Model Aquatic Health Code

Draft Contamination Burden Module ANNEX Sections
Modified after the First 60-day Review that Closed on 10/14/2012

Informational Copy: NOT Currently Open for Public Comment

This version of the MAHC Contamination Burden Module has been modified based on the first round of public comments received. It is being re-posted so users can view how it was modified but is not currently open to public comment. The complete draft MAHC, with all of the individual module review comments addressed will be posted again for a final review and comment before MAHC publication. This will enable reviewers to review modules in the context of other modules and sections that may not have been possible during the initial individual module review. The public comments and MAHC responses can be viewed on the web at http://www.cdc.gov/healthywater/swimming/pools/mahc/structure-content/index.html

The MAHC committees appreciate your patience with the review process and commitment to this endeavor as we all seek to produce the best aquatic health code possible.

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MAHC Contamination Burden Module Abstract

Understanding the types of contaminants and the magnitude of disinfectant demand by various environmental factors (e.g., particulate) is an essential component to design and operate a recirculation and filtration system. Limited data currently exists, but a substantial research agenda has been created. The following is a summary of the existing data and areas where data are lacking. Since the Contamination Burden "module" is informational, this module is ANNEX-based only – NO CODE section accompanies it. After being posted for public comment, the information contained in this module will be merged into the appropriate MAHC modules upon final completion. The section numbering system will be different in this draft as there are no specific code sections yet assigned to any of this information.

Note on the MAHC Annex

Rationale

The annex is provided to:

(a) Give explanations, data, and references to support why specific recommendations are made;
(b) Discuss the rationale for making the code content decisions;
(c) Provide a discussion of the scientific basis for selecting certain criteria, as well as discuss why other scientific data may not have been selected, e.g. due to data inconsistencies;
(d) State areas where additional research may be needed;
(e) Discuss and explain terminology used; and
(f) Provide additional material that may not have been appropriately placed in the main body of the model code language. This could include summaries of scientific studies, charts, graphs, or other illustrative materials.

Content

The annexes accompanying the code sections are intended to provide support and assistance to those charged with applying and using Model Aquatic Health Code provisions. No reference is made in the text of a code provision to the annexes which support its requirements. This is necessary in order to keep future laws or other requirements based on the Model Aquatic Health Code straightforward. However, the annexes are provided specifically to assist users in understanding and applying the provisions uniformly and effectively. They are not intended to be exhaustive reviews of the scientific or other literature but should contain enough information and references to guide the reader to more extensive information and review.

It is, therefore, important for reviewers and users to preview the subject and essence of each of the annexes before using the document. Some of the annexes (e.g., References, Public Health Rationale) are structured to present the information in a column format similar to the code section to which they apply. Other annexes or appendices provide information and materials intended to be helpful to the user such as model forms that can be used, recreational water illness outbreak response guidelines, and guidelines for facility inspection.

Appendices

Additional information that falls outside the flow of the annex may be included in the Model Aquatic Health Code Annex

Acronyms in this Module:

DBP	Disinfection By-Products
HOCl	Hypochlorous acid
PHMB	Polyhexamethylene biguanide hydrochloride
PPM	Parts per million
US-EPA	United States Environmental Protection Agency
UV	Ultraviolet

Glossary Terms in this Module:

"Aquatic Facility" means a physical place that contains one or more aquatic venues and support infrastructure under a single management structure.

"Bather" means a person at an aquatic venue who has contact with water either through spray or partial or total immersion. Bathers can be exposed to contaminated water as well as potentially contaminate the water.

"Chlorine" means an element that at room temperature and pressure is a heavy green gas with characteristic odor and is extremely toxic. It can be compressed in liquid form and stored in heavy steel tanks to be used as a swimming pool disinfectant, but most pools now add other chlorine compounds (e.g. calcium hypochlorite or sodium hypochlorite) as disinfectants. Chlorine and chlorine-based disinfectants release hypochlorous acid and hypochlorite ion when dissolved in water. Chlorine is a general term used in the MAHC which refers to hypochlorous acid. Chlorinating agents are the most commonly used disinfectants for pools. [1]

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[1] ATSDR. Toxicological Profile for Chlorine. (2010) Available at: http://www.atsdr.cdc.gov/tfacts172.pdf. Accessed on: 05/01/2013.

"Contaminant" means a substance that soils, stains, corrupts, or infects another substance by contact or association.

