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Regular short-term peak exposure to benzene in the supply chain of petroleum products

Review of exposure and existing industry practices for targeted risk management

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Regular short-term peak exposure to benzene in the supply chain of petroleum products

Review of exposure and existing industry practices for targeted risk management

Prepared by Caesar Consult Nijmegen

D. Huizer
J.G.M. van Rooij

for the Concawe Health Management Group Exposure Assessment Task Force (H/STF-29 – the list below reflects group members and positions held at the time of the project):

J. Urbanus (Chair)
G. Pizzella
M. Banton
T. Dudzina
R. Tibaldi
B. Geudens
R. Jones

H. Ketelslegers (Concawe Science Executive, Health)
M. Trantallidi (Concawe Research Associate, Health)

Brussels
May 2018

ABSTRACT

Exposures to benzene and benzene-containing products are generally well controlled within industry. However, given the recent findings of a possible association of myelodysplastic syndrome with exposure levels that approach some Short Term Exposure Limits, an evaluation of jobs/tasks across the supply chain for petroleum products, which may be associated with similar exposure levels, was undertaken. Review and summarisation of existing industry practices and control strategies in place for regular short-term peak exposures to benzene may support the formulation of best practices in these areas.

In this context, benzene exposure data, from the year 2000 onwards, were collected from Concawe member companies and sector reports, representing primarily the following work areas: refining, road tanker terminals, rail car terminals, and ship terminals. The exposure data were used to characterize tasks with potential short-term, regular, exposure to benzene vapor across the supply chain for petroleum products.

For the majority of tasks the 95th percentile of the benzene exposure levels was found to be generally low compared to existing reference values (for example TLV ACGIH, UE L.V or from literature). Only for a limited number of tasks and conditions, i.e. sample collection at road terminals (open system), tank dipping, and handling of hoses at ship terminals (products with high benzene content; >20%) measured exposures may occasionally peak. However, the use of proper respiratory protective equipment, as incorporated in benzene control programs in many member companies and also reflected in the contextual data as provided, will protect these workers against adverse health effects.

The collected data was additionally utilized to assess the indicative effect of risk management measures and their effect on the short-term benzene exposure levels. Closed system sampling (refining, products with low benzene content) may reduce the benzene concentration in air by 50-70% in comparison with open sampling. However, data availability is limited and for both conditions, measurements were found below the level of detection. Vapor recovery during top loading may reduce the benzene concentration by 30-70% in comparison with top loading without vapor recovery.

For majority of the analysed tasks, air concentrations were below the applied reference values for benzene. Limitations of this study include the limited coverage of identified tasks in the defined work areas, and the lack of contextual data from the collected measurements.

KEYWORDS

Benzene, short-term exposure, risk management measures, petroleum products

INTERNET

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SUMMARY

Benzene exposure data, from the year 2000 onwards, were collected from Concawe member companies and sector reports. The exposure data were used to characterize tasks with potential short-term, regular, exposure to benzene vapor across the supply chain for petroleum products. Approximately 2200 short-term benzene measurements were provided by 8 member companies, representing primarily the following work areas: refining, road tanker terminals, rail car terminals, and ship terminals.

For typical short-term activities such as sample collection, bulk transfer (top loading, bottom loading), equipment maintenance, and laboratory activities, a large number of benzene measurements were retrieved. Descriptive statistical parameters were calculated on task level. When the data allowed, these descriptive parameters were also calculated as a further breakdown of the task by sample duration (3 categories) and benzene content of handled products (5 categories). Additional analyses per work area, job group and process related characteristics, such as the availability of vapour recovery (VR) and closed systems were also performed when significant numbers of measurement results were provided.

For the majority of tasks the 95th percentile of the benzene exposure levels was found to be generally low compared to existing reference values (for example TLV ACGIH, UE L.V or from literature). Only for a limited number of tasks and conditions i.e. sample collection at road terminals (open system), tank dipping, and handling of hoses at ship terminals (products with high benzene content; >20%) measured exposures may occasionally peak. However, the use of proper respiratory protective equipment, as incorporated in benzene control programs in many member companies and also reflected in the contextual data as provided, will protect these workers against adverse health effects.

The collected data was additionally utilized to assess the indicative effect of risk management measures (RMMs) and their effect on the short-term benzene exposure levels. This review was based on a comparison of the average (GM) and 95th percentile of the available measurement data on task level. Although an in-depth analysis was constrained by a lack of contextual information related to the workplace sampling, available measurement data, and little contrast in the applied RMMs across the job sites, the following indicative RMM efficiencies were found:

- *Closed system sampling* (refining, products with low benzene content) may reduce the benzene concentration in air by 50% (based on GM) to 70% (based on 95th percentile) in comparison with open sampling. However, data availability is limited and for both conditions, measurements were found below the level of detection (LOD).

- *Vapor recovery* (VR) during top loading may reduce the benzene concentration by 30% (based on GM) to 70% (based on 95th percentile) in comparison with top loading without vapor recovery.

In conclusion the findings of this study outline measured benzene concentrations in air during regular, short-term activities across the supply chain for petroleum products and the indicative effects of RMMs that are currently in place in the sector. Limitations of this study are the limited coverage of identified tasks in the defined work areas, which prevents a complete picture of exposure throughout the supply chain. Also, the lack of contextual data from the collected measurements limited the data analyses in particular to few exposure determinants, process conditions, and RMMs. For majority of the analysed tasks, air concentrations were below the applied reference values for benzene.

1. INTRODUCTION

Research has suggested that regular, short-term exposures to benzene, defined as at least weekly exposures of 15 - 60 minutes above 3 ppm (10 mg/m^3), may be associated with an increased risk of developing myelodysplastic syndrome (MDS) that includes haematological (blood-related) medical conditions with ineffective production of the myeloid class of blood cells.[1]

It is generally believed that exposures to benzene and benzene-containing products are well controlled within industry. However, given the recent findings of a possible association of MDS with exposure levels that approach some Short Term Exposure Limits (STELs), an evaluation of jobs/tasks across the supply chain for petroleum products, which may be associated with similar exposure levels, was undertaken. Review and summarisation of existing industry practices and control strategies in place for regular short-term peak exposures to benzene may support the formulation of best practices in these areas.

[1] A. Robert Schnatter, Deborah C. Glass, Gong Tang, Richard D. Irons, Lesley Rushton - Myelodysplastic Syndrome and Benzene Exposure Among Petroleum Workers: An International Pooled Analysis. Journal of the National Cancer Institute DOI: 10.1093/jnci/djs411

2. OBJECTIVES

1. Review of published short-term benzene exposure data for tasks across the supply chain for petroleum products.

2. Development of an appropriate template for the collection of existing benzene exposure data from Concawe member companies, with particular focus upon detailed task descriptions, operational conditions and information on risk management measures to create a robust data set.

3. Report measured benzene exposure levels by task, based on data from literature and Concawe member companies.

4. Identify data gaps and situations in which further assessment of benzene exposure levels may be useful.

5. Review the efficiency of control measures in place to reduce benzene exposure levels.

3. METHODS

3.1. COLLECTION AND REVIEW OF MEASURED BENZENE EXPOSURE DATA

Benzene exposure data for jobs and tasks associated with potential for regular, short-term peak exposures to benzene vapor across the supply chain for petroleum products were collected from scientific literature (§3.1.1) and sector reports (§3.1.2). Relevant work areas, job groups, and tasks/activities within the job groups were identified in accordance with the Concawe STF/29 Exposure Assessment Task Force inventory.[2]

3.1.1. Peer-reviewed literature

A base line review of short-term benzene exposure data, published in peer-reviewed literature, was performed, starting from an overview of potentially relevant publications as provided by Concawe. In consultation with the Concawe working group it was decided to consider exposure data that were published from the year 2000 onwards. A total of 25 peer-reviewed publications were reviewed for the collection of relevant short-term benzene exposure data (Appendix 1).

3.1.2. Sector reports

In addition to the peer-reviewed literature, ten Concawe sector reports with potentially relevant exposure data were reviewed (Appendix 1).

3.1.3. Non-published benzene exposure data

To support the collection of non-published benzene exposure data from Concawe member companies, a standardized collection format (MS Excel) was developed and sent out to the members in spring 2015 (Appendix 2).

This 'standardized collection format' addressed information items such as: job/task (e.g. frequency, duration, RMMs), year of measurement, sampling method (sampling media, passive/active sampling), measurement strategy (representative/worst case), type of sampling (personal/stationary), duration of sampling, and the descriptive statistical parameters of the measurement results (i.e. number of samples, number of sampled workers, AM, SD, GM, GSD, Range [3]).

Anonymized data was provided by 8 member companies in the standardized collection format in the second and third quarters of 2015. Issues with data processing and requests for additional information were resolved in cooperation with the member companies via the Concawe secretariat. Also, possible overlap of published peer-reviewed data and data as provided by the members was checked.

In addition to the data that were collected by means of the standardized collection format, one company provided an unpublished report from which data were extracted after translation and data transcription.

3.1.4. Aggregated database with short-term benzene exposure data

All collected data were aggregated into one overall database, containing all exposure data and available contextual information. The database structure is described in Appendix 3.

[2] 'A review of European gasoline exposure data for the period 1993-1998', Concawe Report no. 2/00 (December 2000)
[3] AM = arithmetic mean, SD = standard deviation, GM = geometric mean, GSD = geometric standard deviation, range = minimum and maximum value.

3.2. DATA ANALYSIS OF MEASURED BENZENE EXPOSURE DATA

In order to summarize the collected benzene exposure data for the identified tasks, the quality of the raw data was checked first and (when possible) missing information was retrieved by reviewing data from the same measurement campaign or by consultation of Concawe experts (§3.2.1). Next, descriptive statistical parameters (such as n, GM, GSD) were calculated when not provided and benzene exposure data that were collected from multiple sources were aggregated by benzene content and task duration for each task across all data sources (§3.2.2).

3.2.1. Preparation of raw data (prior to analysis)

Exclusion criteria

Data were excluded for the following reasons: 1) The measurement year was unknown; 2) The measurement year was prior to the year 2000; 3) The measurement year was reported as a range including the year 2000 (e.g. 1998 – 2001) and from which the exact year could not be retrieved; 4) The measurement was source oriented (stationary measurements); 5) The measurement was flagged as 'calamity', 'emergency' or data that were provided with remarks on deviating circumstances.

Literature data

Data from peer-reviewed publications and Concawe sector reports were excluded from the aggregated database due to a large overlap with ´raw data´ as provided by members. Also, for many of the published data the exact year of collection could not be retrieved. Excluding these data reduced the total number of collected exposure measurements in the aggregated database with less than 2%.

Benzene content

In case contextual information on the benzene content of the relevant petroleum products was lacking, the missing data were at first retrieved from the member companies. For the remaining data Concawe experts provided typical benzene content ranges per product. The following categories for benzene content were applied in the data analysis: 0 – 1%, 1 – 5%, 5 – 20% and > 20%. Products for which the benzene content could not be retrieved were classified as 'not available' (N/A). Appendix 4 summarizes the benzene content for all relevant products.

Treatment of data below detection limit (< LOD)

In several cases remarks were added by the member companies indicating that (part of the) results were below detection limit (*censored data*). Only one company (no.2, n=563) provided data that were corrected for LOD. Their method for recalculation of these values by ½ x LOD was followed for all other data points that were reported < LOD and for which the LOD could be retrieved.

Data with high LOD values (i.e. resulting from small sample volumes or short sampling duration) were excluded from further analysis to prevent an artificial skewness in the aggregated data distributions and therewith corresponding calculated statistical parameters. High LOD values were defined as >50% of possible reference values for benzene (3 ppm or 10 mg/m^3 for task durations up to 1 hours and 1 ppm or 3,25 mg/m^3 for task durations above than 1 hour).

Recalculation of units

Exposure data that were provided in ppm were recalculated to mg/m^3 for further analysis based on the molecular weight of benzene (78,11 g/mol) assuming a pressure of 1 atmosphere and room temperature: 1 ppm ≈ 3,25 mg/m^3.

3.2.2. Calculation of descriptive statistics

Aggregating individually reported measurement data

Although member companies were requested to enter only aggregated measurement data on task/activity level in the collection format, in many cases individually reported measurement results (n=1) were provided (over 70% of the reported measurement results). In order to aggregate the individually reported data with the already aggregated data as provided, the following steps were taken:

First, all reported measurement data were arranged according to the Concawe STF/29 Exposure Assessment Task Force inventory and the corresponding data collection format (Work area -> Job Group -> Task-activity -> ID-source ->ID) [see also Appendix 3].

Next, descriptive statistical parameters (n, GM, GSD[4]) were calculated from the individually reported measurements on task/activity-level and grouped by task duration (3 categories, see also §4.1) and benzene content (5 categories, see also §4.1) for each data source, indicated by *ID-source-agg* in the database). Aggregated data based on only two observations were split to individual ID's and treated as described above.

Calculation of missing descriptive statistics

From the aggregated measurement data that were provided by the members, several descriptive statistical parameters were lacking. Descriptive statistical parameters that were required for further analyses but not provided, were estimated per task/activity for each ID-source based on the equations that are presented in Table 1. These equations are described by Lavoue et al. (2007).[5]

Table 1 – Equations for recalculation of descriptive statistical parameters.

Equation	Purpose
$GM = \frac{AM}{\exp\left(\frac{(\ln(GSD))^2}{2}\right)}$	Estimating the GM from the AM and GSD
$GSD = \exp\sqrt{2 \times \ln\left(\frac{AM}{GM}\right)}$	Estimating the GSD from the AM and the GM
$GSD = \exp\left(\frac{(\ln(b) - \ln(\alpha))}{W_{median}}\right)$	Estimating the GSD from the minimum (α) and maximum (b) values of a measurement series
$p95 = GM \times GSD\ GSD^{1,645}$	Estimating the 95th percentile from the GM and GSD

[4] N = number of observations, AM = arithmetic mean, SD = standard deviation, GM = geometric mean

[5] Lavoué J, Bégin D, Beaudry C and Gérin M (2007) Monte Carlo Simulation to Reconstruct Formaldehyde Exposure Levels from Summary Parameters Reported in the Literature. Ann Occup. Hyg. 51: 161-172.

Aggregating data by task

To derive descriptive statistics for each defined task, duration category and benzene content category, multiple data sources (ID-source) with aggregate data and corresponding descriptive statistics were aggregated based on their relative weight following the equations [6] in Table 2. In this equation N is the number of samples in each distribution.

Table 2 – Equations for aggregating distributions based on relative weight

$$\ln\left(GM_{agg}\right) = \left.\sum_{x=1}^{x=n}\left(N_x \cdot \ln(GM_x)\right)\right/ \sum_{x=1}^{x=n} N_x$$

$$\ln\left(GSD_{agg}\right) = \sqrt{\frac{\sum_{x=1}^{x=n}\left(N_x - 1\right)\cdot \ln(GSD_x)^2 + N_x \cdot \ln(GM_x)^2 - 2 \cdot N_x \cdot \ln(GM_x) \cdot \ln\left(GM_{agg}\right) + N_x \cdot \ln\left(GM_{agg}\right)^2}{\left(\sum_{x=1}^{x=n} N_x\right) - 1}}$$

GMagg – aggregated GM; GSDagg – aggregated GSD; n - number of individual distributions; Nx - number of samples in aggregated distribution x.

3.3. EVALUATION OF RISK MANAGEMENT MEASURES EFFICIENCY

The format that was utilised to collect benzene exposure data and corresponding contextual information in a standardized fashion, also contained data fields related to the application of RMMs. This includes local exhaust ventilation (7 categories), dilution ventilation (5 categories), used of personal protective equipment for inhalation (5 categories) and skin (6 categories) and other possible control measures (optional field, free text).

Measurement data from comparable situations with contrasting RMM use were analysed on task level based on descriptive statistical parameters (GM and p95) for measured benzene concentration in air when data allowed.

