Int Arch Occup Environ Health
DOI 10.1007/s00420-011-0616-9

ORIGINAL ARTICLE

Occupational exposure levels to benzene in Italy: findings from a national database

Alberto Scarselli · Alessandra Binazzi · Davide Di Marzio

Received: 3 June 2010 / Accepted: 12 January 2011

Abstract
Purpose Benzene is classified as human carcinogen and the association with lymphohaematopoietic cancer has been observed in many occupational epidemiological studies. The aim of this study is to summarize data about occupational exposure levels to benzene in Italy.
Methods Airborne concentrations of benzene were selected from the Italian database on occupational exposure to carcinogens in the period 1996–2007. Descriptive statistics were calculated for exposure-related variables. The number of workers potentially exposed was estimated for the industrial sectors better characterized in the database. An analysis through linear mixed model was performed to determine factors affecting the exposure level.
Results The total number of benzene exposure measurements was 15,776, with an overall arithmetic mean of 0.09 ppm and a geometric mean of 0.02 ppm. Economic sectors with a higher number of measurements (N) were the manufacturing of chemicals ($N = 10,480$) and the petrochemical industry ($N = 2,652$). The number of workers potentially exposed in the selected sectors was 37,137, and the most predictive independent variables of the exposure level were measurement year and job category.
Conclusions Occupational benzene exposure is still widespread in many different industries, and proactive measures are needed to reduce its impact on the workers' health. The potential of occupational exposure databases as a source of data for exposure assessment is confirmed.

Keywords Benzene · Exposure assessment · Database · Surveillance system · Workplace

Introduction

Benzene is a highly volatile liquid and is classified by the major international research agencies as a human carcinogen on the basis of epidemiological evidences (IARC 1987; ACGIH 2007). The most common ways of exposure are by inhalation and skin absorption, and benzene vapours are currently present in many industrial sectors (NTP 2009). The main industries using or generating benzene are the petrochemical, the manufacturing of chemical products, and sale and repair of motor vehicles. Uses of benzene range from the production of ethylbenzene (plastics, elastomers), cumene (phenol, acetone) and cyclohexane (nylon resins) to its presence as a component of gasoline, thus involving industrial sectors where emissions from mobile sources are prevalent (e.g. repair of motor vehicles) and pump stations (Weisel 2010; Wilbur et al. 2008). In the past, benzene was commonly used as a solvent or an additive in the printing industry, in the rubber, adhesives and shoe manufacturing, and in paint and varnish removers (Zenz 1978; ATSDR 1995). The physical property of volatility influences the environmental transport and sharing out of benzene, and a large amount of personal exposure to benzene derives from cigarette smoke.

Several studies on benzene exposures have observed an increased risk for lymphohaematopoietic cancers, particularly for all leukaemias and acute non-lymphocytic leukaemias (Bloemen et al. 2004; Collins et al. 2003; Sorahan

A. Scarselli · A. Binazzi · D. Di Marzio
ISPESL Area, Occupational Medicine Department, Epidemiology Unit, Italian Workers' Compensation Authority (INAIL), Rome, Italy

A. Scarselli (✉)
I.S.P.E.S.L.—Dipartimento di Medicina del Lavoro, Via Alessandria 220/E, 00198 Rome, Italy
e-mail: alberto.scarselli@ispesl.it

Published online: 04 February 2011

et al. 2005). Other cancers attributable to benzene exposures are multiple myeloma, lung cancer and non-Hodgkin's lymphoma (Huff 2007). To date, some polymorphisms in candidate genes have been identified, which confer susceptibility to benzene hematotoxicity (Lan et al. 2004). Benzene affects the blood-forming system and there is no evidence of a threshold level for its toxic effects (Smith 2010).

The extensive use of benzene as a solvent has declined in recent years as a result of EPA's action (EPA 1981). Following the new OSHA's standard of benzene concentrations (OSHA 1987), in Italy, an occupational exposure limit value, measured as 8-hour time-weighted average (TWA-8), was established by law in 2001 at 1 ppm (or 3.25 mg/m^3) at 20°C and 1 atmosphere of pressure (Italian Legislative Decree 2000). Previously, this limit was set at 3 ppm (or 9.75 mg/m^3). Anyway, the employers are recommended to record the exposed workers and the exposure levels to benzene in a register for monitoring the exposure risk. Such register is regularly sent (every 3 years) to the Italian Institute for Occupational Safety and Prevention (ISPESL), responsible for collecting and managing the exposure data at national level.

