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Assessment of Occupational and Public Exposure to Trichloramine in Swiss Indoor Swimming Pools: A Proposal for an Occupational Exposure Limit

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Objectives: The presence of trichloramine in the air in different indoor swimming pools has been studied in several countries. In almost all studies, the results show a possible health impact due to trichloramine among pool attendants. The main objectives of our study were to evaluate, for the first time in Switzerland, occupational and public trichloramine exposure in a representative panel of indoor pools and to propose an occupational exposure limit for trichloramine.

Methods: Measurements were done in 30 indoor swimming pools located in three regions of Switzerland: Jura, Neuchâtel, and Fribourg. All investigations were performed during the 2007–2008 winter season in order to assure closed windows and standard ventilation conditions. Trichloramine air samplings were performed at 130 cm above the floor around the pool. Analyses of free chlorine and bounded chlorine were performed on-site, and water samples were immediately sent to the laboratory for analysis of trihalomethanes, urea, and dissolved organic carbon. A health questionnaire was distributed to all the participants.

Results: Our results indicate that in all the studied facilities except one, the trichloramine concentrations were below the French reference value of 0.5 mg m^{-3}, and only three were equal to or slightly over 0.3 mg m^{-3}. Overall, our results point out a very low and consistent range of trichloramine concentrations (mean concentration of trichloramine: 0.114 ± 0.043 mg m^{-3}). A total of 184 questionnaires were filled out by pool workers. Of the study population, 66% were men (*n* = 117), 21% were smokers (9 women and 29 men), and only 7% (*n* = 13) were ex-smokers. The control group was composed of 71 persons (38 men and 33 women); 22% (*n* = 15) were smokers and 24% (*n* = 16) ex-smokers.

Conclusions: Our results demonstrate an increasing risk of irritative symptoms up to a level of 0.2–0.3 mg m^{-3} of trichloramine. The health data in our study, as well as the review of the literature, strongly suggest fixing the trichloramine occupational exposure limit at 0.3 mg m^{-3}. Severe technical standards (on flocculation, filters, water flow, and ventilation systems) and regulations on water quality (free and combined chlorine, urea, and amount of fresh water) contribute to reducing trichloramine formation and, consequently, occupational and public trichloramine exposure. In addition, to ensure good public hygiene (showering before swimming), correct and regular public awareness campaigns should be undertaken.

Keywords: ambient trichloramine levels; disinfection by-products; exposure assessment; indoor swimming pool; occupational exposure limit; pool water quality; trichloramine

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INTRODUCTION

Chlorine is a commonly used agent for disinfection of pool water. Besides its sanitizing effect by removing pathogens, however, free chlorine reacts with nitrogen-containing organic matter brought by swimmers (urea, sweat, skin squama, cosmetics, etc.) to form a large variety of so-called disinfection by-products, among them mono-, di-, and trichloramine (Héry *et al.*, 1994; Seux, 1988; WHO, 2006). Due to its relatively low water solubility, trichloramine (NCl_3) is easily released into the swimming pool atmosphere, whereas mono- and dichloramines are more likely to be released in droplets ejected by the shaking of the water surface. Trichloramine is considered to be strongly irritating to the eyes and upper airways. Gagnaire *et al.* (1994) compared the expiratory bradypnea indicative of upper airway irritation in mice during both chlorine and trichloramine exposure. They estimated an RD50 (airborne concentration resulting in a 50% decrease in the respiratory rate of mice) of 2.5 p.p.m. (12.3 mg m^{-3}) for trichloramine and 3.5 p.p.m. (10.2 mg m^{-3}) for chlorine. They concluded that the irritant potency of trichloramine is of the same order of magnitude as that of allylic compounds or formaldehyde. Barbee *et al.* (1983) demonstrated that the acute inhalation toxicity of trichloramine is similar qualitatively and quantitatively to that of chlorine. Based on the method developed by Schaper (1993), they proposed a threshold limit value–time-weighted average (TLV–TWA) of 0.1 p.p.m. (0.5 mg m^{-3}) and a TLV–short-term exposure limit (STEL) of 0.3 p.p.m. for trichloramine.

Swimming pool workers, such as pool attendants, technicians, swimming teachers, or physiotherapists, are exposed to trichloramine during their professional activities. Jacobs *et al.* (2007) showed that higher exposure was followed by higher upper airway respiratory symptoms in employees. In France, Thoumelin *et al.* (2005) observed elevated risks [odds ratios (ORs)] for eye and nose irritation and voice extinction. Occupational asthma caused by exposure to trichloramine was described in lifeguards and swimming teachers by Thickett *et al.* (2002) and Tafrechian (2008). Following the studies of Héry *et al.* (1995), in 13 swimming pools, and Massin *et al.* (1998), the National Research and Safety Institute for occupational accidents prevention in France (INRS) and the WHO (2006) recommended a reference value of 0.5 mg m^{-3} for trichloramine in the air. In addition, asthma caused by trichloramine has been recognized as a professional disease in France (Pairon and Choudrat, 2003).

The public attending indoor swimming pools (recreational swimmers, athletes, and babies) are naturally subject to chloramine exposure, both at the water surface as well as in the hall atmosphere. Swimmers are exposed to the substances contained in water and those splashing or evaporating from aerosols from the water. Several authors found ocular and respiratory irritative symptoms to be common in swimmers (Lévesque *et al.*, 2006; Bowen *et al.*, 2007). The studies of Bernard *et al.* (2003, 2006, 2007, and 2008) and Nickmilder and Bernard (2007) focused on the possible elevated risk of asthma and allergy during adolescence consequent to early attendance at chlorinated indoor swimming pools. They also observed that young people exclusively attending an indoor pool disinfected with a copper–silver method showed a decreased risk of asthma and allergy (Carbonnelle *et al.*, 2002). In Norway, Nystad *et al.* (2008) suggested that early baby swimming may be related to wheeze up to the age of 18 months. Others authors (Schoefer *et al.*, 2008) found no verifiable detrimental effect of early swimming in terms of developing atopic diseases, possibly due to lower use of chlorine in German pools.

A large review of the literature concerning occupational and recreational exposure to trichloramine was published by Kohlhammer and Heinrich (2007). Various authors (Nemery *et al.*, 2002; Thoumelin *et al.*, 2005; Jacobs *et al.*, 2007) reported that the quantity of trichloramine emitted from pool water depends on various factors, such as the shaking of the water, the number of swimmers, the concentration of chloramine precursors (especially urea and free chlorine), the air ventilation conditions, etc. Complaints from indoor swimming pool workers and users are usually related to the characteristic 'chlorine odour'.

The main objectives of our study were to evaluate, for the first time in Switzerland, occupational and public trichloramine exposure in a representative panel of indoor pools. We aimed to evaluate the consequences of working in trichloramine-contaminated areas on the well-being and health of workers. Our second purpose was to evaluate the effect of various factors (water quality, type of pool, and number of attendees) on the trichloramine concentration in the air. Finally, we formulated recommendations to the Swiss authorities to improve the protection of the public and pool workers.

