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EXPOSURE TO CHLORAMINES IN THE ATMOSPHERE OF INDOOR SWIMMING POOLS

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Abstract—Specific sampling and analytical methods were developed to assess the concentration of chloramines in the atmosphere of indoor swimming pools because swimming instructors had complained of irritation (mainly eye and lung). The sampling method is based upon the reduction of chloramines to chlorides which are then analysed by ion chromatography. The chloramine concentration in the atmosphere of 13 swimming pools (including five recreational centres and one re-education centre) was measured, showing that the concentrations were higher in the recreational centres. The influence of slides, bubbling baths, waves and other activities were demonstrated. A correlation was made between the level of pollutants and the complaints registered, leading to the proposal of a 'comfort' limit value.

INTRODUCTION

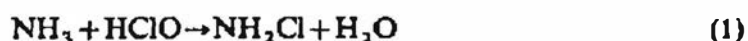
The use of chlorine-containing agents (e.g. calcium or sodium hypochlorite and chlorinated isocyanuric acids) for the disinfection of water in swimming pools leads to the formation of various by-products, resulting from reaction with the pollutants introduced by humans (sweat, urine, etc.). Various derivatives, for example aldehydes, halogenated hydrocarbons and chloramines are quoted by Person *et al.* (1990). Some of these compounds are likely to be transferred to the atmosphere of swimming pools, either as gases, owing to their hydrophobic behaviour in solution, or as droplets if the surface of the water is churned up. In the context of the pollution of the atmosphere of swimming pools, halogenated hydrocarbons have been the pollutants most extensively studied.

Lahl *et al.* (1981) have described the chemical reactions leading to the formation of these compounds, emphasizing that chloroform is the most common. Aggazzotti *et al.* (1990, 1993) studied the consequence of exposure, with regard to the concentrations in blood plasma or in alveolar air of people frequenting swimming pools, to this pollutant.

Given their concentration in the air of indoor swimming pools, halogenated hydrocarbon compounds are not likely to be the cause of the irritative phenomena currently described, which might be caused by well-known irritants such as chloramines, and especially nitrogen trichloride, which has been shown by Barbee *et al.* (1983) to be a strong irritant and lachrymator.

Few studies have been devoted to the measurement of the chloramine concentration in indoor swimming pools. Among these, Jessen (1986) measured chloramines in these atmospheres at concentrations between 0.2 and 0.5 mg m⁻³.

The reactions leading to the formation of inorganic chloramines (mono-, di- or tri-, this last being also called nitrogen chloride) have been described by numerous authors (see for example Hailin *et al.*, 1990) as:



The relative amounts of the different chloramines formed depends on the pH of the solution and the Cl/N ratio. NCl_3 is predominant for low values of pH and when the Cl/N ratio increases. However, more basic conditions (pH > 8 for example) favours the formation of NH_2Cl .

Given the solubilities of these compounds in water, nitrogen trichloride is the species most likely to be found in the swimming pool atmospheres. The Henry's law constants of different chloramines were estimated by Holzwarth *et al.* (1984), and their results indicate that mono- and dichloramine are more likely to be released in droplets produced by the disturbance of the surface of the water than as an insoluble gas.

The aim of the study described in the present paper was to assess the exposure of swimming instructors who had complained of irritation phenomena during the time they spend at work out of water.

This study had two objectives:

- the development of a specific sampling and analysis method for chloramines;
- the assessment of the exposure of swimming instructors in various swimming pools in order to determine the concentration at which complaints of irritation appear.

DEVELOPMENT OF THE SAMPLING METHOD: MATERIALS AND METHODS

Generation of nitrogen trichloride in the laboratory

Because of the solubility characteristics of the different inorganic chloramines (see Holzwarth *et al.*, 1984), it was decided that the method should be adapted mainly to the sampling and analysis of nitrogen trichloride, which is likely to be the principal pollutant. The laboratory apparatus shown in Fig. 1 was designed for this purpose.

