This is Part II of a study investigating the disinfection of swimming pools. Part I appeared in March, 1970. The results show that the sanitation of swimming pools can be improved, and that free available chlorine is a better disinfecting agent than combined chlorine. Other findings are presented.

THE DISINFECTION OF SWIMMING POOL WATER

PART II. A FIELD STUDY OF THE DISINFECTION OF PUBLIC SWIMMING POOLS

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THERE has been a rapid increase in the number of public swimming pools constructed in this country in recent years, and their proper disinfection and operation is becoming an increasingly important public health problem. The results of a recent study of 193 typically operated public pools indicate the need for the promulgation and enforcement by state or local health departments of adequate codes of practice covering all aspects of pool operation, and, hopefully, of minimum qualifications for their operators. In the preparation or revision of these codes, it is extremely important that critical terms be *exactly* defined. Specifically, for each disinfectant, the *type* of residual required should be clearly stated, and also the method or methods approved for its determination.

The objective of this study was to sample many different types of public swimming pools in order to get a statistically sound evaluation of the safety, operational practices, and maintenance problems encountered in typically operated pools. During the study, which was conducted in two parts—one in August of 1967 and the other in August of 1968—four of the authors traveled over 2,200 miles sampling 193 pools, ranging in size from 11,000 gallons to over 600,000 gallons, located along the Atlantic and Gulf coasts of Florida. They included the two Hall of Fame pools at Fort Lauderdale, and all readers of this paper will be glad to know that both met all of the standards used for the study.

Distribution by Pool Size

Of the 193 pools, 7 had a capacity under 20,000 gallons and 7 were above 300,000 gallons; 52 were between 20,000 and 40,000 gallons; 52 between 40,000 and 60,000 gallons; 23 between 60,000 and 80,000 gallons; 13 between 80,000 and 100,000 gallons; and 39 were between 100,000 and 300,000 gallons.

Distribution by Pool Use

Of the 193 pools, 108 were located at hotels or motels along Florida's "Gold Coast," including a great many of the most beautiful establishments in this highly tourist-oriented area; 41 were located at large apartments or condominiums; 26 were municipal pools; 11 were YMCA or YWCA pools; and 7 were located at country clubs.

Distribution by Method of Disinfection

Of the 193 pools, 88 were disinfected with chlorine gas; 49 with sodium hypochlorite; 26 with calcium hypochlorite; and 28 with cyanuric acid-stabilized chlorine. In one pool, no treatment of any kind was being used.

Distribution by Filter Type

Of the 193 pools, 56 had sand filters; 49 pressure diatomite filters; 76 vacuum diatomite filters; 8 had cartridge filters; 2 had anthracite filters and 2 were flow-through pools.

The only significant difference between the two studies was that fewer motel pools and more apartment pools were used on the 1968 trip. Relative distribution of capacity and type of disinfection were the same. Two anthrafilt pools were tested in 1967 and two flow-through type pools in 1968.

Materials and Methods

The following parameters were evaluated or recorded for the 193 pools:

1. Indicator organisms and bacteriological quality
2. Level and forms of chlorine
3. Precision and accuracy of the orthotolidine test
4. pH and water temperature
5. Turbidity (see below)
6. Type of filter
7. Type of pool surface
8. Type of algae, if present
9. Pool capacity, circulation and bather load
10. Pool operation in general.

In addition to the above, a record was made of weather conditions at the time each sample was collected.

Turbidity of pool water was rated on the following arbitrary scale:

0. No visible turbidity, pool water sparkling, main drain outline sharp
1. Very slight haziness observable in deep water
2. Main drain not clearly visible
3. Main drain visible only as a dark spot, water milky
4. Unable to see main drain.

A Beckman Model N battery-operated pH meter was used to measure pH. Free available chlorine and total chlorine residuals were measured by amperometric titration and also with an orthotolidine test kit, both at pool water temperature and, in the 1968 study, on samples chilled to approximately 1° C. Additional parameters used in the 1968 study were alkalinity and cyanuric acid level. Cyanuric acid was determined turbidimetrically using a commercial* test kit. Total alkalinity was measured with a commercial test kit employing a 25 ml sample.