MATERIALS AND METHODS

Study design

We analyzed 30 indoor swimming pools located in three regions of Switzerland: Jura, Neuchâtel, and

Fribourg. All investigations were performed during the 2007–2008 winter season in order to assure closed windows and standard ventilation conditions. Whenever possible, air and water samplings were conducted during maximal activity in the pool. A minimum of four stationary air samplings were performed simultaneously at 130 cm above the floor around the pool. The locations were selected by trained occupational hygienists, taking into account the ventilation conditions and the organization of the swimming pool (number of pools, presence of whirlpool, location of the workplaces, etc.). During air samplings, the occupancy of the pool was counted and the water quality surveyed by direct measurements of pH and free and bounded chlorine. Two water samples (1000 and 200 ml) were taken and immediately sent, inside a cooled box, to the laboratory for analysis of trihalomethanes (THM), urea, and dissolved organic carbon (DOC). The analyses were performed during the following 24 h. Using a standardized form, the main characteristics of the facility (volume and dimensions of the rooms, volume and surface of the various pools, method of water sanitation, type of water filtration and pH adjustment, amount of water renewal, ventilation conditions, etc.) were compiled during the air sampling. A questionnaire and an informed consent form were distributed to all the employees of the facility. The documents were immediately filled out by the persons present during the sampling, while absent workers filled them out later and sent them back to the authors. Besides the usual questions, such as age, sex, and professional status, we requested data about the work durations at various locations in the facility. Further questions focused on the presence of typical symptoms, such as asthma; eye, throat, or nose irritations; cough; sinusitis; breathlessness; and thorax pain, during and before the last 12 months. We also asked about possible skin irritation (eczema, dry skin, red skin, and itching). Finally, we asked the employees to indicate whether or not the marked symptoms could have been caused by their working conditions. A control group consisting of office colleagues of our three labor inspectorates was created.

Trichloramine air sampling and analysis

Sampling and analysis of trichloramine were performed according to the INRS (2007) method, also described in Héry *et al.* (1995) and Massin *et al.* (1998). The air was sampled using calibrated Casella pumps (Blanc-Labo, Lonay, Switzerland) at a flow rate of 1.0 l min^{-1} during 2 h. The pumps were calibrated using a DryCal Primary Calibrator (SKC) before and after sampling. The airflow passed through a tube containing silica gel (Silica gel E, 0.5–1 mm; Fluka number 03563) coated with sulphamic acid to trap hypochlorite and mono- and dichloramine. From the tube, the air-containing trichloramine passed through a cassette (37 mm diameter; Millipore) containing two glass fiber filters (37 mm diameter; Pall Corporation; Supelco), one coated with sodium carbonate and the other with diarsenic trioxide. Before coating, the filters were washed with ~10 ml bidistilled water and dried for 1 h at 60°C.

Both filters were desorbed simultaneously in 20 ml bidistilled water. The resulting chloride was quantified by ion chromatography (Dionex Ion Chromatograph, conductivity detector). The detection limit was 0.1 mg l^{-1} of chloride. The method was validated by a series of sampling sessions performed in one test swimming pool and by simultaneous sampling and analysis of air using sample cassettes provided by the INRS (Nancy, France) and the Laboratoire intercommunal Bruxellois (Brussels, Belgium). The results were used as external controls.

Pool water quality

Analyses of free chlorine and bounded chlorine were performed on-site by the DPD method (Swan Chematest 25) with a quantification limit of 0.02 mg l^{-1}. This standard method is used daily in Switzerland by the operators of all public swimming pools to check for compliance with the required water levels of free and bounded chlorine.

THM were analyzed by headspace gas chromatography coupled with mass spectrometry (GC–MS ThermoQuest Trace). The following THM were systematically quantified: 1,1-dichloroethylene, dichloromethane, trans-1,2-trichlorethylen, cis-1,2-dichloroethylene, chloroform, 1,2-dichloroethane, 1,1, 1-trichloroethane, tetrachloromethan, trichlorethylene, bromodichloromethan, dibromochloromethan, and bromoform. The quantification limit was 0.1 μg l^{-1} for each substance except for chloroform (0.15 μg l^{-1}) and dibromochloromethane and bromoform (both 0.20 μg l^{-1}). The results were recalculated as total THM in chloroform equivalent. Urea was quantified by colorimetry at 650 nm (Varian Cary 50 UV Spectrometer) after hydrolysis of urea in ammonium in the presence of urease. Ammonium was transformed into chloramine with active chlorine and combined with phenols to form a blue–green indophenol. The quantification limit was 0.015 mg l^{-1}. DOC was indirectly quantified by analyzing [ultraviolet (UV)] the CO_2 produced after pyrolysis (TOC-V Shimadzu) and elimination of mineral carbon by acidification and degassing, with a quantification limit of 0.4 mg l^{-1}. All analyses were done by the accredited Cantonal Laboratory in Delémont (Switzerland).

The statistical analyses were performed using XLSTAT and PEPI. Statistical comparisons between the trichloramine air levels measured in the different types of pools were made using Student's *t*-test.

RESULTS

Trichloramine air levels

In our study, 11 swimming pools were of therapeutic use and located in a medical center, 10 were public pools, and 8 were school swimming pools. Those of the third type were also frequented by the public outside school hours. The last pool in our study was a leisure indoor swimming pool without aerosol-forming devices, such as jacuzzis, artificial waves, fountains, waterfalls, etc. Five facilities disinfected the pool water with chlorine gas, sometimes in combination with UV. The majority of the facilities used sodium hypochlorite for water disinfection, sometimes in combination with ozone. Electrolysis (with sodium chloride or calcium chloride) was used by six facilities. The panel is representative of the situation in Switzerland.

A few samples were lost during handling. In total, 146 samples were available for statistical analysis. The overall mean concentration of trichloramine was 0.114 ± 0.043 mg m^{-3} (n = 30 pools). The median value was 0.070 mg m^{-3}, with first quartile at 0.038 and third quartile at 0.158 mg m^{-3}. Eighteen facilities (67%) showed an average concentration <0.1 mg m^{-3}, and 8 (27%) had a concentration between 0.1 and 0.2 mg m^{-3}. Four facilities (13%) showed a trichloramine level ≥0.3 mg m^{-3}, with the highest concentration at 0.52 mg m^{-3} in Facility 12 (see Fig. 1). There were no statistically significant differences in trichloramine air levels between the public, school, and therapeutic pools (Student's *t*-test). The disinfection method or the use of charcoal-filled filters did not influence the trichloramine concentration at a statistically significant level.