The objective of this study is to describe figures of occupational exposure levels to benzene in Italy by economic activity sector, worker's occupation and gender, geographical location and workforce size of the firm.

Methods

Data on measurements of benzene exposure are recorded in the Italian Information System on Occupational Exposure to Carcinogens (SIREP) and refer to the exposure period 1996–2007. SIREP is a relational database whose design and contents have been fully described elsewhere (Scarselli et al. 2007). In brief, it records information about the firm (economic activity sector, geographical location and workforce size), the worker (demographic data and occupational characteristics) and the exposure (carcinogenic agent, magnitude, frequency and duration). Each firm is responsible for the procedures of exposure measurement and the methods of air sampling. The type of samples (personal or environmental) and the analytical methods performed for the measurement were not always available (36 and 15% of cases, respectively), while the sampling period was a typical 8-hour work day. A total of 16,271 measurements out of 17,959 exposures to benzene were available, and 5,326 exposures were measured repeatedly over time. Measurements ($N = 871$) that were below the analytical limit of detection (LOD) were replaced with the LOD value divided by two (LOD/2) (Hornung and Reed 1990). The most frequently reported LOD was 0.001 ppm, representing 84% of the measurements in ppm below the LOD value. Measurements ($N = 5{,}504$) provided in mg/m^3 were converted to ppm using the standard conversion factor derived at 20°C and 1 atmosphere of pressure (1 ppm = 3.25 mg/m^3). The year of measurement, if not available, was set equal to the year of exposure beginning (77% of measurements). Some exposures ($N = 495$) were excluded from the analysis due to a lack in the measurement data ($N = 379$, e.g. the measurement unit was not reported) or the unavailability of worker's occupation ($N = 116$). The remaining 15,776 exposure measurements were used in this analysis. International standard classifications were used to code economic activity sectors (NACE rev. 1) and occupations (ISCO-88).

Descriptive statistical analyses were carried out to estimate the arithmetic and geometric mean of exposure levels (AM and GM) and the measures of variability, by means of the geometric standard deviation (GSD) and the 5–95 percentile range. A sample size of 50 measurements was selected as the minimum number required to perform reliable descriptive statistics. Moreover, the number of workers potentially exposed to benzene was estimated for the industrial sectors better characterized in the database, where the percentage of reported workforce (exposed together with non-exposed) was consistent (more than 1% of the total sector workforce). For the selected industrial sectors, this number was evaluated using the percentage of exposed workers in relation to both the workforce size of each firm and the national statistics on workforce (ISTAT 2004). The selected sectors were as follows: "Extraction of crude petroleum" (NACE code: 11.11.0); "Petroleum refinery" (NACE code: 23.20.1); "Manufacture of other organic basic chemicals" (NACE code: 24.14.0); "Manufacture of basic pharmaceutical products" (NACE code: 24.41.0); "Manufacture of pharmaceutical preparations" (NACE code: 24.42.0); "Retail sale of automotive fuel" (NACE code: 50.50.0); "Wholesale of petroleum products and lubricants" (NACE code: 51.51.1).

A mixed-effects model with random firm-specific intercepts was adopted to evaluate the association between exposure variables and exposure concentrations. The independent variables in the model were activity sector (NACE codes), firm size (classified in thirteen classes: "1" exposed worker(s), "2", "3–5", "6–9", "10–15", "16–19", "20–49", "50–99", "100–199", "200–249", "500–999", "1,000+"), geographical location of the firm ("North East", "North West", "Center", "South and Islands"), worker's gender, job category (ISCO-88 codes) and year of measurement. Exposure measurements were natural log transformed because data were positively skewed and approximately log-normal distributed. A $p$value ≤ 0.05 was considered as statistically significant and the restricted maximum likelihood method was used as estimation method.

