Study of Bromate Formation in Outdoor Swimming Pools Treated With Sodium Bromide and Sodium Hypochlorite

Scott Hamilton | March 31st, 2026

This study investigates the formation of bromate, a disinfection byproduct (DBP) with potential carcinogenicity, in outdoor swimming pools treated with sodium bromide and chlorine. The research aimed to determine whether bromates form under typical conditions and to assess the influence of organics (algae), pH suppressants (sulfamic acid), and ammonia (ammonium sulfate) on their formation. The study also examined the impact of dosing amounts and chlorine frequency.

Eight outdoor above-ground vinyl liner pools were used in three phases: Phase I with algae, Phase II without algae, and Phase III with higher and repeated superchlorination. Water samples were analyzed for bromate content.

Results indicate that bromate formation occurs, primarily driven by the chlorine-to-bromine ratio, with most occurring within the first 60 minutes of dosing. The presence of organic matter (algae), sulfamic acid, and ammonium sulfate was found to suppress bromate formation, particularly in the initial stages. Swimmer load (simulated with artificial sweat) also showed a small mitigating effect. The study concludes that the risk associated with bromate exposure from sodium bromide use in pools is considerably less than initially feared by the EPA and falls within generally accepted limits; however, further research is needed.

I. DISCLOSURE

United Chemical, the sponsor of these studies, manufactures sodium bromide-based algicides for outdoor swimming pool use. While great care has been taken to maintain the transparency and integrity of the results and discussion points, this conflict of interest and potential bias needed to be acknowledged.

II. INTRODUCTION

Sodium Bromide is a popular and effective algaecide used in chlorinated swimming pools. The most common application of Sodium Bromide in the pool industry is for the treatment of Xanthophytes (also known as Yellow or Mustard Algae). Sodium bromide acts as a reducing agent to chlorine and produces hypobromous acid at a greater ratio than hypochlorous acid at a given pH.

Treatment typically consists of 5 ounces (141 g) of Sodium bromide in a 10,000-gallon pool, followed by superchlorination (also known as “shocking”). It is also used as a preventive algaecide at similar or lower dosages in conjunction with typical chlorine sanitation.

There is evidence that chlorinating water containing bromine in the presence of sunlight can result in up to 50% of the bromine being converted to bromate (Macalady et al. 1977). This finding was also reported

to the EPA by Arch Chemical, which conducted its own study (Arch 2005). Bromate is an undesirable disinfecting by-product (DBP) due to its potential carcinogenicity (Kurokawa et al., 1990).

Existing research has already identified potential mitigating factors for bromate formation, specifically the presence of organics, ammonia, and pH suppressants (Pinkernell et al., 2001; Buffle et al., 2004). However, the complexity of Bromate formation pathways and the pool environment makes it difficult to predict how the above research relates to typical sodium bromide use in outdoor swimming pools.

The primary objective of this study was to develop a better understanding of whether and how Sodium Bromide use in outdoor pools may lead to the formation of bromate as a disinfectant byproduct (DBP), and the potential influence of organics, pH suppressants, and ammonia on its formation is also being investigated. Specifically:

1. Determine if bromates form in outdoor swimming pools, under normal expected conditions, with typical treatment of pools with sodium bromide
2. Determine if the presence of organics (e.g., algae) upon initial treatment reduces the formation of bromate when treating with sodium bromide.
3. Determine if the presence of sulfamic acid reduces the formation of bromate when treating with sodium bromide.
4. Determine if ammonium sulfate reduces or eliminates the formation of bromate when treating with sodium bromide.
5. Determine if the combination of organics (e.g., algae) and sulfamic acid reduces or eliminates the formation of bromate when treating with sodium bromide.
6. Determine whether bromate formation depends on dosing amount and chlorine frequency when treating with sodium bromide.

