review of european oil industry benzene exposure data (1986 - 1992)

Prepared for CONCAWE by the Health Management Group's Industrial Hygiene Subgroup.

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ABSTRACT

This report summarizes over 2,000 occupational exposure data on benzene, measured in the period 1986-1992.

Exposures for the various types of jobs are reviewed against a number of time-weighted average (TWA) criteria, including 1 ppm and 0.5 ppm.

Most of the 8-hour TWA exposures were below 1 ppm and 62-100% at, or less than, 0.5 ppm, depending on the job being undertaken. The results are similar to those found in a survey conducted in 1977-85.

KEYWORDS

Benzene, occupational exposure, health, gasoline, exposure limits, CONCAWE.

CONTENTS

SUMMARY

This report summarizes the results of over 2000 measurements taken by CONCAWE member companies in Western Europe over the period 1986-1992 to assess exposure to benzene vapour during a range of refinery, distribution and retail activities. It updates CONCAWE Report No. 3/86, which summarized the results of benzene exposure measurements taken during the period 1977-1985.

Overall, the results are similar to those recorded previously, with most of the 8-hour time-weighted average (TWA) exposures below 1 ppm.

The percentage of 8-hour TWA results exceeding 0.5 ppm ranged from 62 to 100 depending on the job. The highest benzene exposures occurred during the following activities:

- rail loading of motor gasolines over extended periods;
- open loading of ships and barges with motor gasoline cargoes;
- refinery off-site tasks;
- top road tanker filling of motor gasolines by full-time loaders.

1. INTRODUCTION

Benzene continues to attract considerable attention from a health point of view, both in the workplace and in neighbouring communities. As far as the work environment is concerned, individual oil companies conduct personal exposure measurements at their facilities, during the manufacture and distribution of motor gasolines. This forms part of their health protection programmes, in order to check that benzene levels in employee breathing zones are within the prevailing occupational exposure limit.

In 1986 CONCAWE summarized available benzene exposure data from a number of studies in the period 1977-1985 undertaken by member companies and by European National Petroleum Industry Associations for various types of oil industry job. The results were reviewed in the light of the then proposed EU Benzene Directive, which incorporated an 8-hour time-weighted average (TWA) 'Limit Value' of 5 ppm and an 8-hour TWA 'Action Level' of 1 ppm. [1]

The EU proposal was never adopted, but the trend to more stringent occupational exposure limits for benzene in individual European countries has continued with the result that current 8hour TWA limits in most countries are now in the 1 - 5 ppm range. However, one organization, namely the American Conference of Governmental Industrial Hygienists, that promulgates the list of so-called 'Threshold Limit Values' - adopted in some European countries - proposed that its 8hour TWA limit for benzene should be reduced from 10 ppm to 0.1 ppm. Whilst the latter criterion has now been revised to a 0.3 ppm proposal, the overall downward trend is clear.

These pressures on the permissible occupational exposure limit have led to attention being focused on the prevailing levels of exposure in the oil industry. To this end, the CONCAWE Industrial Hygiene Sub-Group has collected, collated and summarized available data from member companies for the period 1986-1992, in order to assess the current situation and to make a comparison with the previous CONCAWE report.

2. EXPOSURE DATA

More than 2000 personal benzene exposure data have been submitted to this CONCAWE compilation by member companies and are summarized in **Tables 1 - 25**. Over 80% of the results are representative of 8-hour time-weighted average (TWA) full shift exposures, whilst the remainder are shorter period measurements during particular job activities. All were obtained using similar sampling and analytical techniques to those reported previously – and therefore are comparable. They correspond to the following job activities:

- refinery operators **Tables 2a, 2b, 3**
- refinery off-site workers **Tables 4a, 4b, 5**
- refinery maintenance workers **Tables 6, 7**
- road tanker drivers (top loading) **Tables 8, 9, 10, 11**
- road tanker drivers (bottom loading) **Tables 12, 13**
- rack operators & supervisors **Tables 14, 15**
- rail car loaders (top loading) **Tables 16, 17**
- deck crew (marine loading) **Tables 18, 19**
- jetty staff (marine loading) **Tables 20, 21**
- service station attendants **Tables 22, 23**
- service station cashiers **Table 24**
- miscellaneous **Tables 25, 26**

A summary of the 8-hour TWA exposures for 11 job categories is given in **Table 1** and the percentage of results at or below an 8-hour exposure level of 1 ppm is shown in **Figure 1**.

Table 1 Summary of 8-hour TWA Exposures to Benzene (1986-1992)

	Number of Samples	Range of Results (ppm)	Arithmetic Mean (ppm)	% Results = 0.5 ppm	% Results = 1 ppm
1. Refineries					
1.1 Operators	449	<0.05 - 7.9	0.18	94	96
1.2 Off-site Workers	426	<0.05 - 13.3	0.57	79	85
1.3 Maintenance Staff	55	<0.05 - 19.3	0.79	91	93
2. Distribution - Road					
2.1 Tanker Drivers (top loading)	186	<0.05 - 2.06	0.25	90	98
2.2 Rack Operators & Supervisors	40	<0.05 - 18.9	0.59	95	95
3. Distribution - Rail					
3.1 Loaders (top loading)	183	<0.05 - 41.6	1.57	62	74
4. Distribution - Shipping					
4.1 Deck Crew (marine loading)	19	<0.05 - 3.56	0.72	63	79
4.2 Jetty Staff	92	<0.05 - 83.1	1.98	80	86
5. Service Stations					
5.1 Attendants	82	<0.05 - 3.34	0.19	93	96
5.2 Cashiers	24	<0.05 - 0.05	<0.05	100	100
6. Miscellaneous					
6.1 Laboratories, Engine Test Houses, Used Barrel Cleaning	193	<0.05 - 1.28	0.11	97	99