The mixed-effects model is described by the following equation:

$$\ln(Y_i) = \sum(\text{Fixed effects}) + (\text{Firm effects})_i + (\text{Error})_i$$

for $i = 1,\ldots, n$ (firms), where Y_i is the exposure level. The model assumptions are random effect corresponding to firm (Firm effect) is approximately normally distributed with a mean of 0 and a variance of σ_B^2; residual (Error) is approximately normally distributed with a mean of 0 and a variance of σ_W^2; and (Firm effect) and (Error) are statistically independent. Eta squared (η^2) was computed for each specific effect to measure the degree of association using the following formula:

$$\eta^2 = F_{\text{effect}}(\text{DF}_{\text{effect}})/F_{\text{effect}}(\text{DF}_{\text{effect}}) + \text{DF}_{\text{error}}$$

Statistical analyses were performed using SAS software v. 9.1 (SAS Institute, Inc., Cary, N.C.), whereas geographical data were mapped using MapInfo software v. 8 (Pitney Bowes, Inc., Troy, N.Y.).

Results

Overall, the mean level of exposure to benzene was 0.09 ppm ($N = 15{,}776$, GM = 0.02, GSD = 0.34), and was higher in men ($N = 15{,}439$, AM = 0.09, GM = 0.02, GSD = 0.34) that in women ($N = 337$, AM = 0.03, GM = 0.01, GSD = 0.05). In the sub-analysis by type of sampling and analytical method, the mean values of exposure were 0.03 ppm ($N = 1{,}768$, GM = 0.01, GSD = 0.10) for personal sampling, and 0.01 ppm ($N = 4{,}355$, GM = 0.01, GSD = 0.03) when the UNI 11090 method was selected.

According to the NACE classification, the industries at a higher risk were “60-Land transports” ($N = 291$, AM = 0.11, GM = 0.09, GSD = 0.05), “29-Manufacture of mechanic machinery” ($N = 261$, AM = 0.18, GM = 0.04, GSD = 0.33) and “50-Sale, maintenance and repair of motor vehicles; retail sale of automotive fuel” ($N = 753$, AM = 0.04, GM = 0.02, GSD = 0.09). When only personal sampling or UNI 11090 standard method were selected, the mean values remain generally lower (e.g. NACE = “23-Manufacture of coke, refined petroleum products” with personal sampling type: $N = 1{,}517$, AM = 0.01, GM = 0.01, GSD = 0.02; NACE = “24-Manufacture of chemicals and chemical products” with UNI 11090 analytical method: $N = 2{,}016$, AM = 0.02, GM = 0.01, GSD = 0.02). The distribution by industrial sector and gender is displayed in Table 1.

The occupational groups (according to the ISCO-88 classification) with the highest value for benzene exposure were “8324-Heavy truck and lorry drivers” ($N = 306$, AM = 0.11, GM = 0.08, GSD = 0.06), “7233-Agricultural- or industrial-machinery mechanics and fitters” ($N = 569$, AM = 0.14, GM = 0.04, GSD = 0.19) and “4131-Stock clerks” ($N = 153$, AM = 0.11, GM = 0.03,

Table 1 Number of measurements (N), arithmetic mean (AM), geometric mean (GM), geometric standard deviation (GSD) and range (5–95 percentiles) of benzene exposure by gender and sector of economic activity (SIREP, 1996–2007)

Gender	Sector of economic activity (NACE code)	N[a]	AM	GM	GSD	5°-ile	95°-ile
Women	Manufacture of chemicals and chemical products (24)	170	0.04	0.01	0.07	<0.001	0.13
	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel (50)	78	0.03	0.02	0.03	0.003	0.08
	Other sectors	89	–	–	–	–	–
Men	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction, excluding surveying (11)	356	0.03	0.01	0.08	0.001	0.30
	Manufacture of coke, refined petroleum products and nuclear fuel (23)	2,621	0.02	0.01	0.06	0.001	0.05
	Manufacture of chemicals and chemical products (24)	10,310	0.11	0.02	0.40	0.002	0.40
	Manufacture of machinery and equipment n.e.c. (29)	260	0.18	0.04	0.33	0.002	0.77
	Manufacture of other transport equipment (35)	199	0.14	0.02	0.72	<0.001	0.15
	Electricity, gas, steam and hot water supply (40)	235	0.01	<0.01	0.04	0.002	0.01
	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel (50)	675	0.04	0.02	0.10	0.003	0.15
	Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)	110	0.03	0.01	0.04	0.025	0.09
	Land transport; transport via pipelines (60)	291	0.11	0.09	0.05	0.002	0.15
	Supporting and auxiliary transport activities; activities of travel agencies (63)	94	0.01	0.01	0.01	0.001	0.02
	Sewage and refuse disposal, sanitation and similar activities (90)	114	0.04	0.01	0.16	0.000	0.11
	Other sectors	174	–	–	–	–	–