Nitrogen trichloride is generated by mixing a 0.5 M sodium hypochlorite solution with a 0.1 M solution ammonium sulphate in a pH 3 phosphate buffer solution, using peristaltic pumps. The nitrogen trichloride thus generated is then stripped from the reactor by air flow. The air flow is then successively washed in two scrubbers, the first containing sulphamic acid solution (renewed continuously) to trap any sodium hypochlorite or chlorine vapours (that may be present), and the second containing water (also renewed continuously) in order to trap any mono- and dichloramine vapours. Finally, a Teflon filter is used to capture droplets generated in the scrubbers. The air flow containing nitrogen trichloride can be diluted before it enters the sampling chamber.

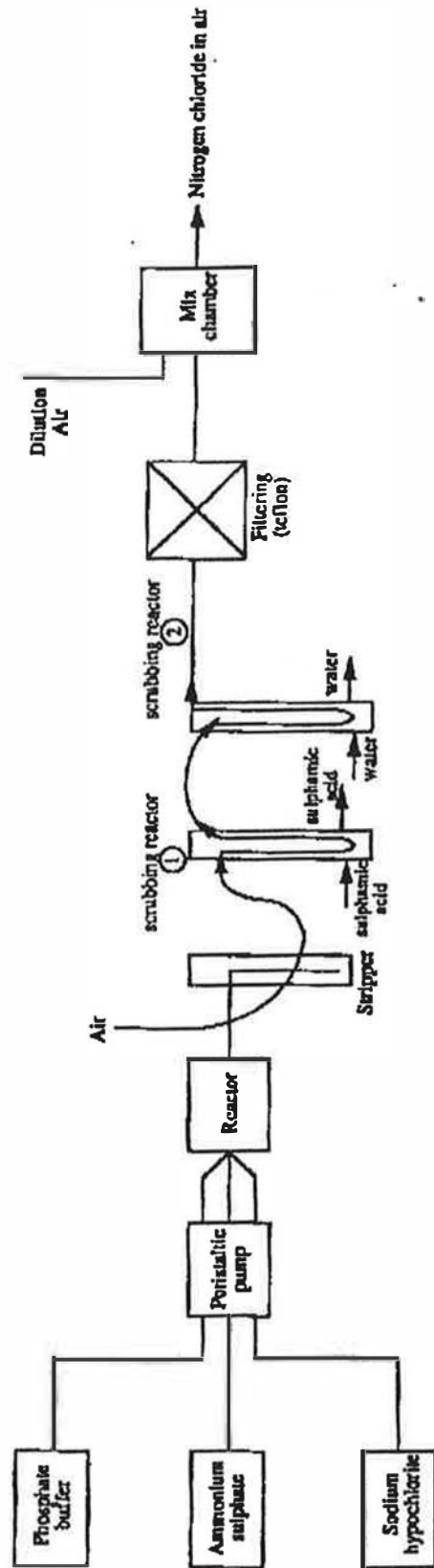


Fig. 1. Device for the generation of chloramines.