Figure 1 Personal exposure to benzene (1986-1992)
% 8-hour TWA Exposures ≤ 1ppm

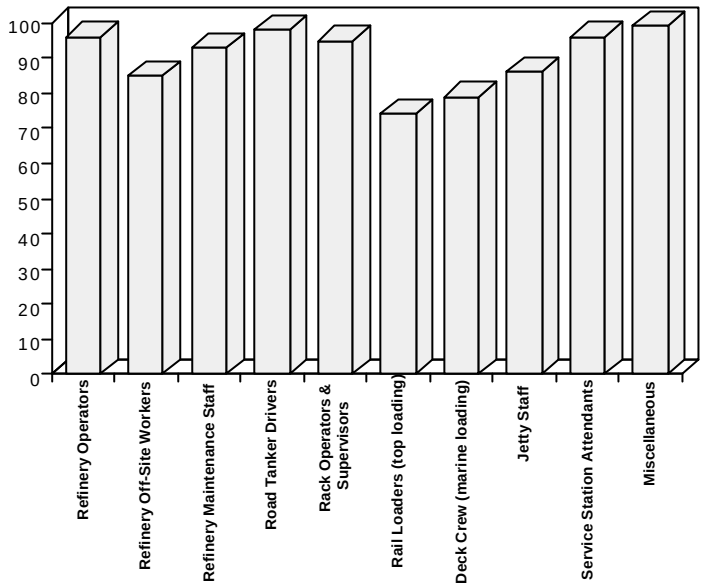
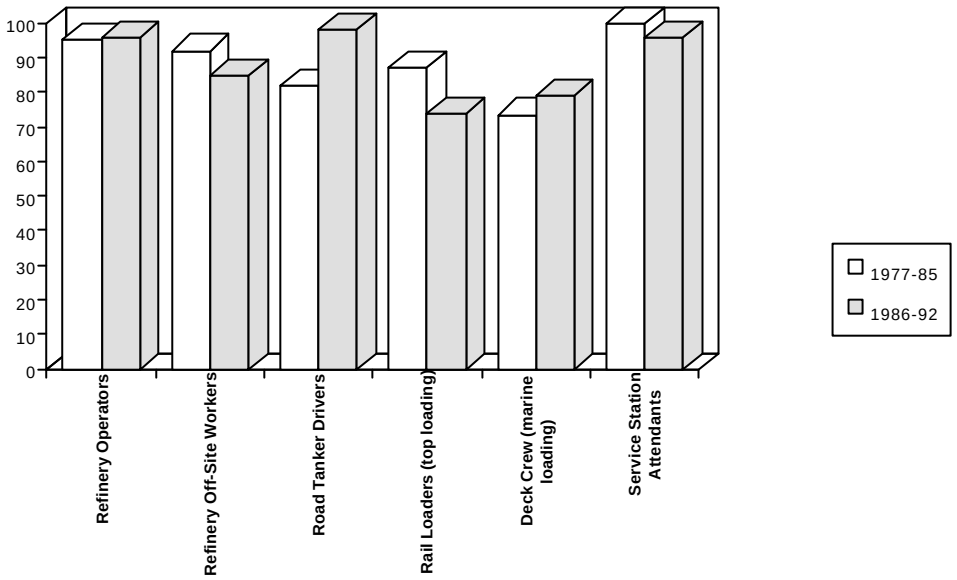


Figure 2 compares the results for 6 of the job categories with the corresponding CONCAWE data recorded in Report 3/86. [1] This indicates that the recent benzene exposure data are within ±10% of those recorded in the late 1970s and early 1980s for tasks which are conducted in a similar manner.

For the purpose of discussion, each category of job, including some short period tasks, is considered separately below.

Figure 2 Comparison of personal exposures to benzene in periods 1977-85 and 1986-92.
% 8-hour TWA Exposures ≤ 1ppm



2.1 REFINERY OPERATORS (TABLES 2a, 2b, 3)

The 8-hour TWA results (<0.05 - 7.9 ppm), derived from 449 full shift personal exposure measurements on refinery operators involved on a range of different units, indicate that 96% were below 1 ppm and all but one value were less than 5 ppm, including those for the catalytic reformer where process streams with a higher than usual benzene content are present (**Tables 2a & 2b**). These data are very similar to those recorded in the 1986 report, for which the corresponding percentages were 95 and 99, respectively. The results suggest that the 8-hour TWA exposures of refinery operators to benzene over the working day are normally below 1 ppm.

A number of short period personal exposure measurements were also taken during specific tasks (**Table 3**). The highest results were associated with the taking and testing of process samples of benzene-containing streams, for which 25% of the breathing zone samples exceeded 5 ppm over sampling times of up to 24 minutes.

