1.30
TAME	13	0.3	0.30
THCs	44	0.009 - 80.0	9.29

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	1	-	1.30
Toluene	1	-	8.0
Xylenes	1	-	4.0
Pentanes	-		
n-Hexane	1	-	5.0
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	1	-	3.0
MTBE	1	-	15.5
TAME	1	-	5.0
THCs	1	-	67

Table A14 Road Tanker Terminal Workers - Miscellaneous (2.1.9)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	12	0.015 - 1.45	0.18
Toluene	5	0.1 - 1.5	0.56
Xylenes	5	0.08 - 0.5	0.14
Pentanes	-		
n-Hexane	5	0.08 - 0.2	0.09
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	-		

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	3	0.4 - 5.0	2.83
Toluene	3	0.4 - 10.2	5.13
Xylenes	3	0.5 - 3.8	2.50
Pentanes	-		
n-Hexane	3	0.9 - 4.6	3.17
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	-		

Table A15 Rail Car Terminal Operators, Top Loading (2.2.1) (without vapour recovery)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	69	0.008 - 14.8	1.34
Toluene	40	0.08 - 27.3	2.69
Xylenes	40	0.03 - 17.9	1.11
Pentanes	-		
n-Hexane	49	0.023 - 289.0	21.57
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	2	0.1 - 0.55	0.33
MTBE	6	0.5 - 36.0	8.10
TAME	-		
THCs	22	1.1 - 309.5	33.81

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	9	0.67 - 5.5	2.20
Toluene	9	1.3 - 11.0	4.40
Xylenes	9	0.69 - 6.25	2.34
Pentanes	-		
n-Hexane	9	0.74 - 4.8	2.00
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	9	30.0 - 153.2	67.70

Biomonitoring Data for Benzene			
	No. of Samples	**Range of Exposure Results (ng/l)**	**Mean Exposure (ng/l)**
blood	26	0 - 1014	262

Table A16 Rail Car Terminal Operators, Top Loading (2.2.2)
(with vapour recovery)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	8	No data	0.23
Toluene	8	No data	3.0
Xylenes	8	No data	3.0
Pentanes	-		
n-Hexane	8	0.3 - 0.4	0.30
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	5	0.80 - 1.1	0.80
TAME	3		0.30
THCs	8	<7.5 - 10.0	7.5

Table A17 Rail Car Terminal Operators, Off-Loading (2.2.5)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	43	0.03 - 9.3	1.29
Toluene	40	0.06 - 17.5	2.71
Xylenes	40	0.04 - 3.6	0.80
Pentanes	-		
n-Hexane	40	0.03 - 8.05	1.77
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	6	0.3 - 0.66	0.48
MTBE	-		
TAME	-		
THCs	46	2.3 - 167.1	37.74

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	4	0.38 - 2.4	1.70
Toluene	4	1.4 - 7.4	4.30
Xylenes	4	0.91 - 4.2	2.40
Pentanes	-		
n-Hexane	-		
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	-		

Table A18 Rail Car Terminal Workers, Miscellaneous (2.2.7)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	35	0.008 - 22.5	1.19
Toluene	32	0.02 - 17.8	1.83
Xylenes	32	0.008 - 5.1	0.51
Pentanes	-		
n-Hexane	13	0.008 - 0.23	0.21
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	14	0.7 - 1708	130

Table A19 Ship Deck Crew, Open Loading (2.3.1.1)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	41	0.08 - 5.4	0.56
Toluene	41	0.08 - 58	2.80
Xylenes	41	0.08 - 46	2.73
Pentanes	26	0.08 - 433	46.58
n-Hexane	67	0.08 - 12.2	7.48
Heptanes	26	0.08 - 24.1	3.85
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	7	0.3 - 23.0	5.16
TAME	6	0.3 - 2.1	0.63
THCs	35	1.0 - 804	77.80

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	4	0.23 - 0.3	0.23
Toluene	4	3.0 - 4.0	3.25
Xylenes	4	3.0 - 4.0	3.25
Pentanes	-		
n-Hexane	4	0.3 - 1.0	0.33
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	2	0.3 - 4.0	2.15
TAME	4	1.3 - 4.0	2.65
THCs	4	5.0 - 62.0	24.38

Table A20 Ship Deck Crew, Unloading (2.3.1.2)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	32	0.023 - 3.7	0.51
Toluene	32	0.023 - 3.0	0.98
Xylenes	32	0.03 - 3.0	0.76
Pentanes	-		
n-Hexane	29	0.023 - 0.3	0.17
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	6	0.3 - 3.0	0.30
TAME	6	<0.3	<0.3
THCs	6	<7.5	<7.5

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	2	0.23 - 1.2	0.7
Toluene	2	3.0 - 8.0	6.0
Xylenes	2	3.0 - 4.0	4.0
Pentanes	-		
n-Hexane	2	0.3 - 4.0	2.0
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	2	0.3 - 9.7	5.0
TAME	2	0.3 - 8.8	4.5
THCs	2	7.5 - 86.0	48

Table A21 Ship Deck Crew, Closed Loading (2.3.2)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	2	0.51 - 0.6	0.56
Toluene	2	0.82 - 6.2	3.51
Xylenes	2	0.84 - 25.0	0.83
Pentanes	-		
n-Hexane	1	-	1.90
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	-		

