Scand J Work Environ Health. 2011;37(2):147–158. doi:10.5271/sjweh.3128

Airborne concentrations of benzene for dock workers at the ExxonMobil refinery and chemical plant, Baton Rouge, Louisiana, USA (1977–2005) [1]

by Thomas E Widner, MS, Shannon H Gaffney, PhD,[2] Julie M Panko, BS, Kenneth M Unice, MS, Amanda M Burns, MSPH, Marisa Kreider, PhD, J Ralph Marshall, MS, Lindsay E Booher, MS, Richard H Gelatt, MS, Dennis J Paustenbach, PhD

1 Supplementary tables A–D

2 Corresponding author [e-mail: sgaffney@chemrisk.com].

Appendix: Supplemental tables A-D

Table A. Summary statistics for the non-task dataset, by job category, including arithmetic mean and percentiles where appropriate. [NC=not calculated because the proportion of results below the detection limit exceeds the stated percentile or N<10.]

Job title	N	Detection frequency (%)	Benzene concentration (parts per million)						
			Arithmetic mean	5th percentile	25th percentile	50th percentile	75th percentile	95th percentile	Max detected
Dock-specific employees									
Dock connecting crew	179	57	0.30	NC	NC	0.021	0.13	0.92	15
Dock assistant operator	123	27	0.037	NC	NC	NC	0.018	0.14	1.3
Dock controller	3	0	<0.01	NC	NC	NC	NC	NC	NC
Other employees working at docks									
Pipefitter/welder	40	23	0.037	NC	NC	NC	NC	0.13	0.67
Electrician	6	0	<0.06	NC	NC	NC	NC	NC	NC
Instrument technician	3	33	0.0084	NC	NC	NC	NC	NC	0.018
Machinist	2	0	<0.02	NC	NC	NC	NC	NC	NC
Maintenance	1	0	<0.05	NC	NC	NC	NC	NC	NC
Contract workers									
Contractor – tankerman	38	95	1.4	0.010	0,030	0.31	1,0	6.4	9.8
Contractor – pipefitter	7	0	<0.02	NC	NC	NC	NC	NC	NC
Contractor – gauging/inspection	4	75	0.025	NC	NC	NC	NC	NC	0.070
Summary									
Dock employees	305	44	0.19	NC	NC	NC	0.088	0,59	15
Other employees	52	19	0.030	NC	NC	NC	NC	0.12	0.67
Contract workers	49	80	1.1	NC	0.016	0.13	0.65	5,9	9.8
All non-task samples	406	45	0.28	NC	NC	NC	0.10	0.94	15

Table B. Summary statistics for the non-task dataset, for samples for which loading berth was reported, including arithmetic mean and percentiles where appropriate. [NC=not calculated because the proportion of results below the detection limit exceeds the stated percentile or N<10].

Job title	N	Detection frequency (%)	Benzene concentration (parts per million)						
			Arithmetic mean	5th percentile	25th percentile	50th percentile	75th percentile	95th percentile	Max detected
Berth 4 – gasoline/benzene barge loading									
Dock connecting crew	28	71	0.71	NC	NC	0.030	0.33	5.0	6.3
Dock assistant operator	15	27	0.026	NC	NC	NC	0.010	0.13	0.14
Contractor – tankerman	1	100	9.8	NC	NC	NC	NC	NC	9.8
Berths 1, 2, 3, and 5									
Dock connecting crew	19	32	0.019	NC	NC	NC	0.022	0.082	0.10
Dock assistant operator	76	26	0.047	NC	NC	NC	0.023	0.16	1.3
Dock controller	1	0	<0.01	NC	NC	NC	NC	NC	NC
Contractor – tankerman	8	75	0.12	NC	NC	NC	NC	NC	0.36

Table C. Summary statistics for the task-related dataset, including arithmetic mean and percentiles where appropriate. [NC=not calculated because the promotion of results below the detection limit exceeds the stated percentile or N<10].