Bacteriological Parameters Used

Bacteriological parameters used were coliform density—both by the multiple tube technique and membrane filtration—fecal streptococci, total staphylococci, Pseudomonas aeruginosa, and 48-hour standard plate count. Two samples were taken from each pool. A 100 ml sample was taken in a bottle containing sodium thiosulfate and sent to a board of health laboratory for coliform determination by membrane filtration. This provided a check on results obtained by the Earle B. Phelps Sanitary Engineering Laboratory of the University of Florida, which made the other bacteriological determinations.

During the 1967 study, a 300 ml composite sample from the shallow end of each pool was collected for the bulk of the determinations in a Roux bottle sterilized between samples in a strong hypochlorite solution, then rinsed thoroughly in pool water. This bottle was attached to a special rod and pulled

* Manufactured by the Hach Chemical Co., P. O. Box 907, Ames, Iowa 50011

around the shallow end of the pool at a depth of approximately 18 inches. A 300 ml portion was decanted into a sterile BOD bottle containing thiosulfate. This procedure was simplified in the 1968 study by the use of sterilized BOD bottles pulled through the water in the above manner. Samples were sent to the university laboratory each night by bus and were processed within 24 hours.

The confirmed multiple tube test for coliforms and MPN for fecal streptococci were run by techniques from the 12th edition of *Standard Methods for the Examination of Water and Wastewater*, and 48-hour plate counts were run on tryptone glucose yeast extract agar at 35° C. Staphylococci were enumerated by membrane filtration of 100 ml of sample and incubation on m-Staphylococcus broth (Difco). Pseudomonas aeruginosa was determined by the most probable number method, described by Favero, Drake, and Randall,[1] using asparagine enrichment broth followed by confirmation in acetamide broth.

Results

Bacteriological Quality of Pool Water

Table 1 summarizes the bacteriological results from all pools. Die-off studies showed that in many instances plate counts would tend to increase and numbers of staphylococci and fecal streptococci to decrease, on standing for 24 hours. Pseudomonas aeruginosa and Escherichia coli did not show significant fluctuations when tested. Therefore, plate count, staphylococci, and fecal streptococci data can only be used for comparison between groups in this study. Coliforms and membrane filter results, however, appear to be valid as maximum storage time allowable for membrane filter tests is 30 hours, and samples were run well within this time limit.

With respect to the presence of coli-

Table 1—Summary of all bacteriological data grouped as to type and level of chlorine residuals

Disinfectant and level found	No. of pools: Total	No. of pools: Free from coliforms	Average bathing load per 10^4 gal	No. of pools: Showing confirmed coliforms	No. of pools: Unsatisfactory with membrane filter	No. of pools: With fecal streptococci	Median of staphlococci per 100 ml	No. of pools: With Ps. aeruginosa	No. of pools: With plate counts ≥200/ml
Free available chlorine ≥0.3 mg/l	55	45	3	4	7	0	2	1	22
Total chlorine ≥0.3 mg/l*	49†	35	3	5	14	2	5	5	29
Total chlorine <0.3 mg/l	44	21	3	13	17	10	16	12	29
Cyanuric acid stabilized chlorine	28	18	2	4	8	2	4	6	22
No residual	16	4	3	9	10	9	TNTC	7	14

* Where free available chlorine is <0.3 mg/l.
† This category included 50 pools, but the sample from one of them was broken in shipment.

forms and to plate counts, the APHA recommends the following:[2]

1. Not more than 15 per cent of samples examined shall show the presence of confirmed coliforms in any of five 10 ml portions.
2. Not more than 15 per cent of the samples examined shall contain 1.0 coliform organisms per 50 ml when the membrane filter test is used.
3. Not more than 15 per cent of the samples examined shall contain over 200 bacteria per milliliter.