2.2 REFINERY OFF-SITE WORKERS (TABLES 4a, 4b, 5)

This classification includes bottle washing, some laboratory work, tank farm activities and the waste water treatment plant. 426 full shift exposure measurements have been reported and an analysis of the 8-hour TWA results (<0.05 - 13.3 ppm) indicates that 85% were at or below 1 ppm and 98% less than 5 ppm (**Tables 4a & 4b**). The highest benzene results were associated with the bottle washing activity, for which only 48% of the 8-hour TWA results were less than 1 ppm.

Overall the results are similar to those recorded in the 1986 Report. However, if a 1 ppm (or lower) limit were to be introduced, some additional control measures may need to be implemented.

2.3 REFINERY MAINTENANCE WORKERS (TABLES 6, 7)

As indicated in the previous CONCAWE report, refinery maintenance workers carry out a variety of tasks, some of which may involve exposure to benzene vapour when draining, cleaning, opening up and working on enclosed equipment, for example on a catalytic reformer.

The 8-hour TWA results (<0.05 - 19.3 ppm), derived from 55 full shift personal exposure measurements on refinery maintenance workers, indicate that 93% were below 1 ppm and 96% were less than 5 ppm (**Table 6**), very similar to the results recorded in the 1986 report.

The overall nature of the duties of refinery maintenance workers is such that irregular exposures are likely, with the potential for high breathing zone concentrations when containment is broken. Accordingly, some shorter period monitoring was conducted during refinery maintenance activities **(Table 7)**. This indicated that whilst daily exposures to benzene may normally be below 1 ppm **(Table 6)**, the few shorter period results suggested that caution is necessary in making an assessment of risk.

2.4 ROAD TANKER DRIVERS / TOP LOADING (TABLES 8, 9, 10, 11)

The 8-hour TWA results (<0.05 - 2.06 ppm), derived from 186 full shift personal exposure measurements on drivers engaged in the top filling of road tankers with motor gasolines, delivery of these cargos to service stations and their discharge, indicate that 98% were below 1 ppm, and all were less than 5 ppm (**Table 8**). These percentages are slightly higher than those recorded in the 1986 report, for which 90% of the benzene results were below 1 ppm over the working day.

Short period personal exposure measurements were also carried out during the actual loading of road tankers and the results (<0.05 - 9.7 ppm) are summarized in **Table 9**, with information about the loading times set down in **Table 10**. The data suggest slightly lower exposures in the current study as compared to previously, with none of the results in excess of 10 ppm and only 9% greater than 5 ppm during this 'critical' task in the working day. The mean loading time was 24.8 minutes, similar to that recorded in the 1986 report.

A few breathing zone measurements have been taken for drivers during the delivery of motor gasolines to service stations (**Table 11**). These indicate delivery times of 12 - 58 minutes and corresponding benzene exposures ranging from <0.05 - 3.34 ppm.

2.5 ROAD TANKER DRIVERS / BOTTOM LOADING (TABLES 12, 13)

No full shift results are reported for bottom loading road tanker drivers. However, personal benzene exposure data (<0.05 - 3.4 ppm) were obtained during the actual loading of road tankers (**Table 12**) and information about the loading times is given in **Table 13**. The driver exposures are fairly similar to those reported in 1986, with 79% below 1 ppm and all below 5 ppm. As in the 1986 CONCAWE report, higher driver exposures are associated with top loading than with bottom loading. The mean loading time was 23.7 minutes, slightly shorter than in the previous study.

From the information obtained - and knowledge of the daily job - it is unlikely that the 8-hour TWA exposures of bottom loading road tanker drivers to benzene vapour normally exceed 1 ppm.

2.6 RACK OPERATORS AND SUPERVISORS (TABLES 14, 15)

The 8-hour TWA data for rack operators and supervisors (<0.05 - 18.9 ppm), derived from 40 full shift personal exposure measurements, indicate that 95% of the results were below 1 ppm, and 98% less than 5 ppm (**Table 14**). Although there is a higher potential for exposure, as compared to road tanker drivers the results are similar to the 8-hour TWA exposures recorded for top loading road tanker drivers.

A few shorter period benzene measurements for rack operators and supervisors, taken over periods from 5 to 79 minutes, are reported in **Table 15**. The results range from <0.05 - 2.6 ppm, with 67% of the benzene values below 1 ppm.

2.7 RAIL CAR LOADERS/TOP LOADING (TABLES 16, 17)

The 8-hour TWA results (<0.05 - 41.6 ppm), derived from 183 full shift personal exposure measurements on rail car loaders, indicate that 74% of the benzene exposures were at or below 1 ppm and 95% less than 5 ppm (**Table 16**). These data are very similar to those reported in 1986, when the corresponding percentages were 75 and 98 respectively.

There is only one data point for shorter period exposures and therefore no firm conclusions can be drawn **(Table 17**).

The measurements suggest that whilst 8-hour TWA exposures are not normally above 5 ppm, compliance with a limit of 1 ppm, or less, would not be achieved.