III. METHODOLOGY

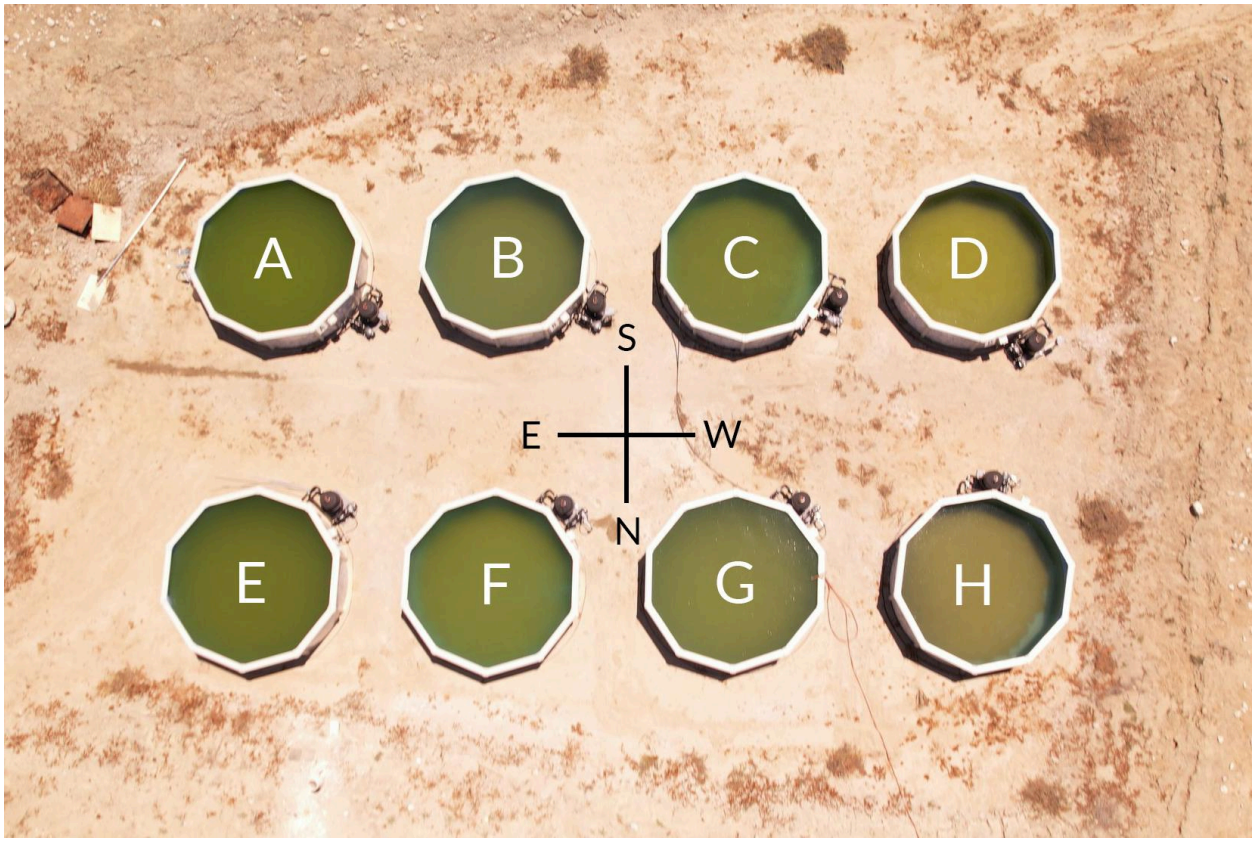
Study Design

Eight (8) outdoor above-ground vinyl liner pools were constructed at United Chemical Corporation facilities located at 3741 E. Telegraph Rd., Fillmore, CA 93015.

Each pool was filled with water from the same source. Vinyl liner pools were selected because they interact less with water chemistry than concrete or plaster surfaces, and are less expensive to construct.

The study was conducted over three (3) phases to model bromate formation under a variety of conditions:

1. **Phase I** was conducted to study the potential for bromate formation in pools with algae.
2. **Phase II** was conducted to study bromate formation in pools without algae
3. **Phase III** was added to study bromate formation in pools that undergo higher and repeated levels of superchlorination



Materials & Methods

Each pool (Hollowell Industries, Embassy Pools brand Century 15’ round) was filled with approximately 5000 gallons (18927.06 L) and treated with a combination of sodium bromide and sodium hypochlorite.

Sodium hypochlorite was chosen as the chlorination method based on its widespread use in swimming pool treatment, its relevance to salt chlorine generators, which produce sodium hypochlorite via electrolysis, and its potential to form bromate due to its high pH and hypochlorite component.

Water samples were collected at the surface using 500mL HDPE bottles (VPET Plastics, H028H-032-01-058NA1-BX1-1-CP) held vertically just below the water line. We assumed that if UVA radiation plays an essential role in bromate formation, the surface concentration of bromate would be highest. This is also where swimmers would ingest the most water.

At the time of sampling and before the addition of any reagents, various measurements and readings were taken of each pool:

1. UVA readings were recorded using an Extech SDL470 UVA/UVC Light Meter Datalogger, with the meter pointed directly at the sun and recording the highest mw/cm² from approximately 12 inches or less above the water.
2. pH and Temperature were recorded using Extech PH100 ExStik pH Waterproof Meter

3. ORP was recorded using EXTECH Instruments RE300 ExStik ORP Meter

Readings were recorded in both the Study Log Book and on each sample container's label.

Containers were sealed and shipped at ambient temperature to Eurofins laboratories located at 8598 Commerce Drive, Easton, Maryland 21601, via UPS 3-Day Shipping. The analytical testing facility analyzed samples for Bromate content and summarized the methods and results in an analytical sub-report.

All granular reagents onsite were measured using a US Solid Analytical Balance Model USS DBS15-3. Sodium hypochlorite was measured using a Karter Scientific 1000mL Plastic Graduated Cylinder.

No water was added to the pools during each test phase. It was estimated that each pool, on average, lost approximately 372 L per day (approximately 1.97%) based on water-level measurements taken at the end of each phase. This value was used to calculate the relative concentrations of the constituent chemicals and to analyze the reactions in the test.

Table 1: Equipment Used

Item	**Model**	**Manufacturer**
Embassy Pools	Century 15' round	Hollowell Industries
Analytical Balance	USS DBS15-3	US Solid
1000ml Plastic Graduated Cylinder	237O2	Karter Scientific
UVA/UVC Light Meter Datalogger	SDL470	Extech
pH Waterproof Meter	PH100 ExStik	Extech
pH Waterproof Meter	PH100 ExStik	Extech
ORP Meter	RE300 ExStik	Extech
500 mL HDPE Bottle	H028H-032-01-058NA1-BX1-1-CP	VPET Plastics

Table 2: Reagents

Chemical	**CAS**	**Manufacturer**
Sodium Bromide 98.5% Tech Grade	7647-15-6	ICL
Sodium Hypochlorite (12.5%)	7681-52-9	Hasa
Sulfamic Acid	5329-14-6	Cellmark
Ammonium Sulfate Fine NSF	7783-20-2	J R Simplot
Artificial Human Sweat	7732-15-5	Biochemazone
Bromate Standard for IC*		Sigma Aldrich

** Eurofin Labs used the bromate Standard for IC for analysis.*

Phase I Methods

All pools were left untreated for approximately 30 days after filling. Each pool developed a significant amount of algae.

Pools A-D were used as control pools treated with 77 g Sodium Bromide to yield an estimated 2.93 ppm Free Available Bromine (FAB) and 887 mL Sodium Hypochlorite for an estimated 6.13 ppm Free Available Chlorine (FAC) for an approximate ratio of 2.13:1 Chlorine to Bromine.

Pools E-H were treated in the same fashion. 33 g of Sulfamic Acid was also added at the time of dosing.

Samples and readings were taken from each pool immediately before dosing, and then at 24, 48, and 72 hours after dosing.

Phase II Methods

Pools were cleaned through repeated superchlorination and backwashing to remove all visible algae. Pools were then treated in the same fashion as Phase I, with Pools A-D serving as controls, while Pools E-H were also dosed with Sulfamic Acid.

Phase III Methods

For Phase III, all water was completely drained, and the pools were thoroughly cleaned using sodium hypochlorite and water. They were then refilled with fresh water.