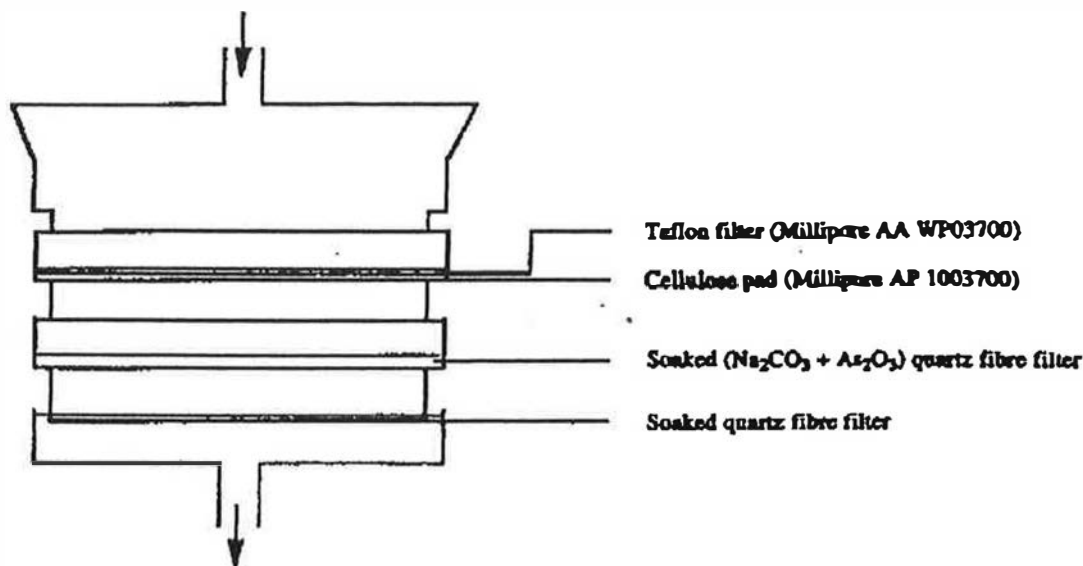


Fig. 2. Configuration of the chloramine sampling cassette tested in swimming pools.

Development of the sampling method

The sampling method is based on two successive chemical reactions:

- at high pH values, the chloramines are decomposed into ammonia and hypochlorite;
- the hypochlorite ion is reduced to chloride by trivalent arsenic.

The principle of the method is consequently based on the sampling of nitrogen trichloride on a specific filter soaked with a solution of sodium carbonate and diarsenic trioxide.

The nature of filters and their configuration in the sampling cassette are shown in Fig. 2.

The Teflon filter prevents any chlorides contained in airborne water droplets from being included in the analysis of nitrogen chloride (which is finally estimated as chloride). The disinfection of the pool water by gaseous chlorine or by hypochlorites does indeed result in the introduction of chloride ions into water. The droplets, which are mechanically dispersed into suspension in the air, are of a composition analogous to that of the pool water, and thus contain chlorides coming directly from the disinfection agent. The Teflon filter is discarded after sampling.

For use in the sampling cassettes the quartz fibre filters are initially thoroughly rinsed with twice-distilled water in order to eliminate all the chlorides they might contain. They are then soaked with 500 μl of a solution of sodium carbonate (40 g l^{-1}), diarsenic trioxide (4 g l^{-1}) and glycerol (40 ml l^{-1}) in twice-distilled water. After drying at 50°C, these filters are settled in the sampling cassette as shown in Fig. 2.

The cassettes sample at a flow rate of 1 l. min^{-1} , in closed-face configuration, i.e. with a 4.1 mm diameter inlet, using Gilian HFS 113 sampling pumps.

Analytical method

After sampling, the carbonate-arsenic impregnated filters are desorbed in 10 ml of twice-distilled water. The resulting solution is passed through a cation exchange resin to eliminate carbonate, which interferes with the analysis of chloride.

This resin is contained in cartridges prepared as follows: a polyethylene frit disk (Bond-Elut 20 μm porosity), resin in the H^+ form (Bio-Rad 50W-X12, 100–200 mesh), which has been previously put into suspension by stirring twice-distilled water to a depth of about 15 mm, and a second disk are successively placed in a cylinder cartridge (Bond-Elut 4 ml volume and 9 mm diameter cartridge). During this filling stage the cartridge is kept under a slight vacuum. Before use, the filled cartridge is washed with twice-distilled water and dried.

After the desorption solution is passed through the cartridge, the chlorides are analysed by ion chromatography (Spectra Physics SP8810 HPLC pump; Alltech 15 cm Universal Anion column; Waters 430 conductivity detector). The mobile phase used in chromatographic analysis is a 3×10^{-3} M phthalic acid solution, the pH of which has been adjusted to 4.2 by adding lithium hydroxide; the flow rate is 1 ml min^{-1} .