"Dichloramine" means a disinfection by-product formed when chlorine binds to nitrogenous waste in pool water to form an amine- containing compound with two chlorine atoms ($NHCl_2$). It is a known acute respiratory and ocular irritant.

"Disinfection" means a treatment that kills or inactivates microorganisms (e.g., bacteria, viruses, and parasites); in water treatment, a chemical (commonly chlorine, chloramine, or ozone) or physical process (e.g., ultraviolet radiation) can be used.

"Disinfection By-Product" means an undesirable chemical compound formed by the reaction of a disinfectant (e.g. chlorine) with a precursor (e.g. natural organic matter, nitrogenous waste from bathers) in a water system (pool, water supply).

"EPA Registered" means all products registered by the US EPA will have a registration number on the label (usually it will state "EPA Reg No." followed by a series of numbers). This registration number can be verified by using the EPA National Pesticide Information Retrieval System (http://ppis.ceris.purdue.edu/#)

"Oxidation" means the process of changing the chemical structure of water contaminants by increasing the number of oxygen atoms or reducing the number of electrons of the contaminant. This allows the contaminant to be more readily removed from the water or to become more soluble in the water. It is the "chemical cleaning" of pool water. Oxidation can be achieved by chlorine, bromine, ozone, and potassium monopersulfate.

"pH" means a term that expresses the negative log of the concentration of hydrogen ions. When water ionizes, it produces hydrogen ions (H^+) and hydroxide ions (OH^-). If there is an excess of hydrogen ions the water is acidic. If there is an excess of hydroxide ions the water is basic. pH ranges from 0 to 14. Pure water has a pH of 7.0. If pH is higher than 7.0, the water is said to be basic, or alkaline. If the water's pH is lower than 7.0, the water is acidic. As pH is raised, more ionization occurs and chlorine disinfectants decrease in effectiveness.

"Pool" means a subset of aquatic venue designed to have impounded/standing water for total or partial bather immersion.

"Trichloramine" means a disinfection by-product formed when chlorine binds to nitrogenous waste in pool water to form an amine-containing compound with three chlorine atoms (NCl_3). It is a known acute respiratory and ocular irritant. It has low solubility in water and is rapidly released into the air above pools where it can accumulate, particularly in indoor settings.

"Trihalomethanes or THM" means chemical compounds in which three of the four hydrogen atoms of methane (CH_4) are replaced by halogen atoms. THMs are also environmental pollutants, and many are considered carcinogenic.

Preface: *This document does not address all health and safety concerns, if any, associated with its use. It is the responsibility of the user of this document to establish appropriate health and safety practices and determine the applicability of regulatory limitations prior to each use.*

Model Aquatic Health Code
Contamination Burden Module Annex

Section numbers may remain unassigned until final MAHC release

Keyword	Section	Annex
Particle Contamination Burden	***1.0***	***Particle Contamination Burden***

1.1 The particle contamination burden determines the filtration flow rate for a given AQUATIC FACILITY. It is not possible to predict the particle contamination burden for every individual POOL because the sources will likely vary significantly from one facility to another. However, it is important to understand the upper limit of particle contamination to provide information for filtration designs. If the upper limit of the particle contamination burden is known, then it should be possible for the designer to specify a filtration system that can handle the maximum particle burden and ensure that water turbidity does not increase above an allowable or desirable level. Essentially, the recirculation system needs to be designed to remove particles at least at the same rate at which they are being added by the environment (e.g., windblown and settling dust), patrons (e.g., personal care products, body excretions), and other sources.

1.2 The best means for determining this maximum rate of particle contamination is through direct measurement at operating facilities to ensure the data are indicative of normal activity. The rate of contamination (n, particles/time/gallon) is likely to vary by POOL location, patron loading, patron age, time of year, time of day, weather, and proximity to urban and desert environments.