Pools A-D again served as the controls. All pools were dosed with 77g of Sodium Bromide to produce an estimated 2.93 ppm FAB. Pools were then treated with 1,600 mL of Sodium Hypochlorite (12.5%) to produce an estimated 12.17 ppm FAC, resulting in a chlorine-to-bromine ratio of approximately 3.85:1.

Pools E and F were dosed with 74.5 g of Sulfamic Acid. Pools G and H were dosed with 101.4 g of Ammonium Sulfate.

Samples were taken immediately before dosing, 60 minutes after initial dosing, and 24 hours after initial dosing. At the 24-hour mark, pools were dosed again with 1600 mL and sampled again after another 24 hours. This was repeated one more time for a total of three (3) doses of Sodium Hypochlorite.

In Pools A-D, 250 mL of Biochemazone Artificial Human Sweat was added 24 hours after the last chlorine dose to simulate approximately 15 minutes of swimming by an average adult (Henkin et al., 2010). Samples were then taken 24 hours later. This was only done in the control pools.

Limitations

To assess the maximum potential for bromate formation, pools were maintained at approximately pH 8.0, with no pH adjustments made before or after filling each pool. The study did not investigate the impact of various pH levels on bromate formation beyond the slight variations observed. We assume that bromate is more likely to form at higher pH due to increased concentrations of hypobromite and hypochlorite (Fang et al., 2017).

Cyanuric acid was also not added, as the presence of cyanuric acid likely mitigates some bromate formation. While cyanuric acid does not stabilize aqueous bromine in sunlight, its impact on aqueous chlorine is well known, as it reduces the amount of Free Available Chlorine (FAC). This is likely to reduce the amount of bromide oxidized to bromate.

Bromate stability was only examined for up to 72 hours. It remains unclear how persistent bromate is in outdoor pools and by what mechanisms (evaporation, dilution, decomposition, etc.) it may be reduced beyond what was observed in the study over a short timeframe.

IV. RESULTS

Phase I Results

Out of all eight (8) test pools, only pool C showed bromate formation after 24 hours, showing a yield of 0.0172 ppm from an initial dose of approximately 2.926 ppm Bromine. Bromate readings were relatively stable over 72 hours.

Table 3: Phase I test results of Bromate (BrO3) in PPM

Hrs	A	B	C	D	E	F	G	H
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	0.0000	0.0000	0.0172	0.0000	0.0000	0.0000	0.0000	0.0000
48	0.0000	0.0000	0.0171	0.0000	0.0000	0.0000	0.0000	0.0000
72	0.0000	0.0000	0.0179	0.0000	0.0000	0.0000	0.0000	0.0000

For pool C, this is the equivalent of approximately a 0.59% Conversion of available bromide to bromate.

Phase II Results

We discovered that the baseline samples taken at the beginning of Phase II tested positive for bromate. There was a time lag between receiving baseline readings from the samples and treating the pools according to study protocols. It wasn’t apparent that bromate had formed in the pools until phase II treatment and sample collection had been completed.

Records were not kept of which pools received specific amounts of chlorine, nor how many times they were backwashed, as this was not anticipated.

However, based on our purchasing records, we determined that we had used 48.25 gallons of chlorine after completing Phase I testing for cleaning purposes.

Each pool would have received approximately 22.8 liters (6 gallons) of sodium hypochlorite, assuming equal dosing. This would constitute a potential Cl residual of 173.70 ppm, assuming it was added in a single dose.

Assuming a 25% water loss from backwashing and evaporation, this would result in an average conversion of approximately 16% of the available bromine to bromate.

Table 4: Phase II test results of Bromate (BrO3) in PPM

Smpl #	Hrs	A	B	C	D	E	F	G	H
4	0	0.380	0.520	0.210	0.240	0.260	0.890	0.430	0.190
5	24	0.490	0.670	0.700	0.310	0.280	0.910	0.510	0.200
6	48	0.480	0.660	0.700	0.310	0.280	0.900	0.520	0.190
7	72	0.510	0.660	0.700	0.310	0.280	0.890	0.510	0.190

Following dosing, all pools tested positive for additional bromate formation, with an average increase of 0.04 ppm.

Pools A-D showed an average of 0.0692 ppm increase, with Pool C showing the most significant formation of bromate again at 0.490 ppm.

Pools E-H treated with 33g Sulfamic Acid showed an average increase of 0.011, roughly 4.5 times less than the comparison pools.

If we disregard sample 4, which was before dosing, we find the following for the changes in Bromate ppm in Table 5:

Table 5: Phase II changes in Bromate in PPM

Smpl #	Hrs	A	B	C	D	E	F	G	H
5	24	0.110	0.150	0.490	0.0700	0.0200	0.0200	0.0800	0.0100
6	48	-0.0100	-0.010	0.000	0.0000	0.0000	-0.0100	0.0100	-0.0100
7	72	0.0300	0.000	0.000	0.0000	0.0000	-0.0100	-0.0100	0.0000

Assuming that the only available bromide was from the 77 grams of Sodium Bromide added, and an evaporation loss of approximately 372 Liters per day, we can estimate the following conversion rates of bromine to bromate in Table 6:

Table 6: Phase II estimated conversion of Br to Bromate (%)

Smpl #	Hrs	A	B	C	D	E	F	G	H
5	24	3.83%	4.75%	15.5%	2.44%	0.700%	0.700%	2.78%	0.350%
6	48	-0.370%	-0.340%	0.00%	0.00%	0.00%	-0.400%	0.370%	-0.350%
7	72	1.180%	0.00%	0.00%	0.00%	0.00%	-0.460%	-0.400%	0.000%

Phase III Results

All pools in Phase III exhibited varying degrees of bromate formation. Some residual bromate was detected in samples after draining and refilling each pool. Table 7 provides all detected bromate levels in ppm:

Table 7: Phase III bromate test results in ppm

Smpl #	Hrs	A	B	C	D	E	F	G	H
8	0	0.050	0.050	0.050	0.040	0.060	0.050	0.060	0.090
9	1	0.500	0.540	0.570	0.500	0.160	0.080	0.060	0.090
10	24	0.630	0.580	0.540	0.550	0.150	0.100	0.060	0.090
11	24	1.190	1.210	1.180	1.240	0.760	0.720	1.010	1.510
12	24	1.650	1.700	1.660	1.650	1.300	1.230	1.810	2.610
13	24	1.620	1.670	1.640	1.600	-	-	-	-