Of the 193 pools reported on, 123 or 65 per cent contained no coliforms by multiple tube and were satisfactory by membrane filtration. Plate count data were not judged sufficiently reliable to be considered as a criterion for comparison with other studies. However, comparison of plate count data among categories within this study would be valid. Of the 55 pools containing at least 0.3 mg/l of free available chlorine, 45 or 82 per cent contained no coliforms whereas, of the 44 pools containing 0.3 mg/l or less of total chlorine, only 21 or 48 per cent were coliform-free. Of the 28 pools containing chlorine residuals stabilized with cyanuric acid, 18 or 64 per cent were coliform-free. The explanation of the difference between 1967 and 1968 bacteriological data for the latter group is believed to be that only one pool in the 1967 study had greater than 0.3 mg/l free available chlorine, while 8 of the 15 studied in 1968 had at least this much free available chlorine, and all but one of these contained 1.0 mg/l or more.

A calculation of *free chlorine at pool pH*, to be defined later, was made for the 55 pools containing 0.3 mg/l or greater free available chlorine. Forty-five of these had 0.3 mg/l or greater *free chlorine at pool pH*. Of these 45, only 6 had either coliforms or unsatisfactory membrane filters, whereas 4 of the 10 pools not having 0.3 mg/l of *free chlorine at pool pH* showed either coliforms or unsatisfactory membrane filters, even though the latter group contained 0.3 mg/l free available chlorine.

A comparison of pools having 0.3 mg/l free available chlorine, measured by amperometric titration, with those having 0.3 mg/l total chlorine but less than 0.3 mg/l of free available chlorine, showed that free available chlorine is much more effective than combined chlorine. Fewer isolates of all indicator organisms were found in pools in which the principal disinfectant species was free available chlorine than in pools where the major portion of the total chlorine residual was combined. High plate counts also occurred more frequently in the latter. Pools having 0.3 mg/l of total chlorine but less than 0.3 mg/l free available chlorine, however, showed better bacteriology than those pools with 0.3 mg/l free available chlorine but less than 0.3 mg/l *free chlorine at pool pH*.

The last three groups of pools—having low chlorine residuals, no residuals, or stabilized chlorine residuals with no free available chlorine—showed, as expected, a high frequency of occurrence of coliforms and Pseudomonas aeruginosa. Except for the low numbers of staphylococci found in stabilized chlorine-disinfected pools, these organisms were much more numerous in the pools with low residuals than where free available chlorine was present. High plate counts were also encountered more frequently in these three groups than in the pools with 0.3 mg/l free available chlorine.

Physical Parameters

An attempt was made to relate the presence or absence of algae to the type of pool surface and to the type of filter being used. No significant difference was found in the incidence of algal growths as between pools with painted surfaces and those coated with marbleite plaster. Although the incidence of algal growths in pools equipped with vacuum diatomite filters appeared to be somewhat less than in pools using either pressure diatomite or sand filters, the relationship was not significant at the 95 per cent probability level.

An attempt was made to relate clarity of pool water to the type of filter being used. While the percentage of pools with brilliant, turbidity-free water was a little greater in the case of pools with vacuum diatomite filters than those having either sand or pressure diatomite filters, the data do not definitely indicate that one type of filter outperforms another as far as water clarity is concerned. It is believed that individual attention by careful and conscientious operators is the most important single factor (and the one most frequently lacking) in maintaining a clear, clean pool.

Pool pH

The Florida Code requires that pool pH be maintained within the range pH 7.2-8.0. The APHA[2] recommends that the upper limit be extended to pH 8.2. The results of our study seem to indicate clearly that most pool operators are either not aware of these limiting and permissible values or that they make little or no attempt to follow them. Of the 193 pools studied, 51 per cent contained water with pH values either below 7.2 or above 8.2. Specifically, 83 had pH values below pH 7.2 and 16 had pH values above pH 8.2.

Orthotolidine Measurements Misleading

The standard OT test as performed by pool operators gives results which are both erroneous and misleading. Orthotolidine produces a yellow color when oxidized at pH values lower than 1.8 by chlorine, chloramine, nitrites, and the higher oxidation states of iron and manganese. Before we discuss the reactions involved, perhaps some definition of terms would be helpful.

1. *Free Chlorine in Aqueous Solution*—The reaction of chlorine gas with water to form free chlorine can be represented as follows:

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^-$$

That form of chlorine represented as HOCl (hypochlorous acid) is free chlorine as found in swimming pools, and is more powerful both chemically and as a bactericide and algicide than any other form of the element.