[6] Examples in: Ragas AM, Huijbregts MA. Evaluating the coherence between environmental quality objectives and the acceptable or tolerable daily intake. Regul Toxicol Pharmacol. 1998 Jun; 27(3):251-64.
And: Rik Oldenkamp, Mark A. J. Huijbregts & Ad M. J. Ragas Uncertainty and variability in human exposure limits – a chemical-specific approach for ciprofloxacin and methotrexate Critical Reviews in Toxicology Vol. 46 , Iss. 3,2016

4. SHORT-TERM BENZENE EXPOSURE IN THE SUPPLY CHAIN OF PETROLEUM PRODUCTS

4.1. AGGREGATED DATABASE WITH MEASURED BENZENE EXPOSURE DATA

The aggregated database with all collected benzene exposure data from member companies contains 2190 unique measurement results that meet the criteria as defined in §3.

As shown in Figure 1 the collected data originates to a large extent (about 80%) from 3 member companies (no. 2, 6, 8).

Figure 1 – Origin of benzene exposure data in the aggregated database by data source.

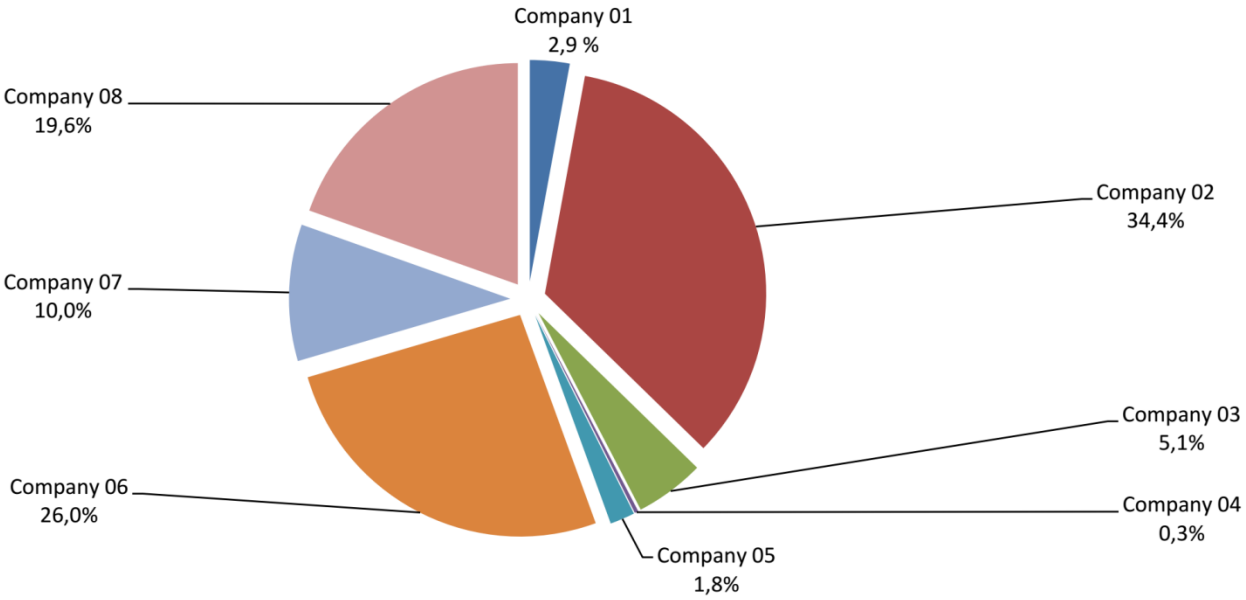
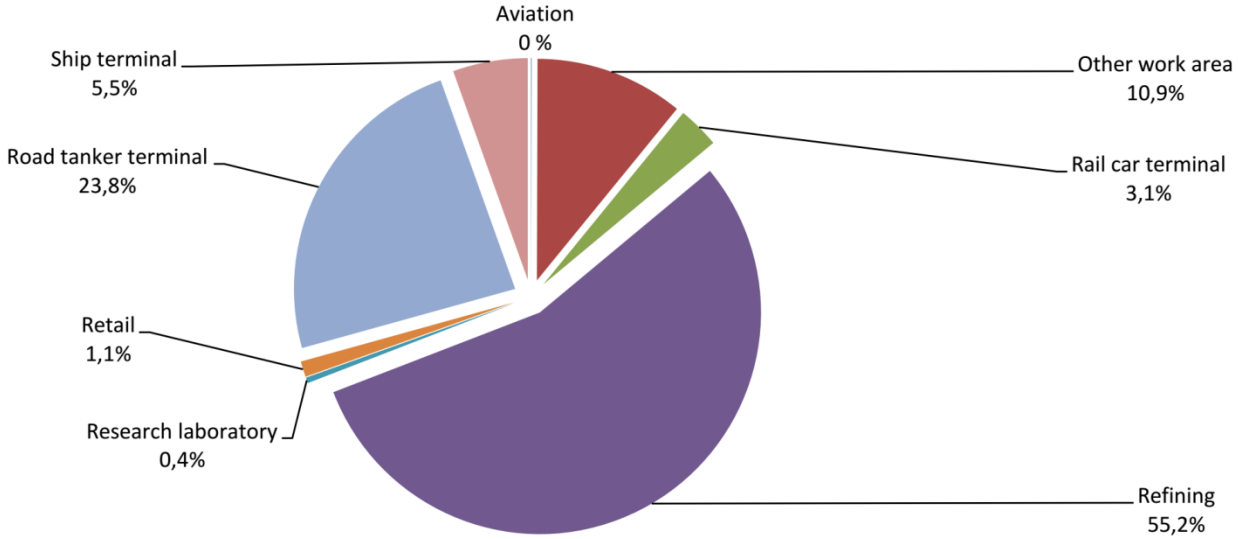


Figure 2 demonstrates that over 50% of the data originate from the work area 'Refining', whereas for other work areas limited data are available (e.g. aviation, retail and research laboratory). One explanation for this lack of data is that some of these work areas are in general privately owned and therefore out of reach for member company sampling programmes.

Figure 2 – Origin of benzene exposure data in the aggregated database by work area.



A breakdown of the data by task (Figure 3) identifies that around 50% of the measurements originate from the task 'Sample collection'. For roughly 20% of the data, task descriptions were not specified or did not meet the descriptions as used in the Concawe inventory ('Other task'). These data were excluded from further analysis in order maintain the quality of the database used in the assessments.

Another 15% of the measurements were collected during the execution of multiple tasks (‘Combination of tasks’) and could therefore not be assigned to a specific task. The corresponding measurement data were analyzed separately in §4.2.

Figure 3 – Origin of benzene exposure data in the aggregated database by task / activity

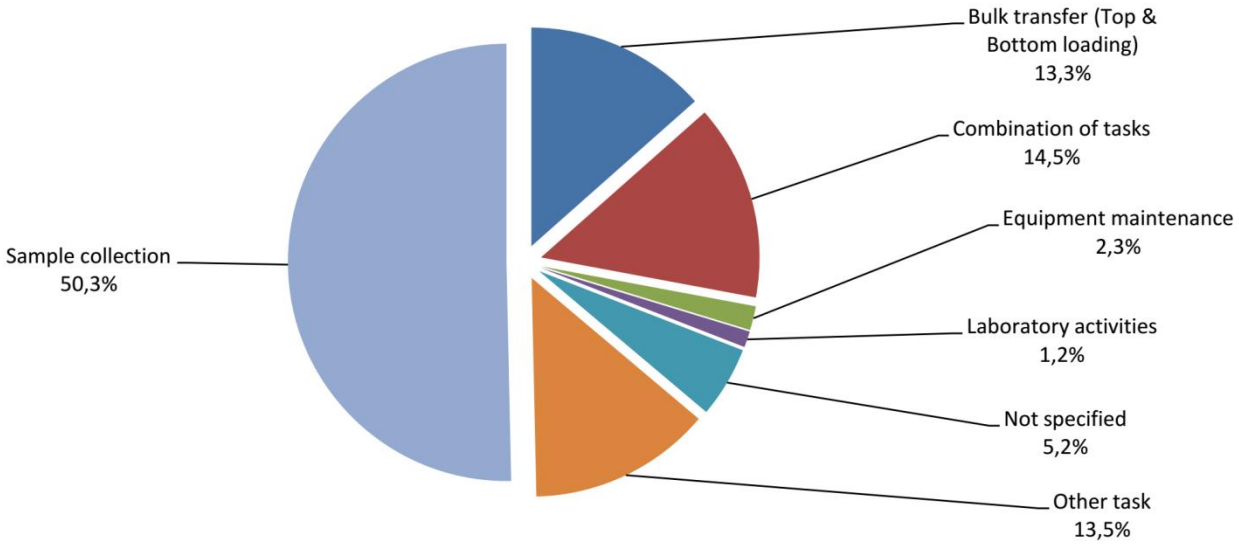
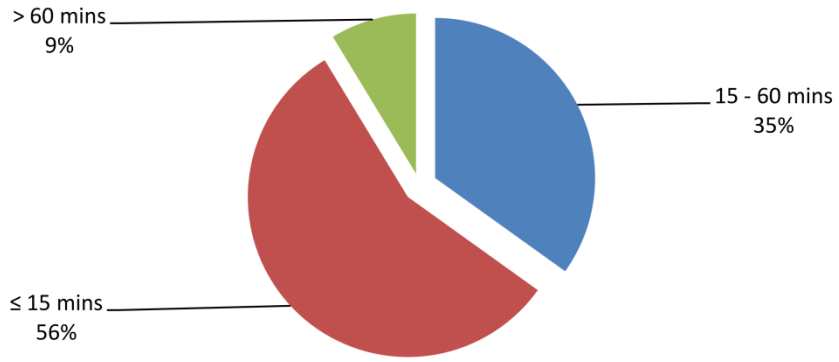


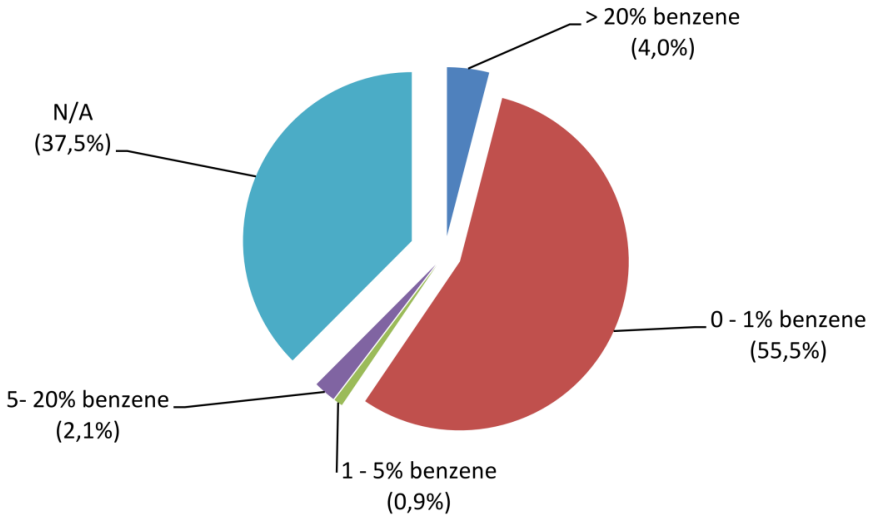
Figure 4 shows that around 90% of the data were collected during activities with a duration up to 1 hour. Over 50% of the data originate from sampling durations up to 15 minutes.

Figure 4 – Origin of benzene exposure data in the aggregated database by task duration category



The collected data cover a petroleum product range with a benzene content up to 100%, although the majority of the data represent the lowest category (0 – 1%) which covers many gasolines and gas oils (Figure 5). For about one third of the data the benzene content could not be retrieved (N/A). The benzene content range per product can be found in Appendix 4.

Figure 5 – Origin of benzene exposure data in the aggregated database by benzene content category



Despite the use of a standardized collection format with various data fields for contextual information, in many cases incomplete or limited contextual data were available. This concerned product related information (product name, concentration benzene in product), use of risk management measures (e.g. use of Local Exhaust Ventilation, Personal Protective Equipment, ventilation), operational conditions (temperature handled product) and sampling related information (sampling method, medium used). Also, information was provided that was not in line with the collection format, i.e. other job group or task descriptions. This lack of information has limited the level of detail of the data analysis.

4.2. OVERVIEW OF BENZENE EXPOSURE LEVELS BY TASK

In the following paragraphs descriptive statistical parameters for short-term benzene exposure concentration in air are presented per task, based on the availability of measurement data. If a sufficient number of measurement data are available per task, breakdowns of the data, such as by work area or by job group, are also presented. On task level statistical parameters were

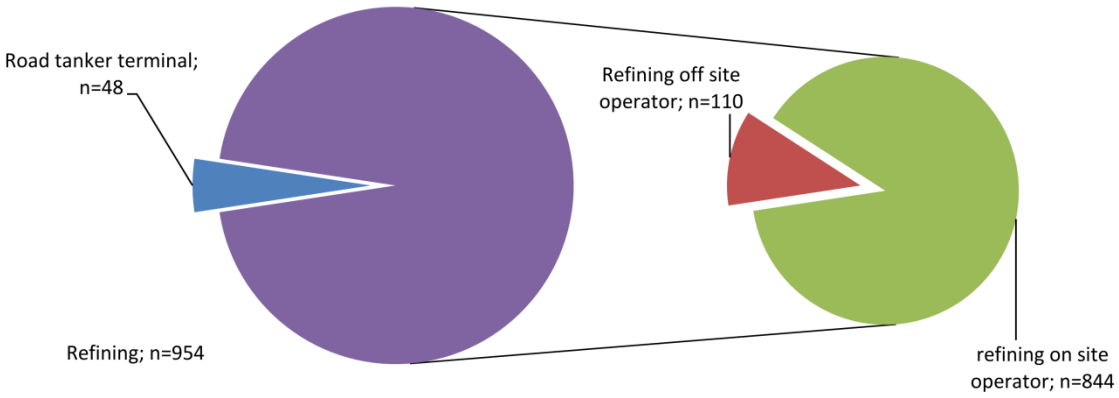
calculated by task duration (3 categories, see also §4.1) and by benzene content (5 categories, see also §4.1) when data allowed.

Descriptive statistical parameters include: K = number of data sources, N = number of measurements, AM = arithmetic mean, SD = standard deviation GM = geometric mean, GSD = geometric standard deviation, min = minimum value, max = maximum value and relevant percentiles such as p5, p25, p75, p90 and p95 (= 95th percentile). A selection of these parameters is presented in the main text of this document. All calculated parameters can be found in Appendix 5.

4.2.1. Sample collection

Approximately, 50% of the available short-term benzene measurement data in this report originate from *sample collection* (Figure 3). For 95% of the sample collection measurements the reported sample duration is shorter than 1 hour and for 70% less than 15 minutes. The majority of these measurements were collected in work area *refining* among *on-site operators* (Figure 6).

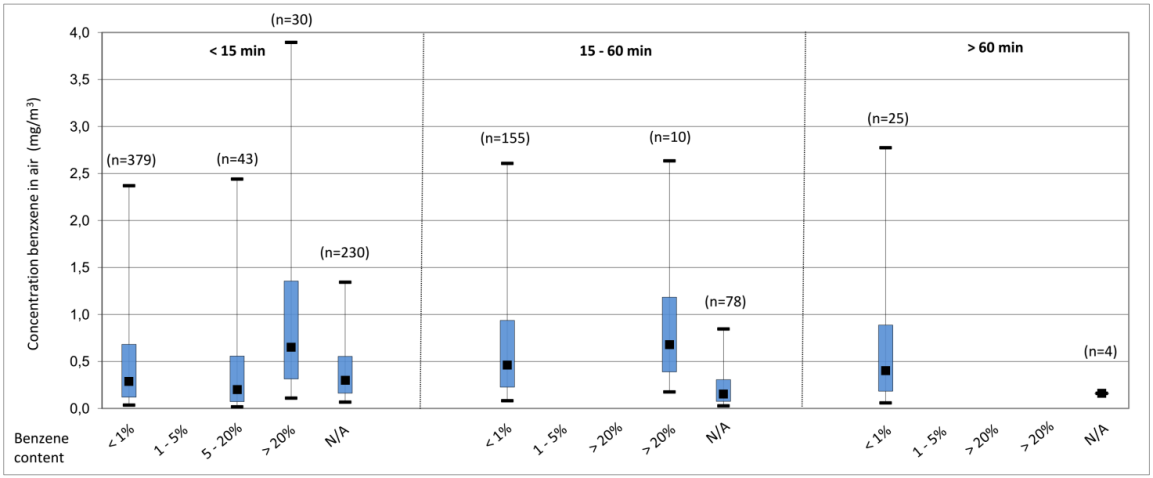
Figure 6 – Task-based benzene measurements in air during sample collection.