If we disregard sample 8, which was before dosing, we find the following for the changes in Bromate ppm in Table 8:

Table 8: Phase III changes in bromate in ppm

Smpl #	Hr	A	B	C	D	E	F	G	H
9	1	0.450	0.490	0.520	0.460	0.100	0.030	0.000	0.000
10	24	0.130	0.040	-0.030	0.050	-0.010	0.020	0.000	0.000
11	24	0.560	0.630	0.640	0.690	0.610	0.620	0.950	1.420
12	24	0.460	0.490	0.480	0.410	0.540	0.510	0.800	1.100
13	24	-0.0300	-0.0300	-0.0200	-0.0500				

Assuming that the only available bromide was from the 77 grams of Sodium Bromide added, as well as any remaining bromide that was not converted to bromate for each dosing of chlorine, and including an evaporation loss of approximately 372 Liters per day, we can estimate the following conversion rates of bromine to bromate in Table 9:

Table 9: Phase III estimated conversion of Br to Bromate (%)

Smpl #	Hrs	A	B	C	D	E	F	G	H
9	1	14.24%	15.5%	16.5%	14.6%	3.16%	0.95%	0.00%	0.00%
10	24	4.40%	1.36%	-1.01%	1.66%	-0.31%	0.62%	0.00%	0.00%
11	24	18.9%	21.2%	21.3%	23.1%	19.2%	19.4%	29.5%	44.0%
12	24	16.7%	18.0%	17.4%	15.0%	18.2%	17.1%	28.1%	41.8%
13	24	-1.15%	-1.19%	-0.790%	-1.96%				

Initial Dose Results - Samples 9 & 10

In Pools A-D, virtually all of the bromate was formed in the first 60 minutes, with an estimated average conversion of 15.2% of available bromide. Pool C once again demonstrated a tendency to form more bromate than the comparison pools. Pools E & F showed a significant reduction in bromate formation compared to Pools A-D in the first hour, with an estimated average conversion of 2.06% of available bromide. Pools G & H showed total suppression of bromate formation over the same period. Little to no additional bromate was formed over the following 24 hours, averaging only a further 1.60% in Pools A-D.

Second Dose Results - Sample 11

All pools demonstrated the highest conversion rates over 24 hours, accounting for the remaining available bromide.

Pools A-D averaged an estimated 21.2% conversion rate to bromate. Pools E & F showed a similar, if slightly lower, average conversion rate of 19.3%. Pools G & H showed the highest estimated conversion rate with an average of 36.7%

Third Dose Results - Sample 12

All pools showed slightly lower bromate formation as a percentage of estimated available bromine, but remained relatively consistent. Pools A-F averaged 17.1% conversion. Pools G & H remained elevated but lower than previously at an average of 34.9%.

Artificial Sweat Results - Samples 13

Pools A-D dosed with 250 mL artificial sweat showed an average reduction in bromate of 1.27%.

V. DISCUSSION

Phase I Discussion

The results of Phase I confirmed our suspicions that the presence of organic matter would suppress bromate formation. This is likely because the available chlorine's oxidative potential is consumed by organic matter, which is converted into less reactive chloramine and other disinfecting byproducts.

It is also possible that the algae itself reduces the amount of UV exposure of available bromine, thereby further suppressing interactions between bromine, chlorine, and UV radiation.

Phase II Discussion

We were surprised to discover the initial sample set of Phase II tests contained bromate.

We anticipated that the time after initial treatment, backwashing, and algae removal would eliminate most, if not all, of the remaining bromine. However, we can only assume that a significant amount of bromine remained at the time of cleanup. Bromine itself is less gaseous than chlorine, and as a result, likely persisted longer in the water than we anticipated.

We concluded that the lack of drainage and the extremely high levels of shock in a short period of time led to the formation of bromate in the water. Hence, we decided to conduct a third phase to investigate further how the bromate may have been formed.

The presence of bromate has a negligible influence on future formation.

An unintended consequence of not accounting for potential bromate formation during Phase II preparation is that we could see the impact of bromate on the subsequent conversion of bromine to bromate.

The Phase II results show a slight negative correlation between the presence of bromate and the potential for further bromate production. Pool C, which had the lowest initial bromate of the control pools, demonstrated the highest conversion rate. In contrast, Pools A,B, and D, which had higher initial bromate, showed significantly less bromate formation. However, this is hard to quantify since only four (4) pools were treated solely with sodium bromide, while the other four (4) were treated with sulfamic acid in addition to sodium bromide. Pool C also demonstrated a higher tendency for bromate formation in Phase I, so this may simply be a coincidence.

Sulfamic acid has some benefit in suppressing bromate formation, as the bromate detected in Pools A-D was approximately 4.5 times higher than in Pools E-H treated with sulfamic acid.

Phase III Discussion

Phase III provided a deeper understanding of the bromate formation process and quantified bromate levels in the initial Phase II samples.