DEVELOPMENT OF THE SAMPLING METHOD: RESULTS

In an initial step, the efficiency of the sodium carbonate–diarsenic trioxide solution for the reduction of chloramines to chlorides was checked. Following the method proposed by Brunetto *et al.* (1987), a u.v. spectrum was made for a mixture of sodium hypochlorite and ammonium sulphate in a pH 3 buffer. Sodium carbonate and diarsenic trioxide were then added and a new u.v. spectrum was recorded. The absorption peaks attributed to nitrogen trichloride vanished on this second spectrum.

Validation of the collection efficiency

Nitrogen trichloride was generated by means of the apparatus shown in Fig. 1. In order to verify the collection efficiency of the carbonate–arsenic-treated filter, a series of cassettes followed by scrubbers containing carbonate–arsenic solution were sampled for various air concentrations. The respective quantities of chlorides measured on each of these sampling media are shown in Table 1.

Given the positive result of this first test, the same experiment was conducted with other buffer solutions (pH 6 and 9), i.e. in conditions where the formation of di- and monochloramine is favoured. The results are also shown in Table 1.

Since it was not possible in the laboratory to generate atmospheres as complex as those of swimming pools, the collection efficiency was measured in several of these establishments by the same method as had been used previously in the laboratory. The collection efficiency of the method proposed was thus checked under real conditions. The results are shown in Table 2. Unlike in the previous experiment, the two filters contained in the sampling cassette were analysed separately.

Influence of the Teflon filter

Several tests of the effect of the Teflon filter during the sampling of the different chloramines species were performed:

- it was shown that no nitrogen trichloride was trapped on the Teflon filter or on the cellulose pad underneath it;
- it was shown that mono- and dichloramine coming from airborne droplets in the atmosphere of swimming pools and trapped on the Teflon filter would quickly be vaporized and adsorbed on the carbonate–arsenic-treated filters.

Table 1. Efficiency of the chloramine sampling cassette tested in the laboratory

Test	pH 3 buffer solution		pH 6 buffer solution		pH 9 buffer solution	
	Quantity of chloride trapped on filters (in mg) (atmospheric concentration in mg m^{-3})	Quantity of chloride trapped in scrubber (mg)	Quantity of chloride trapped on filters (in mg) (atmospheric concentration in mg m^{-3})	Quantity of chloride trapped in scrubber (mg)	Quantity of chloride trapped on filters (in mg) (atmospheric concentration in mg m^{-3})	Quantity of chloride trapped in scrubber (mg)
1	0.29 (2.32)	0.01	0.15 (1.28)	<0.005	0.10 (0.82)	0.005
2	0.18 (1.44)	<0.005	0.04 (0.34)	>0.005	0.07 (0.56)	>0.005
3	0.16 (1.28)	0.005	0.05 (0.43)	<0.005	0.11 (0.90)	0.005
4	0.10 (0.80)	<0.005	0.26 (2.21)	0.02	0.09 (0.76)	0.005
5	0.05 (0.40)	<0.005	0.25 (2.12)	0.01	0.06 (0.48)	>0.005
6	0.07 (0.56)	<0.005	0.22 (1.80)	0.01	0.05 (0.42)	0.005

Sampling duration approximately 2 h.

Table 2. Efficiency of the chloramine sampling cassette tested in swimming pools

Test	Volume sampled (l.)	Atmospheric concentrations of chloramines measured on:		
		first filter in mg m^{-3} (percentage)	second filter in mg m^{-3} (percentage)	scrubber in mg m^{-3} (percentage)
1	360	0.82 (85)	0.12 (12)	0.03 (3)
2	340	0.84 (90)	0.06 (6)	0.03 (4)
3	320	0.84 (90)	0.06 (6)	0.03 (4)
4	480	0.73 (90)	0.05 (6)	0.03 (4)
5	210	0.67 (> 88)	0.07 (> 9)	<0.02 (< 3)
6	420	0.65 (90)	0.05 (7)	0.02 (4)
7	260	0.81 (90)	0.05 (6)	0.04 (4)
8	55	1.00 (> 85)	<0.09 (< 8)	<0.09 (< 8)
9	160	0.22 (96)	0.01 (4)	No scrubber
10	160	0.23 (92)	0.02 (8)	No scrubber
11	150	0.34 (94)	0.02 (6)	No scrubber
12	145	0.26 (93)	0.02 (7)	No scrubber
13	140	0.27 (93)	0.02 (7)	No scrubber
14	130	0.28 (93)	0.02 (7)	No scrubber