In Figure 7 measured benzene concentrations during sampling by both *on site* and *off site operators* in refining are presented. The majority of the data represents sampling of products with low benzene content (0 – 1%), which can be concluded from Table 3.

The average (GM) task-based benzene concentrations for *sample collection* range from 0.15 to 0.68 mg/m^3 and seem to increase with increasing benzene content of sampled products. There is no effect of task duration on the measured concentration.

Figure 7 – Boxplot (p5 – p25 – GM – p75 – p95) representation for task-based benzene concentrations in air during sample collection by on site & off site operators in refining.



For a significant number (N=312) of measurements the benzene content is unknown (N/A). Results for this category show air concentrations that are similar to the lowest benzene category.

Table 3 – Overview of task-based benzene concentrations in air during sample collection by on site & off site operators in refining.

Task Duration	Benzene Content Range	Concentration benzene (mg/m³)						
		K	N	GM	GSD	p75	p90	p95
< 15 min	0 - 1 %	9	379	0,29	3,61	0,68	1,48	2,37
	1 - 5%		*n/a*					
	5 - 20%	6	43	0,20	4,58	0,56	1,40	2,44
	> 20%	1	30	0,65	2,97	1,36	2,62	3,89
	N/A	17	230	0,30	2,49	0,55	0,96	1,34
15 - 60 min	0 - 1 %	7	155	0,46	2,87	0,94	1,77	2,61
	1 - 5%		*n/a*					
	5 - 20%		*n/a*					
	> 20%	2	10	0,68	2,28	1,18	1,95	2,63
	N/A	6	78	0,15	2,85	0,31	0,58	0,84
> 60 min	0 - 1 %	2	25	0,40	3,23	0,89	1,81	2,77
	1 - 5%		*n/a*					
	5 - 20%		*n/a*					
	> 20%		*n/a*					
	N/A	1	4	0,16	1,00	0,16	0,16	0,16

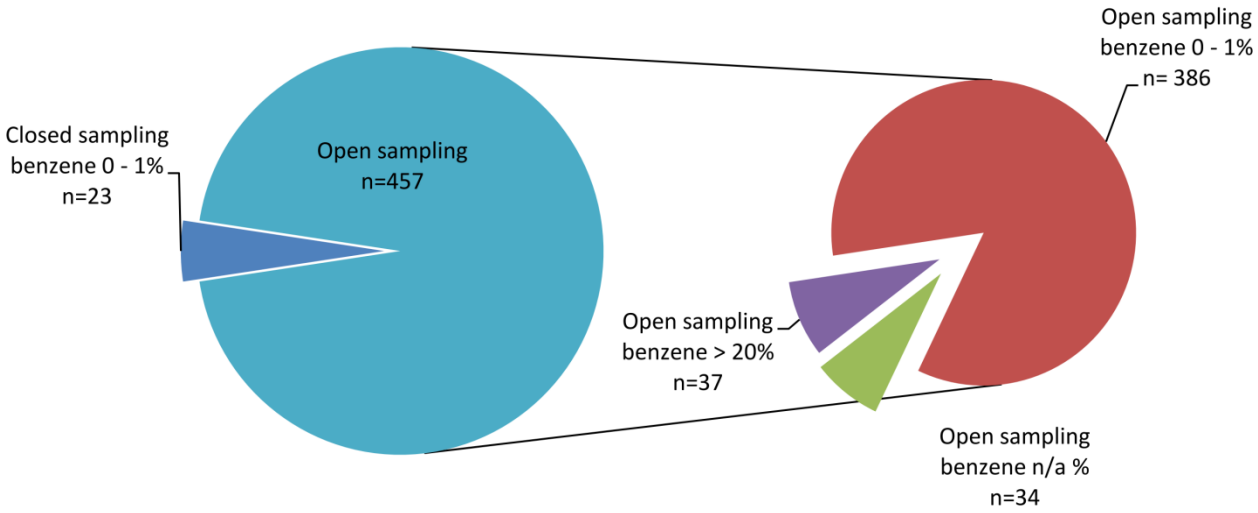
K = number of data sources, N = number of measurements, GM = geometric mean, GSD = geometric standard deviation, p75 = 75th percentile.

Measurement data on sample collection from road tanker terminals only cover products in the 0-1% benzene range and sample duration up to 1 hour. Similar average (GM) concentrations were measured at road tanker terminals in comparison with refining, although 95th percentiles were up to a 5-fold higher as a result of larger variation in these data (Appendix 5).

Open versus closed sampling

The majority of the sampling activities concern 'open' sampling. A total of 32 samples were collected under 'closed' sampling conditions by 2 member companies (n=23 by company x for 0 – 1% benzene content, n=9 by company y for 5 – 20% benzene content). The origin of the sampling data from company x is presented in Figure 8.

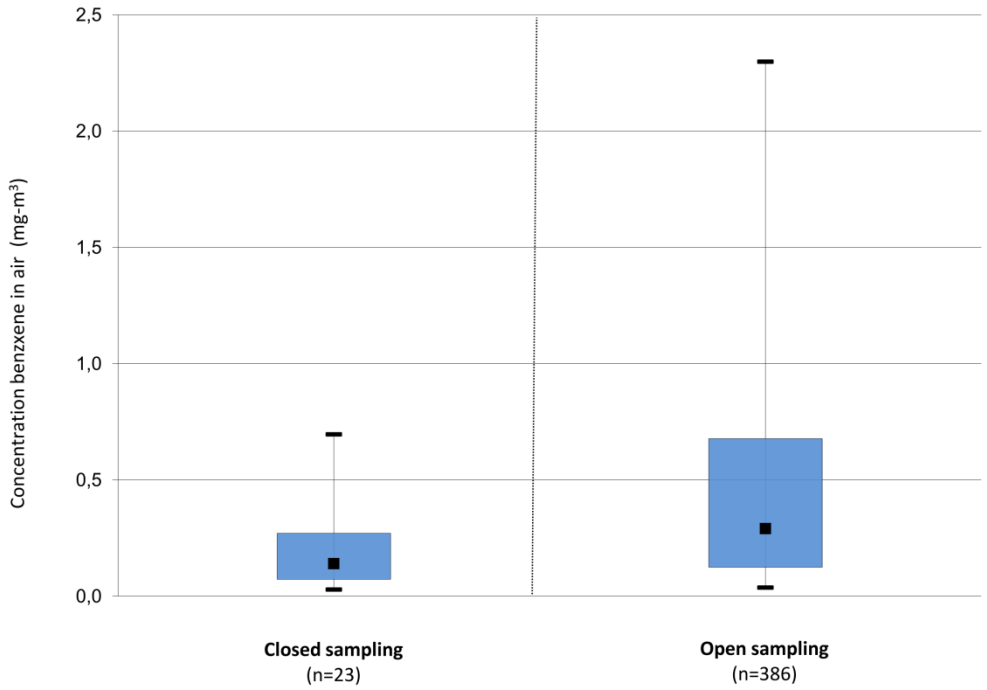
Figure 8 – Task-based benzene measurements in air during sample collection by onsite operators in refining (company x, 0 -1% benzene).



The measured benzene concentrations in air during open versus closed sampling of petroleum products with low benzene content (0 – 1%) by onsite operators in refineries from company 2 are plotted in Figure 9.

Around 60% of both the closed (14 out of 23) and open (231 out of 386) sampling results were below LOD. Average benzene concentrations in air were approximately two times higher for open sampling (GM = 0.29, p95 = 0.70 mg/m^3) in comparison with for closed sampling (GM = 0.14, p95 = 2.30 mg/m^3). Statistical parameters underlying Figure 9 can be found in Appendix 5.

Figure 9 – Box plot (p5 – p25 – GM – p75 – p95) representation for task-based benzene concentrations in air during open versus closed sampling by on site operators in refining (products with 0 - 1% benzene content, company x).

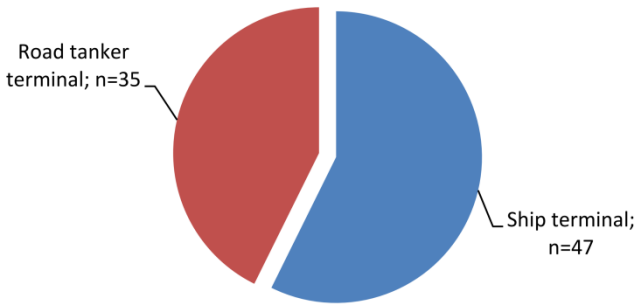


Open versus closed (loop) sampling activities in company y were also performed by *onsite operators*. The benzene content of the handled products ranged from 5 -20%. Similar to the data from company 2 about 50% of the data from both groups (open versus closed sampling) were <LOD. Similar to data from company x measured air concentrations during open sampling (GM = 0.14, p95 = 2.19 mg/m^3) were higher in comparison with closed sampling (GM = 0.04, p95 = 1.32 mg/m^3).

Sampling, tank dipping and handling of hoses (2.3.5)

Data from *sampling, tank dipping and handling of hoses* were available from road tanker terminals (0 – 1% benzene products, < 60 mins duration) and ship terminals (> 20% benzene products, < 15 mins duration) (Figure 10). Measured concentrations at ship terminals are significantly higher (GM = 2.47 mg/m^3) in comparison with road tanker terminals (GM = 0.30 mg/m^3), partly due to the higher benzene content of products handled. Statistical parameters for this task can be found in Appendix 5.

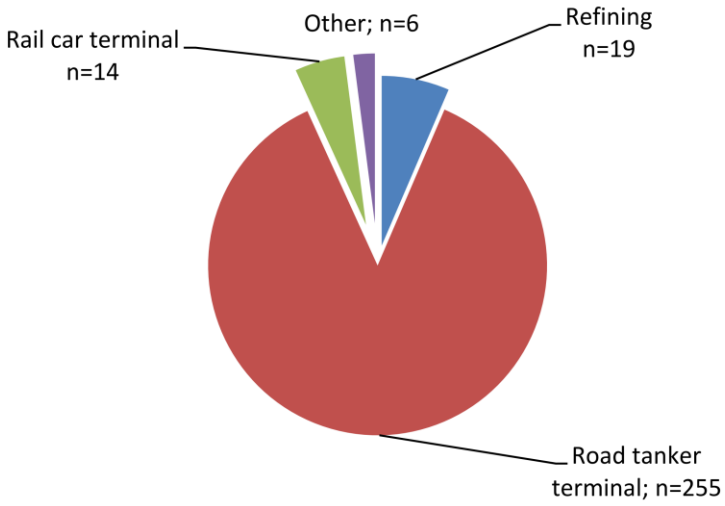
Figure 10 –Task-based benzene measurements in air during sampling, tank dipping, and handling of hoses.



4.2.2. Bulk transfer (bottom loading and top loading)

The majority of the short-term benzene measurements in air during bulk transfer originate from road tanker terminals (Figure 11). For 90% of the measurements the reported sample duration is shorter than 1 hour and for 27% less than 15 minutes. Most air samples (90%) were collected during handling of low benzene petroleum products (0 – 1%). For the remaining 10% of the samples the benzene content is unknown.

Figure 11 –Task-based benzene measurements in air during bulk transfer by work area



Bulk transfer - Bottom loading

Bottom loading accounted for 36% of the measurement data. In most cases vapor recovery (VR) was applied (Figure 12). Measurement data for bottom loading with VR were only available during handling of low benzene petroleum products (0 – 1%).

Figure 12 – Task-based benzene measurements in air – type of bottom loading.

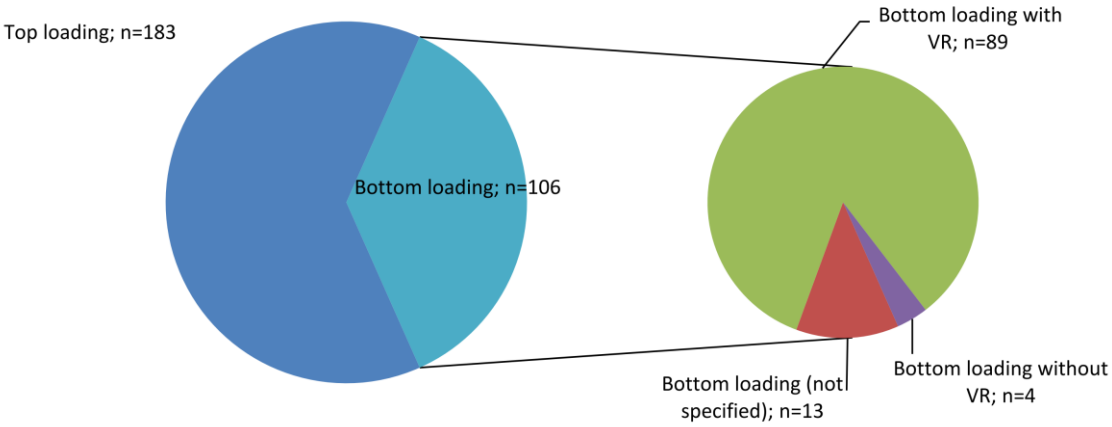


Table 4 presents measurement results from bottom loading with VR at road tanker terminals. The average (GM) benzene concentration in air is 0.29 mg/m^3 for sampling durations between 15 and 60 minutes. For other task durations the number of available data points is too limited to calculate reliable descriptive statistical parameters. The same holds for bottom loading without VR (n=4) and unspecified bottom loading (n=13).

Table 4 – Overview of task-based benzene concentrations in air – bottom loading with VR at road tanker terminals.

task duration	benzene content range	K	N	Concentration benzene (mg/m^3) GM	GSD	p75	p90	p95
< 15 min	0 - 1 %	2	6	0,20	1,58	0,27	0,36	0,42
15 - 60 min	0 - 1 %	10	57	0,29	2,86	0,59	1,12	1,65
> 60 min	0 - 1 %	1	4	0,04	5,88	0,12	0,35	0,66

K = number of data sources, N = number of measurements, GM = geometric mean, GSD = geometric standard deviation, p75 = 75th percentile.

The majority of measurement data from bottom loading with VR (15 - 60 min duration, 0 - 1% benzene) originate from 3 companies. For two of these companies measured average (GM) benzene concentrations are well below 1 mg/m^3 (0,24 mg/m^3 and 0,37 mg/m^3), whereas the average concentration for the other company was significantly higher (4,69 mg/m^3).

The data for this other company (n=11) was viewed as not representative and excluded from further analyses. Despite the data were checked for any reported deviating circumstances, a lack of contextual information prevented a detailed analysis on the cause of the differences.

Bulk transfer - Top loading

Top loading accounts for about two third of the measurement data (Figure 13). Sufficient data are available per top loading type to calculate descriptive statistical parameters (Table 5 and Figure 14). Similar to bottom loading only data from handling of low benzene petroleum products (0 – 1%) are available.

Figure 13 – Origin of task-based benzene concentrations in air – type of top loading.