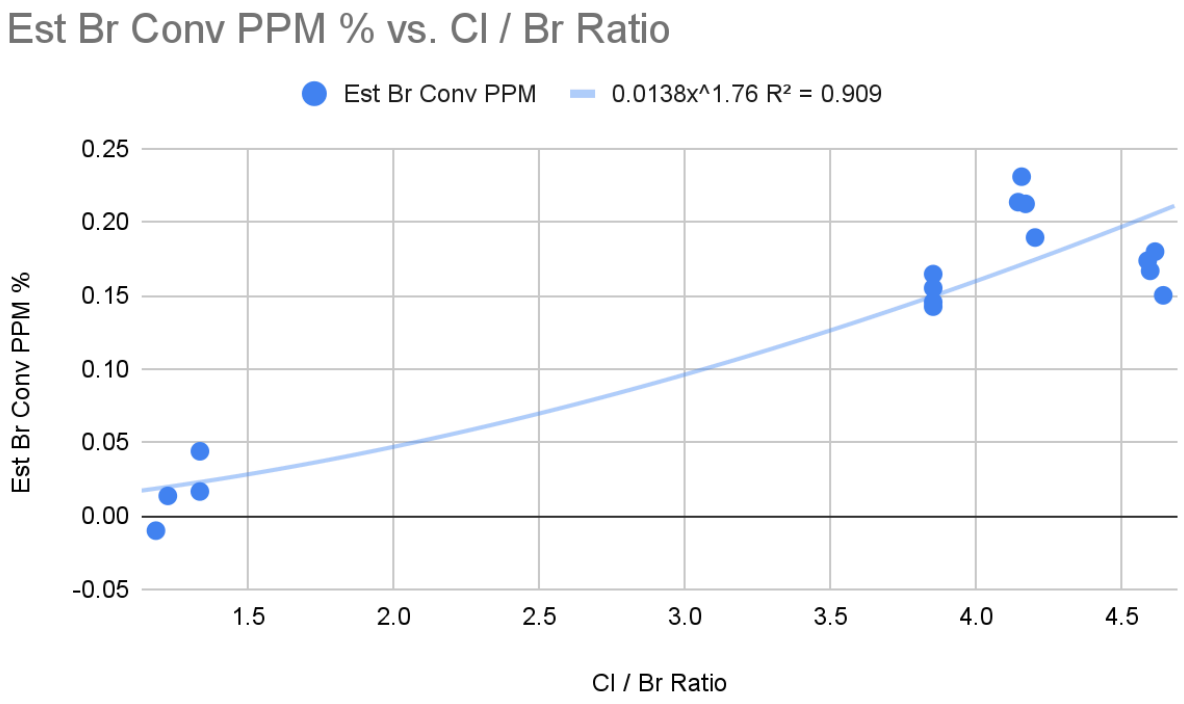
Bromate is formed significantly in the first hour.

We were able to confirm the findings of the Bromate Work Group (Schaefer et al., 2020) that bromate formation occurs nearly "instantaneously". Of the bromate that is formed, approximately 78 to 94% is formed within the first hour of dosing. This suggests that the primary driver of bromate formation is the chlorine-to-bromine ratio rather than the duration of UVA exposure.

The role of UV radiation in bromate formation is unclear. We did not find a direct correlation between measured or average UVA sun exposure and bromate formation. However, a study on DBP in indoor swimming pools showed that no bromate was formed when treated only with chlorine (Michalski et al. 2007). Therefore, its presence is required, but it is only significant within the first 60-minute dosing window, when the chlorine-to-bromine ratio is at its highest.

Chlorine to Bromine Ratio and Possible Model of Formation

The strongest positive correlation we found was between the chlorine-to-bromine ratio and the conversion ratio to bromate.



By plotting the estimated conversion rates of Pools A-D from Phase III, we can obtain the equation 0.0138x^1.76 to achieve an R^2 value of 0.909, thereby deriving the expected conversion rate based on the Cl: Br ratio. This can be used as a function of the ppm of bromide and ppm of chlorine to estimate the amount of bromate formed in ppm as follows:

$$f(x,y) = x * 0.138(x/y)^{1.76}$$

- Or -

$f(x,y) = (0.0138x^{2.76}) / y^{1.76}$

Where:
x is Br ppm
y is Cl ppm
f(x,y) is expected bromate ppm

Using Phase II dosing and the above equation, we expect the bromate conversion to be 5.06%, resulting in a bromate concentration of 0.148 ppm. This is compared to actual observed results in Pools A-D, which averaged 6.49%.

If we include the average conversion rate for Phase II in the model, we obtain a modified equation of 0.0144x^1.74, yielding an R^2 of 0.908 and allowing us to derive the expected conversion rate based on the Cl:Br ratio. This can be used as a function of the ppm of bromide and ppm of chlorine to estimate the amount of bromate formed in ppm as follows:

$f(x,7)= x* 0.0144(x/y)^{1.74}$

- Or -

$f(x,y) = (0.0144x^{2.74}) / y^{1.74}$

Without additional data points to refine the formula, we will use it as an approximation for further analysis.

A typical dose of 5 ounces (141.75 g) of sodium bromide per 10,000 gallons (37854.12 L) of water would produce approximately 2.9 ppm bromine. If we assume a typical superchlorination of 10 ppm, we would have a ratio of 3.45 and expect a conversion rate of 12.49%, yielding 0.36 ppm of bromate.

Assuming a larger dose of 1 pound (453.92 g) of sodium bromide per 10,000 gallons (37854.12 L) of water would produce approximately 9.32 ppm bromide while maintaining a superchlorination rate of 10 ppm, we would expect a conversion of only 1.63% and the formation of 0.15 ppm bromate. Although counterintuitive, this demonstrates that, for a given FAC ppm, a higher sodium bromide dose decreases bromate formation.

These calculations also assume that the water is free of organic matter, cyanuric acid, swimmers, and other mitigating compounds at a relatively high pH. The actual amount observed in real-world scenarios is likely lower.

Both sulfamic acid and ammonium sulfate have the potential to suppress bromate.

We also identified the potential of both sulfamic acid and ammonium sulfate as bromate suppressants, along with their limitations.

Pools E and F showed a significant reduction in bromate formation in the first 24 hours, averaging only 2.2% conversion between the two pools. This effect did not persist beyond the first 24 hours, as subsequent chlorine dosing began to yield more typical results, with approximately 19% conversion of available bromine. Likely, sulfamic acid reacts with bromine to form n-bromosulfamate. The bromine is then liberated through further oxidation by FAC.

Pools G and H show greater potential for bromate suppression, showing 0% conversion of bromine within the first 24 hours. This is likely due to the formation of bromamine and chloramine in the water, which are more stable than the original compounds.

Upon further oxidation by the subsequent superchlorination, the bromine and chlorine are liberated, creating higher available FAC and FAB simultaneously, which can lead to a larger amount of bromate being produced, as observed.

Swimmer load offers some mitigation against bromate.

Swimmer load also appears to reverse some bromate formation. For every one person per 5,000 gallons swimming for 15 minutes, the average bromate level will drop by 1.27%. This is likely due to the formation of bromamines and chloramines, as demonstrated in pools G and H treated with ammonium sulfate.