The hypothesis of a possible gradient of trichloramine above water was tested in Pool 12, where high trichloramine concentrations were measured. We used a floating device mounted on a tripod for collecting a total of 12 air samplings directly over water in the middle of the pool. Sample pairs were collected simultaneously at 16 and 130 cm above water in the presence of swimmers. The mean concentration at 130 cm above water (0.26 ± 0.07 mg m^{-3}, n = 6) was slightly higher than that at 16 cm (0.23 ± 0.05 mg m^{-3}, n = 6). A log-normal test showed that the concentrations from both sampling heights belonged to the same distribution.

Questionnaire

A total of 184 pool workers filled out the questionnaire. Six were excluded because of unrealistic answers. Exactly 66% of the study population were men (n = 117), 21% were smokers (9 women and 29 men), and only 7% (n = 13) were ex-smokers. Teachers accounted for the most common cohort, followed by swimming teachers. Of the participants, 54% worked at the facility 80% of the time or more

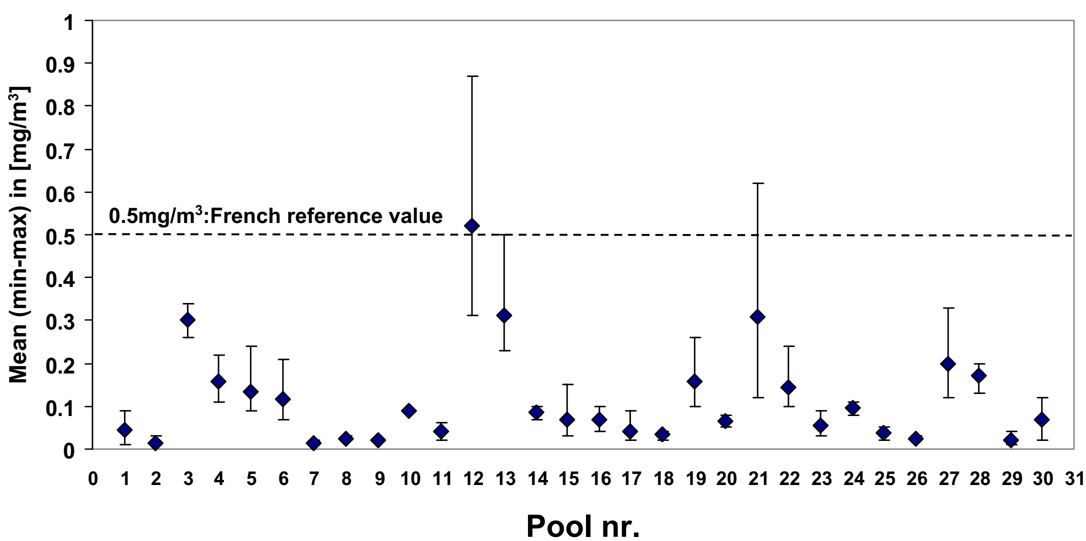

Fig. 1. Trichloramine air concentrations in 30 Swiss indoor swimming pools (average and minimim–maximum). The dotted line represents the French reference value of 0.5 mg m^{-3}.

and were thus considered ‘full-time workers’. The population characteristics are shown in Table 1.

During work, a part of the activity is spent in locations with possible trichloramine exposure, such as the pool surroundings and rooms with technical devices, especially disinfection systems and water buffer tanks. The time spent in such areas (based on information obtained in the questionnaire) combined with the activity rate of the employees allowed the calculation of the time spent in potentially trichloramine-contaminated areas (see Fig. 2). Only 23% ($n = 31$) of the full-time workers spent all their working time in a potentially trichloramine-contaminated area. In contrast, half ($n = 15$) of the respondents who worked at the facility <50% of the time ($n = 30$) performed all their tasks in a potentially trichloramine-contaminated area, which meant that only a few workers were highly exposed to trichloramine.

The control group consisted of 71 persons (38 men and 33 women), including 15 (22%) smokers and 16 (24%) ex-smokers.

We intentionally ignored the mentioned symptoms of asthma because asthma is a complex medical condition, and many breathing problems could be wrongly interpreted by the participants. The certain diagnosis of asthma requires the intervention of a physician, which we did not have the opportunity to obtain.

The prevalence of health symptoms (all mentioned symptoms: the sum of those that appeared before and during the last 12 months) referred as due to working conditions was higher than for the control group (see Table 2). The difference was statistically significant for eye irritation ($P = 0.05$), throat irritation ($P < 0.001$), nose irritation ($P = 0.016$), and skin problems ($P < 0.001$). This suggests that working in an indoor swimming pool is strongly associated with irritative symptoms.

In order to calculate the OR, three exposed groups were created:

1. Group 1: all employees working in facilities with a measured trichloramine concentration

Table 1. Descriptive characteristics of the study population.

	Pool workers			Control group		
	Women, *n* (%)	Men, *n* (%)	Total, *n* (%)	Women, *n* (%)	Men, *n* (%)	Total, *n* (%)
Sex	61 (34)	117 (66)	178	33 (46)	38 (54)	71
Smoker	9 (15)	29 (25)	38 (21)	8 (25)	7 (18)	15 (21)
Ex-smoker	5 (8)	8 (5)	13 (7)	10 (30)	7 (18)	17 (24)
Age						
<18 years old	1	1	2	—	—	—
18–25 years	5	1	6	1 (3)	1 (3)	2 (3)
26–35 years	17 (30)	19 (17)	36 (22)	4 (12)	4 (11)	8 (11)
36–50 years	24 (42)	57 (50)	81 (47)	25 (75)	17 (45)	42 (60)
>50 years	10 (18)	36 (32)	46 (27)	3 (9)	11 (29)	14 (20)
Total	57 (33)	114 (66)	171	33 (50)	33 (50)	66
Part-time job (%)						
<50	27 (48)	34 (29)	61 (35)	3 (10)	—	3 (4)
50–79	13 (23)	5 (4)	18 (11)	14 (42)	—	14 (20)
80–100	16 (29)	78 (67)	94 (54)	16 (48)	—	53 (76)
Total	56 (32)	117 (68)	173	33 (47)	37 (53)	70
Profession						
Teacher	23 (39)	33 (29)	56 (32)			
Swimming teacher	7	27 (24)	34 (20)			
Technician	1	24 (21)	25 (15)			
Physiotherapist	14 (24)	5	19 (11)			
Technician and lifeguard[a]	1	11 (8)	12 (7)			
Exclusively lifeguard	3	7	10			
Cashier	4	—	4			
Other	6	6	12			
Total	59 (34)	113 (66)	172			

[a]Both activities performed by the same person.