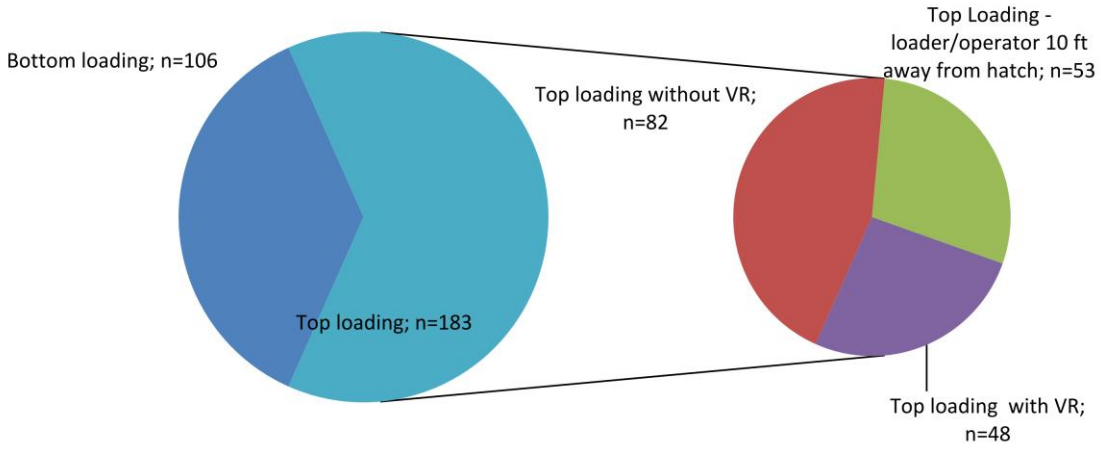
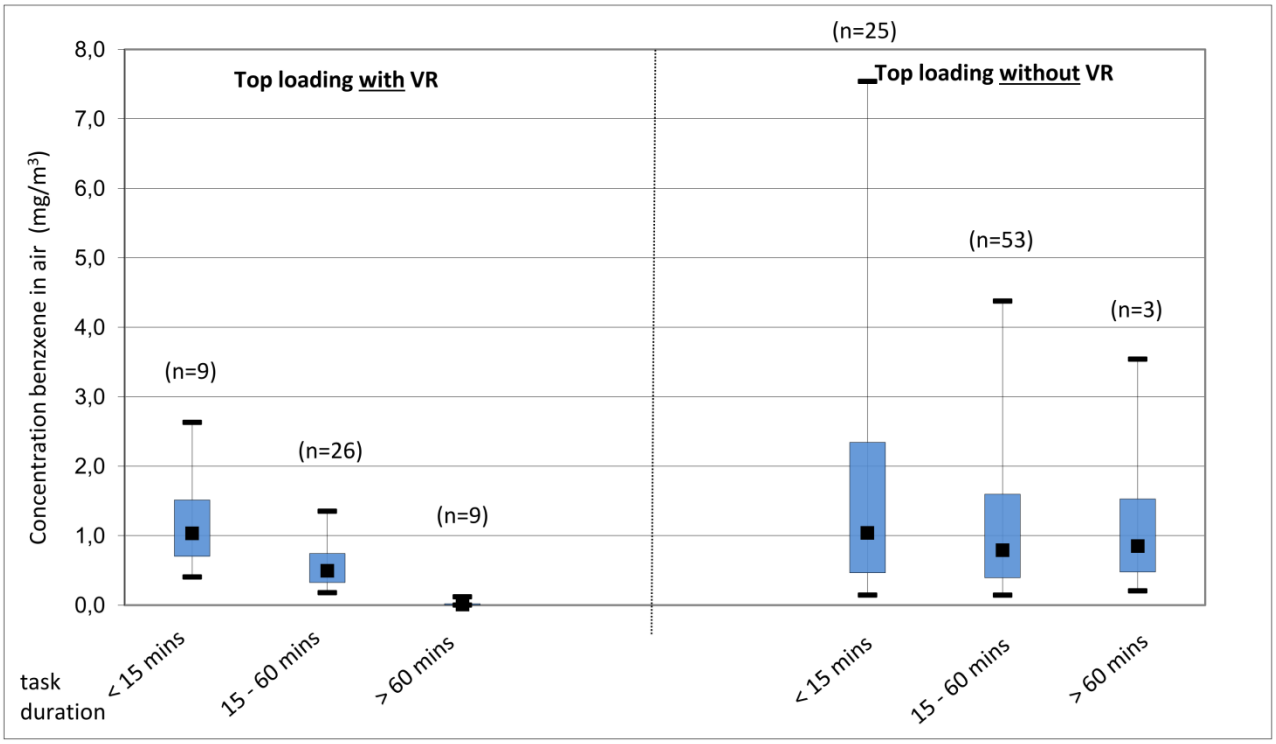


Figure 14 – Boxplot (p5 – p25 – GM – p75 – p95) representation for task-based benzene concentrations in air – top loading (petroleum products containing 0-1% benzene only).



The average (GM) task-based benzene concentrations during top loading range from 0,01 mg/m^3 for top loading with VR (sample duration > 60 mins) to 1.04 mg/m^3 for top loading without VR (sample duration < 15 mins). The statistical range for measured benzene concentrations during top loading without VR is larger in comparison with top loading with VR, indicating a better controlled process.

For both types of top loading in Figure 14 the average benzene concentrations seem to decrease with increasing sample duration. A possible explanation is that the measured concentration during the actual exposure moments, such as coupling and decoupling, are averaged out over time with increasing sample duration.

Table 5a – Overview of task-based benzene concentrations in air – top loading with and without VR.

Type	Task Duration	Benzene content range	K	N	Concentration benzene (mg/m^3) GM	GSD	p75	p90	p95
Top loading with VR	< 15 min	0 - 1 %	2	9	1,03	1,77	1,51	2,14	2,63
	15 - 60 mins	0 - 1 %	3	26	0,49	1,85	0,74	1,08	1,35
	> 60 mins	0 - 1 %	2	9	0,01	6,20	0,02	0,06	0,12
Top loading without VR	< 15 min	0 - 1 %	3	25	1,04	3,33	2,34	4,86	7,54
	15 - 60 mins	0 - 1 %	6	53	0,79	2,83	1,59	2,99	4,38
	> 60 mins	0 - 1 %	1	3	0,85	2,38	1,53	2,58	3,54

K = number of data sources, N = number of measurements, GM = geometric mean, GSD = geometric standard deviation, p75 = 75th percentile.

One company provided data during top loading by operators at larger distance (3m) from the loading hatch (Table 5b). Measured benzene concentrations in air were on average lower in comparison with *top loading without VR* in the proximity of the hatch and higher in comparison with *top loading with VR*.

Table 5b – Overview of task-based benzene concentrations in air – top loading with loader 3m away from hatch.

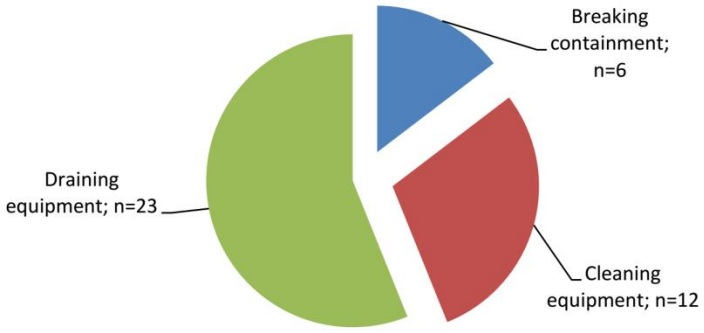
Type	Task Duration	Benzene content range	K	N	Concentration benzene (mg/m^3) GM	GSD	p75	p90	p95
Top Loading (loader/operator 3m away from hatch)	< 15 min	0 - 1 %	2	29	0,79	1,73	1,14	1,59	1,94
	15 - 60 mins	0 - 1 %	3	23	0,69	2,42	1,25	2,14	2,95
	> 60 mins	0 - 1 %		n/a					

K = number of data sources, N = number of measurements, GM = geometric mean, GSD = geometric standard deviation, p75 = 75th percentile.

4.2.3. Equipment maintenance

In accordance with the Concawe STF/29 Exposure Assessment Task Force inventory[7] maintenance tasks as defined in several work areas cover draining of equipment, breaking containment, cleaning of equipment and calibration of equipment. Only 2% of the available measurement data (n= 41) relate to maintenance activities, mostly draining of equipment (Figure 15).

Figure 15 –Task-based benzene measurements in air – equipment maintenance.



All measured benzene concentrations during *breaking of containment* (n=6) were below detection limit (< 0.1 ppm or 0.32 mg/m^3). These data originate from refineries of one member company and cover task durations from <15 minutes up to > 60 minutes. The benzene content of the handled products is unknown. The same applies to the measurement data from *cleaning of equipment* (n=12).

Measurement data from *draining of equipment* originate from road tanker terminal(s) from one member company and cover only handling of low benzene petroleum products (0 – 1%) and sample durations up to 15 minutes. The average (GM) air concentration for this task is 0.37 mg/m^3 (p95 = 1.39 mg/m^3). Around 50% of the samples were below detection limit. Descriptive statistical parameters for maintenance tasks can be found in Appendix 5.

[7] 'A review of European gasoline exposure data for the period 1993-1998', Concawe Report no. 2/00 (December 2000)

4.2.4. Laboratory activities

Few air samples from laboratory activities were available from the aggregated database (Figure 16). Most of the available benzene in air measurement data from QA analyses by laboratory technicians on refineries (11 out of 14) and all but one (10 out of 11) sample results from similar activities on road tanker terminals were below detection limit (< 0.1 ppm or 0.32 mg/m^3).

Figure 16 –Task-based benzene measurements in air – QA analyses (laboratory activities).

The highest benzene concentration as measured during QA analysis on refineries is 1,28 mg/m^3 for tasks up to 15 minutes and 1,92 mg/m^3 for tasks ranging from 15 to 60 minutes (benzene content of handled products unknown). Descriptive statistical parameters for QA activities can be found in Appendix 5.

4.2.5. Combination of tasks

As indicated in Figure 3 13% of the collected exposure measurements (n=278) were collected during the execution of unidentified tasks (‘combination of tasks’) and could therefore not be assigned to a specific task or activity.

These results are considered to reflect day-to-day exposures as they cover multiple tasks for several job groups during normal (routine) operation. They also cover handling of diverse petroleum products with low to high benzene content and sampling durations from <15 minutes up to 8 hours. A breakdown of the available data by work area reveals that most measurements originate from refining, road tanker terminals and ship terminals (Figure 17).

Figure 17 –Task-based benzene measurements in air – combined tasks by work area

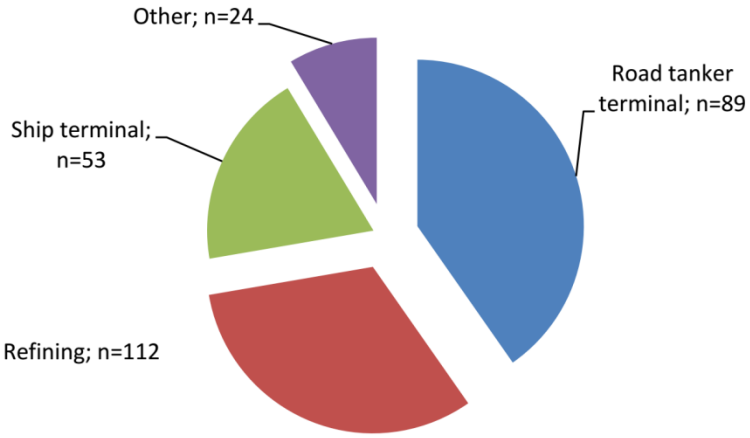


Table 6 shows that measured benzene concentrations in air during 'combined tasks' are on average (GM) highest on road tanker terminals (GM = 0.81 mg/m^3) in comparison with ship terminals and refining (respectively 0.42 mg/m^3 and 0.41 mg/m^3). The calculated GSDs indicate low variability in the data and a uniform sampling, analysis, and compilation routine.

Table 6 – Overview of task-based benzene concentrations in air – combination of tasks by work area.

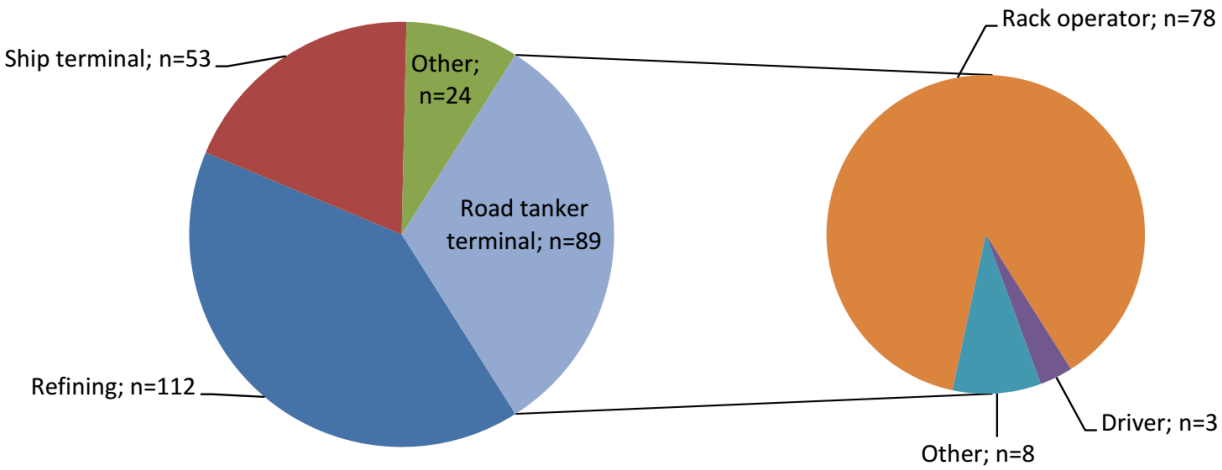
work area	task duration	benzene content range	Concentration benzene (mg/m^3) K	N	GM	GSD	p75	p90	p95
Refining	All	all	21	112	0,41	1,84	0,62	0,90	1,13
Road tanker terminal	All	all	16	89	0,81	3,12	1,74	3,46	5,24
Ship terminal	All	all	8	53	0,42	3,78	1,02	2,29	3,71

K = number of data sources, N = number of measurements, GM = geometric mean, GSD = geometric standard deviation, p75 = 75th percentile.

Measured air concentration from short sampling durations (<15 minutes, n=95) were on average (GM) similar to longer sampling durations (> 15 minutes, n=183), i.e. (0.59 mg/m^3 versus 0.56 mg/m^3).

Figure 18 shows a further breakdown of the data by job group within the work area road tanker terminals. Most data in this work area were collected from rack operators (1 member company, 13 data sources or campaigns). The average measured benzene concentration for this job group was 0.89 mg/m^3.

Figure 18 –Task-based benzene measurements in air – combined tasks by job group for work area road tanker terminal.

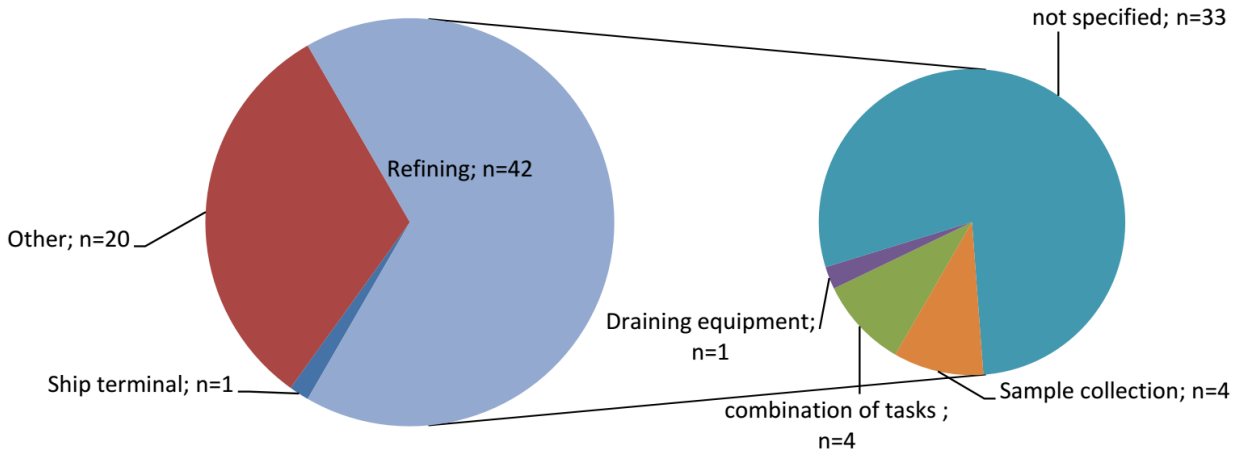


Descriptive statistical parameters for *combined tasks*, grouped by sampling duration, benzene content range, work area and by a number job groups can be found in Appendix 5.