2.8 MARINE LOADING / DECK CREW (TABLES 18, 19)

The 8-hour TWA results (<0.05 - 3.56 ppm), derived from 19 full shift personal exposure measurements on deck crew during the loading of motor gasolines, indicate that 79% of the benzene exposures were below 1 ppm and all were less than 5 ppm (**Table 18**). Although the data appear to suggest that exposures are fairly low, care should be taken when drawing conclusions as only few results were submitted and even these did not always specify whether open or closed loading was involved. Whilst closed loading is likely to be associated with only low levels of exposure to benzene, it is known that higher levels can arise during the open loading of ships and barges, as shown in the 1986 CONCAWE report.

The data obtained from a few short period measurements are shown in **Table 18** (<0.05 - 3.44 ppm). Numerically the results are similar to the 8-hour exposure TWA exposure data summarized in **Table 18.**

2.9 MARINE LOADING / JETTY STAFF (TABLES 20, 21)

Jetty staff duties associated with marine loading include the coupling and uncoupling of hoses and the taking of product samples for analytical quality control purposes. The 8-hour TWA results (<0.05 - 83.1 ppm), derived from 92 full shift personal exposure measurements on jetty staff during the marine loading of motor gasoline cargoes, indicate that 86% of the benzene exposures were below 1 ppm and 95% less than 5 ppm (**Table 20**).

The 28 short period measurements during marine loading all indicate that benzene exposures were below 5 ppm (**Table 21**).

It should be noted that this and other studies have suggested that higher exposures than those generally indicated in **Tables 20 and 21** can occur; indeed the one full shift result which exceeded 80 ppm in this study emphasises the potential. In general the higher results have been found when the weather is warm and still and/or when spillages have occurred. Lower results are to be expected with closed loading operations.

2.10 SERVICE STATION ATTENDANTS (TABLES 22, 23)

The 8-hour TWA results (<0.05 - 3.34 ppm), derived from 82 full shift personal exposure measurements on service station attendants, indicate that 96% of the benzene exposures were below 1 ppm, and all were below 5 ppm. These percentages are almost identical to those recorded in the 1986 report. The data, taken together with the short-term results reported in **Table 23** (<0.05 - 1.63 ppm), suggest that the 8-hour TWA exposures of service station attendants to benzene vapour do not normally exceed 1 ppm.

2.11 SERVICE STATION CASHIERS (TABLE 24)

Table 24 summarizes the results of 24 fixed position measurements taken in service station shops and kiosks (<0.05 - 0.05 ppm). They are included because they are considered to be indicative of the occupational exposure of service station cashiers. All were well below 0.1 ppm.

2.12 MISCELLANEOUS ACTIVITIES (TABLES 25, 26)

Table 25 summarizes the results of nearly 200 full shift personal exposure measurements relating to a number of activities not classified elsewhere. 75% of the measurements related to laboratories and engine test houses during which benzene-containing samples were handled/tested. Only two of the 8hour TWA exposures exceeded 1 ppm.

The small number of short period measurements suggest that peak exposures are relatively low (**Table 26**).

3. CONCLUSIONS

3.1 EXPOSURE LEVELS

- Over 90% of the 8-hour TWA benzene exposure measurements relating to refinery, distribution and retail activities were less than 1 ppm, and more than 95% were below 5 ppm. This is similar to the exposure situation recorded for corresponding tasks by CONCAWE member companies in the 1986 report.

- The jobs for which at least 95% of the 8-hour TWA benzene exposure measurements were less than 1 ppm included:

  – refinery operators;
  – road tanker drivers (top loading);
  – service station attendants and cashiers.

- The highest 8hour TWA benzene exposure measurements were associated with:

  – loaders engaged in the top filling of rail cars with motor gasolines;
  – deck crew and jetty staff involved with the open loading of ships and barges with motor gasolines.

  The results for these particular tasks suggest that compliance with a 1 ppm (or lower) occupational exposure limit would not be achieved with current practices.

- The nature of, and the exposure data for, the following activities indicate that they may also be associated with higher benzene exposure levels:

  – refinery 'off-site' duties;
  – some refinery maintenance;
  – top filling of road tankers with motor gasolines by full-time loaders.

- The benzene exposure measurements suggest that drivers engaged in the top filling of road tankers with motor gasolines may not comply if an 8-hour TWA occupational exposure limit of less than 1 ppm is introduced.

- Some of the laboratories involved in the analyses of the benzene-in-air samples now participate in both quality control and quality assurance schemes. This is a significant development over the past decade in helping to demonstrate that reliable benzene exposure data are being generated.

3.2 ASSESSMENT OF RISK

Although this report is helpful in indicating the main areas and activities of interest to the oil industry from a benzene point of view, it is important that the information is utilised critically in the assessment of local conditions. This is particularly vital, for example, with respect to refinery maintenance tasks and shipping activities because of the differing circumstances that can prevail between different facilities.

3.3 EXPOSURE TRENDS

Current occupational exposures to benzene are likely to be lower than in the 1970s and 1980s because of changes that have occurred in technology and operating practices. The gradual introduction of bottom loading for road tanker vehicles (instead of top loading), the increased utilisation of ships with closed loading facilities (instead of open loading) and the wider operation of self-service retail stations (instead of attended service stations) are some examples of these changes.

3.4 FURTHER WORK

Relatively few exposure measurements were taken on deck crew during the open or closed loading of ships with motor gasoline cargoes and further studies are advocated. Local measurements are also recommended where jetty staff are associated with open loading operations to check on their benzene exposures and the effectiveness of any control measures.