[a] Number of TWA-8 exposure measurements (ppm); only sectors with at least 50 exposure measurements are shown

GSD = 0.32). Again, mean levels of exposure for personal sampling or UNI 11090 standard method were lower (e.g. ISCO-88 = "8159-Chemical-processing-plant operators n.e.c." with personal sampling type: $N = 983$, AM = 0.02, GM = 0.01, GSD = 0.02; ISCO-88 = "8155-Petroleum- and natural-gas-refining-plant operators" with UNI 11090 analytical method: $N = 1{,}475$, AM = 0.01, GM = 0.01, GSD = 0.02). Exposure levels by occupations and gender are reported in Table 2.

Figure 1 shows the temporal trend of exposure levels by year of measurement. Levels of exposure to benzene were initially decreasing over time and steadier in recent years. The highest level was recorded in 1997 (GM > 0.05 ppm) and the lowest in 2006 (GM < 0.01 ppm).

The geographical area at higher risk was the southern part of Italy ($N = 8{,}299$, AM = 0.11, GM = 0.02, GSD = 0.44), whereas the lowest value of exposure was found in the centre ($N = 1{,}367$, AM = 0.07, GM = 0.01, GSD = 0.32). The number and level of benzene exposures in each Italian macro-area are mapped in Fig. 2.

The distribution of benzene exposure levels by firm's workforce size is reported in Table 3. Small-medium firms (20–49 employees) show the highest level of benzene exposure, whereas the lowest was found in the largest firms (more than 1,000 employees).

In the selected industrial sectors, 37,137 workers resulted potentially at risk of benzene exposure. The most represented sector was the "50.50.0-Retail sale of automotive fuel" with 16,041 workers, followed by the "23.20.1-Petroleum refinery" with 6,452 workers. Detailed data of the selected industrial sectors are shown in Table 4.

In the mixed-effects model, exposure variables and all interactions were analysed to test independent effects.

Table 2 Number of measurements (N), arithmetic mean (AM), geometric mean (GM), geometric standard deviation (GSD) and range (5–95 percentiles) of benzene exposure by gender and occupational group (SIREP, 1996–2007)

Gender	Occupational group (ISCO-88 code)	N[a]	AM	GM	GSD	5°-ile	95°-ile
Women	Attendant, service station/automobiles (5220)	75	0.03	0.02	0.03	0.003	0.08
	Petroleum- and natural-gas-refining-plant control-panel operators (8155)	58	0.02	0.01	0.03	0.001	0.06
	Other groups	204	–	–	–	–	–
Men	Chemists (2113)	162	0.03	0.01	0.05	0.002	0.11
	Mechanical engineers (2145)	65	0.02	<0.01	0.10	0.001	0.04
	College, university and higher education professionals (2310)	255	0.03	0.01	0.07	0.001	0.25
	Chemical engineering technician (3116)	123	0.04	<0.01	0.16	<0.001	0.10
	Mechanical engineering technicians (3115)	337	0.03	0.01	0.08	0.001	0.15
	Electrical engineering technicians (3113)	129	0.02	<0.01	0.06	0.001	0.11
	Physical and engineering science technicians not elsewhere classified (3119)	979	0.09	0.02	0.22	0.001	0.35
	Safety, health and quality inspectors (3152)	79	0.09	0.01	0.23	0.001	0.25
	Other office clerks (4190)	76	0.02	0.01	0.03	0.001	0.14
	Stock clerks (4131)	151	0.11	0.03	0.32	0.010	0.74
	Attendant, service station/automobiles (5220)	860	0.05	0.01	0.35	<0.001	0.08
	Fire-fighters (5161)	317	0.04	0.01	0.08	0.001	0.12
	Motor vehicle mechanics and fitters (7231)	234	0.05	0.02	0.09	0.002	0.15
	Agricultural- or industrial-machinery mechanics and fitters (7233)	569	0.14	0.04	0.19	0.002	0.47
	Electronics mechanics, fitters and servicers (7242)	214	0.03	0.01	0.07	0.001	0.11
	Electrical mechanics fitters and services (7241)	106	0.11	0.03	0.30	0.002	0.35
	Mining plant operators (8111)	93	0.06	<0.01	0.13	0.001	0.30
	Chemical-heat-treating-plant operators (8152)	83	0.03	0.01	0.14	0.001	0.07
	Petroleum- and natural-gas-refining-plant operators (except control-panel operators; 8155)	2,320	0.03	0.01	0.07	0.001	0.10
	Petroleum- and natural-gas-refining-plant control-panel operators (8155)	1,113	0.09	0.02	0.15	<0.001	0.27
	Chemical-processing-plant operators not elsewhere classified (8159)	5,892	0.13	0.02	0.51	0.001	0.45
	Power-production plant operators (8161)	232	0.02	0.01	0.06	0.001	0.05
	Incinerator, water-treatment and related plant operators (8163)	51	0.01	0.01	0.01	0.003	0.01
	Heavy truck and lorry drivers (8324)	306	0.11	0.08	0.06	0.025	0.15
	Other groups	693	–	–	–	–	–