4.2.6. Turnaround activities

Although turnaround events are not considered a regular weekly activity, a limited number of measurement data (n=63) from turnaround operation were provided (Figure 19). Since both the relative contribution to the total number of collected data was limited (less than 3%) and the work area or tasks were insufficiently specified, a quantitative comparison at task level with similar activities during normal operation cannot be made.

Figure 19 –Task-based benzene measurements in air – measurements collected during turnaround operations.



4.2.7. Data availability by task

For several identified tasks within the petroleum supply chain8 many measurement results were provided by member companies for the purpose of this project. This is in particular the case for *sampling* and several types of *bulk transfer*. In table 7 data availability (n) is presented by task and when data allow broken down by work area, job group and task duration.

Table 7 – Overview of short-term benzene measurements in air in the petroleum product supply chain, as collected for this project.

Task	(n)	Specification task	(n)	Work area	(n)	Job group	(n)	Task duration	(n)
Sample collection	1017	-		Refining	954	On site operator	844	< 15 mins	611
								15 - 60 mins	208
								> 60 mins	25
						Off site operator	110	< 15 mins	71
								15 - 60 mins	35
								> 60 mins	4
				Road tanker terminal	48	Other job group	48	< 15 mins	20
								15 - 60 mins	28
				Other work area	15				
Sampling, tank dipping, handling of hoses	82	-		Ship terminal	47	Jetty staff	47	< 15 mins	47
				Road tanker terminal	35	Other job group	35	< 15 mins	29
								15 - 60 mins	6
Bulk transfer	289	Bottom loading with VR	89	Road tanker terminal	87	Driver	46	< 15 mins	5
								15 - 60 mins	40
								> 60 mins	1
						Other job group	41	< 15 mins	3
								15 - 60 mins	32
								> 60 mins	6
				Other work area	2				
		Bottom loading without VR	4	Road tanker terminal	4	Other job group	4		
		Bottom loading unspecified	13						
		Top loading with VR	48	Road tanker terminal	35	Driver	24	< 15 mins	5
								15 - 60 mins	19
						Other job group	11		
				Refining	8				
				Rail car terminal	5				

[8] 'A review of European gasoline exposure data for the period 1993-1998', Concawe Report no. 2/00 (December 2000)

Task	(n)	Specification task	(n)	Work area	(n)	Job group	(n)	Task duration	(n)
		Top loading without VR	82	Road tanker terminal	82	Rack operator	50	< 15 mins	17
								15 - 60 mins	30
								> 60 mins	3
						Driver	15		
						Other job group	17		
		Top loading Operator 10ft away from hatch	53	Road tanker terminal	42	Rack operator	26	< 15 mins	23
								15 - 60 mins	3
						Driver	16		
				Refining	11	Other job group	11		
Equipment maintenance	41	Draining equipment	23	Road tanker terminal	23	Other job group	23	< 15 mins	23
		Breaking containment	6	Refining	6	Maintenance worker	6		
		Cleaning equipment	12	Refining	12				
Laboratory activities	25	QA analyses	25	Refining	14	Laboratory technician	14		
				Road tanker terminal	11	Other job group	11		
Combination of tasks	278	-		Refining	112	On site operator	104	< 15 mins	66
								15 - 60 mins	36
								> 60 mins	2
						Other	8		
				Road tanker terminal	89	Rack operator	78	< 15 mins	9
								15 - 60 mins	69
				Ship terminal	53	Deck crew	37	< 15 mins	4
								15 - 60 mins	14
								> 60 mins	19
						Jetty crew	16		
				Other work area	24				

Color of shading is based on number of available measurement results: [n< 10], [10 < n < 25], [n>25]

When compared with the Concawe STF/29 Exposure Assessment Task Force inventory, several tasks had no or limited data available. This was generally the case for tasks in work areas *aviation* and *retail*. Limited data were available for tasks at *rail car terminals* and *ship terminals.*

5. EVALUATION OF SHORT-TERM BENZENE CONCENTRATION BY TASK

The short-term benzene concentrations as presented in §4 are evaluated by comparing the descriptive statistical parameters of the measured concentration per task with reference values for benzene. For tasks with an exposure duration up to 1 hour a reference value of 3 ppm (10 mg/m^3) is used, whereas for tasks with exposure duration between 1 and 4 hours a reference value of 1 ppm (3,25 mg/m^3) is applied (see also §1).

In agreement with international standards for compliance testing, the 95th percentile of the data is compared with these reference values in this paragraph. In the corresponding appendices additional statistical parameters such as the 75th and 90th percentiles are presented as well, which also allows compliance testing based on other criteria.

Sample collection

From table 8 it can be concluded that the calculated 95th percentiles of the task-based benzene concentration during sample collection at refineries is below the corresponding reference values. In particular measurements with a sampling duration up to 1 hour, representing over 95% of the collected data for sampling collection, are well below the short-term reference value of 10 mg/m^3. Data from road terminals with sampling duration up to 1 hour indicate that the reference value for benzene (10 mg/m^3) may be exceeded. However, the calculated 95th percentiles are based on a limited number of data points and part of these data are <LOD.

For sampling, tank dipping and handling of hoses air concentrations may exceed reference values in particular during handling of petroleum products with high benzene content.

Explanation on some high 95th percentile values, marked in table 8, is presented below the table. Additional descriptive statistical parameters are presented in Appendix 5.

Table 8 – Evaluation of short-term benzene concentration in air for sample collection and sampling, tank dipping, handling of hoses.

Task		Sample collection				Sampling, tank dipping, handling of hoses			
Work Area		Refining		Road tanker terminal		Ship terminal		Road tanker terminal	
Task Duration	**Benzene Content Range**	**N**	**p95**	**N**	**p95**	**N**	**p95**	**N**	**p95**
< 15 min	0 - 1 %	379	2,37	20	**13,05[a]**	n/a		29	3,33
	1 - 5%	n/a		n/a		n/a		n/a	
	5 - 20%	43	2,44	n/a		n/a		n/a	
	> 20%	30	3,89	n/a		37	**28,16[b]**	n/a	
	N/A	230	1,34	n/a		10	**18,82[c]**	n/a	
15 - 60 min	0 - 1 %	155	2,61	26	**12,28**	n/a		6	2,86
	1 - 5%	n/a		n/a		n/a		n/a	
	5 - 20%	n/a		n/a		n/a		n/a	
	> 20%	10	2,63	n/a		n/a		n/a	
	N/A	78	0,84	n/a		n/a		n/a	
> 60 min	0 - 1 %	25	2,77	n/a		n/a		n/a	
	1 - 5%	n/a		n/a		n/a		n/a	
	5 - 20%	n/a		n/a		n/a		n/a	
	> 20%	n/a		n/a		n/a		n/a	
	N/A	4	0,16	n/a		n/a		n/a	

N = number of samples, p95 = 95th percentile bold : 95th percentile > reference value (for task duration up to 1 hour the reference value is 10 mg/m^3; task duration > 60 minutes: reference value is 3.25 mg/m^3)
a – large variability in the available data (range < LOD – 5.81, GSD 9.22) may explain high p95 value
b – maximum benzene content of product is unknown, may be well above 20%; unexplained high maximum sample (38,34 mg/m^3).
c - maximum benzene content of product is unknown, may be well above 20%; unexplained high maximum sample (22,68 mg/m^3).

Bulk transfer

For the bulk transfer activities listed in table 9 the calculated 95th percentiles of the task-based benzene concentration are generally well below the reference values for benzene, with the exception of top loading without VR at a Road Tanker Terminal. It must be noted that only measurement data during handling of petroleum products with low benzene content were available and for some activities only a limited number of observations were provided. Additional descriptive statistical parameters are presented in Appendix 5.

Table 9 – Evaluation of short-term benzene concentration in air for bulk transfer tasks.

Task		Bottom loading with VR		Bottom loading without VR		Bottom loading not specified		Top loading with VR		Top loading without VR		Top Loading loader/operator 10 ft away from hatch	
Work Area		Road tanker terminal		Road tanker terminal		Road tanker (n=3) Rail car terminal (n=9)		Road tanker (n=33) Rail car terminal (n=5) Refining (n=8)		Road Tanker Terminal		Road Tanker Terminal (n=41) Refining (n=11)	
Task Duration	Benzene Content	N	p95	N	p95	N	p95	N	p95	N	p95	N	p95
< 15 min	0 - 1 %	6	0,42	2	< LOD	6	3,51	10	2,63	25	7,54	29	1,94
15 - 60 min	0 - 1 %	57	1.65	2	< LOD	6	0,41	26	1,35	53	4,38	23	2,95
> 60 min	0 - 1 %	4	0,66	n/a		n/a		10	0,12	3	**3,54**	n/a	

N = number of samples, p95 = 95th percentile bold : 95th percentile > reference value (for task duration up to 1 hour the reference value is 10 mg/m3; task duration > 60 minutes: reference value is 3.25 mg/m^3)

Equipment maintenance

Measurement data for maintenance activities were limited and a large part of the data were below detection limit. The highest air concentrations were measured during *draining of equipment* at road tanker terminals (p95 = 1.39 mg/m^3, 14% of the reference value). Data was available for low benzene content products and short sample durations (<15 minutes) only. Additional descriptive statistical parameters are presented in A

ppendix 5.

Laboratory activities

Similar to equipment maintenance, limited data was provided for laboratory activities of which about 85% were below detection limit. The data only covers the handling of products with unknown benzene content and short sample durations (Appendix 5). The highest measured air concentration was 1.92 mg/m^3 (highest calculated p95=1.62 mg/m^3).

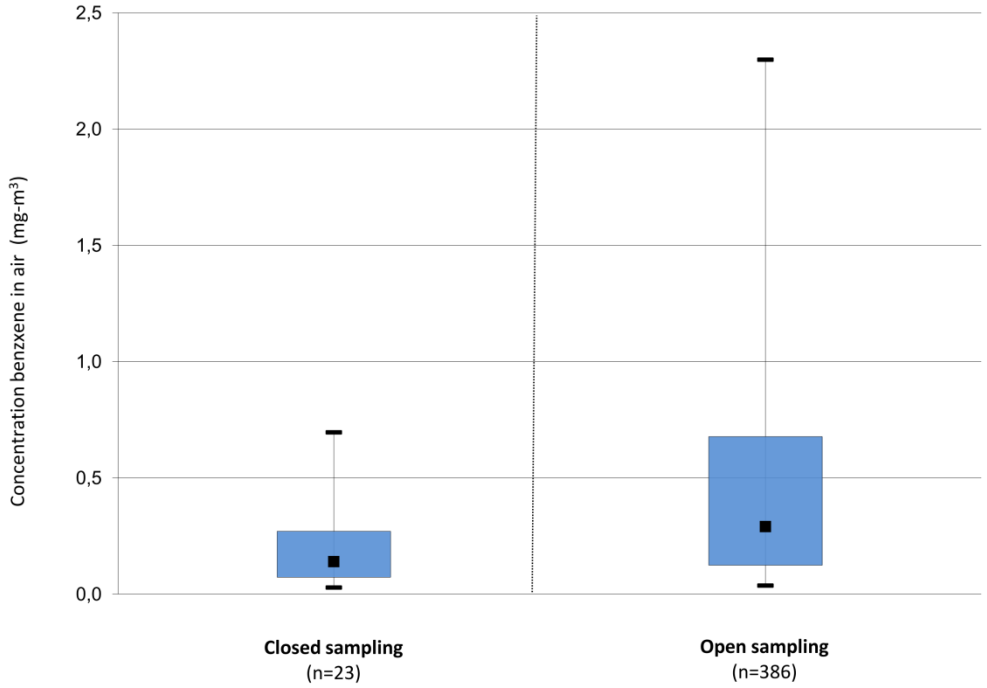
6. EFFICIENCY OF RISK MANAGEMENT MEASURES

The collected exposure data from several Concawe member companies provides an overview of benzene concentrations under actual work situations in the supply chain of petroleum products. This cross-section of data comprises several work situations with RMMs in place to reduce benzene levels. However, this study was not designed as an intervention study from which efficiencies of RMM before and after implementation in actual work situations can be defined. Also, a lack of contextual information for the provided measurements and little contrast in the application of RMM in the data (task-based RMM was either applied in nearly all situations or virtually absent) have constrained an in-depth analysis of the effect of RMMs on the short-term benzene exposure levels. Therefore, the efficiencies that are described in this paragraph should only be considered as indicative.

Closed system sampling (sample collection)

Two member companies provided measurement data for the task 'sample collection' with additional information on open versus closed (loop) system sampling. For sampling of petroleum products with low benzene content (0 – 1%) by onsite operators in refineries 23 closed sampling measurements were provided, of which around 60% (14 out of 23) were below the detection limit. In comparison with open sampling by the same job group and in the same work area (n=386, similar proportion of data <LOD) the average benzene concentrations in air was about a factor two lower for closed sampling (GM = 0.14 versus GM = 0.29 mg/m^3) as is illustrated in Figure 20. Descriptive statistical parameters underlying this figure can be found in Appendix 5.

Figure 20 – Box plot (p5 – p25 – GM – p75 – p95) representation for task-based benzene concentrations in air – open versus closed sampling by on site operators in refining (products with 0 -1% benzene content, company 2).



Open versus closed (loop) sampling activities of petroleum products with higher benzene content (5 -20%) but in the same work area (refining) and performed by the same job group *(on site operators)* show similar results (open sampling GM = 0.14, n=9; closed sampling GM=

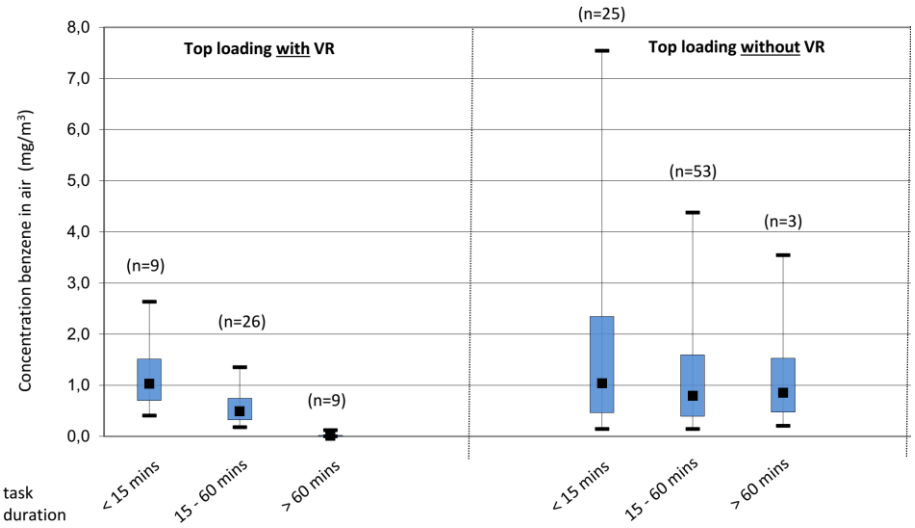
0.04, n=9). However, it must be noted that around 50% of the data from both groups (open versus closed sampling) were <LOD.

Based on the available data closed system sampling (refining, products with low benzene content) may reduce the benzene concentration in air by a factor 2 (based in GM) to 3 (based on 95th percentile) in comparison with open sampling.

Vapor recovery (bulk transfer – top loading)

From Figure 21 can be concluded that the average (GM) benzene concentration during *top loading with vapor recovery (VR)* is lower in comparison with *top loading without vapor recovery (VR)* for sample durations from 15 - 60 minutes and during handling of low benzene products (0-1%) at mostly Road Tanker Terminals. A comparison based on average concentrations indicates a factor 1.5 reduction (GM 0.49 versus 0.79 mg/m^3), while the same comparison based on the 95th percentile indicates a stronger effect (p95 1.35 versus 4.38 mg/m^3, or a factor 3).