Recovery after long-term storage

As it was not possible simultaneously to sample a sufficient number of cassettes to verify the conservation of trapped chloramines, two series of 28 samples were simultaneously prepared from a solution of nitrogen trichloride in carbon tetrachloride. In a closed vessel, solutions of sodium hypochlorite and ammonium sulphate were mixed in a pH 3 buffer. Carbon tetrachloride, which has been described by Brunetto *et al.* (1987) among others as a good solvent for nitrogen trichloride, was introduced into the vessel through the septum.

The two series used for the recovery after storage were composed of:

- sealed flasks containing 10 ml of a solution of 2 g l^{-1} of sodium carbonate, 0.2 g l^{-1} of diarsenic trioxide and 2 ml l^{-1} of glycerol in twice-distilled water, into which 100 μl of the chloramine solution in carbon tetrachloride were introduced through the septum;
- carbonate-arsenic-treated filters on which the same 100 μl had been spiked.

Seven samples of each series were analysed on the day of preparation, 14 others (seven of each series) 3 days later (D + 3), and on D + 10 and D + 30. The results of this experiment are shown in Table 3.

After all these tests, the method was found suitable for use in the assessment of the atmospheres of indoor swimming pools. The particularity of this method is that, unlike usual sampling methods, it is not used to assess the concentration of one single pollutant, but of the whole range of irritative chlorine derivatives likely to be found in the air of swimming pools, mainly chloramines, hypochlorite or hypochlorous acid.

Table 3. Recovery after storage of chloramine spiked on filters

	Day D	Quantity of chloride (mg)		
		D+3	D+10	D+30
In sealed flasks (N=7)	0.162 ± 0.009	0.158 ± 0.005	0.152 ± 0.007	0.162 ± 0.003
On treated filters (N=7)	0.157 ± 0.005	0.156 ± 0.003	0.152 ± 0.004	0.161 ± 0.008

Other pollutants were measured concurrently with the chloramines. It was previously verified that the methods of sampling and of analysis currently used for these pollutants were practical in the special humidity conditions encountered in the atmospheres of swimming pools, namely:

- halogenated hydrocarbons (mainly chloroform), which were sampled on active charcoal and analysed by gas chromatography (electronic capture detection);
- aldehydes (mainly formaldehyde), which were sampled on dinitrophenyl hydrazine treated silica gel and analysed by liquid chromatography (u.v. detection); and
- phenols, which were sampled on silica gel and analysed by liquid chromatography (u.v. detection).

METHOD FOR THE ASSESSMENT OF THE EXPOSURE OF SWIMMING INSTRUCTORS

Thirteen establishments were selected:

- seven classic standard swimming pools (25 or 50 m long);
- five recreational swimming pools with chutes, waves, fountains, etc.;
- a re-education centre.

The characteristics of these establishments are shown in Table 4.

A 2-day pollution measurement campaign was carried out in each of these establishments, except for the recreational swimming pools I and J, for which two campaigns (one in spring and one in autumn) were performed, and for the establishment L where the assessment was restricted to 1 day. The sampling device (filters, cassette, pump) was the same as described previously. Because of the high

Table 4. Main characteristics of the swimming pools considered in the study

Establishment	Equipment description	Remarks
A	One 25 m swimming pool, two wading pools	
B	One 25 m swimming pool, one wading pool	
C	One 50 m swimming pool, one wading pool	
D	Two 50 m swimming pools, one wading pool	
E	One 25 m swimming pool	
F	One 25 m swimming pool	
G	One 25 m swimming pool, one wading pool	
H	One 25 m swimming pool connected with one recreational pool	slides, bubbling baths
I	Recreational centre: several pools connected together	—slides, waves, bubbling baths, 'wild rivers', etc. —two air pollution assessments (spring, autumn)
J	One 25 m swimming pool, one recreational pool	—bubbling baths —two air pollution assessments (spring, autumn)
K	Recreational centre: several pools connected together	—slides, waves, bubbling baths, 'wild rivers', etc.
L	One 50 m swimming pool, one recreational pool	slides, waves, bubbling baths
M	One 8 m pool	physiotherapy centre

humidity of the atmosphere, great care was taken in calibrating the sampling pumps, with the cassette in-line, before and after the sampling. The flow rate was regularly checked during the sampling.