[a] Number of TWA-8 exposure measurements (ppm); only groups with at least 50 exposure measurements are shown

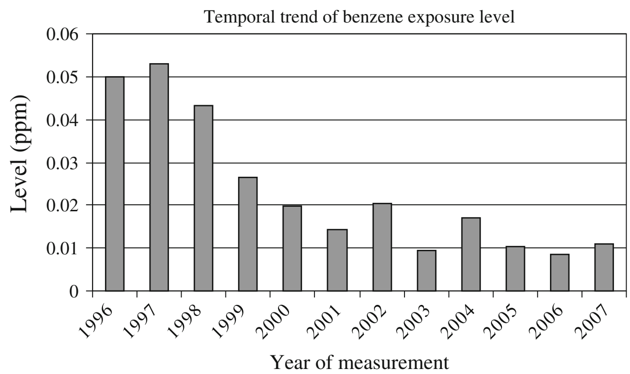

Fig. 1 Temporal trend of benzene exposure level in Italy (SIREP, 1996–2007)

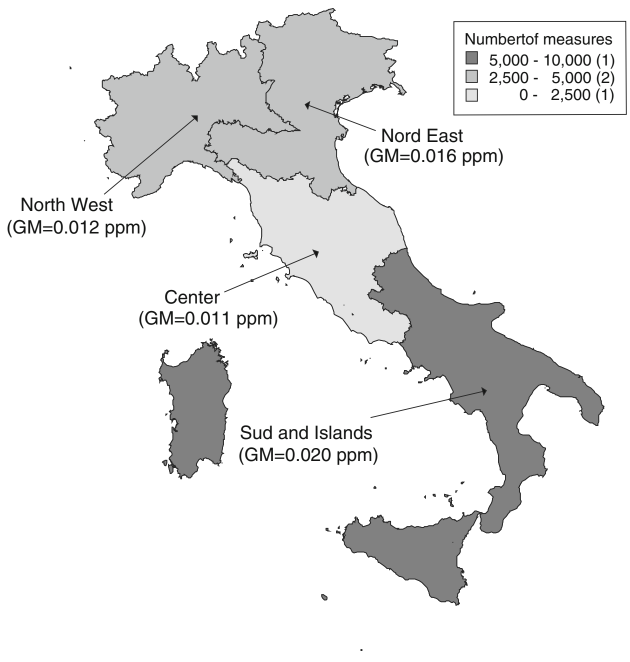

Fig. 2 Distribution of benzene exposure measurements by Italian geographical area (SIREP, 1996–2007)

Non-significant interactions ($p > 0.05$) were excluded step by step from the model. The variables included in the final model were (in decreasing order of statistical significance): measurement year ($\eta^2 = 0.06$), job category ($\eta^2 = 0.03$), activity sector $*$ job category ($\eta^2 = 0.02$), activity sector ($\eta^2 < 0.01$), activity sector $*$ geographical location $*$ firm size ($\eta^2 < 0.01$), geographical location $*$ firm size ($\eta^2 < 0.01$), geographical location ($\eta^2 < 0.01$), firm size ($\eta^2 < 0.01$) and gender ($\eta^2 < 0.01$). The fixed effects of the model explained about 40% of the variance in the observed exposure data. The Akaike Information Criterion (AIC) value of the final model was 55,810.8 and between- and within- firm variances were $\sigma_B^2 = 0.94$, $\sigma_W^2 = 2.02$.