Figure 21 – Boxplot (p5 – p25 – GM – p75 – p95) representation for task-based benzene concentrations in air – top loading (petroleum products containing 0-1% benzene only).



Measured benzene concentrations during bottom loading were almost exclusively available for situations with vapor recovery (VR) in place. Therefore the effect of VR for bottom loading cannot be calculated for this task.

Based on the analyses of available short-term measurement data, the application of vapor recovery (VR) during top loading may reduce the benzene concentration by a factor of 1.5 to 3 in comparison with top loading without vapor recovery (comparison based on GM and p95 respectively).

7. CONCLUSIONS

Available data for short-term benzene exposure

For typical short-term activities such as sample collection, bulk transfer (top and bottom loading), equipment maintenance, and QA analysis a large number of benzene exposure measurements were collected from various work areas and aggregated by task, exposure duration, and benzene content of handled products. A total of 2190 measurement results were retrieved.

Short-term benzene exposure levels in the supply chain of petroleum products

For identified tasks with sufficient data availability statistical descriptive parameters were calculated, as well as a further breakdown of the task work area, job group and process related characteristics. For the majority of tasks the 95th percentile of the benzene exposure levels was generally low in comparison with a reference value of 10 mg/m^3 (3 ppm) for exposure duration up to 1 hour and 3,25 mg/m^3 (1 ppm) for exposure durations between 1 and 4 hours.

Only for a limited number of tasks and conditions the 95th percentile exceeds the reference value (i.e. sample collection at road terminals (open system) and combined sampling, tank dipping, and handling of hoses at ship terminals (for products with high benzene content >20%). However, the use of proper respiratory protective equipment, as commonly used according to the contextual data as provided, will protect these workers against adverse health effects.

Indicative efficiency of Risk Management Measures

The collected data were also used for an indicative review of the application of RMMs and their effect on the short-term benzene exposure levels. This review was based on a comparison of the average (GM) and 95th percentile of the available measurement data on task level.

Although an in-depth analysis was constrained by a lack of contextual information related to the workplace sampling, available measurement data and little contrast in the applied RMMs across the job sites, the following indicative RMM efficiencies were found:

- *Closed system sampling* (refining, products with low benzene content) may reduce the benzene concentration in air by a factor 2 (based on GM) to 3 (based on 95th percentile) in comparison with open sampling. However, data availability is limited and for both types of sampling measurements below detection level were found

- *Vapor recovery* (VR) during top loading may reduce the benzene concentration by a factor 1.5 (based on GM) to 3 (based on 95th percentile) in comparison with top loading without vapor recovery.

APPENDIX 1 – OVERVIEW OF PEER-REVIEWED LITERATURE AND SECTOR REPORTS

ID	Publication title	Source	Remarks
01	A hematology surveillance study of petrochemical workers exposed to benzene	Shan P. Tsai, Erin E. Fox, Jerry D. Ransdell, Judy K. Wendt, Louis C. Waddell, and Robin P. Donnelly - Regulatory Toxicology and Pharmacology 40 (2004) 67–73	No exposure data were extracted, since no exposure measurements were collected for this study.
02	A review of the data quality and comparability of case-control studies of low-level exposure to benzene in the petroleum industry	B. G. Miller, W. Fransman, D. Heederik, J. F. Hurley, H. Kromhout, E. Fitzsimons - International Archives of Occupational and Environmental Health Int Arch Occup Environ Health (2010) 83:69–76	No exposure data were extracted, since no exposure measurements were collected for this study. Only exposure estimates were made to support epidemiological research.
03	A survey of European gasoline exposures for the period 1999-2001)	CONCAWE Report no. 9/02, Brussels, December 2002	Short term exposure data for benzene have been extracted.
04	A review of European gasoline exposure data for the period 1993-1998	CONCAWE Report no. 2/00, Brussels, December 2000	No exposure data were extracted. Measurement period <2000 (1993–1998)
05	A survey of exposures to gasoline vapor	CONCAWE Report no. 4/87, The Hague, June 1987	No exposure data were extracted. Measurement period <2000 (1985–1987)
06	A year-long study of ambient air concentrations of benzene around a service station	CONCAWE Report no. 95/63, Brussels, January 1996	No exposure data were extracted. Only ambient benzene samples were collected (no personal data).
07	Additional human exposure information for gasoline substance risk assessment (period 2002-2007)	CONCAWE Report no. 5/09, Brussels, June 2009	Only individually reported benzene values available without summary statistics. Summary stats were calculated (April 2016)
08	Airborne concentrations of benzene for dock workers at the ExxonMobil refinery and chemical plant, Baton Rouge, Louisiana, USA (1977-2005)	Widner TE, Gaffney SH, Panko JM, Unice KM, Burns AM, Kreider M, Marshall JR, Booher LE, Gelat RH, Paustenbach DJ - Scandinavian Journal of Work, Environment & Health 2011 ;37(2):147-158	Little correspondence between job and activity coding in publication in comparison with our format
09	An overview of occupational benzene exposures and occupational exposure limits in Europe and North America	Alexander C. Capleton, Leonard S. LevyChemico - Biological Interactions 153–154 (2005) 43–53	No exposure data were extracted. Measurement period <2000, data from other sectors and this meta-analysis also contains data from other publications in this overview.
10	Assessment and prediction of exposure to benzene of filling station employees	Spyros P. Karakitsiosa, Costas L. Papaloukasb, Pavlos A. Kassomenosc, Georgios A. Pilidis - Atmospheric Environment 41 (2007) 9555–9569	No exposure data were extracted. Only weekly average concentrations, no descriptive statistics available
11	Benzene and human health: A historical review and appraisal of associations with various diseases	David Galbraith, Sherilyn A Gross, and Dennis Paustenbach - Critical Reviews in Toxicology 2010; 40(S2): 1–46	No exposure data were extracted, since no exposure measurements were collected for this study.
12	Benzene and Total Hydrocarbons Exposures in the Downstream Petroleum Industries	Dave K. Verma , Diane M. Johnson, M. Lorraine Shaw, Karen des Tombe - American Industrial Hygiene Association Journal 62:176–194 (2001)	No exposure data were extracted. Measurement period <2000 (1970–2000) This meta-analysis also contains data from other publications in this overview.
13	Benzene and Total Hydrocarbon Exposures in the Upstream Petroleum Oil and Gas Industry	Dave K. Verma, Diane M. Johnson James D. McLean - American Industrial Hygiene Association Journal 61:255–263 (2000)	Short term exposure data for benzene have been reviewed. Publication also presents data from previously published work (< 2000). These data have not been reviewed
14	Benzene exposure in refinery workers: ExxonMobil Joliet, Illinois, USA (1977-2006)	Marisa L Kreider, Ken M Unice, Julie M Panko, Amanda M Burns, Dennis J Paustenbach, Lindsay E Booher, Richard	Although measurement period was partly < 2000, data were extracted. Poor match between data collection format and

ID	Publication title	Source	Remarks
		H Gelatt and Shannon H Gaffney - Toxicology and Industrial Health 26(10) 671–690	description job group and tasks in publication
15	Benzene Inhalation by Parts Washers: New Estimates Based on Measures of Occupational Exposure to Solvent Coaromatics	Patrick Sheehan, Kenneth T. Bogen, Jeffrey Hicks, Emily Goswami, Gregory Brorby, Edmund C. Lau, and Brian Ott - Risk Analysis *Vol. 30, No. 8, 2010*	No exposure data were extracted. Publication does only concern use of petroleum-derived products (parts washing with mineral spirit solvents).
16	Biological Monitoring of Benzene Exposure for Process Operators during Ordinary Activity in the Upstream Petroleum Industry	M. Bratveit, J. Kirkeleit, B. Eli Hollund, B.E. Moen - Annals of Occupational Hygiene Vol. 51, No. 5, pp. 487–494, 2007	No remarks
17	Economic consequences of limiting benzene/aromatics in gasoline	CONCAWE Report no. 89/57, The Hague, July 1989	No exposure data were extracted, since no exposure measurements were collected for this study.
18	Environmental and Biological Monitoring of Benzene during Self-Service Automobile Refueling	Peter P. Egeghy, Rogelio Tornero-Velez, and Stephen M. Rappaport - Environmental Health Perspectives Volume 108 Number 12, December 2000	No remarks
19	Health aspects of worker exposure to oil mists	CONCAWE Report no. 86/69, The Hague, October 1986	No exposure data were extracted, since no exposure measurements were collected for this study.
20	Low level occupational benzene exposure and haematological parameters	Gerard M.H. Swaen, Ludovic van Amelsvoort , Johannes J. Twisk, Etienne Verstraeten, Ronald Slootweg, James J. Collins, Carol J. Burns - Chemico-Biological Interactions 184 (2010) 94–100	No remarks
21	Myelodysplastic Syndrome and Benzene Exposure Among Petroleum Workers: An International Pooled Analysis	A. Robert Schnatter, Deborah C. Glass, Gong Tang, Richard D. Irons, Lesley Rushton - Journal of the National Cancer Institute DOI: 10.1093/jnci/djs411	No exposure data were extracted, since no exposure measurements were collected for this study.
22	Occupational exposure levels to benzene in Italy: findings from a national database	Alberto Scarselli, Alessandra Binazzi, Davide Di Marzio - International Archives of Occupational and Environmental Health (2011) 84:617–625	No exposure data were extracted. Publication describes 8-h TWA measurements only.
23	Occupational Exposure of Petroleum Depot Workers to BTEX Compounds	M Rezazadeh Azari, Z Naghavi Konjin, F Zayeri, S Salehpour, MD Seyedi - International Journal of Occupational and Environmental Medicine Vol 3 Number 1; January, 2012	unclear whether the presented data are full shift or task-based measurements. Based on presented TLVs interpreted as full shift data.
24	Occupational Exposure to Benzene at the ExxonMobil Refinery at Baton Rouge, Louisiana (1977-2005)	Julie M. Panko, Shannon H. Gaffney, Amanda M. Burns, Ken M. Unice, Marisa L. Kreider, Lindsay E. Booher, Richard H. Gelatt, J. Ralph Marshall, and Dennis J. Paustenbach - Journal of Occupational and Environmental Hygiene 6: 517–529	Data > 2000 cannot be separated from summary stats (April 2016)
25	Occupational exposure to benzene at the ExxonMobil Refinery in Baytown, TX (1978-2006)	SHANNON H. GAFFNEY, JULIE M. PANKO, KEN M. UNICE, AMANDA M. BURNS, MARISA L. KREIDER, RICHARD H. GELATT, LINDSAY E. BOOHER AND DENNIS J. PAUSTENBACH - Journal of Exposure Science and Environmental Epidemiology (2011) 21, 169–185	Although measurement period was partly < 2000, data were extracted
26	Occupational exposure to benzene at the ExxonMobil refinery in Beaumont, TX (1976-2007)	Shannon H. Gaffney, Amanda M. Burns, Marisa L. Kreider, Ken M. Unice, Thomas E. Widner, Dennis J. Paustenbach, Lindsay E. Booher, Richard H. Gelatt, Julie M. Panko	Although measurement period was partly < 2000, task-based data were extracted.

ID	Publication title	Source	Remarks
		- International Journal of Hygiene and Environmental Health 213 (2010) 285–301	
27	Occupational Exposures Associated with Petroleum-Derived Products Containing Trace Levels of Benzene	Pamela R. D. Williams, Julie M. Panko, Ken Unice, Jay L. Brown, and Dennis J. Paustenbach - Journal of Occupational and Environmental Hygiene 5: 565–574	Data > 2000 cannot be separated from summary stats (April 2016)
28	Occupational Safety and Health Guideline for Benzene Potential Human Carcinogen	U.S. Department of Health and Human Services, 1988	No exposure data were extracted, since no exposure measurements were collected for this study.
29	Pilot Study to Investigate Airborne Benzene Levels in Service Station Kiosks	CONCAWE Report no. 98/53, Brussels, June 1998	No exposure data were extracted, since only 14-day ambient exposure measurements were collected for this study.
30	Review of European Oil Industry Benzene Exposure Data (1986-1992)	CONCAWE Report no. 7/94, Brussels, November 1994	No exposure data were extracted. Measurement period <2000 (1986–1992), also mostly 8h TWA measurements
31	Review of European Oil Industry Benzene Exposure Data	CONCAWE Report no. 3/86, The Hague, March 1986	No exposure data were extracted. Measurement period <2000 (early 1980ies) and 8h TWA measurements
32	Risk management among benzene-exposed oil refinery workers	Anna Tompa, Matyas G. Jakab, Jeno Major - International Journal of Hygiene and Environmental Health 208 (2005) 509–516	No exposure data were extracted. Only 24h ambient exposure measurements were collected for this study and no summary statistics were presented.
33	Specific immune responses in workers exposed to benzene	Nelia D. Dimitrova, Ralitsa Y. Kostadinova, Snejina N. Marinova, Todor A. Popov, Teodor I. Panev - International Immunopharmacology 5 (2005) 1554–1559	No exposure data were extracted. Publication describes 8-h TWA measurements only.
34	Characteristics of occupational exposure to benzene during turnaround in the petroleum industry	Eun-Kyo CHUNG, Jung-Ah SHIN, Byung-Kyu LEE, Jiwoon KWON, Naroo LEE, Kwang-Jae CHUNG, Jong-Han LEE, In-Seop LEE, Seong-Kyu KANG and Jae-Kil JANG - Safety and Health at Work 2010;1:51-60	No relevant job groups, no exposure data were extracted.
35	Exposure to MTBE, TAME and aromatic hydrocarbons during gasoline pump maintenance, repair and inspection	S. Vainiotalo, L. Kuusimaki, K. Pekari Journal of occupational health 2006; 48: 347-357	No remarks

APPENDIX 2 – DATA COLLECTION FORMAT FOR NON-PUBLISHED BENZENE EXPOSURE DATA

The standardized Excel spreadsheet sent out to members companies was comprised of the following columns to compile (2 tabs), along with instructions/details on the information requested. Companies were instructed to include only data where the sampling time did not exceed 180 minutes.
The data columns highlighted (indicated as green rows in the table below) were the required fields.