2. *Free Available Chlorine at Pool pH*—The dissociation of HOCl at values above pH 5.0 in aqueous solution establishes an equilibrium with hydrogen and hypochlorite ions so that two species of chlorine, HOCl and OCl^-, are present. The relative amount of each species is dependent upon pH, the absence of ammonia, and of other environmental debris. The following equation represents the dissociation:

$$\underset{\text{Free chlorine}}{HOCl} \rightleftharpoons \underset{\text{Available chlorine}}{H^+ + OCl^-}$$

The meaning of the word "available" must be made clear. The hypochlorite ion, OCl^-, has little or no bactericidal activity but it serves as a reservoir or bank from which *more* free chlorine, HOCl, may be formed as that initially present is removed by pool water demand.

3. *Combined or "Stabilized" Chlorine*—This is the form which chlorine assumes in the presence of such materials as ammonia or its salts, cyanuric acid, sulfamic acid or urea. The relative amount of combined or "stabilized" chlorine and the forms it can take are dependent on pH, temperature, and the concentrations of both HOCl and the stabilizing material. The reaction with NH_3 is as follows:

$$NH_3 + HOCl \rightleftharpoons NH_2Cl + H_2O$$

The product is called monochloramine, which is probably the most common form of combined or stabilized chlorine found in pools. However, its kill time is only about one-thirtieth that of hypochlorous acid[3] which is much too slow for swimming pool disinfection.

According to Zettler and Solsor,[4] free chlorine is produced in water by the general reaction:

$$ACl + H_2O \rightleftharpoons AH + HOCl$$

where A represents the negative part of the molecule to which the positive chlorine is originally attached (in the above case NH_2). This may be Cl^--Cl^+ as in chlorine gas, NAO^-Cl^+, chloramide (cyanuric acid) or chlorimide. The amount of free chlorine released when ACl is added to water depends on the rate and degree of hydrolysis of ACl and the amount of AH present. In the case of chloramine and other N-chloro-inorganic compounds the rate of hydrolysis is so low that very little HOCl is formed, hence the weak disinfecting powers exhibited. The chloramides, in rate and degree of hydrolysis, fall between the complete hydrolysis of chlorine gas and hypochlorite, and the inactivity of chloramine.

The pool operator is primarily interested in the level of free available chlorine in the pool. The method of differentiating free available chlorine and combined chlorine by the standard orthotolidine test is to cool the test sample to 1° C, add orthotolidine solution, and read the flash color within five seconds as free available chlorine. A second sample is treated at pool temperature and allowed to react five minutes after orthotolidine is added, then read. The difference between the two determinations is combined chlorine. During this survey, however, we found no pool operators and only one sanitarian who measured chlorine residuals in the above manner. Most merely read the flash and five minute residuals at pool water temperature, which leads to inaccurate results.

A second, more accurate method of measuring free available chlorine is by means of an amperometric titrator. The free available chlorine is determined by titration with phenylarseneoxide at pH 7.0. Platinum electrodes measure the drop in current as the reaction proceeds. The end point is reached when no further decrease in current occurs upon addition of a small amount of phenylarseneoxide. After the free available chlorine is titrated, the pH is lowered to 4.0 and excess iodide added. Combined chlorine present will oxidize iodide to iodine and the free halogen is titrated with phenylarseneoxide, thereby measuring the amount of combined or "stabilized" chlorine present.

Table 2 and Figure 1 show the percentage of HOCl (free chlorine) and OCl^- (hypochlorite ion or available chlorine) present at pH values from 4-9, for a total chlorine residual of 1.0 ppm.

Table 2 gives the data for the usual pool pH values. It shows that, at a pool pH of 7, about three-fourths of the residual present is "free chlorine" or HOCl. However, at pH 8, less than one-fourth is "free chlorine" and a little more than three-fourths is relatively inactive "available chlorine." No method is available for measuring *free chlorine at pool pH* which is actually what we wish to know and which determines the rate of bacterial kill.