Table 3 Number of measurements (*N*), arithmetic mean (AM), geometric mean (GM), geometric standard deviation (GSD) and range (5–95 percentiles) of benzene exposure by firm size (SIREP, 1996–2007)

Firm size	N^a	AM	GM	GSD	5°-ile	95°-ile
1 worker(s)	32	0.06	0.03	0.09	0.005	0.15
2	110	0.06	0.02	0.17	0.002	0.10
3–5	295	0.04	0.02	0.08	0.005	0.20
6–9	168	0.05	0.02	0.12	0.002	0.20
10–15	388	0.05	0.02	0.13	0.003	0.17
16–19	104	0.06	0.02	0.10	0.001	0.30
20–49	1,956	0.14	0.04	0.26	0.001	0.57
50–99	741	0.11	0.01	0.24	<0.001	0.81
100–199	713	0.40	0.02	1.39	0.001	2.03
200–249	800	0.07	0.01	0.17	<0.001	0.34
250–499	6,673	0.06	0.01	0.12	0.001	0.25
500–999	1,903	0.09	0.03	0.27	0.001	0.37
>1,000	1,893	0.02	0.01	0.04	<0.001	0.09

[a] Number of TWA-8 exposure measurements (ppm)

Discussion

To our knowledge, these results represent the first wide-ranging analysis on benzene exposure levels in the industrial and service sectors in Italy. The mean concentration of the reported measurements of benzene is congruent with the limit sets by law. The observed concentrations of benzene by sector/occupation are similar to those reported in a review on occupational benzene exposures in Europe and North America (e.g. Service station attendants: AM = 0.102 mg/m^3 vs. 0.167 mg/m^3 recorded in the present study, after appropriate conversion) (Capleton and Levy 2005). Moreover, in a recent study on benzene exposure monitoring methods, a common decline of benzene air concentrations (<1 ppm) has been observed, with the exception of some countries/industries (e.g. China/Shoemaking) where concentrations exceeding 100 ppm have been found (Weisel 2010). Results on truck drivers and land transport sector are consistent with a study conducted in Finland on exposure to gasoline vapours (Vainiotalo and Ruonakangas 1999) that found a GM concentrations of benzene of 0.15–0.28 mg/m^3 (corresponding to about 0.05–0.09 ppm). A survey on occupational exposure to volatile organic compounds (VOCs) and aldehydes in the US trucking industry reported that driver exposures are a combination of car and truck emissions associated with driving in traffic on metro area highways and streets, providing the highest exposure conditions to benzene (Davis et al. 2007). Concerning the other high-risk industrial sectors of “Manufacture of mechanic machinery” and “Sale, maintenance and repair of motor vehicles; retail sale of automotive fuel”, comparable findings have

Table 4 Estimates of workers potentially exposed in the selected sectors of economic activity (SIREP, 1996–2007)

Sector of economic activity (NACE code)	*N.* firms[a]	% firms[b]	*N.* workers[c]	%Workers[d]	% exposed[e]	*N.* of estimated exposed
Extraction of crude petroleum (11.11.0)	15	45.45	962	23.10	50.52	2,104
Petroleum refinery (23.20.1)	23	11.79	4,047	28.50	45.44	6,452
Manufacture of other organic basic chemicals (24.14.0)	12	6.09	3,116	27.75	38.48	4,321
Manufacture of basic pharmaceutical products (24.41.0)	10	4.88	1,101	7.26	3.36	509
Manufacture of pharmaceutical preparations (24.42.0)	13	1.84	2,603	4.92	3.53	1,870
Retail sale of automotive fuel (50.50.0)	1,009	4.08	3,768	17.20	73.22	16,041
Wholesale of petroleum products and lubricants (51.51.1)	15	0.59	247	2.12	50.20	5,840
Total	–	–	–	–	–	37,137

[a] Number of firms in SIREP

[b] Percentage of firms in SIREP with respect to the latest industry census data

[c] Number of workers reported by firms (exposed + non-exposed) in SIREP

[d] Percentage of workers reported by firms in SIREP with respect to the latest industry census data