Real-World Use, Safety, Health, and Regulatory Considerations.

Under ideal conditions for its formation (high pH, relatively pure water, no cyanuric acid), bromate does indeed occur, primarily driven by the ratio of free available chlorine to bromine. However, this appears to be far less than initially feared by the EPA (100% conversion) and less than that first proposed by Arch Chemical (up to 50%) under typical dosing conditions.

The results of the study also align with the American Chemistry Council's report to the EPA in November 2005, which stated that the range of observed bromate levels in actual swimming pools averaged 0.56 ppm in residential pools and 0.9 ppm in commercial pools. Commercial pools are more frequently superchlorinated than residential pools due to their higher swimmer load and regulatory requirements. This aligns with our findings that bromate formation is directly correlated with the bromine-to-chlorine ratio.

Organics, such as algae, prevent the formation of bromate. Sulfamates and ammonium in water will also initially suppress bromate formation. Bromates are likely formed only after subsequent superchlorination liberates available chlorine and bromine. Sweat from swimmers also has a small effect on bromate, likely through mechanisms similar to those of ammonium sulfate.

The potential for bromate formation also changes when considering blended products, where less sodium bromide is added per dose. Using our own products, their dosing instructions, and ignoring any impact from other ingredients, we could expect the following bromate to be produced from each product's directions based on the model proposed:

1. A 5 fl ounce (147.87 mL) dose No Mor Problems (41.17% Sodium Bromide by weight) per 10,000 gallons (37854.12 liters) would introduce approximately 1.82 ppm Bromine. Assuming the use of sodium hypochlorite to maintain a five (5) ppm FAC, this would result in approximately 8.35% conversion, producing 0.15 ppm bromate.
2. A 5-ounce (141.748 g) dose of Yellow Treat^2 (68.73% Sodium Bromide by weight) per 10,000 gallons (37854.12 liters) would introduce approximately 2.0 ppm Bromine to the water. Assuming the use of sodium hypochlorite to maintain a ten (10) ppm FAC for superchlorination, this would result in approximately 23.69% conversion, producing 0.47 ppm bromate.
3. An 8-ounce (226.796 g) dose of Swamp Treat (68.73% Sodium Bromide by weight) per 10,000 gallons (37854.12 liters) would introduce approximately 3.2 ppm. Assuming the use of sodium hypochlorite to maintain a ten (10) ppm FAC for superchlorination, this would result in approximately 10.46% conversion, producing 0.33 ppm bromate.

However, in scenarios 2 and 3, algae would be present, suppressing all initial bromate formation. Bromate would only be produced under subsequent superchlorination if performed in close succession to the initial treatment, which is not typical of product directions.

Risk Assessment using Swimodel 3.0

We can utilize the EPA's SWIMODEL 3.0 to calculate cancer risks associated with bromate exposure in swimming pools.

In SWIMODEL 3.0, the **Incidental Oral Exposure Dose** is defined as follows:

$Dose_{oral} = (CW \times IR \times ET) / BW$

Where:

- $Dose_{oral}$: The amount of chemical ingested per unit of body weight (mg/kg/day).
- CW (Chemical Concentration in Water): The concentration of the active ingredient in the pool water (mg/L).
- IR (Ingestion Rate): The volume of pool water accidentally swallowed per hour (L/hour).
- ET (Exposure Time): The duration of the swimming event (Hours/day).
- BW (Body Weight): The weight of the swimmer (kg).

Next, we will need to calculate the **Lifetime Average Daily Dose (LADD)** defined as follows:

$LADD = [(ADD_{child} \times EF \times ED_{child} \times ADAF) + (ADD_{adult} \times EF \times ED_{adult})] / AT$

Where:

- ADD (Average Daily dose): This is the same as $Dose_{oral}$
- EF (Exposure Frequency): This is the number of exposure events in a given year.
- ED (Exposure Duration): The duration of exposure in years.
- AT (Averaging time): 25,550 days (70 years), standard for carcinogens.
- ADAF (Age Dependent Adjustment Factor): Applied to age groups considered high risk for exposure.

We will then multiply the LADD by the cancer risk slope factor for bromate (0.7 mg/kg/day) to arrive at an **Excess Lifetime Cancer Risk**.

We will use the **EPA Standard Reasonable Maximum Exposure (RME)** scenario, which assumes a residential swimmer is exposed for a total of **30 years** (6 years as a child, 24 years as an adult). The default exposure variables are as follows:

Variable	**IR**	**ET**	**EF**	**BW**	**ED**	**ADAF**
Description	Ingestion Rate	Exposure Time	Exposure Freq.	Body Weight	Exposure Duration	Age Dependent Adjustment Factor)
Child (6-11) years	0.05 L/hr	1 hr/event	100 days/yr	32 kg	6 years	3x
Adult	0.025 L/hr	1 hr/event	100 days/yr	80 kg	24 yrs	1x

We will use the highest calculated level of bromate based on our model and products, which is 0.47 ppm bromate, resulting from the use of Yellow Treat[2] as directed in a clean pool with no algae.

The Average Daily Dose (ADD) for each category is:

- ADD_{child} = (0.47 x 0.05 x 1) / 32 = 0.000734 mg/kg/day
- ADD_{adult} = (0.47 x 0.025 x 1) / 80 = 0.000147 mg/kg/day

The **Lifetime Average Daily Dose (LADD)** is:

[(0.000734 x 1 x 100 x 6 x 3) + (0.000147 x 1 x 100 x 24)]/25,550

[(1.32)+(0.353)]/25,550 = 6.55×10^{-5}

We then multiply this by the cancer risk slope factor of 0.7 mg/kg/day to obtain an Excess Lifetime Cancer Risk of 4.58 × 10^-5. This places the risk comfortably within the EPA's acceptable risk range (10^-6 to 10^-4).

Conlusion

The conversion rate of bromide to bromate in outdoor pools is considerably lower than the EPA initially assumed (100%) and Arch Chemical suggested (up to 50%). However, to minimize bromate exposure, it is advisable not to superchlorinate at levels above the recommended dosage or to do so repeatedly in short succession. Adding other mitigating compounds can also reduce initial bromate formation.