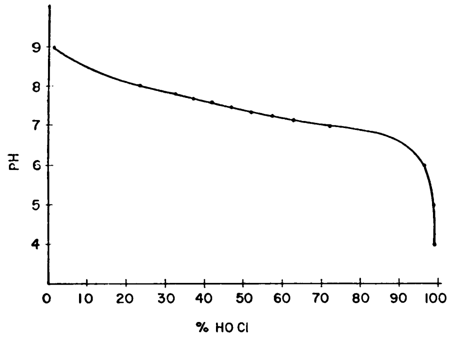
As stated earlier, free available chlorine is determined amperometrically at pH 7.0. The following equation represents the species of chlorine at this pH:

$$\underset{72.5\%}{HOCl} \rightleftharpoons H^+ + \underset{27.5\%}{OCl^-}$$

Table 2—Effect of pH on forms of chlorine[5]

pH	% Cl_2	% HOCl	% OCl^-
4	0.5	99.5	0
5	0	99.5	0.5
6	0	96.5	3.5
7	0	72.5	27.5
8	0	21.5	78.5
9	0	1.0	99.0

Figure 1—Effect of pH on per cent HOCl for any free available chlorine residual



As one titrates the HOCl, the equilibrium shifts to the left and continues to do so until all the HOCl and OCl^- are titrated. The final reading is the sum of both the powerful disinfectant, HOCl and OCl^-, which is bactericidally ineffective. This measurment is *free available chlorine.*

Let us assume that a pool whose pH is 7.5 shows a free available chlorine residual of 1.0 ppm. Reference to Table 3 shows that actually only 0.47 ppm of this is *free chlorine* and the other 0.53 ppm is *available chlorine,* and the pool with a measured 1.0 ppm residual barely meets the 0.4 ppm APHA[2] criterion.

Therefore, to convert any measured *free available* chlorine residual to the equivalent amount of free chlorine at pool pH, one merely multiplies the measured residual by the percentage shown in column 2 (Table 3) for the pool pH and divides the result by 100. For example, to convert 0.45 ppm of free available chlorine, as determined either by the amperometric titrator or the OT test performed at about 1° C, pool pH 7.6:

$$0.45 \times \frac{41.9}{100} = 0.19 \text{ ppm true free chlorine at pH 7.6.}$$

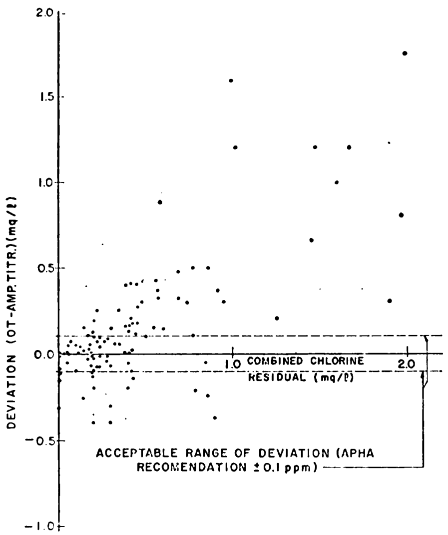
The pool operator could easily determine his free residual by calculation from the pool pH and the residual determined by titration; however, most operators are not fortunate enough to have a titrator and must rely on the orthotolidine test kit. The same free available chlorine is, supposedly, measured by orthotolidine, but one significant difference exists, namely, the pH of the sample is lowered to below 1.8 when orthotolidine is added. At this pH, and at pool temperature, most of the combined or "stabilized" chlorine will be measured as *free available chlorine,* indicating a higher than actual level of active disinfectant. The rate of the reaction with orthotolidine is, therefore, a function of temperature, pH, and concentration.