[e] Percentage of exposed workers with respect to non-exposed workers reported by firms in SIREP

been observed in other studies. In a sample of eight Italian handicraft car painting shops, car repair painters resulted exposed to elevated benzene levels, probably due to fuel vapour from cars in repair, use of gasoline as a diluter or degreaser, and scarce compliance to personal protective devices (Vitali et al. 2006). Also vehicle repair, machinery use and refuelling of motor vehicles exhibited increased exposures to benzene and other VOCs in a cross-sectional study in four Australian cities (Hinwood et al. 2007). Monitoring of benzene exposure in mechanics was previously reported with a significant difference in respect to a control group (Suwansaksri and Wiwanitkit 2000), and a relevant risk for severe myeloproliferative disorders was observed in ordinary automobile petrol use as a solvent-degreaser for metal parts of mechanical parts of car motors (Bernardini et al. 2005).

In the present survey, the information on measurement of benzene levels suffers from several limitations that may bias the results. Data collection and selection of analytic/sampling method are under the responsibility of the employer. The analytic method is reported only in 36% of cases, whereas the type of measurement (personal/environmental) only in 15% (11% are personal measurements and 4% environmental). The most reported analytic method was the standard UNI 11090:2005 with 28%. This standard, developed by the Italian Organization for Standardization (UNI), specifies a method (dynamic adsorption on active carbon, solvent desorption and gas-chromatographic analysis) for the determination of benzene in workplace atmospheres (UNI 2005). Therefore, because of limited data, no full detailed sub-analysis was possible by these variables. Moreover, the study lacks information on some potential factors affecting the air concentration of benzene, such as local environmental conditions (temperature, humidity), the use of control measures (general ventilation, enclosure) and the nature of job task (continuous vs. intermittent), that may imply an incorrect assessment of the exposure (Teschke et al. 2002). Finally, information on the smoking status of workers during sampling was unknown but, presumably, its contribute to the present analysis would have been negligible. In fact, it is reasonable to suppose that during the sampling procedure smoking was forbidden, given also to the smoking ban in all enclosed workplaces and in the presence of flammable agents.

Industrial sectors and occupational groups are differently represented in this data set. Exposure measurements were in large quantities for some industries/occupations (e.g. “Manufacture of chemicals and chemical products”: $N = 10{,}480$), but limited for others (e.g. “Incinerator, water-treatment and related plant operators”: $N = 51$). Even confirmed by this study, workers in the petroleum refinery result significantly exposed to a wide range of petroleum-derived hydrocarbons and chemical substances in the manufacturing of petroleum derivatives. Apart from being a natural component of crude oil and some refined products such as gasoline, since lead-containing antiknock additives have been reduced, more aromatics are currently blended with gasoline for antiknock purposes, raising benzene concentrations to more than 5%. Such benzene exposure in a petroleum refinery aromatics plant in Portugal has resulted in genotoxic effects, with significant increases for all early biological effect biomarkers (chromosome aberrations, aneuploidies, micronuclei and DNA damage) (Roma-Torres et al. 2006). An expert group’s assessment of exposure to selected carcinogens for defined job categories in a Norway’s offshore petroleum industry between 1970 and 2005 classified mechanics and process technicians, laboratory engineers, electricians and insulators as the most exposed to benzene (around 30% of the workers in the offshore cohort) (Steinsvåg et al. 2008). Additionally, the evaluation of airborne concentrations of benzene at a refinery in Louisiana in the period 1977–2005 reported process technician as the most frequently sampled job during routine operations, in tasks as analyzers, coker, hydrofiner, lube blending and storage, waste treatment, though all well below the short-term exposure limit (STEL) of 5 ppm (Panko et al. 2009). In the sub-analysis by sampling type and analytical method, the mean values were lower than the overall ones, presumably due to an increased awareness of preventive measures in firms more accurate in data reporting. However, because of limited data (the sampling type and the analytical method were unknown in the 85 and 64% of measures, respectively), the results reported for these variables should be considered with caution.