EXPOSURE DATA TAB

Column	Description	Comments
A	ID source	Unique reference that relates to the entry in the Tab: SOURCE INFORMATION.
B	**Substance**	**In most cases this will be 'benzene' but may be some other marker for the product e.g. when handling substances of equivalent hazard/risk in non-refinery settings.**
C	**Product**	**Provide details of product e.g. gasoline, naphtha, high benzene naphtha.**
D	Sample year	Provide the year in which the samples were obtained. Where the samples cover a period, then enter the year where most were obtained.
E	**Country**	**Enter country which the data were obtained from.**
F	**Work area**	**Enter the work area from the options listed in the drop down. Where 'other work area' is chosen, provide a description in column I Remarks (workarea_job_task_operation).**
G	**Job group**	**Enter the job group from the options listed in the drop down. Where 'other job group is chosen, provide a description in column I Remarks (workarea_job_task_operation).**
H	**Task activity**	**Enter the task activity from the options listed in the drop down. Where 'other task activity' is chosen, provide a description in column I Remarks (workarea_job_task_operation).**
I	**Operation type**	**Enter the operation type from the options listed in the drop down. Where 'other operation type' is chosen, provide a description in column I Remarks (workarea_job_task_operation).**
J	**Workarea_job_task_operation**	**Use this column to provide free text to supplement information in columns E-H. Examples: Pipeline, Upstream, Chemical Plant**
K	Temperature handled (mean)	Provide mean temperature of product handled if above or below ambient. Enter 20oC if handled at ambient.
L	Temperature handled (range)	Provide temperature range of product handled.
M	Concentration substance (mean)	Provide mean concentration of the substance in the product for which monitoring data are available. Enter 100% if pure substance is handled.
N	Concentration substance (range)	Provide concentration range of the substance in the product handled.
O	**Local exhaust ventilation**	**If local exhaust ventilation of any form is used in conjunction with the task, then enter the assumed effectiveness (using the TRA criteria listed on p.10 of ECETOC Technical Report 107).**
P	**Dilution ventilation**	**If dilution ventilation of any form is used as a control (including carrying out the task outdoors) then use the pick**

Column	Description	Comments
		list to describe the form of dilution ventilation that most closely matches the conditions for the task.
Q	**PPE skin**	**If dermal protection is worn during the task, then enter the assumed effectiveness (using the TRA criteria listed on p.21 of ECETOC Technical Report 114). If the material of construction of gloves etc. is also known, please record this in Column M of the 'source information' Tab).**
R	Materials of glove construction	If dermal protection is worn during the task, then enter the materials of glove construction.
S	**PPE inhalation**	**If respiratory protection is worn during the task, then enter the assumed effectiveness (using the TRA criteria listed on p.11 of ECETOC Technical Report 107).**
T	**Other exposure controls**	**List any other specific measures that are implemented and designed to control exposure. Examples: Closed loop sampling, Remotely operated**
U	Purpose	Describe the purpose of the sampling using the pick list options.
V	Sampling strategy	Choose from drop down pick list.
W	Sampling method	Choose from drop down pick list.
X	Sampling medium	Choose from drop down pick list.
Y	Sampling duration (mean)	Enter the mean sampling period (when known).
Z	**Sampling duration (range)**	**Choose from drop down pick list.**
AA	Unit of measurement	Enter the unit of measurement from the pick list options.
AB	**Mean concentration**	**Enter the mean concentration (when known).**
AC	Median concentration	Enter the median concentration (when known).
AD	Geometric mean concentration	Enter the geometric mean concentration (when known).
AE	Standard deviation	Enter the standard deviation (when known).
AF	GSD concentration	Enter the geometric standard deviation (when known).
AG	**Minimum concentration**	**Enter the minimum recorded concentration. Avoid entering 'not detected'. Instead, enter half the calculated lower limit of detection for the method.**
AH	**Maximum concentration**	**Enter the maximum recorded concentration.**
AI	10th percentile	Enter the calculated 10th% value for the dataset (when known).
AJ	90th percentile	Enter the calculated 90th% value for the dataset (when known).
AK	95th percentile	Enter the calculated 95th% value for the dataset (when known).
AL	**# samples**	**Enter the number of samples obtained for the monitoring campaign. Include repeat samples on the same worker(s).**
AM	**# workers**	**Enter the number of workers monitored.**
AN	**# companies**	**Enter the number of companies covered by the monitoring campaign. Enter '1' if the data only relate to one site.**
AO	**Remarks measurement results**	**Enter any free text that helps to further interpret the data e.g. other analyses of the data such as the 95th percentile.**
AP	**Data entry date**	**Enter date on which the entry into the spreadsheet was completed.**
AQ	**Data entry name contributor**	**Enter the name of the person responsible for the entry.**
AR	**Data entry company contributor**	**Enter the name of the company responsible for the data.**
AS	**Data entry email contributor**	**Enter the contact email of the person responsible for the entry (in case of queries arising during subsequent Concawe analyses).**

Column	Description	Comments
AT	**Data entry phone contributor**	**Enter the contact telephone number of the person responsible for the entry (in case of queries arising during subsequent Concawe analyses).**

SOURCE INFORMATION TAB

Column	Description	Comments
A	ID source	Unique reference that relates to the entry in the Tab: SOURCE INFORMATION.
B	Source author	Enter the author(s) of the article or report.
C	Source title	Enter the title of the article or report.
D	Source type	Enter the source type from the pick list.
E	Article magazine	Enter the name of the journal in which the article is published (where relevant).
F	Article issue number	Where the source is a published article, enter the volume and issue number.
G	Article page	Where the source is a published article, enter the page numbers at which.
H	Article year	Where the source is a published article, enter the year of publication.
I	Report institute company	Where the source is a report, enter name of the organisation responsible for its publication.
J	Report place	Where the source is a report, enter the city of publication.
K	Report country	Where the source is a report, enter the country of publication.
L	Report year	Where the source is a report, enter the year of publication.
M	Remark source type	Enter any free text that is of further help in identifying the source.

NOTE:

- Column H: Task should be known
- Column J: Insert here “Other Operations” such as ”Pipeline”, “Upstream”, “Chemical plant”
- Columns O-S: Insert information on control measures
- Column T: Insert here “Other Controls” such as “Closed Loop Sampling”, “Remotely Operated”
- Columns AL-AO: For data from monitoring campaigns

APPENDIX 3– STRUCTURE OF AGGREGATED SHORT-TERM BENZENE EXPOSURE DATABASE

xxx	originating from data collection format
xxx	column / label added
source	data provided by member or peer-reviewed literature
ID	Unique ID
ID_source_agg	Aggregated ID-source for complete database
ID_source	ID-source as provided by member company
Substance	more information in original collection format
Product	more information in original collection format
Sampling_year	more information in original collection format
Country	more information in original collection format
Work_area	more information in original collection format
Job_group	more information in original collection format
Task_activity	more information in original collection format
Operation_type	more information in original collection format
Remarks_workarea_job_task_operation	more information in original collection format
Temperature_handeled_product_mean	more information in original collection format
Temperature_handled_product_range	more information in original collection format
Concentration_substance_mean	more information in original collection format
Concentration_substance_range	more information in original collection format
Local_exhaust_ventilation	more information in original collection format
Dilution_ventilation	more information in original collection format
PPE_skin	more information in original collection format
PPE-skin_glove material	more information in original collection format
PPE_inhalation	more information in original collection format
Other_exposure_controls	more information in original collection format
Purpose_of_study	more information in original collection format
Sampling_strategy	more information in original collection format
Sampling_method	more information in original collection format
Sampling_medium	more information in original collection format
Sampling_duration_mean	more information in original collection format
Sampling_duration_range	more information in original collection format
Unit_of_measurement	more information in original collection format
Data_(partly) _<LOD	provided data <LOD, y/n
Mean_conc_< LOD	provided mean <LOD, y/n
Mean_conc_uncorr	uncorrected (for < LOD measurement data))Mean value
Mean_conc	more information in original collection format
Mean_conc_mgm3	mean recalculated to mg/m3 (instead of ppm)
Median_conc_< LOD	provided median <LOD, y/n
Median_conc	more information in original collection format
Median_conc_mgm3	median recalculated to mg/m3 (instead of ppm)

GM_conc_< LOD	provided GM <LOD, y/n
GM_conc_uncorr	uncorrected (for < LOD measurement data) GM
GM_conc	more information in original collection format
GM_conc_mgm3	GM recalculated to mg/m3 (instead of ppm)
SD_conc	more information in original collection format
GSD_conc	more information in original collection format
Min_conc_< LOD	provided min <LOD, y/n
Min_conc_uncorr	uncorrected (for < LOD measurement data) min
Min_conc	more information in original collection format
Min_conc_mgm3	min recalculated to mg/m3 (instead of ppm)
Max_conc_< LOD	provided max <LOD, y/n
Max_conc_uncorr	uncorrected (for < LOD measurement data) max
Max_conc	more information in original collection format
Max_conc_mgm3	max recalculated to mg/m3 (instead of ppm)
10%_conc	more information in original collection format
10%_conc_mgmg3	10th percentile recalculated to mg/m3 (instead of ppm)
90%_conc	more information in original collection format
90%_conc_mgm3	90th percentile recalculated to mg/m3 (instead of ppm)
95%_conc	more information in original collection format
95%_conc_mgmg3	95th percentile recalculated to mg/m3 (instead of ppm)
N_samples	more information in original collection format
k_workers	more information in original collection format
m _companies	more information in original collection format
Remarks_measurement_results	more information in original collection format
Data_entry_date	more information in original collection format
Data_entry_name contributor	more information in original collection format
Data_entry_company contributor	more information in original collection format
Data_entry_email contributer	more information in original collection format
Data_entry_phone contributer	more information in original collection format

APPENDIX 4 – OVERVIEW OF BENZENE CONTENT RANGE FOR PETROLEUM PRODUCTS

Product name	Benzene content range used for data analysis	Additional information, remarks and translation
Acetone	N/A	-
Amine/Sulfur recovery	N/A	-
Aviation gasoline	0 - 1%	-
Bensiini	0 - 1%	Gasoline
Bensiini/diesel	0 - 1%	Gasoline/diesel
Bentseeni	> 20%	Benzene
Benzene	> 20%	-
Bitumen	0 - 1%	-
Brackish water	N/A	-
Bru recovered hydrocarbon	N/A	-
Chemicals stream	N/A	-
Condensate	5 - 20%	-
Cracked gas oils	0 - 1%	-
Crude Oil	0 - 1%	*very dependent on source (light or heavy crude), but expected to be <1% and in most cases <0.1%"*
Diesel, Dick	0 - 1%	Diesel
Gas condensate	> 20%	-
Gasoline	0 - 1%	-
Gasoline	1 - 5%	-
Gasoline	1 - 5%	-
Gasoline	0 - 1%	-
Gasoline	0 - 1%	-
Gasoline	1 - 5%	-
Gasoline + diesel	0 - 1%	-
Heavy fuel oil components	0 - 1%	-
Isomerate products	0 - 1%	-
Kerosines	0 - 1%	-
Kesälaatu, BE95	0 - 1%	Summer grade, gasoline
Kesälaatu, BE95EK, BE98ER	0 - 1%	Summer grade, gasoline
Kesälaatu, BE95EK, BE98ER, POR L, DI	N/A	Summer grade, gasoline, heavy fuel oil, diesel
Kesälaatu, BE95ER	0 - 1%	Summer grade, gasoline
Kesälaatu, BE98, BE95, DI, POK	0 - 1%	Summer grade, gasoline, diesel, fuel oil
Kesälaatu, BE98, BE95, DIKC	0 - 1%	Summer grade, gasoline, diesel
Kesälaatu, BE98ERN, BE95ERN, DICK, POK	0 - 1%	Summer grade, gasoline, diesel, fuel oil
Lentopetroli, JET A1	0 - 1%	JETA1
Low boiling point naphthas (gasolines)	0 - 1%	-
Metanoli	N/A	Methanol
Muu	N/A	Other
Muut tuotteet	N/A	Other products
Naphta	5 - 20%	*generic name, but in this context could cover various gasolines, and blending streams. Suggest 0-20%.*
Not indicated	N/A	-
Oil products	N/A	-
Oily water	N/A	-
Other petroleum gases	0 - 1%	-
Petroleum derivates	N/A	-
Platformate	5 - 20%	Potentially high (~40% or greater) depending on feedstock and subsequent processing following reforming process.
Process stream	N/A	-
Process streams	N/A	-

Product name	Benzene content range used for data analysis	Additional information, remarks and translation
Produced water	N/A	-
Raaka öljy	0 - 1%	Crude oil
Raakaöljy, akzaicru	0 - 1%	Crude oil
Raskas polttoöljy, por B	0 - 1%	Heavy fuel oil
Raskas polttoöljy, por L	0 - 1%	Heavy fuel oil
Raskaskondensaatin (AKZAI) ja raakaöljyn (URALSK)	1 - 5%	Heavy gas condensate and crude oil
Reformate	> 20%	*may contain higher levels of benzene, although further fractionation may produce sub-fractions low in benzene. Generically 0-20%.*
Slop Oil	N/A	-
Sour water	N/A	-
Straight-run gas oils	0 - 1%	-
Vacuum gas oils, hydrocracked gas oils, and distillate fuel	0 - 1%	-

APPENDIX 5 – OVERVIEW OF DESCRIPTIVE STATISTICAL PARAMETERS BY TASK, SAMPLE DURATION AND BENZENE CONTENT

Sample collection

Task / activity	Work area	Duration	Benzene Content Range	Concentration benzene (mg/m³) K	N	AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
Sample collection	Refining	< 15 min	0 - 1 %	9	379	0,65	1,04	0,29	3,61	0,01	15,97	0,03	0,12	0,68	1,48	2,37
		< 15 min	1 - 5%		n/a											
		< 15 min	5 - 20%	6	43	0,64	1,10	0,20	4,58	0,00	4,51	0,02	0,07	0,56	1,40	2,44
		< 15 min	> 20%	1	30	1,18	1,65	0,65	2,97	0,05	9,33	0,11	0,31	1,36	2,62	3,89
		< 15 min	N/A	17	230	0,45	0,54	0,30	2,49	0,02	4,47	0,07	0,16	0,55	0,96	1,34
		15 - 60 min	0 - 1 %	7	155	0,80	1,10	0,46	2,87	0,01	6,84	0,08	0,23	0,94	1,77	2,61
		15 - 60 min	1 - 5%		n/a											
		15 - 60 min	5 - 20%		n/a											
		15 - 60 min	> 20%	2	10	0,95	1,02	0,68	2,28	0,04	9,33	0,17	0,39	1,18	1,95	2,63
		15 - 60 min	N/A	6	78	0,26	0,35	0,15	2,85	0,00	5,43	0,03	0,07	0,31	0,58	0,84
		> 60 min	0 - 1 %	2	25	0,80	1,20	0,40	3,23	0,03	9,33	0,06	0,18	0,89	1,81	2,77
		> 60 min	1 - 5%		n/a											
		> 60 min	5 - 20%		n/a											
		> 60 min	> 20%		n/a											
		> 60 min	N/A	1	4	0,16	0,00	0,16	1,00	0,16	0,16	0,16	0,16	0,16	0,16	0,16

Sample collection

Task / activity	Work area	Duration	Benzene Content Range	Concentration benzene (mg/m³) K	N	AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
Sample collection	Road Tanker Terminal	< 15 min	0 - 1 %	2	20	3,98	5,51	0,34	9,22	0,00	5,81	0,01	0,08	1,51	5,80	**13,05**
		< 15 min	1 - 5%		n/a											
		< 15 min	5 - 20%		n/a											
		< 15 min	> 20%		n/a											
		< 15 min	N/A		n/a											
		15 - 60 min	0 - 1 %	3	26	3,34	5,44	0,49	7,12	0,00	5,08	0,02	0,13	1,83	6,00	**12,28**
		15 - 60 min	1 - 5%		n/a											
		15 - 60 min	5 - 20%		n/a											
		15 - 60 min	> 20%		n/a											
		15 - 60 min	N/A		n/a											
		> 60 min	0 - 1 %		n/a											
		> 60 min	1 - 5%		n/a											
		> 60 min	5 - 20%		n/a											
		> 60 min	> 20%		n/a											
		> 60 min	N/A		n/a											
Sample collection	Refining + Road Tanker Terminal	< 15 min	0 - 1 %	11	399	0,71	1,17	0,29	3,83	0,00	15,97	0,03	0,12	0,71	1,61	2,63
		< 15 min	1 - 5%		n/a											
		< 15 min	5 - 20%	6	43	0,64	1,10	0,20	4,58	0,00	4,51	0,02	0,07	0,56	1,40	2,44

Sample collection

Task / activity	Work area	Duration	Benzene Content Range	Concentration benzene (mg/m³) K	N	AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
		< 15 min	> 20%	1	30	1,18	1,65	0,65	2,97	0,05	9,33	0,11	0,31	1,36	2,62	3,89
		< 15 min	N/A	17	230	0,45	0,54	0,30	2,49	0,02	4,47	0,07	0,16	0,55	0,96	1,34
		15 - 60 min	0 - 1 %	10	181	0,98	1,50	0,46	3,39	0,00	6,84	0,06	0,20	1,05	2,21	3,45
		15 - 60 min	1 - 5%		n/a											
		15 - 60 min	5 - 20%		n/a											
		15 - 60 min	> 20%	2	10	0,95	1,02	0,68	2,28	0,04	9,33	0,17	0,39	1,18	1,95	2,63
		15 - 60 min	N/A	6	78	0,26	0,35	0,15	2,85	0,00	5,43	0,03	0,07	0,31	0,58	0,84
		> 60 min	0 - 1 %	2	25	0,80	1,20	0,40	3,23	0,03	9,33	0,06	0,18	0,89	1,81	2,77
		> 60 min	1 - 5%		n/a											
		> 60 min	5 - 20%		n/a											
		> 60 min	> 20%		n/a											
		> 60 min	N/A	1	4	0,16	0,00	0,16	1,00	0,16	0,16	0,16	0,16	0,16	0,16	0,16
Sampling, tank dipping, handling of hoses	Ship Terminal + Road Tanker Terminal	< 15 min	0 - 1 %	1	29	0,47	0,68	0,25	3,04	0,16	3,93	0,04	0,12	0,54	1,06	1,58
		< 15 min	1 - 5%		n/a											
		< 15 min	5 - 20%		n/a											
		< 15 min	> 20%	5	37	7,38	12,63	2,47	4,39	0,05	38,34	0,22	0,91	6,69	16,41	**28,16**
		< 15 min	N/A	1	10	6,90	7,03	5,07	2,19	2,46	18,82	1,39	2,98	8,61	13,86	**18,46**