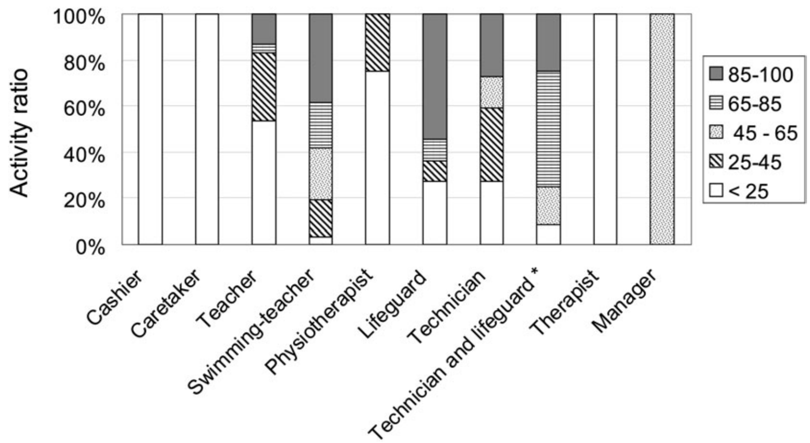

Fig. 2. Percentage of time spent in a potentially trichloramine-contaminated area by employees of 30 indoor swimming facilities (n = 133). *Both activities performed by the same person.

Table 2. Prevalence of mentioned health symptoms considered as due to the working conditions.

	Exposed employees			Control, %	P
	All symptoms[a]	Work-related symptoms	%		
Asthma	40	3	8	0	—
Allergy	19	3	16	11	0.371
Eye irritation	38	20	53	22	**0.05**
Throat irritation	24	19	79	7	**<0.001**
Cough	24	8	33	0	—
Nose irritation	37	14	38	7	**0.016**
Sinusitis	21	8	38	0	—
Breathlessness	9	3	33	11	0.128
Chest pain	10	6	60	0	—
Skin problems	46	28	61	8	**0.001**

The bold value correspond to OR with $P < 0.5$ (same as the *). Proposed only for a visual effect.
[a]All symptoms refers to the sum of all symptoms mentioned as having appeared during the last 12 months and all symptoms mentioned as having appeared before the last 12 months.

<0.1 mg m^{-3}. $N = 102$ in 18 facilities. Mean ± SD: 0.05 ± 0.02 mg m^{-3}; minimum: 0.02; maximum: 0.09.

2. Group 2: all employees working in facilities with a measured trichloramine concentration between 0.1 and 0.29 mg m^{-3}. $N = 61$ in eight facilities. Mean ± SD: 0.15 ± 0.03 mg m^{-3}; minimum: 0.19; maximum: 0.20.
3. Group 3: all employees working in facilities with a measured trichloramine concentration >0.29 mg m^{-3}. $N = 20$ in four facilities. Mean ± SD: 0.36 ± 0.11 mg m^{-3}; minimum: 0.30; maximum: 0.52.

The calculated OR (Table 3) in the higher exposed group (Group 3) was statistically significant ($P < 0.05$) for eye irritation for symptoms in the last 12 months and for nose irritation in the same group for both all symptoms and symptoms in the last 12 months of work.

We calculated the OR and 95% confidence intervals (CIs) for the different professional activities among the participants (Table 4). Swimming teachers (n = 35) presented a statistically significant OR ($P < 0.05$) for eye irritation for all symptoms [OR (95% CI): 2.7 (1.0–7.4)] and during the last 12 months of exposure [OR (95% CI): 4.8 (1.3–17.5)]. The OR for nose irritation was statistically significant for physiotherapists (n = 21) for all symptoms only [OR (95% CI): 2.9 (1.9–8.2)]. The OR for skin problems was statistically significant for all symptoms in the case of swimming teachers [OR (95% CI): 2.6 (1.0–6.9)] and physiotherapists [OR (95% CI): 5.3 (1.7–16.7)]. The OR for skin problems by physiotherapists was also

Table 3. OR for three exposed groups of employees in 30 indoor swimming facilities. Only ORs >1 are provided.

Group	1		2		3	
	$N = 102$		$N = 61$		$N = 20$	
NCl_3 (x ± SD)	0.05 ± 0.02 mg m^{-3}		0.15 ± 0.03 mg m^{-3}		0.36 ± 0.11 mg m^{-3}	
	All symptoms	Symptoms during the last 12 months	All symptoms	Symptoms during the last 12 months	All symptoms	Symptoms during the last 12 months
Asthma	1.4 (0.65–2.98)				2.0 (0.6–6.2)	2.4 (0.6–9.1)
Allergy		2.6 (0.7–1.0)		1.25 (0.2–6.5)		
Eye irritation		**3.8(1.2–11.8)***		1.6 (0.4–6.2)	3.0 (0.9–9.8)	**5.6(1.3–23.7)***
Throat irritation					1.2 (0.3–4.1)	1.4 (0.4–5.1)
Cough					1.2 (0.3–4.2)	1.3 (0.4–4.7)
Nose irritation		1.3 (0.6–3.0)			**4.3(1.5–12.6)***	**4.2(1.4–13.1)***
Sinusitis		1.3 (0.4–3.7)			1.2 (0.3–4.8)	2.1 (0.5–9.4)
Breathlessness						
Chest pain					1.7 (0.4–7.4)	2.0 (0.5–9.1)
Skin problems		1.7 (0.7–4.0)	1.4 (0.6–3.5)	1.4 (0.5–3.3)	2.8 (0.9–8.5)	2.1 (0.6–7.2)

All symptoms refers to the sum of symptoms mentioned as having appeared during the last 12 months and symptoms mentioned as having appeared before the last 12 months.
*P (Fischer's test) < 0.05.

statistically significant for symptoms during the last 12 months. The calculated CIs were relatively large because of the low number of events in each group.

For each employee, a cumulative exposure index was defined by combining the rate of professional activity, the time spent working in potentially trichloramine-contaminated areas, and the measured trichloramine concentration. Five groups of exposure were defined.

The calculated ORs (see Table 5) for eye irritation and all irritation symptoms together (eyes, nose, and throat) were statistically higher for Groups D and E than for the control group ($P < 0.05$ for all symptoms and during the last 12 months). The OR for nose irritation was also statistically higher for Group E, with OR (95% CI) = 5.1 (1.5–17.3) for all symptoms and OR (95% CI) = 4.4 (1.2–15.2) for symptoms in the last 12 months.

In Group E, skin problems were significantly more frequent than in the control group [$P < 0.05$, OR (95% CI) = 3.6 (1.0–12.2) for symptoms before and during the last 12 months]. Due to the relatively large CIs of the calculated OR, the power of our results was reduced.

Water quality

The results of the water quality analysis are presented in Fig. 3. Thirteen results (43%) for free chlorine exceeded the official Swiss reference value of 0.4 mg free chlorine per liter of water, but only two were over the tolerance value of 0.8 mg free chlorine per liter of water. With regard to bounded chlorine, 19 (63%) water samples were over the reference value of 0.2 mg l^{-1}, while 12 results (40%) exceeded the tolerance value of 0.3 mg m^{-3}. As for the THM results ($n = 27$), 14 (52%) were above the reference value of 30 μg l^{-1}. The urea reference value of 1 mg l^{-1} was exceeded in four samples (15%).