1.3 An extensive literature search turned up no relevant data defining the particulate contamination burden in aquatic facilities. It is recommended that a model be developed that describes particle addition and subsequent removal by the filtration system. This would include developing a correlation between particle size and turbidity or clarity index; this correlation is needed from a practical point of view since regulations are likely to be developed based on turbidity or clarity. These data could then be used for making concrete, data-based decisions on removal rate requirements and help with defining the required filtration

Keyword	Section	Annex
		and circulation capacities.
Disinfectant Demand	***2.0***	***Disinfectant Demand***
	2.1	Disinfectant consumption can occur by the reaction of the disinfectant with BATHERS, BATHER waste, and other environmentally-introduced CONTAMINANTS, as well as simple decomposition of the active halides (i.e. hypochlorous acid, HOCl or hypobromous acid, HOBr) into inactive halide ions (chloride or bromide). Disinfectant decomposition rates will also vary depending on a variety of factors including PH, water temperature, ultraviolet light, and BATHER load. Data on disinfectant demand are generally lacking in the literature on all EPA-registered disinfectants. There are some data available for CHLORINE disinfectant demand, but there is very little data for bromine, PHMB, and metal systems.
Chlorine Demand	***3.0***	***Chlorine Disinfectant Demand***
	3.1	Several studies have investigated BATHER load contribution to CHLORINE demand in POOL water; however, there is a lack of consistency in how BATHER load was measured. Some studies report data as CHLORINE demand, others as potassium permanganate demand, dissolved organic carbon or total organic carbon. [2, 3, 4, 5]
	3.2	The available data for CHLORINE disinfectant demand indicates that that the CHLORINE demand from BATHERS can vary by over an order of magnitude, with the largest value measured being 10 g Cl_2/bather (or 2.2 lb/100 bathers).[5]
	3.3	There are few published data on the CHLORINE demand

[2] Judd SJ, Black SH. Disinfection by-product formation in swimming pool waters: a simple mass balance. Water Research (2000); 34(5):1611-1619.
[3] Judd SJ, Bullock G. The fate of chlorine and organic materials in swimming pools, Chemosphere (2003); 51:869-879.
[4] Keuten MGA,et al. Definition and quantification of initial anthropogenic pollutant release in swimming pools. Water Res. 2012;46:3682-3692.
[5] Seux R. The development of pollution caused by swimmers in swimming pool water in relation to the effect of free chlorine. Translation from Journal Francais d'Hydrologie (1988);19(2):151-168.

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that occurs in POOLs due to the simple decomposition of CHLORINE. It is well known that CHLORINE is not stable at high temperatures and in the presence of UV. Both of these factors will reduce active CHLORINE to inactive chloride, without any BATHER waste being present.

3.4 The rate of CHLORINE loss (pounds of CHLORINE per hour) due to UV degradation will depend on a number of factors, including the size of the POOL, the depth of the water and the intensity of the sunshine. It will also depend on the concentration of cyanuric acid present, since cyanuric acid can help prevent the decomposition of CHLORINE by UV. Given the number of variables, it is difficult to predict CHLORINE decomposition rates in specific POOLS.

3.5 The rate of CHLORINE loss can be reduced by the use of other oxidizers, including potassium monopersulfate and ozone, or UV, which can destroy contaminants which would otherwise react with CHLORINE. Additional research on the contributing factors to disinfectant demand (i.e. nitrogenous waste) may be warranted in the future as treatment methods are developed to reduce or eliminate them by means other than OXIDATION. It is anticipated that this research would identify the introduction rate of the CONTAMINANT, resulting concentrations, and the effect that reduction or elimination of this CONTAMINANT would have on disinfectant demand or other ancillary benefits (i.e. reduction of combined CHLORINES).

3.6 Further data collection on CHLORINE usage in real world POOL situations under different environmental and operational conditions could be used to develop an effective rate law from which the sizing of chemical feed pumps could then be calculated.[6, 7] The criteria for specifying a chemical feed pump for a swimming POOL

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[6] March JG, et al. A kinetic model for chlorine consumption in grey water. Desalination (2005); 181:267-273.
[7] Haas CN, Karra SB. Kinetics of wastewater chlorine demand exertion. J Water Pollution Control Federation. 1984;56:170-3.

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		are based on its ability to feed against the process piping pressure and to provide sufficient feed rate to maintain a disinfectant residual in the water. Several states require chemical feed pumps for CHLORINE to be capable of providing up to 10 ppm of CHLORINE in the pipe returning water from the recirculation system back to the POOL. Once actual CHLORINE usage is obtained, a surplus safety factor could be introduced to slightly oversize the feed pump to ensure that the disinfectant dosing amount can be increased to meet increases in demand. Any such sizing requirements need to specify the timeframe within which the pump must be able to satisfy the chlorine dosing required.
Disinfection Byproduct Issues	***4.0***	***Disinfection Byproduct Issues***
	4.1	Chlorination, using CHLORINE as the disinfectant, is the most common procedure for swimming POOL water DISINFECTION and inactivation of waterborne microbial pathogens. Swimmers' activity and environmentally-introduced material provides a broad range of precursors with which disinfectants can react (e.g., perspiration, urine, mucus, skin particles, hair, body lotions, fecal material, soil, etc.). When CHLORINE reacts with these precursors, a variety of chemical reactions take place, including the formation of DISINFECTION BY-PRODUCTS (DBPs)[8,9,10,11,12]. DBPs may also be introduced into the POOL via the water used to fill the POOL depending on the supply water quality. Municipal fill water can also include chloramines as some municipal systems switch from chlorination to chloramination to meet EPA