Sample collection

Task / activity	Work area	Duration	Benzene Content Range	K	N	Concentration benzene (mg/m³) AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
		15 - 60 min	0 - 1 %	1	6	0,95	1,17	0,61	2,56	0,16	3,07	0,13	0,32	1,15	2,03	2,87
		15 - 60 min	1 - 5%		n/a											
		15 - 60 min	5 - 20%		n/a											
		15 - 60 min	> 20%		n/a											
		15 - 60 min	N/A		n/a											
		> 60 min	0 - 1 %		n/a											
		> 60 min	1 - 5%		n/a											
		> 60 min	5 - 20%		n/a											
		> 60 min	> 20%		n/a											
		> 60 min	N/A		n/a											

Task / activity	Work area	Duration	Benzene Content Range	K	N	Concentration benzene (mg/m³) AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
Sample collection - closed	Refining - on site operator	all	0 - 1 %		23	0,23	0,29	0,14	2,65	0,03	1,21	0,03	0,07	0,27	0,49	0,70
Sample collection - open	Refining - on site operator	all	1 - 5%		386	0,64	1,01	0,29	3,52	0,01	15,97	0,04	0,12	0,68	1,45	2,30

Bulk transfer																
Task / activity	**Work area**	**Duration**	**Benzene Content Range**	**K**	**N**	**Concentration Benzene (mg/m³) AM**	**SD**	**GM**	**GSD**	**min**	**max**	**p5**	**p25**	**p75**	**p90**	**p95**
Bottom loading (with VR)	Road tanker terminal	< 15 min	0 - 1 %	2	6	0,22	0,12	0,20	1,58	0,11	3,07	0,09	0,15	0,27	0,36	0,42
		< 15 min	1 - 5%		n/a											
		< 15 min	5 - 20%		n/a											
		< 15 min	> 20%		n/a											
		< 15 min	N/A		n/a											
		15 - 60 min	0 - 1 %	10	57	0,51	0,69	0,29	2,86	0,02	3,72	0,04	0,17	0,59	1,12	1,65
		15 - 60 min	1 - 5%		n/a											
		15 - 60 min	5 - 20%		n/a											
		15 - 60 min	> 20%		n/a											
		15 - 60 min	N/A		n/a											
		> 60 min	0 - 1 %	1	4	0,17	0,30	0,04	5,88	0,01	0,35	0,00	0,01	0,12	0,35	0,66
		> 60 min	1 - 5%		n/a											
		> 60 min	5 - 20%		n/a											
		> 60 min	> 20%		n/a											
		> 60 min	N/A		n/a											
Bottom loading (without VR)	Road tanker terminal	< 15 min	0 - 1 %	1	2	< LOD										
		< 15 min	1 - 5%		n/a											
		< 15 min	5 - 20%		n/a											
		< 15 min	> 20%		n/a											
		< 15 min	N/A		n/a											
		15 - 60 min	0 - 1 %	1	2	< LOD										
		15 - 60 min	1 - 5%		n/a											
		15 - 60 min	5 - 20%		n/a											

Bulk transfer																
Task / activity	**Work area**	**Duration**	**Benzene Content Range**	**K**	**N**	**Concentration Benzene (mg/m³) AM**	**SD**	**GM**	**GSD**	**min**	**max**	**p5**	**p25**	**p75**	**p90**	**p95**
		15 - 60 min	> 20%		n/a											
		15 - 60 min	N/A		n/a											
		> 60 min	0 - 1 %		n/a											
		> 60 min	1 - 5%		n/a											
		> 60 min	5 - 20%		n/a											
		> 60 min	> 20%		n/a											
		> 60 min	N/A		n/a											
Bottom loading (not specified)	Road tanker (n=3) + Rail car terminal (n=9)	< 15 min	0 - 1 %	2	6	1,01	1,52	0,49	3,29	0,01	3,55	0,07	0,22	1,10	2,27	3,51
		< 15 min	1 - 5%		n/a											
		< 15 min	5 - 20%		n/a											
		< 15 min	> 20%		n/a											
		< 15 min	N/A		n/a											
		15 - 60 min	0 - 1 %	1	6	0,29	0,07	0,29	1,25	0,16	0,32	0,20	0,25	0,33	0,38	0,41
		15 - 60 min	1 - 5%		n/a											
		15 - 60 min	5 - 20%		n/a											
		15 - 60 min	> 20%		n/a											
		15 - 60 min	N/A		n/a											
		> 60 min	0 - 1 %		n/a											
		> 60 min	1 - 5%		n/a											
		> 60 min	5 - 20%		n/a											
		> 60 min	> 20%		n/a											
		> 60 min	N/A		n/a											

Bulk transfer																
						Concentration Benzene (mg/m³)										
Task / activity	Work area	Duration	Benzene Content Range	K	N	AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
Top loading (with VR)	Road tanker (n=33) + Rail car terminal (n=5) + Refining (n=8)	< 15 min	0 - 1 %	2	9	1,21	0,86	1,03	1,77	0,16	2,47	0,40	0,70	1,51	2,14	2,63
		< 15 min	1 - 5%		n/a											
		< 15 min	5 - 20%		n/a											
		< 15 min	> 20%		n/a											
		< 15 min	N/A		n/a											
		15 - 60 min	0 - 1 %	3	26	0,59	0,46	0,49	1,85	0,09	1,53	0,18	0,32	0,74	1,08	1,35
		15 - 60 min	1 - 5%		n/a											
		15 - 60 min	5 - 20%		n/a											
		15 - 60 min	> 20%		n/a											
		15 - 60 min	N/A		n/a											
		> 60 min	0 - 1 %	2	9	0,03	0,05	0,01	6,20	0,00	0,53	0,00	0,00	0,02	0,06	0,12
		> 60 min	1 - 5%		n/a											
		> 60 min	5 - 20%		n/a											
		> 60 min	> 20%		n/a											
		> 60 min	N/A		n/a											
Top loading (without VR)	Road Tanker Terminal	< 15 min	0 - 1 %	3	25	2,15	3,28	1,04	3,33	0,03	16,61	0,14	0,46	2,34	4,86	7,54
		< 15 min	1 - 5%		n/a											
		< 15 min	5 - 20%		n/a											
		< 15 min	> 20%		n/a											
		< 15 min	N/A		n/a											
		15 - 60 min	0 - 1 %	6	53	1,36	1,83	0,79	2,83	0,01	5,05	0,14	0,39	1,59	2,99	4,38

Bulk transfer																
						Concentration Benzene (mg/m³)										
Task / activity	Work area	Duration	Benzene Content Range	K	N	AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
		15 - 60 min	1 - 5%		n/a											
		15 - 60 min	5 - 20%		n/a											
		15 - 60 min	> 20%		n/a											
		15 - 60 min	N/A		n/a											
		> 60 min	0 - 1 %	1	3	1,24	1,40	0,85	2,38	0,01	2,62	0,20	0,47	1,53	2,58	3,54
		> 60 min	1 - 5%		n/a											
		> 60 min	5 - 20%		n/a											
		> 60 min	> 20%		n/a											
		> 60 min	N/A		n/a											
Top Loading (loader/operator 3m away from hatch)	Road Tanker Terminal (n=41) + Refining (n=11)	< 15 min	0 - 1 %	2	29	0,92	0,62	0,79	1,73	0,01	3,10	0,32	0,55	1,14	1,59	1,94
		< 15 min	1 - 5%		n/a											
		< 15 min	5 - 20%		n/a											
		< 15 min	> 20%		n/a											
		< 15 min	N/A		n/a											
		15 - 60 min	0 - 1 %	3	23	1,02	1,18	0,69	2,42	0,08	4,47	0,16	0,38	1,25	2,14	2,95
		15 - 60 min	1 - 5%		n/a											
		15 - 60 min	5 - 20%		n/a											
		15 - 60 min	> 20%		n/a											
		15 - 60 min	N/A		n/a											
		> 60 min	0 - 1 %		n/a											

Bulk transfer																	
				Concentration Benzene (mg/m³)													
Task / activity	Work area	Duration	Benzene Content Range	K	N	AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
		> 60 min	1 - 5%		n/a											
		> 60 min	5 - 20%		n/a											
		> 60 min	> 20%		n/a											
		> 60 min	N/A		n/a											

Equipment maintenance																
				Concentration benzene (mg/m³)												
Task / activity	Work area	duration	benzene content range	K	N	AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
Breaking containment	Refining	< 15 min	0 - 1 %		-											
		< 15 min	1 - 5%		-											
		< 15 min	5 - 20%		-											
		< 15 min	> 20%		-											
		< 15 min	N/A	1	1	< LOD										
		15 - 60 min	0 - 1 %		-											
		15 - 60 min	1 - 5%		-											
		15 - 60 min	5 - 20%		-											
		15 - 60 min	> 20%		-											
		15 - 60 min	N/A	1	1	< LOD										
		> 60 min	0 - 1 %		-											
		> 60 min	1 - 5%		-											

Equipment maintenance																
Task / activity	**Work area**	**duration**	**benzene content range**	**Concentration benzene (mg/m³)**												
				K	**N**	**AM**	**SD**	**GM**	**GSD**	**min**	**max**	**p5**	**p25**	**p75**	**p90**	**p95**
		> 60 min	5 - 20%		-											
		> 60 min	> 20%		-											
		> 60 min	N/A	1	4	< LOD										
Cleaning equipment	Refining	< 15 min	0 - 1 %		-											
		< 15 min	1 - 5%		-											
		< 15 min	5 - 20%		-											
		< 15 min	> 20%		-											
		< 15 min	N/A		-											
		15 - 60 min	0 - 1 %		-											
		15 - 60 min	1 - 5%		-											
		15 - 60 min	5 - 20%		-											
		15 - 60 min	> 20%		-											
		15 - 60 min	N/A	2	10	< LOD										
		> 60 min	0 - 1 %		-											
		> 60 min	1 - 5%		-											
		> 60 min	5 - 20%		-											
		> 60 min	> 20%		-											
		> 60 min	N/A	1	2	< LOD										
Draining	Road Tanker Terminal	< 15 min	0 - 1 %	4	23	0,51	0,54	0,37	2,25	0,16	2,01	0,10	0,21	0,63	1,03	1,39

Equipment maintenance																	
Task / activity	**Work area**	**duration**	**benzene content range**	**Concentration benzene (mg/m³)**													
				K	**N**	**AM**	**SD**	**GM**	**GSD**	**min**	**max**	**p5**	**p25**	**p75**	**p90**	**p95**
		< 15 min	1 - 5%		-											
		< 15 min	5 - 20%		-											
		< 15 min	> 20%		-											
		< 15 min	N/A		-											
		15 - 60 min	0 - 1 %		-											
		15 - 60 min	1 - 5%		-											
		15 - 60 min	5 - 20%		-											
		15 - 60 min	> 20%		-											
		15 - 60 min	N/A		-											
		> 60 min	0 - 1 %		-											
		> 60 min	1 - 5%		-											
		> 60 min	5 - 20%		-											
		> 60 min	> 20%		-											
		> 60 min	N/A		-											

Laboratory activities																
Task / activity	**Work area**	**Duration**	**Benzene Content Range**	**Concentration Benzene (mg/m³)**												
				K	**N**	**AM**	**SD**	**GM**	**GSD**	**min**	**max**	**p5**	**p25**	**p75**	**p90**	**p95**
QA analysis	Road tanker Terminal	< 15 min	0 - 1 %	3	9	< LOD										
		< 15 min	1 - 5%		-											

Laboratory activities																
				Concentration Benzene (mg/m³)												
Task / activity	Work area	Duration	Benzene Content Range	K	N	AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
		< 15 min	5 - 20%		-											
		< 15 min	> 20%		-											
	Refining	< 15 min	N/A	1	3	0,53	0,66	0,34	2,59	< LOD	1,28	0,07	0,18	0,64	1,14	1,62
	Road tanker Terminal	15 - 60 min	0 - 1 %	1	2	-				< LOD	0,83					
		15 - 60 min	1 - 5%		-											
		15 - 60 min	5 - 20%		-											
		15 - 60 min	> 20%		-											
	Refining	15 - 60 min	N/A	1	4	< LOD										
		> 60 min	0 - 1 %		-											
		> 60 min	1 - 5%		-											
		> 60 min	5 - 20%		-											
		> 60 min	> 20%		-											
		> 60 min	N/A	1	7	0,46	0,62	0,26	2,86	< LOD	1,92	0,05	0,13	0,53	1,01	1,48

Combined activities																
				Concentration Benzene (mg/m³)												
Task / activity	Work area	Duration	Benzene Content Range	K	N	AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
Combination of activities	Refining + Road tanker + Ship terminal	< 15 min	0 - 1 %	6	31	0,66	0,63	0,50	2,10	0,16	5,94	0,15	0,30	0,83	1,30	1,70

Combined activities																
Task / activity	Work area	Duration	Benzene Content Range	Concentration Benzene (mg/m³) K	N	AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
		< 15 min	1 - 5%		-											
		< 15 min	5 - 20%		-											
		< 15 min	> 20%		-											
		< 15 min	N/A	11	64	1,25	1,85	0,64	3,18	0,26	127,79	0,10	0,29	1,40	2,81	4,29
		15 - 60 min	0 - 1 %	19	113	1,25	1,71	0,71	2,87	0,02	15,65	0,13	0,35	1,45	2,76	4,05
		15 - 60 min	1 - 5%		-											
		15 - 60 min	5 - 20%		-											
		15 - 60 min	> 20%	1	4	8,63	9,85	5,88	2,40	0,32	20,45	1,39	3,26	10,61	18,04	24,84
		15 - 60 min	N/A	7	31	0,80	0,99	0,51	2,59	0,16	5,91	0,11	0,27	0,97	1,72	2,43
		> 60 min	0 - 1 %													
		> 60 min	1 - 5%													
		> 60 min	5 - 20%													
		> 60 min	> 20%													
		> 60 min	N/A													
	All	< 15 mins	all	17	22	0,41	0,64	0,19	3,48	0,00	4,15	0,02	0,08	0,44	0,93	1,46
		> 15 mins	all	33		-										
						-										
	Refining	all	all	21		-										
	Road tanker terminal	all	all	16	13	0,36	0,33	0,28	2,03	0,16	0,96	0,09	0,17	0,45	0,69	0,90
	Ship terminal	all	all	8	53	1,01	1,64	0,42	3,78	0,11	20,45	0,05	0,17	1,02	2,29	3,71

Combined activities																
Task / activity	Work area	Duration	Benzene Content Range	Concentration Benzene (mg/m³) K	N	AM	SD	GM	GSD	min	max	p5	p25	p75	p90	p95
	Road tanker terminal - rack operator	alll	all	13	78	1,62	2,29	0,89	3,00	0,06	15,65	0,15	0,42	1,86	3,61	5,39
	Ship terminal - deck crew	15 - 60 min	all	4	37	0,39	0,49	0,25	2,60	0,16	4,15	0,05	0,13	0,47	0,85	1,20
	Ship terminal - jetty staff	> 60 min	all	1	6	0,61	0,56	0,47	2,04	0,16	1,97	0,15	0,29	0,76	1,18	1,53

Concawe
Environmental Science
for European Refining

Concawe
Boulevard du Souverain 165
B-1160 Brussels
Belgium

Tel: +32-2-566 91 60
Fax: +32-2-566 91 81
e-mail: info@concawe.eu
http://www.concawe.eu

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