The lack of measurements in some industries/occupations may have implied an under/overestimation of benzene concentrations. To increase the power of estimates, sectors and occupations were considered for the analysis only if the recorded measurements were over 50. Similarly, only the sectors better characterized in the database were taken into account to estimate the number of workers potentially exposed. As a consequence, certain sectors were excluded because of the limited information on the size of reported workforce ("Land transport", "Sewage and refuse disposal" and "Maintenance and repair of motor vehicles"). The number of exposed workers in each sector was calculated assuming the same ratio between exposed and non-exposed workers in firms notifying and non-notifying exposures data to ISPESL. This assumption may have likely introduced further bias in the estimates. Moreover, it should be considered that workers exposed to benzene are typically exposed to other carcinogens, depending on industry and occupation. On average, they are exposed to at least three-four different carcinogens, considering the polycyclic aromatic hydrocarbons (PAHs) as a single agent. Ruchirawat and colleagues (2010) have observed implications for carcinogenic risk in concurrent exposures to benzene, 1,3-butadiene and PAHs, especially in activities involving combustion processes. Main industries with exposure to multiple carcinogens include the manufacture of chemicals, and the sewage and refuse disposal. In a recent study, workers involved in earlier gasholders decommissioning resulted exposed to relevant concentrations of benzene upon removing discarded tanks content and during tar excavation/removal (Coulon et al. 2009). Additionally, in some industrial sectors and occupational groups, data variability was larger than in others, and the measures of central tendency could underestimate the exposures.

Other issues may concern the representativeness of the data from this study. Small firms (classes "1" and "2" workers) are underreported in the SIREP database, as shown in the comparison with industry census data (1% for class "1" and 3% for class "2" vs. a mean of 10%). The possibility that firms neither keeping and nor transmitting data on exposures to ISPESL have higher exposure levels, may have affected our estimates. However, the magnitude of sample size guarantees the accuracy of the estimate, particularly for the industrial sectors and occupational groups more appropriately characterized in the database. Furthermore, the adopted statistical model allows to account for fixed effects, as well as random effects, and to handle unbalanced data. A firm random effect was included in the model since measurements reported by the same firm may be correlated with each other. The number of firms and workers expected to be included in the SIREP database should be much higher if compared to a former evaluation of exposed workers to benzene (Mirabelli and Kauppinen 2005). This difference may be due to the difficulty in determining whether a worker is occupationally exposed to carcinogens, particularly when the exposure level is low (next to the environmental background), the carcinogen is a contained substance, and in presence of mixtures. Some results of the analysis of exposure determinants confirm the findings of a previous study with a similar design, based on occupational exposure to hardwood dust recorded in the SIREP database (Scarselli et al. 2008). Particularly, in the southern part of Italy, the mean exposure resulted higher than in the others. Again, some determinants (such as the size of firm and the geographical area) are likely surrogates for other factors (not stored in SIREP) which directly influence exposure, such as the use of engineering control measures (Teschke et al. 1999). Finally, the purpose of exposure sampling in this survey (regulatory compliance) may also have generated further underestimation. Anyhow, despite the reported limitations on exposure measurements (unreported information) and the incompleteness of data for a number of industrial sectors, the estimates here produced may be useful in conducting industry- and job-specific investigations. Most importantly, some risk conditions resulting in higher exposure may be identified and targeted for control.

Conclusions

The present study suggests that occupational benzene exposure is widespread in many different industries using or generating benzene, and proactive measures are needed to reduce its impact on the workers' health. Data herewith presented may be useful to perform epidemiological analytical studies and to develop job-exposure matrix.

Exposure assessment is often the weakness of many occupational epidemiological surveys and an exposure database like SIREP may be useful in producing highly detailed data. Moreover, the systematic and standardized collection of relevant information on exposure is important especially in the context of low-level concentrations, given the ubiquitous presence of benzene in the environment coming from a variety of different sources (smoking, pollution, natural sources) (Wilbur et al. 2008). Currently, the key to determine how to reduce benzene exposure in workers at risk is the combination of microenvironment exposure analysis, together with valid biomarkers measurements (Weisel 2010). Epidemiological studies are still investigating the relationship between low-level benzene exposures (well below 1 ppm) and adverse health effects in occupational groups of workers (Lan et al. 2004; Qu et al. 2002; Williams et al. 2008).

Acknowledgments The authors are grateful to the personnel at the Laboratory of Epidemiology of the Department of Occupational Medicine, for the support provided in the archiving and managing of data. This work was supported by the Italian Institute for Occupational Safety and Prevention.

Conflict of interest The authors declare that they have no conflict of interest.

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