4. REFERENCE

1. CONCAWE (1986) Review of European oil industry benzene exposure. Report 3/86. Brussels: CONCAWE.

Table 2a 8 - Hour TWA exposures of refinery operators (ppm)

Year	Process	Number of samples	Benzene exposures				% of measurements at or below				
			min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1986	Aromatics plant	14	<0.05	7.9	0.80	0.24	29	50	86	93	93
	Cat. cracker	9	<0.05	0.3	0.12	0.05	44	100	100	100	100
	Cat. reformer	8	<0.05	2.66	0.50	0.10	38	75	75	88	100
	Crude distillation	33	<0.05	0.31	0.15	0.10	30	88	100	100	100
	Crude storage	10	<0.05	0.26	0.07	<0.05	70	100	100	100	100
	Hydrocracker	9	<0.05	0.49	0.17	0.06	44	78	100	100	100
	LPG	6	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Unspecified	9	<0.05	0.2	0.10	0.07	67	100	100	100	100
	White oils unit	35	<0.05	0.25	<0.05	<0.05	86	100	100	100	100
1987	Alkylation	4	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Aromatics plant	12	<0.05	2.7	0.87	0.42	17	33	50	58	100
	Butamer	1	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Cat. cracker	9	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Cat. cracker/reformer	10	<0.05	1.02	0.34	0.09	50	50	60	90	100
	Crude distillation	4	<0.05	0.09	0.06	0.06	100	100	100	100	100
	Merox	2	<0.05	0.13	0.07	<0.05	50	100	100	100	100
	Unspecified	5	0.08	1.17	0.37	0.21	60	60	80	80	100
	Vac. distillation	2	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Vac distiln./vis breaker	2	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Visbreaker	4	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
1988	Aromatics plant	21	<0.05	1.2	0.12	<0.05	62	95	95	95	100
	Boiler house	6	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Cat cracker/reformer	8	<0.05	2	0.37	0.05	63	75	75	88	100
	Cat ref/unifiner/hydrotr.	5	0.05	0.42	0.21	0.14	40	60	100	100	100
	Cat. reformer	18	<0.05	0.08	<0.05	<0.05	100	100	100	100	100
	Crude distillation	12	<0.05	0.36	0.06	<0.05	83	92	100	100	100
	Fireman	5	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Pumphouse	10	<0.05	0.36	0.07	<0.05	80	90	100	100	100
	Sulphur recovery	6	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Unifiner/hydrotreater	6	<0.05	0.06	<0.05	<0.05	100	100	100	100	100
	Unspecified	1	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Vac. distillation	4	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Visbreak/sulphur rec.	3	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Visbreaker	7	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
1989	Aromatics plant	11	<0.05	0.41	0.09	<0.05	73	91	100	100	100
	Unspecified	8	<0.05	4.9	0.96	0.15	63	75	75	75	100
1990	Aromatics plant	18	0.05	2.4	0.33	0.15	50	78	83	94	100
	Cat. reformer	1	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Cyclar plant	8	<0.05	1.94	0.31	<0.05	75	75	88	88	100
	Unspecified	5	<0.05	2.07	0.47	0.10	60	80	80	80	100
1991	Aromatics plant	23	<0.05	1.6	0.30	0.14	57	74	83	91	100
	Drainage & sampling	10	<0.05	0.2	0.10	0.06	70	100	100	100	100
	Gas testing	7	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100

Table 2a 8 - Hour TWA exposures of refinery operators (ppm) cont....

Year	Process	Number of samples	Benzene exposures				% of measurements at or below				
			min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1992	Act. carbon handling	4	<0.05	0.2	0.06	<0.05	75	100	100	100	100
	Activated sludge plant	4	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Cat. cracker	15	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Compressor room	1	<0.05	<0.05	<0.05	<0.05	100	300	100	100	100
	Crude distillation	3	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Emulsion handling	3	<0.05	0.1	<0.05	<0.05	100	33	100	100	100
	Flash Gas Recovery	1	<0.05	<0.05	<0.05	<0.05	100	200	100	100	100
	Hexane separator	2	<0.05	<0.05	<0.05	<0.05	100	300	100	100	100
	Hydrodesulphn.	6	<0.05	<0.05	<0.05	<0.05	100	50	100	100	100
	Hydrotreating	3	<0.05	<0.05	<0.05	<0.05	100	33	100	100	100
	Platforming	3	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Unspecified	5	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Vapour recovery unit	3	<0.05	0.3	0.14	0.07	67	100	100	100	100
	Visbreaker	5	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
86-92	All	449	<0.05	7.9	0.18	<0.05	71	88	94	96	100

Table 2b Summary of 8 - Hour TWA exposures of refinery operators, 1986-1992 (ppm)