Additional studies will be necessary to understand bromate formation in the presence of cyanuric acid across various pH ranges and over extended periods of use. However, we hope that the data provided in this study will help regulators, manufacturers, and consumers make better, more informed decisions about risk tolerance and exposure.

VI. REFERENCES

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VII. TABLES AND GRAPHS

Table 11: All Phase I Readings

Date	Time	Duration (hh:mm:ss)	Pool	Sample	UVA (mw/cm^2)	Temp (F)	pH	ORP (mv)	BrO3 PPM
7/21/2025	3:07 PM	0:00:00	A	0	3.49	80.2	8.19	126	<LOD
7/22/2025	2:14 PM	23:07:00	A	1	3.66	77.7	8.18	114	<LOD
7/23/2025	2:25 PM	47:18:00	A	2	4.05	79	8.22	119	<LOD
7/24/2025	1:39 PM	70:32:00	A	3	3.99	78.7	8.20	136	<LOD
7/21/2025	3:35 PM	0:00:00	B	0	3.6	79.8	7.89	170	<LOD
7/22/2025	2:31 PM	22:56:00	B	1	3.8	76.9	7.92	119	<LOD
7/23/2025	2:31 PM	46:56:00	B	2	4.03	78.5	7.93	126	<LOD
7/24/2025	1:47 PM	70:12:00	B	3	3.99	77.9	7.92	126	<LOD
7/21/2025	4:40 PM	0:00:00	C	0	2.96	79.6	7.98	134	<LOD
7/22/2025	2:37 PM	21:57:00	C	1	3.97	77.0	7.91	120	0.0172
7/23/2025	2:38 PM	45:58:00	C	2	3.82	78.9	7.97	135	0.0171
7/24/2025	1:56 PM	69:16:00	C	3	4.02	79.2	7.95	124	0.0179
7/21/2025	3:56 PM	0:00:00	D	0	3.45	79.7	8.17	160	<LOD
7/22/2025	2:54 PM	22:58:00	D	1	3.81	77.9	8.17	127	<LOD
7/23/2025	2:46 PM	46:50:00	D	2	3.99	79.4	8.18	140	<LOD
7/24/2025	2:04 PM	70:08:00	D	3	4.08	79.9	8.14	135	<LOD
7/21/2025	4:03 PM	0:00:00	E	0	3.33	80.7	8.21	132	<LOD
7/22/2025	3:04 PM	23:01:00	E	1	3.8	79.5	8.2	132	<LOD
7/23/2025	2:53 PM	46:50:00	E	2	3.99	80.4	8.22	141	<LOD
7/24/2025	3:29 PM	71:26:00	E	3	3.87	81.4	8.23	140	<LOD
7/22/2025	3:42 PM	0:00:00	F	0	3.56	81.7	8.14	183	<LOD
7/23/2025	2:58 PM	23:16:00	F	1	3.98	79.2	8.12	145	<LOD

Table 11: All Phase I Readings

Date	Time	Duration (hh:mm:ss)	Pool	Sample	UVA (mw/cm^2)	Temp (F)	pH	ORP (mv)	BrO3 PPM
7/24/2025	3:38 PM	47:56:00	F	2	3.82	79.8	8.09	145	<LOD
7/25/2025	1:52 PM	70:10:00	F	3	4.22	78.9	8.06	117	<LOD
7/22/2025	3:51 PM	0:00:00	G	0	3.44	78.7	7.35	186	<LOD
7/23/2025	3:07 PM	23:16:00	G	1	3.75	79.3	7.42	162	<LOD
7/24/2025	3:43:00 PM	47:52:00	G	2	3.43	79.9	7.49	144	<LOD
7/25/2025	2:01 PM	70:10:00	G	3	4.25	78.2	7.55	121	<LOD
7/22/2025	4:02 PM	0:00:00	H	0	3.37	79.2	8.25	162	<LOD
7/23/2025	3:23 PM	23:21:00	H	1	3.73	80.1	8.23	157	<LOD
7/24/2025	3:49 PM	47:47:00	H	2	3.66	81.1	8.19	142	<LOD
7/25/2025	2:08 PM	70:06:00	H	3	4.24	79.4	8.18	128	<LOD

Table 12: All Phase II Readings

Date	Time	Duration (hh:mm:ss)	Pool	Sample	UVA (mw/cm2)	Temp (F)	pH	ORP (mv)	BrO3 PPM
8/21/25	2:44 PM	0:00:00	A	4	3.75	86.6	7.79	71	0.3800
8/22/25	1:34 PM	22:50:00	A	5	4.02	82.2	7.84	56	0.4900
8/23/25	2:42 PM	25:08:00	A	6	3.89	83.3	7.76	113	0.4800
8/24/25	1:34 PM	22:52:00	A	7	4.11	82.9	7.73	97	0.5100
8/21/25	3:01 PM	0:00:00	B	4	3.28	85	7.94	119	0.5200
8/22/25	1:47 PM	22:46:00	B	5	3.96	83.2	7.93	85	0.6700
8/23/25	2:48 PM	25:01:00	B	6	3.72	83.4	7.98	125	0.6600
8/24/25	1:44 PM	22:56:00	B	7	3.99	84.1	7.93	131	0.6600
8/21/25	3:11 PM	0:00:00	C	4	3.68	85.9	8.07	130	0.2100
8/22/25	1:53 PM	22:42:00	C	5	3.82	84.4	7.91	109	0.7000
8/23/25	2:57 PM	25:04:00	C	6	3.52	84.3	8.01	128	0.7000
8/24/25	1:50 PM	22:53:00	C	7	3.95	84.3	7.99	141	0.7000
8/21/25	3:21 PM	0:00:00	D	4	3.5	87.3	7.8	142	0.2400
8/22/25	2:00 PM	22:39:00	D	5	3.83	85.1	7.7	127	0.3100
8/23/25	3:03 PM	25:03:00	D	6	3.47	84.7	7.64	143	0.3100
8/24/25	1:57 PM	22:54:00	D	7	3.96	84.9	7.55	149	0.3100