DISCUSSION

Our results indicated that in all the studied facilities except one, the trichloramine concentrations were below the French reference value of 0.5 mg m^{-3}, and only three were equal to or slightly over 0.3 mg m^{-3}. Overall, our results pointed out a very low and consistent range of trichloramine concentrations (mean air concentration of trichloramine: 0.114 ± 0.043 mg m^{-3}). This reflects the good maintenance of the studied facilities.

The measured trichloramine levels in our panel of 30 indoor swimming pools appeared to be very low compared to other results in various countries (France: Héry *et al.* (1994) and Massin *et al.* (1998); Belgium: Bernard *et al.* (2003) and Charlier *et al.* (2003); USA: Chen *et al.* (2008); and

Table 4. ORs for the different professional activities exposed to trichloramine in 30 indoor swimming facilities. Only ORs >1 are provided.

Group	Teachers		Swimming teachers		Physiotherapists		Technicians + technicians/lifeguards	
	$N = 58$		$N = 35$		$N = 21$		$N = 37$	
	All symptoms	Symptoms during the last 12 months	All symptoms	Symptoms during the last 12 months	All symptoms	Symptoms during the last 12 months	All symptoms	Symptoms during the last 12 months
Asthma					2.2 (0.7–6.4)		2.1 (0.8–5.2)	
Allergy			1.3 (0.4–4.3)	4.3 (1.0–19.5)	1.9 (0.5–7.0)	4.3 (0.8–23.7)		1.4 (0.2–8.5)
Eye irritation		1.2 (0.3–5.2)	**2.7(1.0–7.4)***	**4.9(1.3–17.5)***	2.8 (0.8–9.1)	3.9 (0.9–17.4)		2.0 (0.5–8.4)
Throat irritation								
Cough								
Nose irritation			1.5 (0.6–3.9)	1.4 (0.5–4.2)	**2.9(1.9–8.2)***	2.3 (0.7–7.4)		1.2 (0.4–3.6)
Sinusitis					2.1 (0.6–7.2)	1.2 (0.2–6.7)		1.5 (0.4–5.5)
Breathlessness								
Chest pain								1.4 (0.4–5.4)
Skin problems	1.2 (0.5–3.0)	1.15 (0.4–3.0)	**2.6(1.0–6.9)***	2.1 (0.7–5.8)	**5.3(1.7–16.7)***	**3.2(1.0–10.7)***		1.4 (0.4–4.0)

All symptoms refers to the sum of symptoms mentioned as having appeared during the last 12 months and symptoms mentioned as having appeared before the last 12 months.
*P (Fischer's test) < 0.05.

Table 5. ORs for cumulative exposure levels. For each employee, a cumulative exposure index was defined by combining the ratio of professional activity, the time spent working in potentially trichloramine-contaminated areas, and the measured trichloramine concentration. Only ORs > 1 are provided.

Group	A		B		C		D		E	
	$N = 98$		$N = 110$		$N = 22$		$N = 22$		$N = 14$	
Mean cumulative NCl_3 exposure (x ± SD)	1.8 ±1.4 mg m^{-3}		2.6 ± 2.2 mg m^{-3}		6.4 ± 1.2 mg m^{-3}		22.8 ± 5.9 mg m^{-3}		28.8 ± 5.9 mg m^{-3}	
	All symptoms	Symptoms during the last 12 months	All symptoms	Symptoms during the last 12 months	All symptoms	Symptoms during the last 12 months	All symptoms	Symptoms during the last 12 months	All symptoms	Symptoms during the last 12 months
Asthma	1.1 (0.5–2.4)		1.2 (0.6–2.7)		1.2 (0.4–4.4)		1.7 (0.6–5.3)	2.1 (0.6–8.0)	2.7 0.8–9.6)	2.7 (0.6–12.0)
Allergy			1.2 (0.5–2.9)		1.2 (0.3–5.5)	4.4 (0.8–23.6)				
Eye irritation	1.3 (0.5–3.2)	1.5 (0.4–5.5)	1.7 (0.7–4.0)	2.5 (0.7–9.4)			**3.7(1.2–11.2)***	**5.9(1.5–23.4)***	**4.8(1.4–17.2)***	**6.3(1.4–29.3)***
Throat irritation				2.8 (0.9–8.9)			1.3 (0.4–1.1)	1.2 (0.3–4.0)	1.7 (0.5–6.3)	1.4 (0.3–5.6)
Cough					1.2 (0.3–4.2)				1.3 (0.3–5.2)	
Nose irritation				1.1 (0.5–2.7)			2.7 (1.0–7.5)	2.7 (0.9–8.3)	**5.1(1.5–17.3)***	**4.4(1.2–15.2)***
Sinusitis				1.5 (0.6–4.2)			1.4 (0.3–6.1)	1.8 (0.4–7.7)		1.9 (0.3–10.7)
Breathlessness										
Chest pain								1.7 (0.4–7.5)	1.6 (0.3–8.5)	1.9 (0.3–10.4)
Skin problems	1.2 (0.5–2.9)		1.9 (0.9–4.0)	1.6 (0.7–3.6)	1.8 (0.6–6.1)	1.7 (0.5–6.2)	2.4 (0.8–7.1)	1.8 (0.6–6.2)	**3.6(1.0–12.2)***	2.4 (0.6–9.0)

All symptoms refers to the sum of symptoms mentioned as having appeared during the last 12 months and symptoms mentioned as having appeared before the last 12 months.
Cumulative exposure: NCl3 concentration in pool i × activity ratio × 40 h $week^{-1}$ × time spent in a potentially NCl3-contaminated area × 100.
*P (Fischer's test) < 0.05.

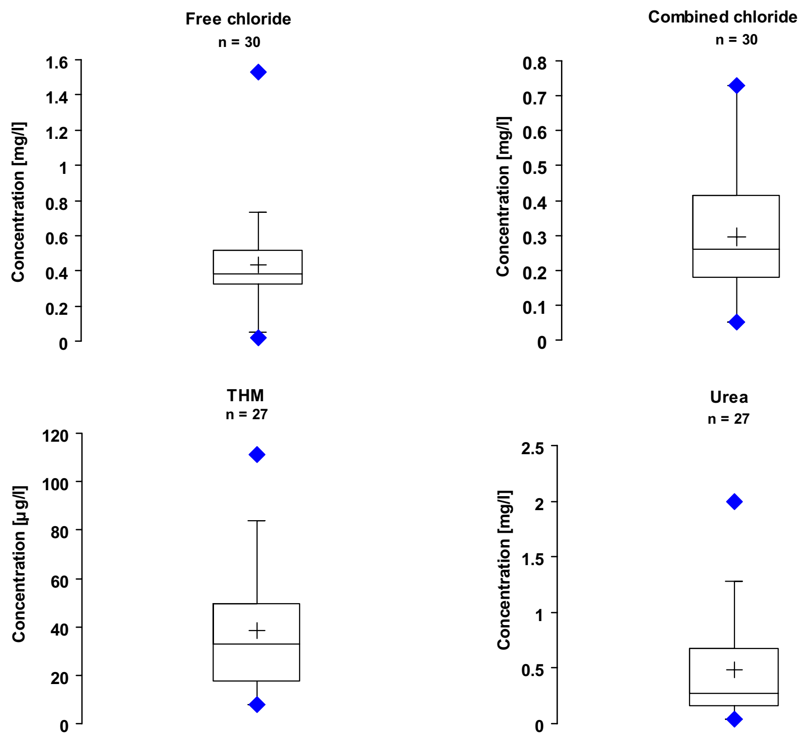

Fig. 3. Water quality in 30 Swiss indoor swimming pools.