Given the static character of their task, the swimming instructors were not asked to carry the sampling devices (pumps and cassettes), which were simply placed at various points around the establishment. These points were chosen so as to be representative of the exposure of the swimming instructors: they were situated at places where the members of the staff generally stayed during their work. In a general way most jobs were equivalent and were composed of watching periods at the different points which we selected for sampling.

To avoid saturating the filters the sampling duration of each cassette was restricted to a maximum of 3 h. Different cassettes were sampled successively at each sampling point during the hours when the swimming pools were open. In some cases, when instructors were complaining of irritative phenomena, samples were taken every 30 min in order to allow us to evaluate better the concentrations at which irritation occurs.

EXPOSURE ASSESSMENT RESULTS

A comprehensive view of the concentrations recorded during the study is given in Table 5. As mentioned previously, most jobs consisted of watching periods at the

Table 5. Range of chloramine concentrations in the atmosphere monitored during the study

Establishments	N	First day		N	Second day	
		Mean	Range		Mean	Range
A	13	0.29	0.21-0.36	13	0.29	0.16-0.40
B	9	0.26	0.20-0.29	27	0.25	0.12-0.66
C	20	0.19	0.10-0.26	30	0.19	0.12-0.37
Pool reserved for the public	14	0.38	0.34-0.47	13	0.39	0.31-0.47
D						
Pool reserved for the clubs	12	0.21	0.17-0.25	10	0.15	0.11-0.21
E	23	0.42	0.23-0.90	23	0.21	0.14-0.43
F	20	0.22	0.14-0.40	29	0.15	0.06-0.25
25 m pool	18	0.36	0.17-0.55	18	0.31	0.20-0.52
G						
Wading pool	18	0.43	0.23-0.80	18	0.23	0.08-0.41
H	20	0.87	0.59-1.14	20	0.75	0.61-1.03
Spring campaign	11	0.36	0.24-0.46	16	0.43	0.17-0.72
I						
Autumn campaign	18	0.70	0.44-1.02	30	1.25	0.57-1.92
Spring campaign	17	0.56	0.38-0.82	19	0.35	0.08-0.96
J						
Autumn campaign	22	0.59	0.26-1.49	24	0.52	0.28-1.15
K	26	0.46	0.19-0.67	23	0.50	0.21-0.95
Swimming pool	16	0.33	0.21-0.50			
L						
Recreational pool	28	0.36	0.16-0.73			
M	4	<0.05		4	<0.05	

N, number of samplings.

All results are expressed in mg m^{-3} (NCl_3 equivalent).

different points which we selected for taking our samples. The best estimate of the time-weighted average exposure of the swimming instructors at each swimming pool is given by the mean values of chloramine concentrations given in Table 5. In a general way the values are comparable from one day to the next. Differences may be more marked between the spring campaign and the autumn campaign.

This representation does not correctly show the variability of the concentrations with seasons, functioning of different attractions, customer attendance, etc. These variations are better illustrated in Tables 6, 7 and 8.

In Table 6 the influence of outside ventilation and air recycling is shown by the differences registered in the air pollution of recreation centre I when working conditions are modified. It is noticeable that during the autumn campaign, on the second day, the pollution concentration went on increasing at some points, although the air recycling had been reduced at that moment to a minimum (i.e. when the feeding of fresh, non-polluted air was at its maximum value).

Recreational swimming pools promote the use of slides, fountains and other sorts of activities which are likely to affect the concentration of chloramines in the air, as the results collected in Table 7 show. These concentrations were monitored at swimming pool J.