Task	Jobs	N	Detection frequency (%)	Benzene concentration (ppm)						
				Arithmetic mean	5th percentile	25th percentile	50th percentile	75th percentile	95th percentile	Max detected
Disconnect cargo hoses	Dock connecting crew	134	64	11	NC	NC	0.46	4.9	64	179
Connect cargo hoses	Dock connecting crew	87	38	0.56	NC	NC	NC	0.36	1.8	14
Gauge cargo vessel tanks	Contractor – gauging; Contractor – tankerman; Dock connecting crew	65	29	3.2	NC	NC	NC	0.56	6.4	99
Sample cargo vessel product	Dock connecting crew	34	91	8.3	NC	0,13	0.49	3.9	40	119
Repair undrained equipment	Pipefitter/welder; Instrument technician	15	67	2.9	NC	NC	0.18	2.5	12	23
Load benzene/gasoline barge	Contractor – tankerman	3	100	71	NC	NC	NC	NC	NC	130
Load sulfidic caustic barge	Contractor – tankerman; Dock assistant operator	4	25	0.13	NC	NC	NC	NC	NC	0.36
Inspect hose disconnection	Dock assistant operator	1	100	8.7	NC	NC	NC	NC	NC	8.7
All task samples [a]	All job titles	343	54	6.6	0.0073	0.065	0.26	1.7	26	179

[a] Does not include 54 samples where task could not be assigned

Table D.1. *Non–task sampling.* Airborne benzene concentrations from published studies of marine handling of petroleum products and petrochemicals [O=open system; C=closed system; NS=Not specified; NV=no vapor recovery; TD=tanker deck; ND=not detected.]

Row	Location	Period	Worker type	Activity	Open or closed	Averaging time (minutes)	N	Benzene concentration (ppm)				
								Arith-metic mean	SD	Geo-metric mean	Geo-metic SD	Range of results
Runion & Scott ,1985 (1)												
1	US	1978–83	Chemical	Barge loading	NS	≥240	36	2.31	1.3	2.00	1.7	0.10–10.0
2	US	1978–83	Petroleum	Ship/barge benzene	NS	≥240	90	13.2	67.4	1.30	9.2	<0.10–>10
3	US	1978–83	Petroleum	Ship/barge benzene, mixed	NS	≥240	63	5.10	49.6	0.09	20.0	<0.10–>10
4	US	1978–83	Petroleum	Ship/barge other	NS	≥240	457	1.22	6.2	0.12	9.2	<0.10–>10
Christian & Eyres, 1986 (2)												
5	Europe	1977–85	Deck crew	Barge loading	C	480	12	2.4	·	·	·	0.1–11.7
6	Europe	1977–85	Deck crew	Barge loading	O	480	19	8.8	·	·	·	0.6–61.0
7	Europe	1977–85	Deck crew	Load coastal vessels	C	480		·	·	·	·	0.1–0.2
8	Europe	1977–85	Deck crew	Load coastal vessels	O	480		·	·	·	·	0.2–14
9	Europe	1977–85	Deck crew	Load estuarial vessels	C	480		·	·	·	·	0.2–2.3
10	Europe	1977–85	Deck crew	Load estuarial vessels	O	480		·	·	·	·	3–54
11	Europe	1977–85	Jetty staff	Marine loading	NS	480	12	·	·	·	·	0.2–2.5
12	Europe	1977–85	Jetty staff	Marine loading	NS	480	51	0.45	·	·	·	0.02–3.10