In order to evaluate the discrepancies between residuals determined with orthotolidine and those determined amperometrically, both tests were carried out at each pool. Of the 110 pools disinfected with chlorine or hypochlorite and which had measurable residual by both methods, residuals measured by orthotolidine were almost uniformly significantly higher than those measured by amperometric titration. This can be seen when the deviations are plotted in Figure 2 as orthotolidine residual minus amperometric residual versus the com-

Table 3—Amount of *free available* chlorine required to provide 0.40 ppm *free chlorine at pool pH*

pH of pool water	Percentage of free available chlorine present as HOCl	Conversion factor	*Free available* chlorine required to provide 0.4 ppm *free* chlorine
7.2	62.3	1.60	0.64
7.3	57.2	1.77	0.70
7.4	52.1	1.94	0.77
7.5	47.0	2.14	0.85
7.6	41.9	2.37	0.95
7.7	36.8	2.70	1.09
7.8	31.7	3.14	1.26

Figure 2—Relationships of (OT_T—AMP_T) in mg/ρ to combined chlorine present



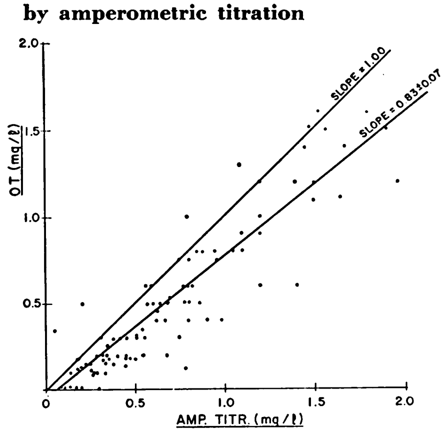
bined chlorine residual obtained by amperometric titration. The discrepancy became strongly positive in cases where greater than 0.40 ppm of combined chlorine was present. It was felt, after the 1967 survey, that chilling the sample to 34° F might reduce the strong interference in the orthotolidine test by concentrations of combined chlorine. However, tests conducted during the 1968 study show that chilling does not bring any improvement. Furthermore, discrepancy did not appear to be influenced by either pH or alkalinity.

The parallel lines of Figure 2 enclose the area within which are found all measured residuals which were within ±0.1 ppm of amperometric values. In this study 52.8 per cent of the measured residuals fell outside this satisfactory area.

The orthotolidine test also has shortcomings as a measure of total chlorine residual. The test kit usually failed to show any residual in cases where total chlorine by amperometric titration was less than approximately 0.15 ppm. In three cases, no orthotolidine residual was found when total chlorine was greater than 0.25 ppm (one as high as 0.45 ppm), when measured by amperometric titration. Figure 3 shows the distribution of the 103 total chlorine residuals measured by both methods. If the two methods of measurement were equivalent, the points plotted would have fallen along a line with a slope of 1.0. It is apparent that they do not but were found to lie about a line with slope of 0.83±0.07 with an intercept at 0.06 ppm. This shows that the orthotolidine residual becomes slightly less sensitive at high residuals than at low residuals, and that it fails to pick up residuals less than 0.06 ppm, which is in the range of the consistent failure at residuals less than 0.15 ppm. A frequency distribution of the deviation of the orthotolidine test and amperometric titration method for total chlorine is given in Table 4. Only 31 per cent were within the ±0.1 ppm agreement recommended by the APHA.

In 27 of the 28 pools employing cyanuric acid stabilized chlorine, orthotolidine residuals were compared with residuals measured by amperometric titration. Eleven of these 22 pools showed no measurable free available

Figure 3—Comparison of chlorine residuals determined with orthotolidine and by amperometric titration



chlorine residual by amperometric titration. Two had free available chlorine residuals less than 0.3 ppm and nine showed values greater than 0.3 ppm. *It is noteworthy that each of the 22 pools showed a high free available chlorine residual* with orthotolidine "flash" test.

Behavior of the titrator was sluggish in measuring free available chlorine at 9 of the 28 pools, with significant free available chlorine residuals. In titrating free available chlorine in the absence of cyanuric acid, the microammeter needle drop is sharp with incremental addition of phenylarseneoxide, and the end point in sharp. When cyanuric acid was present, both in the field study and in the laboratory, needle response is slow and irregular and the end point difficult to define due to needle drift. This opens the question of whether the cyanuric acid stabilized chlorine so measured is really free as HOCl and OCl^-, or whether it is merely bound loosely enough to react with the reducing agent added. The cyanuric acid level was tested in the 15 pools encountered in the 1968 study. In pools showing free available chlorine, the average cyanuric acid level was 58 mg/l as opposed to 80 mg/l in those without measurable free available chlorine residuals. This agrees with findings of other investigators[6,7,8] who found that hydrolysis was greatly suppressed by levels of cyanuric acid greater than approximately 50 mg/l.