[8] Richardson SD, et al. What's in the pool? A comprehensive identification of disinfection by-products and assessment of mutagenicity of chlorinated and brominated swimming pool water. Environmental Health Perspectives. 2010 Nov;118(11):1523-30.
[9] LaKind JS, et al. The good, the bad, and the volatile: can we have both healthy pools and healthy people? Environ Sci Technol. 2010;44(9):3205-10.
[10] Zwiener C, et al. Drowning in disinfection byproducts/ assessing swimming pool water. Environ. Sci. Technol. (2007); 41(2):363–372.
[11] EPA. Drinking Water Contaminants. Available at: http://water.epa.gov/drink/contaminants/index.cfm. Accessed on: 05/01/2013.
[12] Praus P. Drinking water disinfection and formation of by-products. Sborník vědeckých prací Vysoké školy báňské – Technické univerzity Ostrava (2003); 49(2): 95-102.

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disinfection byproduct requirements[11]. Chlorine gas, if used, is also extremely toxic.[1,13,14]

4.2 DBPs can be organic[8,15] [e.g., TRIHALOMETHANES, chlorinated phenols, haloketones, haloacetic acids, and haloacetonitriles (HANs)] or inorganic[16,17,18] (e.g. chloramines and cyanogen chloride). The major by-products of DISINFECTION using hypobromous acid (HOBr) and hypochlorous acid (HOCl) are bromoform ($CHBr_3$) and chloroform ($CHCl_3$), respectively. Chloroform and bromoform are highly volatile compounds that can be inhaled in swimming POOL environments and also readily absorbed through the skin.[19,20,21]

4.3 Some classes of organic DBPs [16] are:

- TRIHALOMETHANES *(total TRIHALOMETHANE is the sum of the concentrations of chloroform, bromoform, bromodichloromethane, and dibromochloromethane)*,
- chlorinated phenols *(2-chloro-, 2,4-dichloro- and 2,4,6-trichlorophenol)*, haloketones *(1,1-dichloropropanone, 1,1,1-trichloropropanone)*,
- haloketones (bromopropanone, 1,1-dichloropropanone, 1,1,1-trichloropropanone, etc.)
- haloacetic acids *(Total haloacetic acids include the sum of the concentrations of mono-, di-, and*

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13 Decker WJ, Koch HF. Chlorine poisoning at the swimming pool: an overlooked hazard. Clinical Toxicology (1978); 13(3): 377-381.
14 Drobnic F, et al. Assessment of chlorine exposure in swimmers during training. Medicine and Science in Sports and Exercise (1996); 28(2): 271-274.
15 Weng AS, Li J, Blatchley III E. Effects of UV254 irradiation on residual chlorine and DBPs in chlorination of model organic-N precursors in swimming pools. Water Res. 2012;46:2674-268.
16 Erdinger L, et al. Chlorate as an inorganic disinfection by product in swimming pools. Zentralbl Hyg Umweltmed (1999); 202: 61-75.
17 Beech JA, et al. Nitrates, chlorates and trihalomethanes in swimming pool water. American Journal of Public Health (1980); 70(1): 79-82.
18 Robson HL. Chloramines and bromamines; Encyclopedia of Chemical Technology, Kirk-Othmer, 4d ed, Interscience, New York.
19 Aggazzotti G, et al. Blood and breath analyses as biological indicators of exposure to trihalomethanes in indoor swimming pools. Science of the Total Environment (1998); 217: 155-163.
20 Erdinger L, et al. Haloforms in spas. Zentralbl Hyg Umweltmed (1997);200: 309-317.
21 Hanna JG, Siggia S. Determination of chloroform and bromoform. Anal Chemistry(1950);22(4):569-570.