Some establishments are not equipped with air extraction systems of sufficient capacity, which leads to a steady increase in the chloramine concentration in the air throughout the day. Such an example is given in Table 8, for measurements made in swimming pool E.

Regardless of the swimming pool considered, the concentrations of pollutants other than chloramine were found to be low: they were close to the detection limit for formaldehyde and phenol, and always lower than 0.02 mg m^{-3} . The concentrations of chloroform ranged from 0.03 to 0.36 mg m^{-3} depending on the establishment, that is to say well below the French limit value of 25 mg m^{-3} .

Table 6. Influence of air recycling on the chloramine concentration in the atmosphere (swimming pool I)

Sampling points	Spring assessment			Autumn assessment				
	First day (windows open) 3 p.m.– 7 p.m.	Second day (10 a.m.–1 p.m.: windows closed 1 p.m.–5 p.m.: windows open)		First day (recycling at minimum)		Second day (10 a.m.–3 p.m.: recycling at maximum 3 p.m.–6 p.m.: recycling at minimum)		
		10 a.m.– 1 p.m.	1 p.m.– 5 p.m.	10 a.m.– 2 p.m.	2 p.m.– 6 p.m.	10 a.m.– 12 p.m.	12 p.m.– 3 p.m.	3 p.m.– 6 p.m.
1	0.30	0.72	0.40	0.71	0.48	1.54	1.85	1.94
2	0.47	n.m.	n.m.	0.72	n.m.	1.46	1.35	1.40
3	0.26	0.31	0.17	0.98	0.57	0.90	1.21	1.27
4	0.29	0.45	0.27	0.85	0.51	0.91	1.23	1.48
5	0.27	0.38	0.31	0.84	0.47	0.73	1.17	1.30
6	0.24	0.32	0.31	0.72	0.59	0.59	0.96	1.16
7	0.49	0.46	0.57	0.76	0.54	0.93	1.15	1.16
8	0.43	0.62	0.61	0.88	0.75	1.17	1.58	1.69
9	n.m.	n.m.	0.38	1.02	0.59	1.09	1.42	1.06
10	n.m.	n.m.	0.54	0.69	n.m.	1.06	1.47	1.25

n.m., not measured.

All results are expressed in mg m^{-3} (NCl_3 equivalent).

Table 7. Influence of recreational activities on the chloramine concentration in the atmosphere (swimming pool J)

	Date	Air pollution (mg m ⁻³)		
		Bath working (4.30 p.m.-7 p.m.)	Bath stopped (2 p.m.-4.30 p.m.)	Mean of other samplings (4.30 p.m.-7 p.m.)
J1 bubbling bath	Spring assessment (second day)	0.96	0.38	0.22
	Autumn assessment (first day)	1.48	0.56	0.47
	Autumn assessment (second day)	1.08	0.28	0.43
J2 bubbling bath	Spring assessment (second day)	0.76	0.38	0.22
	Autumn assessment (first day)	1.39	0.56	0.47
	Autumn assessment (second day)	1.15	0.29	0.43

All results are expressed in mg m⁻³ (NCl₃ equivalent).

Table 8. Evolution of chloramine concentration in the atmosphere during 1 day (swimming pool E)

	Points	Chloramine concentration in atmosphere		
		2 p.m.-4 p.m.	4 p.m.-6 p.m.	6 p.m.-7 p.m.
Day 1	1	0.26	0.60	0.67
	2	0.24	0.64	0.68
	3	0.28	0.40	0.91
Day 2	4	0.15	0.25	0.38
	5	0.14	0.21	0.43
	6	0.19	0.24	0.25

All results are expressed in mg m⁻³ (NCl₃ equivalent).