13	Europe	1977–85	Jetty staff	Marine loading	O	480	4	0.8	·	·	·	0.4–1.6
14	Europe	1977–85	Deck crew	Ship loading	C	480	9	1.5	·	·	·	0.1–7.3
15	Europe	1977–85	Deck crew	Ship loading	O	480	18	4.5	·	·	·	0.1– 21.0
16	Europe	1977–85	Deck crew	Marine loading	C	480	34	1.053 [a]	·	·	·	0.04–6.5
17	Europe	1977–85	Jetty staff	Marine loading	C	480	31	0.537 [b]	·	·	·	0.06–9.5
18	Europe	1977–85	Deck crew	Marine loading	O	480	138	5.39 [c]	·	·	·	0–62
Halder et al, 1986 (3)												
19	US	-	Marine loading	Ship/barge loading	O	480	11	0.7	1.8	0.2	5.5	0.0–6.1
Coker et al, 1987 (4)												
20	Europe	1984–85	Deck crew	Barge loading	C	480	11	1.47	3.07	0.044	54.5	··
21	Europe	1984–85	Deck crew	Ship loading	C	480	9	1.44	2.16	0.69	4.2	··
22	Europe	1984–85	Deck crew	Loading of ships	O	480	8	0.47	0.50	0.41	4.1	··
23	Europe	1984–85	Jetty staff	Loading supervision	NS	480	21	0.47	0.56	0.13	4.6	··
Kawai et al, 1990 (5)												
24	Japan	~1988	Auxiliary worker	Load benzene/unload petroleum	NS	~480	3	1.91	0.79	1.80	1.6	1.1–2.67
25	Japan	~1988	Delivery worker	Connect/disconnect benzene hose	NS	250	1	0.1	·	·	·	· ·
26	Japan	~1988	Delivery worker	Unload petroleum/load product	NS	489 ± 61	8	0.19	0.09	0.15	2.4	0.3–0.29
Bates et al, 1994 (6)												
27	Europe	1986–92	Deck crews	Marine loading	NS	480	19	0.72	·	0.28	·	<0.05–3.56
28	Europe	1986–92	Jetty staff	Marine loading	NS	480	92	1.98	·	0.09	·	<0.05–83.1
Moen et al, 1995 (7)												
29	Norway/US	-	TD crew	Load/unload crude oil	NS	480	14	·	·	·	·	ND–0.47
Moen et al, 1995 (8)												
30	Norway	-	TD crew	Load/unload oil products	NS	≥180	5	0.07	·	·	·	<0.01–0.21
Armstrong et al, 1996 (9)												
31	US	-	Deck attendant	NS	NS	Estimate [d]	26	0.25	·	·	·	··
Lewis et al, 1997 (10)												
32	UK	-	Jetty operator	NS	NS	480	14	0.37	0.25	·	·	0.09 – 0.92
Clayden et al, 2000 (11)												
33	UK	1993–98	Deck crew	Ship loading	C	≥480	2	0.176	·	·	·	0.160–0.188
34	UK	1993–98	Deck crew	Ship loading	O	≥480	41	0.176	·	·	·	0.025–1.69
35	UK	1993–98	Deck crew	Ship unloading	NS	≥480	32	0.160	·	·	·	0.007–1.16
36	UK	1993–98	Jetty staff	Supervise, sample, handle hoses	NS	≥480	46	0.116	·	·	·	0.0072–0.533
Glass et al, 2000 (12)												
37	Australia	-	Jetty crew	NS	NS	Estimate [d]	23 [e]	0.41	0.71	·	·	··
Carter et al, 2002 (13)												
38	Europe	2001	Jetty crew	Connect/disconnect loading arms, sampling, supervise	NV	≥480	2	0.0313	·	·	·	0.0313–0.0313
39	Europe	2000	Jetty crew	NS	NS	≥480	2	0.0313	·	·	·	0.0313–0.0313