Year	Process	Number of samples	Benzene exposures				% of measurements at or below				
			min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
86-92	Aromatics plant	99	<0.05	7.9	0.38	0.11	49	73	84	90	99
86-92	Cat. cracker	33	<0.05	0.3	<0.05	<0.05	85	100	100	100	100
86-92	Cat. cracker/ref	18	<0.05	2	0.35	0.07	56	61	67	89	100
86-92	Cat. reformer	27	<0.05	2.66	0.16	<0.05	81	93	93	96	100
86-92	Crude distillation	52	<0.05	0.36	0.12	0.07	49	90	100	100	100
86-92	Unspecified	33	<0.05	4.9	0.39	0.07	70	85	88	88	100
86-92	Visbreaker	16	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
86-92	White oils unit	35	<0.05	0.25	<0.05	<0.05	86	100	100	100	100
86-92	Miscellaneous	136	<0.05	1.94	0.08	<0.05	85	95	99	99	100
86-92	All	449	<0.05	7.9	0.18	<0.05	71	85	94	96	100

Table 3 Short period exposures of refinery operators (ppm)

Year	Process	Number of samples	Benzene exposures				% of measurements at or below				
			min	max	Arithmetic mean	Sampling time (min)	0.1	0.3	0.5	1.0	5.0
1988	Taking samples	8	<0.05	7.8	1.03	13 - 24	75	75	88	88	88
	Testing samples	6	2.74	7.97	5.20	6 - 21	0	0	0	0	33
1991	Draining tank	5	<0.05	1.8	0.62	3 - 5	40	40	60	80	100
	Draining tank/taking samples	4	<0.05	4.3	1.93	7 -43	50	50	50	50	100
	Taking samples	10	<0.05	13.6	1.75	4 - 22	40	60	60	80	90
1992	Cat. Cracker	8	<0.05	<0.05	<0.05	4 - 88	100	100	100	100	100
	Visbreaker	3	<0.05	<0.05	<0.05	5 - 94	100	100	100	100	100
86-92	All	44	<0.05	13.6	1.51	3 - 94	57	61	66	73	86

Table 4a 8 - Hour TWA exposures of refinery "off-site" workers (ppm)

Year	Process	Number of samples	Benzene exposures				% of measurements at or below				
			min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1986	Bottle washer	29	<0.05	6.16	1.93	0.99	7	10	24	45	90
	Lab. worker	28	<0.05	11.1	1.14	0.19	46	64	75	82	89
	Tank farm	19	<0.05	0.42	0.13	0.07	68	84	100	100	100
	Tank storage	9	<0.05	1.4	0.24	0.08	78	89	89	89	100
1987	API separator	2	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
	Bottle washer	31	<0.05	13.3	1.82	0.38	29	35	35	42	94
	Lab. worker	19	<0.05	9.84	0.95	0.32	11	42	74	89	95
	Tank farm	10	<0.05	0.74	0.23	0.12	60	80	80	100	100
	Unspecified	2	0.05	0.58	0.32	0.17	50	50	50	100	100
	Waste water plant	4	<0.05	4.1	1.26	0.32	50	50	50	75	100
1988	Bottle washer	15	<0.05	1.73	0.63	0.23	27	33	60	67	100
	Lab. worker	94	<0.05	1.84	0.17	0.07	56	87	95	97	100
	Tank farm	23	<0.05	0.21	0.06	<0.05	74	100	100	100	100
	Tank storage	4	0.1	0.84	0.35	0.24	50	50	75	100	100
	Unspecified	8	<0.05	4.2	1.29	0.43	13	50	50	50	100
	Waste water plant	9	<0.05	0.08	<0.05	<0.05	100	100	100	100	100
1989	Lab. worker	27	<0.05	1.4	0.20	0.06	67	89	89	93	100
	Tank farm	6	<0.05	0.2	0.08	<0.05	67	100	100	100	100
	Tank storage	5	0.15	2.56	1.11	0.49	0	60	60	60	100
	Unspecified	6	<0.05	1.53	0.39	0.18	33	83	83	83	100
1990	Lab. worker	28	<0.05	2.08	0.16	0.07	79	93	93	96	100
	Tank farm	8	0.05	0.08	0.06	0.06	100	100	100	100	100
	Tank storage	6	<0.05	1.85	0.98	0.45	17	33	33	33	100
	Unspecified	4	0.07	0.3	0.17	0.14	25	100	100	100	100
1991	Lab. worker	22	0.05	0.49	0.15	0.11	73	86	100	100	100
	Tank farm	8	<0.05	0.1	0.06	<0.05	100	100	100	100	100
1992	-	-	-	-	-	-	-	-	-	-	-
86-92	All	426	<0.05	13.3	0.57	<0.05	52	72	79	85	98

Table 4b Summary of 8-Hour TWA exposures of refinery "off-site" workers, 1986-1992 (ppm)

Year	Process	Number of samples	Benzene exposures				% of measurements at or below				
			min	max (ppm)	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
86-92	Bottle Washer	75	<0.05	13.3	1.62	0.50	20	25	36	48	93
86-92	Lab. worker	218	<0.05	11.1	0.37	0.09	57	81	90	94	98
86-92	Tank farm	74	<0.05	0.74	0.10	0.05	76	93	97	100	100
86-92	Tank storage	24	<0.05	2.56	0.62	0.21	42	58	67	71	100
86-92	Unspecified	20	<0.05	4.2	0.70	0.24	25	70	70	75	100
86-92	API Separator	2	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
86-92	W.W.T.P*	13	<0.05	4.1	0.42	0.06	85	85	85	92	100
86-92	All	426	<0.05	13.3	0.57	<0.05	52	72	79	85	98