These results conclusively indicate the obsolescence of the orthotolidine test for measurement of chlorine in swimming pools for two reasons. First, it does not differentiate between free and combined chlorine, but reports a substantial percentage of combined chlorine as "free available." Second, it does not meet that criterion of APHA which recommends an accuracy of ±0.1 ppm.

Discussion

The results show again that free available chlorine is a much better disinfecting agent than combined chlorine. The over-all total of 35 pools showing the presence of coliforms represents 18 per cent of the total pools and is slightly higher than the 15 per cent maximum isolation rate recommended by APHA. However, the 56 pools yielding unsatisfactory membrane filters is much higher than the maximum. Most of these isolates were found in pools with little or no *free chlorine at pool pH.*

In this study, fecal streptococci were found much less frequently than coliforms, even though Streptococcus fecalis is more resistant to chlorine than E. coli.[3,9] Additionally, fecal streptococci were usually associated with the presence of other indicator bacteria.

Pseudomonas aeruginosa, a potential pathogen and a causative agent of ear infection among swimmers,[10] was found in alarming frequency in pools where less than 0.3 mg/l *free chlorine at pool pH* was present. This organism was not found more frequently than coliforms in any disinfectant group studied.

Staphylococci were found in a very large proportion of the pools, but were found in large numbers only in pools with low chlorine residuals. These data do not agree well with previous work reported in the literature,[11] a fact probably due to die-off in shipment. It has been shown that staphylococci are present in high numbers in heavily used pools in the absence of coliform organ-

Table 4—Frequency distribution of (Amp_T—OT_T) in 103 pools

Deviation	Number of pools
0	7
±0.01–0.05	9
±0.06–0.10	16
±0.11–0.15	12
±0.16–0.20	17
±0.21–0.25	10
±0.26–0.30	12
>0.30	20

isms, and that staphylococci are more resistant to disinfecting agents than E. coli.

Staphylococci are derived from the skin and mucous membranes of human beings; their presence in pool water indicates the possibility of transmittance of staphylococcal infections, and also that other pathogenic organisms from the skin or mucous membranes may be present. The high numbers found in the absence of adequate or marginal chlorination provide further that large populations of these organisms may build up.

A standard of 100 staphylococci per 100 ml in swimming pools has been proposed by Favero, et al.[1] This allows a tremendous number of staphylococci to contact the skin of a bather immersed in a pool. This number was only rarely exceeded both in this study and in a previous study in which more heavily used pools were sampled. Therefore, it is felt that this criterion offers no great degree of safety. A more conservative figure of perhaps 30 staphylococci/100 ml of pool water would be more rational. Robinton, et al.,[11] showed that in pools with greater than 1.0 ppm free available chlorine no more than four staphylococci per 100 ml were present, even where loads were reasonably heavy. Keirn and Putnam[3] found approximately 20 staphylococci/100 cc in pools containing free available chlorine, but in these pools residuals averaged much lower than in those investigated by Robinton.

Summary

1. A field study was made of the chemical and bacteriological quality of the water of 193 below-ground public pools in Florida. These pools ranged in size from 11,000 to 624,000 gallons. Parameters investigated included turbidity, type of filter, presence or absence of algae, pH, determination of chlorine residual by amperometric titration, and orthotolidine, coliform density by both multiple tube and membrane filtration, fecal streptococci, total staphylococci, and Pseudomonas aeruginosa.

2. The study indicates that the operation of public swimming pools is not as good as it should be. One hundred and five of the 193 pools failed to have the residual required by the state health code, and 106 failed to have pH values within the acceptable limits. Eighteen per cent of the pools studied contained coliforms or showed unsatisfactory membrane filtration results. In many instances, pool operators knew little more than the simple details of mechanical operation. All too many of them had little or no conception of the significance of pH or chlorine residual, or how to maintain a residual within acceptable limits. Many monthly reports, to be submitted to the health department, were found filled out days in advance.