[a] Weighted average of three different studies reported in Verma & Tombe (14): Europe(N=6, mean 0.5). Finland (N=11, mean 0.2). UK (N=17, mean 1.8).
[b] Weighted average of three different studies reported in Verma & Tombe (14): Europe (N=2, mean 0.3). Finland (N=18, mean 0.8). UK (N=11, mean 0.15).
[c] Weighted average of three different studies reported in Verma & Tombe (14): UK (N=65, mean 2.2). Norway (N=51, mean 9.8). Germany (N=22, mean 4.6).
[d] Base estimate includes short-term and full shift data of unspecified duration.
[e] Activity estimates were determined for 23 activities defined by the time-weighted average of tasks included in the activity that was performed. These estimates were not normalized to an 8–hour time-weighted average.

Table D.2. *Task sampling*. Airborne benzene concentrations from published studies of marine handling of petroleum products and petrochemicals [O=open system; C=closed system; NS=Not specified; NA=not available.]

Location	Period	Worker type	Activity	Open or closed	Averaging time (minutes)	N	Benzene concentration (parts per million)	
							Arithmetic mean	Range of results
Cheremisinoff et al, 1979 (15)								
US	-	Barge crew	At vent line	NS	NS	1	1400	..
US	-	Barge crew	Connecting load line	NS	NS	1	3	..
US	-	Barge crew	Disconnecting load line	NS	NS	1	10	..
US	-	Barge crew	Downwind	NS	NS	1	30	..
US	-	Barge crew	Gauging, breathing zone	NS	NS	1	130	..
US	-	Barge crew	Loading tank	NS	NS	1	12	..
US	-	Barge crew	Making connections	NS	NS	1	10	..
US	-	Barge crew	Not specified	NS	NS	1	1	..
US	-	Barge crew	Ullage port	NS	NS	1	600	..
Berlin, 1985 (16)								
Sweden	-	Coast tanker crew	Gasoline handling	NS	45	.	6.56	0.33–22.8
Nordlinder & Ramnas, 1987 (17)								
Sweden	-	Deck crew	Duties other than loading	O	5–15	3	3.01	0.846–6.27
Sweden	-	Ship-loading staff	Manual sounding during gasoline loading	O	5–15	8	33.5	5.96–114
Spear et al, 1987(18)								
US	1978–84	NS	Barge transfer operations	NS	5–30	18	NA [a]	..
Moen et al, 1988 (19)								
Norway	-	Tanker crew	Loading benzene products	NS	3–8	4	155 [b]	15–374
Moen et al, 1993/1994 (20)								
Norway	-	Tanker deck crew	Loading gas oil	O	50	3	.	..
Bates et al, 1994 (6)								
Europe	1989	Deck crew	Marine loading	NS	15–70	6	0.87	<0.05–3.44
Europe	1986–92	Jetty staff	Marine loading	NS	10–83	28	0.32	<0.05–3.08
Moen et al, 1995 (7)								
Norway	-	Tanker deck crew	Load/unload oil products	NS	<180	20	0.3085	<0.01–1.15
Armstrong et al, 1996 (9)								
US	-	Marine pumpman	NS	NS	Estimate [c]	3	1.1	..
Clayden et al, 2000 (11)								
UK	1993–98	Deck crew	Ship loading	O	<60	4	0.072	0.072–0.094
UK	1993–98	Deck crew	Ship unloading	NS	<60	2	0.219	0.072–0.376
UK	1993–98	Jetty staff	Supervise, transfers, sample, handle hoses	NS	<60	24	0.248	0.0721–1.818
Davenport et al, 2000 (21)								
US	1996	Inspectors on gasoline barges	Various	NS	15–30	43	.	<0.1–0.5
Glass et al, 2000 (12)								
Australia		Barge-loading crew	Loading gasoline	NS	Estimate [d]	20	2.21	..
Australia		Deck crew	Ship dip/gauge	NS	Estimate [d]	23	5.41	..
Australia		Jetty crew	Ship loading/unloading	NS	Estimate [d]	77	0.11	..
Glass et al, 2001 (22)								
Various		Barge-loading crew	Loading gasoline	NS	Validation data [e]	700	2.30	..
Various		Transfer crew	Ship loading/unloading	NS	Validation data [e]	>304	0.51	..
Carter et al, 2002 (13)								
Europe	1999	Deck crew	Connecting product-free line	NS	29	2	0.188	0.188–0.188
Europe	1999	Jetty crew	Connecting product-free line	NS	20–29	2	0.1565	0.125–0.188
Europe	1999	Deck crew	Disconnecting	NS	36–142	2	0.0627	0.0627–0.0627
Europe	1999	Jetty crew	Disconnecting	NS	36–136	2	0.047	0.0313– 0.0627
Europe	1999	Deck crew	Loading	NS	121–157	2	0.0470	0.0313– 0.0627
Europe	1999	Jetty crew	Loading	NS	121–155	2	0.0313	0.0313–0.0313

[a] 95% of values were above 0.5; 72% above 5.0; 56% above 10.0.
[b] Geometric mean of 87 parts per million was also reported.
[c] Base estimate determined by extrapolation of short term hydrocarbon data of unspecified duration.
[d] The base estimate for these tasks includes personal samples of short- (<180 minutes) and long-term (≥180 minutes) sampling times. The inclusion criteria was that samples not be normalized to an 8-hour time-weighted average.
[e] Data sets include data already presented in this table, including references 1, 2, 6, 11, 13–15, and 23. These data sets were used to validate the base estimate.

References (Appendix)