DISCUSSION

The chloramine concentrations monitored in the atmosphere of the 13 swimming pools investigated during the course of the study show that, as has already been described by Lawrence (1990) in Canada, these concentrations are generally higher in the pools with recreational activities. Several factors allow us to explain this difference:

- the air and water temperatures are higher in the recreational swimming pools where customers stay for longer periods than in standard swimming pools. This warmth has a commercial implication for the managements, who are reluctant to drop the temperature since their customers appreciate the warmth of the environments;
- the cost of that high temperature is high too, inciting the swimming pool managements to promote the use of air recycling devices in order to save some money in the heating of the air. Even if most of the moisture of the recycled air is removed, some pollutants, including the prevailing nitrogen trichloride, are recycled as well;

- the disturbance of the water surface is important because waves, fountains or slides, promote the dispersion of the different pollutants (soluble or insoluble) into the air; and
- in several cases, the requirements *vis-à-vis* hygiene are less strict in the recreational centres than in the standard swimming pools since the managements of the former (which are the most often owned and run by private companies, and of which the entrance price is higher) are less strict on the entrance conditions than the managements of the latter (which are in most cases municipal establishments). Apparently trivial aspects such as the shape and the cloth composition of swimming costumes have been shown to have an important effect on water pollution.

That pollution levels are high in recreational centres is not inevitable; the results obtained in swimming pool L, where there is no air recycling when the establishment is open (the air recycling works only at night), are better than the mean results for this kind of establishment.

Similarly, the concentrations are significantly different in swimming pool I, when the air recycling levels are minimum or maximum. In the end the major question is the cost: the justifiable desire to lower the operating costs while ensuring the customers' comfort should not result in degrading the working conditions of the staff, particularly the swimming instructors.

During the course of the study, the working instructors were asked to assess the air quality of the swimming pool while the chloramine concentration in the air was monitored. They were especially asked to warn our staff at the onset of the symptoms of irritative phenomena (eye, throat, etc.), when special air sampling to estimate the concentrations of pollution responsible was started.

Good correlations were found for the corresponding chloramine concentrations between the different swimming pools where these irritation levels were reached. The first complaints were registered for concentrations around 0.5 mg m^{-3} of chloramines (expressed in terms of nitrogen trichloride). Everybody questioned complained of irritation when the concentrations reached 0.7 mg m^{-3} . It must be emphasized that in order to avoid the possibility that any irritation was directly caused by the water only people who had not been in the swimming pool water the day of the monitoring were considered.

These low values are roughly confirmed by an experiment conducted on mice by Gagnaire *et al.* (1994). The irritative characteristic of nitrogen trichloride was then assessed according to an American standard of the American Society for Testing and Material (ASTM, 1984), and found roughly equivalent to that of chlorine. That experiment was conducted using the generation device, shown in Fig. 1, which had been previously used to develop the sampling method described above. From their own results on the irritative characteristics of nitrogen trichloride and from a report by Alarie (1981) evaluating the prediction of acceptable levels of exposure in man from tests on mice, Gagnaire *et al.* proposed a short-term limit value (equivalent to the ACGIH TLV-STEL or the French VLE) of 1.5 mg m^{-3} , and a long-term limit value (equivalent to the ACGIH TLV-TWA or the French VME) of 0.5 mg m^{-3} . These two values are expressed in terms of nitrogen trichloride.

In both cases, the limit value established from our monitoring of pollutants concentration and the limit value assessed from the experimentation on animals by

Gagnaire *et al.*, the limit values proposed must be considered as 'comfort' limit values, that is to say that no investigation was conducted beyond the irritative phenomena.

CONCLUSION

The complexity of the composition of the atmospheres of swimming pools and the high reactivity of the main compounds present in these atmospheres prohibited the usual process which consists of developing sampling and analysis methods specially adapted to a particular pollutant. In the case of swimming pools, such a process was impossible since the pollutants are too numerous and their chemical properties are too similar to permit any practical differentiation on an analytical level.

That is why it must be emphasized that the limit value proposed in this paper, 0.5 mg m^{-3} expressed in terms of nitrogen trichloride, must be associated with the sampling and analysis method described here. Other methods, based for example on the oxidative properties of chlorine and its derivatives, could lead to the proposal of other values. The eventual consequences on the respiratory function of swimming instructors will be assessed in a future dose-effect study.

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