Netherlands: Jacobs *et al.* (2007)). The levels in Germany were also slightly higher, with 50th and 90th percentiles at 0.12 and 0.37 mg m^{-3}, respectively (Schmoll *et al.*, 2009).

We observed that the presence of a whirlpool in Facilities 6, 11, 13, 16, 21, and 30 did not result in a significant increase in trichloramine in the air. This could be explained by their large building volume and good ventilation systems.

Because of the lack of leisure indoor swimming pools in our study, we could not verify the intuitive explanation of increased trichloramine emission by disturbance of the water surface (Massin *et al.*, 1998), a hypothesis that is supported by the results of Schmoll *et al.* (2009).

Our results did not reveal any dilution effect of the trichloramine in the air above the water surface. Badinier-Paganon and Deschamps (2001) and Schmoll *et al.* (2009) identified a gradient, whereas other authors (Charlier *et al.*, 2003; Hamel, 2007; Jacobs *et al.*, 2007) did not. A large air volume, controlled ventilation devices, air movement due to the presence of swimmers, and a gradient effect due to the evaporation of water are likely to be sufficient to assure the homogenous distribution of trichloramine in the air.

Occupational exposure assessment

Considering that between 1500 and 3000 persons could be professionally exposed to trichloramine in indoor swimming pools in Switzerland, our study included 5–10% of all potentially exposed Swiss professionals. We assume that this is sufficient to take preventive decisions to control possible adverse health effects or to prevent health symptoms at the workplaces and public facilities concerned.

In this study, despite the low activity rate in potentially trichloramine-contaminated areas, the reported prevalence of eye and nose irritations were relatively high, even surprisingly high for Group E, which corresponded to 40-h exposure to trichloramine levels between 0.2 and 0.39 mg m^{-3}. The ORs reached 4.8 and 6.3, respectively, for both all symptoms and symptoms in the last 12 months of exposure. The risk increased at a lower proportion for Group D (ORs of 3.7 and 5.9, respectively), corresponding to exposure levels between 0.1 and 0.39 mg m^{-3}. We conclude that when the trichloramine concentration in the air is >0.3 mg m^{-3}, the workers' irritation symptoms increase significantly. The same conclusion can be observed for skin problems, although these are certainly the most prominent due to the use of aggressive chemicals for the disinfection and cleaning of surfaces in the facilities and/or due to repetitive contact with pool water during swimming training.

Our results confirmed the irritative effects of trichloramine identified by Gagnaire *et al.* (1994), which are similar to those obtained by Massin *et al.* (2007), Jacobs *et al.* (2007), Lévesque *et al.* (2006), and Thoumelin *et al.* (2005). Thoumelin *et al.* (2005) estimated a higher incidence of irritative symptoms at a trichloramine concentration of 0.21 mg m^{-3}. These findings are similar to ours and emphasize that even relatively low trichloramine exposure (up to 0.3 mg m^{-3}) might cause health problems.

With regard to professions, the risk of irritation symptoms was highest for swimming teachers and physiotherapists. No statistically significant increase in risk was found for technicians and technicians with lifeguard tasks. These employees often spent their time in areas with reduced trichloramine levels (ventilated guard cages, ventilated locker rooms, and outdoors).

The power of our results was limited by the relatively small number of subjects and the well-known healthy worker effect.

Pool attendants

Swimmers are exposed to the substances contained in water and those splashing or evaporating from aerosols from the water. Several authors found ocular and respiratory irritative symptoms to be common in swimmers (Lévesque *et al.*, 2006; Bowen *et al.*, 2007). Concerning public exposure to trichloramine, Lévesque *et al.* (2006) quantified the limit for an increasing incidence of irritative symptoms at 0.37 mg m^{-3}. Other authors evidenced a higher prevalence of hay fever and allergic respiratory effects in persons who started swimming early in life (Zwick *et al.*, 1990; reviewed by Kohlhammer and Heinrich, 2007) or demonstrated some of the mechanisms that are involved in the hyperpermeability of lung tissues (Helenius *et al.*, 2002; Bernard *et al.*, 2003; Lagerkvist *et al.*, 2004).

Other studies, which did not support the increase in irritant effects and allergic incidence, were interesting because they showed that low values of chlorine, as was the case in Germany (Schoefer *et al.*, 2008), or its absence, in the case of copper-silver disinfection (Carbonnelle *et al.*, 2002), might reduce or prevent these health symptoms. Studies in Germany underlined two periods of German regulations. Kohlhammer *et al.* (2006) showed that adults had higher rates of hay fever when they were frequently exposed at school age during the years 1950 and 1969, whereas a study on children who started swimming in the late 1990s did not show evidence of such an increase (Schoefer *et al.*, 2008). This might suggest that a better regulation contributes to less exposure for swimmers and consequently results in minor health effects in terms of atopic diseases. However, these authors noted a higher risk of diarrhea in baby swimmers. A conflict between low exposure to chlorine by-products and insufficient disinfection might not be inevitable.

Pool water quality

The Swiss reference and tolerance values for free and combined chlorine, along with those of Germany, are among the lowest. In swimming pools, free chlorine should be between 0.2 and 0.4 mg per liter of water (reference value) and should not exceed 0.8 mg l^{-1} (tolerable limit), while combined chlorine should be $<$0.3 mg l^{-1} (SIA, 2000). France, for example, has a free chlorine tolerance value fixed between 0.4 and 1.4 mg l^{-1}, while that of Belgium is between 0.5 (minimum tolerable) and 1.5 mg l^{-1}. The Swiss reference value is below or equal to the minimum tolerable value in Belgium and France.