Note:
* W.W.T.P = Waste Water Treatment Plant

Table 5 Short period exposures of refinery "off-site" workers (ppm)

Year	Process	Number of samples	Benzene exposures				% of measurements at or below				
			min	max	Arithmetic mean	Sampling time (min)	0.1	0.3	0.5	1.0	5.0
1988	Bottle washer	6	0.25	1.53	0.84	10 - 15	0	17	17	67	100
1990	Lab. worker	2	<0.05	0.06	<0.05	10 - 13	100	100	100	100	100
86-92	All	8	<0.05	1.53	0.64	10 - 15	25	38	38	75	100

Table 6 8-Hour TWA exposures of refinery maintenance workers (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1987	20	<0.05	19.3	2.11	0.15	60	65	75	80	90
1990	18	<0.05	0.3	0.06	<0.05	78	100	100	100	100
1992	17	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
86-92	55	<0.05	19.3	0.79	<0.05	78	87	91	93	96

Table 7 Short period exposures of refinery maintenance workers (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Sampling time (min)	0.1	0.3	0.5	1.0	5.0
1986	14	6.9	202	47.22	67 - 265	0	0	0	0	0
1990	1	0.15	0.15	0.15	30	0	100	100	100	100
86-92	15	0.15	202	44.08	30 - 265	0	7	7	7	7

Table 8 8-Hour TWA exposures of road tanker drivers (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1987	39	<0.05	1.21	0.24	0.12	36	69	85	97	100
1988	28	0.08	1.72	0.37	0.27	18	54	86	96	100
1989	51	<0.05	0.91	0.18	0.11	47	84	92	100	100
1990	27	<0.05	2.06	0.23	0.11	48	81	93	96	100
1991	41	<0.05	0.90	0.26	0.19	24	66	93	100	100
86-92	186	<0.05	2.06	0.25	0.14	35	72	90	98	100

Table 9 Exposures during actual top loading of road tankers (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1986	48	<0.05	9.7	2.75	1.61	6	8	13	23	85
1987	15	0.3	5.3	1.48	1.12	0	7	7	47	93
1988	8	<0.05	5.1	1.51	0.62	13	25	25	63	88
1989	27	<0.05	3.59	0.57	0.35	7	37	63	93	100
1990	13	<0.05	5.19	2.29	1.45	8	8	15	23	85
1991	26	<0.05	6.7	1.83	1.11	8	8	15	31	92
86-92	137	<0.05	9.7	1.89	1.00	7	15	23	43	91

Table 10 Exposure periods (6-78 min) during top loading of road tankers

Year	% of exposure periods up to (min)		
	= 20	= 30	5
1986	35	90	100
1987	27	73	87
1988	25	75	100
1989	93	93	100
1990	31	69	85
1991	8	69	96
86-92	39	82	96

Arithmetic Mean = 24.8 minutes

Table 11 Driver exposure during delivery at service stations (ppm)

Year	Number of samples	Benzene exposures		
		min	max	Sampling time (min)
1986	13	<0.05	3.34	24 - 58
1989	6	<0.05	1.06	25 - 45
1990	9	<0.05	2.88	12 - 28
86-92	28	<0.05	3.34	12 - 58

Table 12 Exposures during actual bottom loading of road tankers (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1988	30	<0.05	3.4	0.88	0.37	17	33	37	67	100
1989	5	0.34	1.2	0.69	0.62	0	0	40	80	100
1990	3	<0.05	0.06	<0.05	<0.05	100	100	100	100	100
1991	18	0.2	1.6	0.73	0.64	0	11	39	94	100
86-92	56	<0.05	3.4	0.77	0.40	14	27	41	79	100

Table 13 Exposure periods (10-45 min) during bottom loading of road tankers (ppm)

Year	% of exposure periods up to (min)		
	= 20	= 30	= 40
1988	47	80	100
1989	20	60	100
1990	50	100	100
1991	22	61	89
86-92	38	73	96

Arithmetic Mean = 23.7 minutes

Table 14 8-Hour TWA exposures of rack operators and supervisors (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1986	1	0.3	0.3	0.30	0.30	0	100	100	100	100
1987	1	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
1988	7	0.05	0.14	0.08	0.08	71	100	100	100	100
1989	5	<0.05	0.08	<0.05	<0.05	100	100	100	100	100
1991	26	<0.05	18.9	0.87	0.06	73	92	92	92	96
86-92	40	<0.05	18.9	0.59	0.06	75	95	95	95	98

Table 15 Short period exposures of rack operators and supervisors (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Sampling time (min)	0.1	0.3	0.5	1.0	5.0
1990	21	<0.05	2.25	0.69	5 - 79	24	52	62	71	100
1991	3	<0.05	2.6	1.31	15 - 60	33	33	33	33	100
86-92	24	<0.05	2.6	0.77	5 - 79	25	50	58	67	100