3. The standard orthotolidine test for chlorine residual, as performed by most pool operators, yields misleading and erroneous results. At pool water temperature, the flash reading of free available chlorine residual also includes a portion of the combined chlorine residual, the amount depending upon the ratio of free and combined chlorine. This interference is especially bad at low free available chlorine residuals. At present, the only foolproof way of obtaining the free available chlorine residual is by amperometric titration, a method requiring expensive laboratory apparatus.

4. Coliforms were present in 18 per cent of the pools studied, mostly in pools with inadequate chlorine residuals. Fecal streptococci were found much less frequently than coliforms. Staphylococci were isloated in a very large proportion of the pools and were present in high numbers in pools with low chlorine residuals. Pseudomonas aeruginosa was

isolated with about the same frequency as coliforms.

5. The bacteriological data clearly show the importance of pH to the bactericidal effectiveness of chlorine. Pools in which most of the free available chlorine was calculated to be OCl^- showed much worse bacteriology than those pools where the predominant species was HOCl.

6. The authors strongly recommend that *free chlorine residuals at pool pH* be included in any swimming pool code and, further, that more effective operation of public pools could be obtained by requiring licensing of operators and complete automatic control of chlorination and pH adjustment.

ACKNOWLEDGMENTS — The authors wish to acknowledge the valuable assistance of Miss V. A. Morgan and Mrs. Albertha Pringley in making the bacteriological analyses in the Earle B. Phelps Laboratory in the Bioenvironmental Engineering Department, University of Florida. Appreciation is also expressed for bacteriological analyses made by laboratories of the Florida State Board of Health at Jacksonville and Miami, and the County Health Department Laboratory at Sarasota.

REFERENCES

1. Favero, M. S.; Drake, C. H.; and Randall, G. B. Use of Staphylococci as Indicators of Swimming Pool Pollution. Pub. Health Rep. 79:61, 1964.
2. Suggested Ordinance and Regulations Covering Public Swimming Pools. Prepared by the Joint Committee on Swimming Pools of the APHA in cooperation with USPHS, 1964.
3. Keirn, M. A., and Putnam, H. D. The Resistance of Staphylococci to Halogens as Related to a Swimming Pool Environment. Health Lab. Sc. 5:180, 1968.
4. Zettler, T. T., and Solsor, J. Q. Swimming Pool Sanitizers. Soap & Chemical Specialties (Mar.) 1966, p. 51.
5. Black, A. P.; Kinman, R. N.; Thomas, W. C., Jr.; Freund, G.; and Bird, E. D. Use of Iodine for Disinfection. J. Am. Waterworks A. 57:1401, 1965.
6. Andersen, J. R. A Study of the Influence of Cyanuric Acid on the Effectiveness of Chlorine. Presented at NSPI Convention, Chicago, 1964.
7. Fitzgerald, G. P., and Der Vartanian, M. E. Factors Influencing the Effectiveness of Swimming Pool Bactericides. Applied Microbiol. 15:504, 1967.
8. Robinton, E. D., and Mood, E. W. An Evaluation of the Inhibitory Influence of Cyanuric Acid Upon Swimming Pool Disinfection. A.J.P.H. 57:301, 1967.
9. Stuart, R. S., and Ortenzio, R. F. Swimming Pool Chlorine Stabilizers. Presented at the 50th Midyear Meeting, Chemical Specialties Manufacturing Association, Chicago (May 19), 1964.
10. Cothran, Walter W., and Hatlan, Jack B. A Study of an Outdoor Swimming Pool Using Iodine for Water Disinfection. Student Med. 10,4:493, 1962.
11. Robinton, E. D.; Mood, E. W.; and Elliot, L. R. A Study of the Bacterial Flora in Swimming Pool Water Treated with High Free Residual Chlorine. A.J.P.H. 47:1101, 1957.

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Work on this project was supported by Demonstration Grant WPD-19-05-67, WPD-19-06-68 awarded by the FWPCA of the Department of the Interior.

The paper was presented before a Joint Session of the Conference of Local Environmental Health Administrators, the Conference of State Sanitary Engineers, the National Association of Sanitarians, and the Engineering and Sanitation and Laboratory Sections of the American Public Health Association at the Ninety-Sixth Annual Meeting in Detroit, Mich., November 14, 1968.