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trichloroacetic acids and mono- and dibromoacetic acids);
- haloacetonitriles (HANs) include (dichloro-, trichloro-, dibromo- and bromochloroacetonitrile), chloropicrin, chloral hydrate, 3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone, etc.
- Organic Chloramines

4.4 According to European Union regulations, the concentration of TRIHALOMETHANEs in drinking water should not exceed one hundred micrograms per liter (100 µg/L) of water for consumption[22]; while in the United States the Environmental Protection Agency (US-EPA) has established a legal maximum of 80 µg/L[11]. The DIN 19643 swimming pool standard specifies a standard maximum of 20 µg/L.[23]

4.5 Inorganic DBPs include chloramines and cyanogen chloride. Inorganic chloramines include monochloramine (NH_2Cl), DICHLORAMINE ($NHCl_2$) and trichloramine (NCl_3) and are generated from the reaction of hypochlorite with ammonia and amino-compounds that originate from sweat and urine of the swimmers. Trichloramine is relatively volatile and partitions easily from water into air.[24]

4.6 The conditions that determine production and air levels of DBPs have been suggested to depend on several factors:
- Number of swimmers in the POOL, and their associated hygiene
- CHLORINE concentration,
- water temperature
- concentration of organic precursors in the pool water,
- chemical structure of the organic precursors,

[22] Council Directive 98/83/EC on the Quality of Water Intended for Human Consumption, 1998 O.J. L 330/32.
[23] German Standard DIN 19643, 2012. Treatment of Water of Swimming-Pools and Baths..Deutsches Institut Fur Normung E.V. (German National Standard).
[24] Holzwarth G, et al. The fate of chlorine and chloramines in cooling towers. Water Res. 1984;18:1421–1427.

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- bromide content,
- indoor air circulation,
- the extent of out-gassing of volatile DBPs,
- pH,
- level of water agitation (undisturbed vs. being sprayed), and
- concentration of inorganic chloramine from the fill water.

Further research is needed to determine how much DBP's are being created in pool water, including the production and retention rate.

4.7 Studies have examined the link between air quality in indoor aquatic facilities and respiratory effects, including asthma. If there is poor ventilation in the buildings or swimming pool, it could be the cause of negative health effects for bathers from inhalation exposure to the chloramines[25,26,27]. To date, however, research results on the link to asthma are mixed and inconclusive[28,29,30,31]. The one prospective study available[32] suggests swimming does not increase the risk of asthma. To the contrary, the study found swimming increased lung function and reduced the risk of asthma symptoms at age seven. The health benefits associated with swimming

[25] Yoder JS, et al. Surveillance for waterborne disease outbreaks associated with recreational water – US, 2001-2002 MMWR Surveill Summ 53, 1-22.
[26] Mustchin CP, Pickering CA. Coughing water: bronchial hyper-reactivity induced by swimming in a chlorinated pool. Thorax (1979); 34(5): 682-683.
[27] Bowen AB, et al. Outbreaks of short-incubation ocular and respiratory illness following exposure to indoor swimming pools. Environmental Health Perspectives (2007); 115(2): 267-271.
[28] Williams A, et al. Increased concentration of chlorine in swimming pool water causes exercise-induced bronchoconstriction (EIB). Medicine and Science in Sports and Exercise (2004); 36(5) Supplement abstract 2046.
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[30] Nordberg GF, et al. Lung function in volunteers before and after exposure to trichloramine in indoor pool environments and asthma in a cohort of pool workers. BMJ Open. 2012 Oct 8;2(5).
[31] Lagerkvist BJ, et al. Pulmonary epithelial integrity in children: relationship to ambient ozone exposure and swimming pool attendance. Environ Health Perspect (2004);112:1768-1771.
[32] Font-Ribera L, et al. Swimming pool attendance, asthma, allergies, and lung function in the Avon Longitudinal Study of Parents and Children cohort. Am J Respir Crit Care Med. (2011 Mar 1);183(5):582-8. doi: 10.1164/rccm.201005-0761OC.