Unlike other studies (Schmoll *et al.*, 2009), we did not identify a clear correlation between pollutants in water (free chlorine, bounded chlorine, THM, or urea) and trichloramine in the air around the swimming pools. Nevertheless, the question arises as to whether low contents of free and combined chlorine in water could partly explain the low air concentrations of trichloramine measured during our study. On one side, this hypothesis seems to be confirmed by studies in Germany where the free and combined chlorine concentrations were found to be similar to those measured in Switzerland and the air levels of trichloramine were also pretty low (Schmoll *et al.*, 2009). On the other side, studies in Belgium and France showed higher trichloramine concentrations in pool air, with some very high values (Héry *et al.*, 1995; Massin *et al.*, 1998; Bernard *et al.*, 2003). Recently, Belgium reduced the reference value for combined chlorine from $<$2.0 to $\leq$0.8 mg l^{-1} (A. Bernard, personal communication), but no data are available to assess the effect of the new benchmark.

The Swiss SIA (2000) and the German DIN 19643 standards for pool construction, technical and chemical characteristics, and maintenance rules permit the use of low amounts of disinfectants while guaranteeing the hygiene of pools. These norms require the installation and maintenance of severe technical standards (including the flocculation of water particles, the correct use and cleaning of filters, and good water circulation in the pools) and set regulations on water quality (free and combined chlorine, urea, etc.). These measures seem to reduce trichloramine formation and, consequently, occupational and public trichloramine exposure. In addition, the SIA norm requires fresh water supply of at least 30 l for each swimmer attending the pool and demands good water circulation in the pool. A ventilation system with 30% fresh-pulsed air guarantees good management practice.

CONCLUSIONS

An occupational exposure limit for trichloramine

As has been done for a large variety of chemicals (Schaper, 1993), the occupational exposure limit should be based on the substance's irritative properties when there is a lack of chronic toxicological data. The TLV documentation on chlorine (ACGIH, 2001) indicates, for example, that the TLV–TWA and TLV–STEL values are intended to minimize the potential ocular, mucous membrane, and respiratory tract irritation. The available evidence indicates that TWA exposure to 1 p.p.m. of chlorine results in annoying symptoms in the nose, throat, and conjunctiva among exposed workers. Therefore, the proposed TLV for chlorine is 0.5 p.p.m.

For trichloramine, our results, as well as those obtained by Massin *et al.* (2007) and Thoumelin *et al.* (2005), demonstrated similar increasing risks of irritative symptoms up to a trichloramine level of 0.2–0.3 mg m^{-3}. In contrast, Jacobs *et al.* (2007) did not find any correlation between health symptoms and trichloramine air concentrations. Despite the large sample of exposed people in their field study ($n = 628$), we noted that only six facilities were quantified. The trichloramine air concentrations in the other 32 facilities were recalculated, which might have caused an important bias in the study.

Following a literature review, Bonvallot *et al.* (2010) selected a lowest-observed-adverse-effect level of 0.355 mg m^{-3} based on objective measurements rather than self-reported effects. Furthermore, occupational asthma was described by Thickett *et al.* (2002) as an important impairment of the lung function at a level of 0.5 mg m^{-3}. According to Nemery *et al.* (2002), the report of Thickett *et al.* (2002) is clinically important because it provided evidence that swimming pool-induced asthma might occur as an occupational disease. In the case of trichloramine, the precautionary principle has to be applied, too. Therefore, we recommend fixing the trichloramine occupational exposure limit at a ceiling of 0.3 mg m^{-3} (0.06 p.p.m.). This limit is below the proposed reference limit in France (0.5 mg m^{-3}) but is in accordance with recent studies in this country (ANSES, 2010). Héry *et al.* (2000) emphasized that the 0.5 mg m^{-3} reference level does not assure sufficient protection of employees exposed to trichloramine. Moreover, our results, as well as those of Schmoll *et al.* (2009), showed that low concentrations of trichloramine in air are possible.

Longitudinal studies with a pluridisciplinary approach have to be performed to evaluate the possible risk of asthma among persons who are professionally exposed to trichloramine, not only in indoor swimming pools but also during various cleaning activities, such as vegetable washing (Héry *et al.*, 1998).

Recommendations for reducing trichloramine precursor concentrations

In indoor swimming pools, the use of a ventilated ''guard cage'' seems to be an excellent way to control occupational exposure to trichloramine. Among others, Li and Blatchley (2007) and Schmalz *et al.* (2011) claimed that urea and free chlorine are major precursors of trichloramine synthesis. Based on our results and experience, we understand that the control of all parameters during the water disinfection process is a determinant factor in minimizing trichloramine production. Before implementing the technical solutions for improving trichloramine elimination from swimming pool, as proposed by Gérardin *et al.* (1999, 2005), the trichloramine precursors have to be under control. Correct technical management and conscientious daily follow-up of the whole disinfection and water filtration systems ensure the good microbiological quality of the water and minimize the production of undesirable trichloramine. Because of energy costs, the fresh air ratio is often reduced, leading to insufficient by-product reduction. Heat recovery systems would improve energy conservation. Finally, besides all these technical parameters, good public hygiene (showering before swimming) should be assured by undertaking correct and regular public awareness campaigns.

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REFERENCES

ACGIH. (2001) Documentation of threshold limit values, chlorine. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

ANSES. (2010) Rapport de l'AFSSET: risques sanitaires liés aux piscines. Maison-Alfort Cedex, France: Agence nationale de sécurité sanitaire, de l'alimentation, de l'environnement et du travail. Available at http://www.afsset.fr/upload/bibliotheque/413996977197053340489872262883/10_06_piscines_reglementees_vdef_2010.pdf. Accessed 23 June 2011.

Badinier-Paganon I, Deschamps F. (2001) Exposition des maîtres-nageurs aux dérivés chlorés. Arch Mal Prof; 62: 477–81.

Barbee SJ, Thackara JW, Rinehart WE. (1983) Acute inhalation toxicology of nitrogen trichloride. Am Ind Hyg Assoc J; 44: 145–6.

Bernard A, Carbonnelle S, De Burbure C *et al*. (2006) Chlorinated pool attendance, atopy and the risk of asthma during childhood. Environ Health Perspect; 114: 1567–73.

Bernard A, Carbonnelle S, Dumont X *et al*. (2007) Infant swimming practice, pulmonary epithelium integrity, and the risk of allergic and respiratory diseases later in childhood. Pediatrics; 119: 1095–103.

Bernard A, Carbonnelle S, Michel O *et al*. (2003) Lung hyperpermeability and asthma prevalence in schoolchildren: unexpected associations with the attendance at indoor chlorinated pools. Occup Environ Med; 60: 385–94.

Bernard A, Nickmilder M, Voisin C. (2008) Outdoor swimming pools and the risks of asthma and respiratory allergies during adolescence. Eur Respir J; 32: 1–10.

Bonvallot N, Glorennec P, Zmirou D. (2010) Derivation of a toxicity reference value for nitrogen trichloride as a disinfection by-product. Regul Toxicol Pharmacol; 56: 357–364.

Bowen AB, Kile JC, Otto C *et al*. (2007) Outbreaks of short-incubation ocular and respiratory illness following exposure to indoor swimming pools. Environ Health Perspect; 115: 267–71.