Table 16 8-Hour TWA exposures during top loading of rail cars (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1986	33	<0.05	22.38	1.77	0.26	24	52	61	76	91
1987	48	0.09	41.6	3.38	1.02	4	19	35	54	90
1988	17	<0.05	3.84	1.27	0.40	24	35	47	65	100
1990	11	<0.05	1.19	0.28	0.07	64	73	73	91	100
1991	58	<0.05	6.7	0.61	0.08	57	74	79	83	98
1992	16	<0.05	3.6	0.39	0.08	56	75	94	94	100
86-92	183	<0.05	41.6	1.57	0.23	34	52	62	74	95

Table 17 Short period exposures during top loading of rail cars (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Sampling time (min)	0.1	0.3	0.5	1.0	5.0
1990	1	<0.05	<0.05	<0.05	19	100	100	100	100	100
86-92	1	<0.05	<0.05	<0.05	19	100	100	100	100	100

Table 18 8-Hour TWA exposures during marine loading* (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1989	13	<0.05	3.56	0.97	0.37	31	46	46	69	100
1991	6	0.1	0.22	0.16	0.15	17	100	100	100	100
86-92	19	<0.05	3.56	0.72	0.28	26	63	63	79	100

Table 19 Short period exposures during marine loading* (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Sampling time (min)	0.1	0.3	0.5	1.0	5.0
1989	6	<0.05	3.44	0.87	15 - 70	17	17	67	83	100
86-92	6	<0.05	3.44	0.87	15 - 70	17	17	67	83	100

Note:
* Open or closed marine loading was not specified

Table 20 8-Hour TWA exposures of jetty staff during marine loading (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1986	23	<0.05	83.1	5.75	0.23	35	39	61	74	91
1987	6	<0.05	0.41	0.20	0.15	17	83	100	100	100
1988	50	<0.05	14.3	0.96	0.07	62	74	82	86	94
1989	1	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
1990	2	0.06	0.06	0.06	0.06	100	100	100	100	100
1991	10	<0.05	0.1	0.06	<0.05	100	100	100	100	100
86-92	92	<0.05	83.1	1.98	0.09	58	70	80	86	95

Table 21 Short period exposures of jetty staff during marine loading (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Sampling time (min)	0.1	0.3	0.5	1.0	5.0
1989	6	<0.05	1.09	0.26	14 - 44	67	67	83	83	100
1990	22	<0.05	3.08	0.34	10 - 83	36	68	91	95	100
86-92	28	<0.05	3.08	0.32	10 - 83	43	68	89	93	100

Table 22 8-Hour TWA exposures of service station* attendants (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1986	54	<0.05	3.34	0.17	<0.05	67	93	94	96	100
1987	6	<0.05	<0.05	<0.05	<0.05	100	100	100	100	100
1988	11	0.07	1.06	0.44	0.34	9	45	73	91	100
1989	11	<0.05	0.4	0.15	<0.05	64	73	100	100	100
86-92	82	<0.05	3.34	0.19	0.06	61	84	93	96	100

Table 23 Short period exposures of service station* attendants (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Sampling time (min)	0.1	0.3	0.5	1.0	5.0
1986	5	<0.05	1.63	0.67	2 - 5	40	40	40	80	100
86-92	5	<0.05	1.63	0.67	2 - 5	40	40	40	80	100

Note:
* The type of service station was unspecified

Table 24 12-Hour TWA measurements in service station shops** (ppm)

Year	Number of samples	Benzene exposures				% of measurements at or below				
		min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
86-92	24	<0.05	0.05	<0.05	<0.05	100	100	100	100	100

Note:
** Fixed position monitoring indicative of the occupational exposure of the service station cashiers.

Table 25 8-Hour TWA exposures of miscellaneous activities (ppm)

Year	Process	Number of samples	Benzene exposures				% of measurements at or below				
			min	max	Arithmetic mean	Geometric mean	0.1	0.3	0.5	1.0	5.0
1990	Laboratory	26	<0.05	0.3	<0.05	<0.05	85	100	100	100	100
1991	Laboratory	80	<0.05	0.3	0.07	<0.05	85	100	100	100	100
1992	Laboratory	38	<0.05	1.1	0.14	<0.05	71	84	95	97	100
1986	Engine test house	1	1.28	1.28	1.28	1.28	0	0	0	0	100
1987	Engine test house	6	0.05	0.47	0.23	0.17	33	67	100	100	100
1988	Engine test house	8	0.05	0.6	0.22	0.17	38	88	88	100	100
1991	Engine test house	6	<0.05	1	0.27	0.11	67	67	83	100	100
1990	Used barrel cleaning	13	<0.05	0.7	0.17	0.06	69	77	92	100	100
1991	Used barrel cleaning	12	<0.05	0.2	0.06	<0.05	92	100	100	100	100
1992	Used barrel cleaning	3	0.2	0.4	0.30	0.29	0	67	100	100	100
86-92	All	193	<0.05	1.28	0.11	0.04	76	92	97	99	100

Table 26 Short period exposures of miscellaneous activities (ppm)

Year	Process	Number of Samples	Benzene exposures				% of measurements at or below				
			min	max	Arithmetic mean	Sampling time (min)	0.1	0.3	0.5	1.0	5.0
1988	Engine test house	2	<0.05	0.31	0.16	75 - 140	50	50	100	100	100
1991	Engine test house	3	0.06	1.97	0.94	15 - 50	33	33	33	67	100
86-92	All	5	<0.05	1.97	0.63	15 - 140	40	40	60	80	100