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include improvement of asthma symptoms and cardiovascular fitness. Pediatricians have long recommended swimming for asthmatic children because of its lower asthmogenicity compared to other forms of exercise. The Belgian Superior Health Council[33] reviewed the available science related to pool swimming and the development of childhood asthma. The Council, in its 2011 report No. 8748 (and reiterated in its 2012 report) concludes swimming remains highly advisable, even in the case of asthma. According to the Council, "For this target group, the advantages of swimming under good hygienic conditions in monitored pools outweigh the risk of toxicity linked to chlorine and its by-products."[34,35,36,37, 9]

4.8 Despite the health risks of DISINFECTION BY-PRODUCTS (DBPs) in general, the concentration of organic DBPs found in POOLS is generally low. Therefore, although research results have shown that DBPs do form in detectable concentrations in most POOLS[38],[39],[40] and levels of exposure can be measured[41,42], it appears that the benefits of DISINFECTION far outweigh the risks posed by

[33] Belgian Superior Health Council. Publication no. 8748: The issue of chlorine in swimming pools: Risk attendant on baby swimming and reflections on the different methods used to disinfect swimming pools.
[34] Bernard A, et al. Lung hyperpermeability and asthma prevalence in schoolchildren: unexpected associations with the attendance at indoor chlorinated swimming pools. Occupational and Environmental Medicine (2003); 60: 385-394.
[35] Goodman M, Hays S. Asthma and swimming: A meta-analysis. J of Asthma (2008);45(8):639-647.
[36] Thickett KM, et al. Occupational asthma caused by chloramines in indoor swimming-pool air. Eur. Respir. J. (2002)19: 827-832.
[37] Weisel CP, et al. Childhood asthma and environmental exposures at swimming pools: State of the science and research recommendations. Environmental Health Perspectives (2009); 117: 500-507.
[38] Kim H, et al. Formation of disinfection by-products in chlorinated swimming pool water. Chemosphere (2002); 46:123-130.
[39] Bessonneau V, et al. Determinants of chlorination by-products in indoor swimming pools. Int Hyg Environ Health. 2011;215:76-85.
[40] Weng S, Blatchley E. DBP dynamics in a chlorinated, indoor swimming pool under conditions of heavy use: National swimming competition. Water Res. 2011;45(16):5241-5248.
[41] Cammann K, Hubner K. Trihalomethane concentrations in swimmers' and bath attendants' blood and urine after swimming or working in indoor swimming pools. Archives of Environmental Health (1995); 50(1): 61-65.
[42] Lindstrom AB, et al. Alveolar breath sampling and analysis to assess trihalomethane exposures during competitive swimming training. Environmental Health Perspectives (1997); 105(6):636-642

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its by-products[43]. The World Health Organization, states that “the risks from exposure to chlorination by-products in reasonably well-managed swimming POOLs would be considered to be small and must be set against the benefits of aerobic exercise and the risks of infectious disease in the absence of DISINFECTION.”[44] Improved water quality management is recommended to minimize formation and accumulation of these compounds.

4.9 A major contaminant in POOL water is urea. Urea is chiefly derived from swimmers urinating in pool water, but is also present in swimmer’s sweat. It has been shown that urea reacts with hypochlorous acid to produce trichloramine. However, while breakpoint destruction of ammonia is very fast, reaction of hypochlorous acid with urea is very slow. Therefore, urea is difficult to remove quickly by shocking the pool water. There are no guidelines in the U.S. for monitoring the urea concentration in pool water or suggested levels of concern. Input of urea is most effectively minimized by changes in swimmers’ behavior and hygiene.[45,46, 47,48,49]

[43] WHO (2000). Environmental Health Criteria 216 (including corrigenda from 11/30/2004). http://whqlibdoc.who.int/ehc/WHO_EHC_216.pdf
[44] WHO (2006). Guidelines for safe recreational-water environments, Volume 2: Swimming pools, spas and similar recreational-water environments.
[45] Blatchley E, Cheng M. Reaction mechanism for chlorination of urea. Environ Sci Technol. 2010 Nov 15;44(22):8529-34. doi: 10.1021/es102423u. Epub 2010 Oct 21.
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[48] Fuchs J. Chlorination of pool water: urea degradation rate. Chemiker Ztg. -Chem. Apparatur (1962);86(3): 76-82.
[49] Gunkel K, Jessen HJ. The urea problem in swimming pools. Z. gesamte Hyg. (1988); 34(4):248-50.

A Note About Resources:

The resources used in all MAHC modules come from peer-reviewed journals and government publications. No company-endorsed publications have been permitted to be used as a basis for writing code or annex materials.

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Erdinger L, Kirsch F, Hoeppner A, Sonntag HG. Haloforms in spas. Zentralbl Hyg Umweltmed (1997);200: 309-317.

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