1. Runion HE, Scott LM. Benzene exposure in the United States 1978-1983: An overview. Am J Ind Med. 1985;7:385-93.
2. Christian F, Eyres AR. Review of European oil industry benzene exposure data. The Hague, Netherlands: Conservation of Clean Air and Water in Europe (CONCAWE); 1986. CONCAW Report No 3/86.
3. Halder CA, Van Gorp GS, Hatoum NS, Warne TM. Gasoline vapor exposures. Part I. Characterization of workplace exposures. Am Ind Hyg Assoc J. 1986;47:164-72.
4. Coker DT, Christian F, Claydon MF, Irvine D, Portail C, Tindle P, et al. A survey of exposures to gasoline vapour. The Hague, Netherlands: Conservation of Clean Air and Water in Europe (CONCAWE). 1987. CONCAWE Report No 4/87.
5. Kawai T, Yamaoka K, Uchida Y, Ikeda M. Benzene exposure in a Japanese petroleum refinery. Toxicol Lett. 1990;52:135-9.
6. Bates K, Christian F, Civai M, Claydon M, Dreetz C, Molyneux M, et al. Review of European oil industry benzene exposure data (1986-1992). Brussels, Belgium: Conservation of Clean Air and Water in Europe (CONCAWE); 1994. CONCAWE Report No 7/94.
7. Moen BE, Hollund BE, Berntsen M, Flo R, Kyvik KR, Riise T. Occupational exposure of deck crews to carcinogenic agents on crude oil tankers. Am J Ind Med. 1995;27:555-64.
8. Moen BE, Hollund BE, Berntsen M, Flo R, Kyvik KR, Riise T. Exposure of the deck crew to carcinogenic agents on oil product tankers. Ann Occup Hyg. 1995;39:347-61.
9. Armstrong TW, Pearlman ED, Schnatter AR, Bowes SM, 3rd, Murray N, Nicolich MJ. Retrospective benzene and total hydrocarbon exposure assessment for a petroleum marketing and distribution worker epidemiology study. Am Ind Hyg Assoc J. 1996;57:333-43.
10. Lewis SJ, Bell GM, Cordingley N, Pearlman ED, Rushton L. Retrospective estimation of exposure to benzene in a leukaemia case-control study of petroleum marketing and distribution workers in the United Kingdom. Occup Environ Med. 1997;54:167-75.
11. Clayden MF, Ahlberg RW, Carter M, Dmytrasz BA, Fries HH, Gennart JP, et al. A review of European gasoline exposure data for the period 1993-1998. Brussels, Belgium: Conservation of Clean Air and Water in Europe (CONCAWE); 2000. CONCAWE Report No 2/00.
12. Glass DC, Adams GG, Manuell RW, Bisby JA. Retrospective exposure assessment for benzene in the Australian petroleum industry. Ann Occup Hyg. 2000;44:301-20.
13. Carter M, Clayden M, Giacopetti D, Money C, Pizzella G, Margary A, et al. A survey of European gasoline exposures for the period 1999-2001. Brussels, Belgium: Conservation of Clean Air and Water in Europe (CONCAWE); 2002. CONCAWE Report No 9/02.
14. Verma DK, des Tombe K. Measurement of benzene in the workplace and its evolution process, Part I: Overview, history, and past methods. Am Ind Hyg Assoc J. 1999;60:38-47.
15. Cheremisinoff PN, Morresi AC. Benzene in the environment. In: Cheremisinoff PN, editor. Benzene, basic and hazardous properties. New York, NY: Marcel Dekker Inc; 1979:117-60.
16. Berlin M. Low level benzene exposure in Sweden: Effect on blood elements and body burden of benzene. Am J Ind Med. 1985;7:365-73.
17. Nordlinder R, Ramnas O. Exposure to benzene at different work places in Sweden. Ann Occup Hyg. 1987;31:345-55.
18. Spear RC, Selvin S, Schulman J, Francis M. Benzene exposure in the petroleum refining industry. Appl Ind Hyg. 1987;2.
19. Moen BE, Riise T, Todnem K, Fossan GO. Seamen exposed to organic solvents. A cross-sectional study with special reference to the nervous system. Acta Neurol Scand. 1988;78:123-35.
20. Moen BE, Hollund BE, Berntsen M, Flo R, Kyvik KR, Riise T. Chemical exposure of deck crew on product tankers loading the cargo with the hatches open. Bull Inst Marit Trop Med Gdynia. 1993/1994;44-45(1-4):65-73.
21. Davenport AC, Glynn TJ, Rhambarose H. Coast Guard exposure to gasoline, MTBE, and benzene vapors during inspection of tank barges. Am Ind Hyg Assoc J. 2000;61:865-72.
22. Glass DC, Gray CN, Adams GG, Manuell RW, Bisby JA. Validation of exposure estimation for benzene in the Australian petroleum industry. Toxicol Ind Health. 2001;17:113-27.
23. American Petroleum Institute. An exposure assessment for marketing and marine distribution workers in the petroleum industry with potential exposure to gasoline. Washington, DC: American Petroleum Institute; 1994. Report No: 45552.