Table A22 Jetty Staff (2.3.5)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	46	0.023 - 1.7	0.37
Toluene	43	0.023 - 4.0	1.13
Xylenes	43	0.03 - 4.0	0.93
Pentanes	-		
n-Hexane	42	0.023 - 4.0	0.48
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	4	0.3 - 1.2	0.50
TAME	2	0.3 - 0.8	0.50
THCs	16	0.8 - 66.2	10.86

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	24	0.23 - 5.8	0.79
Toluene	23	0.45 - 38.0	5.65
Xylenes	23	0.15 - 8.0	2.91
Pentanes	-		
n-Hexane	22	0.008 - 2.19	2.20
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	8	1.2 - 169	25.13
TAME	8	0.3 - 29.0	5.56
THCs	19	5.0 - 585.0	59.3

Table A23 Ship Distribution Workers - Miscellaneous (2.3.6)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	69	0.008 - 12.2	1.41
Toluene	-		
Xylenes	-		
Pentanes	-		
n-Hexane	-		
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	-		

Table A24 Service Station Attendants (3.1.1.)
(without vapour recovery)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	417	0.001 - 1.9	0.25
Benzene (Periago 1997)	42	0.10 - 1.60	0.62
Toluene	409	0.012 - 2.774	0.47
Toluene (Periago 1997)	42	0.17 - 2.32	0.90
Xylenes	409	0.003 - 1.483	0.19
Xylenes (Periago 1997)	42	0.09 - 1.12	0.36
Pentanes	-		
n-Hexane	406	0.001 - 1.926	0.27
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	355	0.001 - 0.34	0.06
MTBE	355	0.008 - 1.4	0.28
TAME	-		
THCs	333	2.3 - 77.5	19.02

Table A25 Service Station Cashiers (3.2)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	268	0.001 - 1.92	0.05
Toluene	209	0.001 - 1.13	0.41
Xylenes	209	0.001 - 0.94	0.06
Pentanes	-		
n-Hexane	206	0.001 - 0.34	0.04
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	206	0.001 - 0.26	0.02
MTBE	206	0.008 - 0.75	0.04
TAME	-		
THCs	18	0.15 - 6.40	2.13

Table A26 Petrol Pump Maintenance Workers (3.4)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	2	0.16 - 0.93	0.55
Toluene	1	-	3.30
Xylenes	1	-	2.30
Pentanes	-		
n-Hexane	1	-	1.10
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	1	-	0.56
MTBE	-		
TAME	-		
THCs	1	-	37.40

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	6	0.19 - 11.8*	3.8
Toluene	6	0.86 - 30.8*	10.9
Xylenes	6	0.56 - 17.8*	7.4
Pentanes	-		
n-Hexane	6	0.70 - 12.3*	4.2
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	6	0.22 - 5.2*	2.2
MTBE	-		
TAME	-		
THCs	6	25.5 - 300.6*	117.9

*small spillage associated with the highest result

Table A27 Service Station Workers - Miscellaneous (3.5)
(mainly car wash operator)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	5	0.01 - 0.10	0.03
Toluene	3	0.001 - 0.50	0.20
Xylenes	3	0.001 - 0.39	0.15
Pentanes	-		
n-Hexane	3	0.001 - 0.05	0.02
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	3	0.001 - 0.11	0.04
MTBE	3	0.001 - 0.04	0.03
TAME	-		
THCs	3	0.06 - 3.08	1.19

Table A28 Airport Operators (aviation gasoline) (4.1)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	10	0.008 - 0.60	0.10
Toluene	10	0.008 - 4.20	1.90
Xylenes	10	0.008 - 0.50	0.20
Pentanes	-		
n-Hexane	-		
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	16	0.08 - 31.30	5.83

Short Period (< 1hr) Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	-		
Toluene	-		
Xylenes	-		
Pentanes	-		
n-Hexane	-		
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	7	3.40 - 526.60	107.2

Table A29 Agricultural & Horticultural Workers (5.1)

Full Shift Exposure Data			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene	20	No data	0.52
Benzene (LfU 1994)*	5	0.51 – 5.1	2.1
Toluene	-		
Toluene (LfU 1994)*	5	<1.9 – 13.5	< 6.2
Xylenes	-		
m-Xylene (LfU 1994)*	5	1.9 – 13	5.3
Pentanes	-		
n-Hexane	-		
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
Ethylbenzene (LfU 1994)*	5	0.32 – 3.25	1.2
MTBE	20	0.3 - 0.8	0.6
TAME	-		
THCs	-		

* data for forestry workers; exposure is the combined result of chain saw refuelling and engine exhaust

Table A30 Motor Mechanics (5.2)

Full Shift Exposure Data (literature data only)			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene (Hotz 1997)	156	ND – 0.14	0.01
Benzene (Göen 1997)	26	< 0.40 – 1.36	< 0.40
Toluene	-		
Xylenes	-		
Pentanes	-		
n-Hexane	-		
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs	-		

Short Period (< 1hr) Exposure Data (literature data only)			
Substance	**No. of Samples**	**Range of Exposure Results (mg/m^3)**	**Mean Exposure (mg/m^3)**
Benzene (Laitinen 1994)	12	< 1.5 – 11.8	5.3
Benzene (Popp 1994)	20	< 1 – 13	2.8
Toluene	-		
Xylenes	-		
Pentanes	-		
n-Hexane	-		
Heptanes	-		
1,3 Butadiene	-		
Cyclohexane	-		
Ethylbenzene	-		
MTBE	-		
TAME	-		
THCs (Laitinen 1994)	12	6 – 156	67