Carbonnelle S, Francaux M, Doyle I *et al*. (2002) Changes in serum pneumoproteins caused by short-term exposures to nitrogen trichloride in indoor chlorinated swimming pools. Biomarkers; 7: 464–78.

Chalier G, Burlion G, Schrooten D *et al*. (2003) ISSeP (Liège, Belgique), Convention No. 01/13240. Etude de la qualité de l'air des piscines visant à définir des normes pour le contrôle régulier de ces établissements. Rapport final (Final Report). Available at http://environnement.wallonie.be/cgi/dgrne/plateforme_dgrne/visiteur/anims_v2.cfm?pere=63. Accessed 23 June 2011.

Chen L, Dang B, Mueller C *et al*. (2008) Investigation of employee symptoms at an indoor Waterpark. Health Hazard Evaluation report HETA; 0163–3062. Mason, OH: CDC, NIOSH; pp. 53.

Gagnaire F, Azim S, Bonnet P *et al*. (1994) Comparison of the sensory irritation response in mice to chlorine and nitrogen trichloride. J Appl Toxicol; 14: 405–9.

Gérardin F, Gerber JM, Héry M *et al*. (1999) Extraction de chloramines par contact gaz/liquide dans les eaux de piscines. Cahiers de notes documentaires; 177: 21–9.

Gérardin F, Hecht G, Hubert-Pelle G *et al*. (2005) Traitement UV: suivi de l'évolution des concentrations en chloroforme et en trichlorure d'azote dans les eaux de baignade d'un centre aquatique. Cahiers de notes documentaires; 201: 19–29.

Hamel H. (2007) Etude de l'évolution du trichlorure d'azote et des trihalométhanes dans l'eau et l'air des piscines chlorées. Thèse présentée devant l'Université de Rennes 1. Reims, France: Université of Reims.

Helenius I, Rytilä P, Sarna S *et al*. (2002) Effect of continuing or finishing high-level sports on airway inflammation, bronchial hyperresponsiveness, and asthma: a 5-year prospective follow-up study of 42 highly trained swimmers. J Allergy Clin Immunol; 109: 962–8.

Héry M, Hecht G, Gerber JM *et al*. (1994) Exposition aux chloramines dans les atmosphères des halls de piscines. Cahiers de notes documentaires; 156: 285–92.

Héry M, Hecht G, Gerber JM *et al*. (1995) Exposure to chloramines in the atmosphere of indoor swimming pools. Ann Occup Hyg; 39: 427–39.

Héry M, Gerber JM, Hecht G *et al*. (1998) Exposure to chloramine in a green salad processing plant. Ann Occup Hyg; 42: 437–51.

INRS. (2007) Trichlorure d'azote et autres composés chlorés: fiche no. 007/V01.1, see the Metropol Datebase. Available at www.inrs.fr. Accessed 6 Jan 2012.

Jacobs J, Spaan S, van Rooy G *et al*. (2007) Exposure to trichloramine and respiratory symptoms in indoor swimming pool workers. Eur Respir J; 29: 690–8.

Kohlhammer Y, Döring A, Schäfer T *et al*. (2006) Swimming pool attendance and hay fever rates later in life. Allergy; 61: 1305–9.

Kohlhammer Y, Heinrich J. (2007) Chlorine, chlorination by-products and their allergic and respiratory health effects. Curr Respir Med Rev; 3: 39–47.

Lagerkvist BJ, Bernard A, Blomberg A *et al*. (2004) Pulmonary epithelial integrity in children: relationship to ambient ozone exposure and swimming pool attendance. Environ Health Perspect; 112: 1769–71.

Lévesque B, Duchesne J, Gingras S *et al*. (2006) The determinants of prevalence of health complaints among young competitive swimmers. Int Arch Occup Environ Health; 80: 32–9.

Li J, Blatchley ER, III. (2007) Volatile disinfection byproduct formation resulting from chlorination of organic-nitrogen precursors in swimming pools. Environ Sci Technol; 41: 6732–9.

Massin N, Bohadana A, Wild P *et al*. (1998) Respiratory symptoms and bronchial responsiveness in lifeguards exposed to nitrogen trichloride in indoor swimming pools. Occup Environ Med; 55: 258–63.

Massin N, Hecht G, Ambroise D *et al*. (2007) Respiratory symptoms and bronchial responsiveness among cleaning and disinfecting workers in the food industry. Occup Environ Med; 64: 75–81.

Nemery B, Hoet PHM, Nowak D. (2002) Indoor swimming pools, water chlorination and respiratory health. Eur Respir J; 19: 790–3.

Nickmilder M, Bernard A. (2007) Ecological association between childhood asthma and availability of indoor chlorinated swimming pools in Europe. Occup Environ Med; 64: 37–46.

Nystad W, Haberg SE, London SJ *et al*. (2008) Baby swimming and respiratory health. Acta Paediatr; 97: 657–62.

Pairon JC, Choudrat D. (2003) Nouveaux tableaux de maladies professionnelles. Rev Mal Res; 20: 501–9.

Schaper M. (1993) Development of a database for sensory irritants and its use in establishing occupational exposure limits. Am Ind Hyg Assoc J; 54: 488–544.

Schmalz C, Frimmel FH, Zwiener C. (2011) Trichloramine in swimming pools—formation and mass transfer. Water Res; 45: 2681–90.

Schmoll B, Kellner R, Breuer D *et al*. (2009) Trichloramin in der Schwimmhallenluft—Ergebnisse aus dem Forschungsprojekt der Deutschen Gesetzlichen Unfallversicherung. Archiv des Badewesens; 10: 591–611.

Schoefer Y, Zutavern A, Brockow I *et al*. (2008) Health risks of early swimming pool attendance. Int J Hyg Environ Health; 211: 367–73.

Seux R. (1988) Evolution de la pollution apportée par les baigneurs dans les eaux de piscine sous l'action du chlore. J Fr d'Hydrol; 19: 151–68.

SIA. (2000) Zürich, Switzerland: Société des ingénieurs et architectes; Norme 385/1.

Tafrechian S. (2008) L'asthme aux chloramines chez le personnel des piscines. Mémoire pour la capacité de médecin en santé et travail et de prévention des risques professionnels. Paris, France: Université R. Descartes, Faculté de Médecine Paris 5.

Thickett KM, McCoach JS, Gerber JM *et al*. (2002) Occupational asthma caused by chloramines in indoor swimming-pool air. Eur Respir J; 19: 827–32.

Thoumelin P, Monin E, Armandet D *et al*. (2005) Troubles d'irritation respiratoire chez les travailleurs des piscines. Documents pour le Médecin du Travail; 101: 43–61.

WHO. (2006) Guidelines for safe recreational water environments, volume 2, swimming pools and similar environments. Geneva, Switzerland: Work Health Organisation.

Zwick H, Popp W, Budik G *et al*. (1990) Increased sensitization to aeroallergens in competitive swimmers. Lung; 168: 111–5.