Table 12: All Phase II Readings

Date	Time	Duration (hh:mm:ss)	Pool	Sample	UVA (mw/cm2)	Temp (F)	pH	ORP (mv)	BrO3 PPM
8/21/25	3:33 PM	0:00:00	E	4	3.19	87.2	7.89	153	0.2600
8/22/25	2:05 PM	22:32:00	E	5	3.82	91.3	7.8	153	0.2800
8/23/25	3:10 PM	25:05:00	E	6	3.45	83.8	7.74	143	0.2800
8/24/25	2:02 PM	22:52:00	E	7	3.9	84.6	7.73	154	0.2800
8/21/25	3:44 PM	0:00:00	F	4	2.72	85.2	7.9	149	0.8900
8/22/25	2:46 PM	23:02:00	F	5	3.53	86.2	7.83	146	0.9100
8/23/25	3:14 PM	24:28:00	F	6	3.44	84.3	7.82	145	0.9000
8/24/25	2:07 PM	22:53:00	F	7	3.9	84.3	7.76	156	0.8900
8/21/25	3:57 PM	0:00:00	G	4	2.71	87	7.99	168	0.4300
8/22/25	2:54 PM	22:57:00	G	5	3.67	85.5	7.94	153	0.5100
8/23/25	3:20 PM	24:26:00	G	6	3.39	84.4	7.95	148	0.5200
8/24/25	2:14 PM	22:54:00	G	7	3.93	84.9	7.94	164	0.5100
8/21/25	4:00 PM	0:00:00	H	4	2.79	87	7.78	178	0.1900
8/22/25	3:01 PM	23:01:00	H	5	3.46	85.5	7.68	162	0.2000
8/23/25	3:27 PM	24:26:00	H	6	3.27	84.4	7.62	158	0.1900
8/24/25	2:21 PM	22:54:00	H	7	3.85	84.9	7.58	169	0.1900

Table 13: All Phase III Readings

Date	Time	Duration	Pool	Sample	UVA	Temp	pH	ORP (mv)	BrO3 PPM
9/30/25	1:26 PM	0:00:00	A	8	3.71	74.6	8.01	57	0.05
9/30/25	2:27 PM	1:01:00	A	9	3.34	75.5	7.99	587	0.5
10/1/25	1:18 PM	22:51:00	A	10	3.8	73.5	8.02	292	0.63
10/2/25	1:07 PM	23:49:00	A	11	3.87	73.6	8.08	232	1.19
10/3/25	12:22 PM	23:15:00	A	12	3.92	73.2	8.12	195	1.65
10/4/25	1:33 PM	25:11:00	A	13	3.86	72.4	8.18	226	1.62
9/30/25	1:41 PM	0:00:00	B	8	3.46	75.2	7.97	107	0.05
9/30/25	2:47 PM	1:06:00	B	9	3.1	75.7	7.95	629	0.54
10/1/25	1:28 PM	22:41:00	B	10	3.8	74.2	8.01	279	0.58
10/2/25	1:16 PM	23:48:00	B	11	3.88	73.6	8.07	239	1.21
10/3/25	12:31 PM	23:15:00	B	12	4.06	73.1	8.11	211	1.7

Table 13: All Phase III Readings

Date	Time	Duration	Pool	Sample	UVA	Temp	pH	ORP (mv)	BrO3 PPM
10/4/25	1:38 PM	25:07:00	B	13	3.82	71.7	8.16	240	1.67
9/30/25	1:53 PM	0:00:00	C	8	3.5	75.4	7.95	106	0.05
9/30/25	3:00 PM	1:07:00	C	9	3.03	75.8	7.94	653	0.57
10/1/25	1:40 PM	22:40:00	C	10	3.74	74.5	7.99	273	0.54
10/2/25	1:23 PM	23:43:00	C	11	4.03	73.9	8.04	241	1.18
10/3/25	12:36 PM	23:13:00	C	12	3.82	72.9	8.1	221	1.66
10/4/25	1:43 PM	25:07:00	C	13	3.78	71.7	8.12	245	1.64
9/30/25	2:09 PM	0:00:00	D	8	3.38	75.7	7.92	111	0.04
9/30/25	3:09 PM	1:00:00	D	9	2.87	75.7	7.94	687	0.5
10/1/25	1:46 PM	22:37:00	D	10	3.72	74.6	7.96	267	0.55
10/2/25	1:30 PM	23:44:00	D	11	3.77	74.2	8.03	240	1.24
10/3/25	12:41 PM	23:11:00	D	12	3.92	74	8.05	224	1.65
10/4/25	1:50 PM	25:09:00	D	13	3.78	72.2	8.12	258	1.6
9/30/25	2:36 PM	0:00:00	E	8	3.21	76.2	8.1	257	0.06
9/30/25	3:31 PM	0:55:00	E	9	2.68	76.8	8.11	623	0.16
10/1/25	1:52 PM	22:21:00	E	10	3.71	74.6	8.03	259	0.15
10/2/25	1:37 PM	23:45:00	E	11	3.67	74.6	8.1	232	0.76
10/3/25	12:47 PM	23:10:00	E	12	4.03	74	8.12	215	1.3
9/30/25	3:17 PM	0:00:00	F	8	2.54	75.7	8.08	437	0.05
9/30/25	4:23 PM	1:06:00	F	9	1.79	76	8.07	609	0.08
10/1/25	2:00 PM	21:37:00	F	10	3.67	74.4	7.98	256	0.1
10/2/25	1:49 PM	23:49:00	F	11	3.68	74.9	7.9	249	0.72
10/3/25	12:51 PM	23:02:00	F	12	3.92	74.5	8.1	219	1.23
9/30/25	3:38 PM	0:00:00	G	8	2.54	75.7	8.08	453	0.06
9/30/25	4:38 PM	1:00:00	G	9	1.44	76	8.07	367	0.06
10/1/25	2:08 PM	21:30:00	G	10	3.65	75	8.06	272	0.06
10/2/25	1:57 PM	23:49:00	G	11	3.69	75.4	8.11	244	1.01
10/3/25	12:55 PM	22:58:00	G	12	3.92	74.5	8.16	219	1.81
9/30/25	3:48 PM	0:00:00	H	8	2.35	75.4	7.97	353	0.09
9/30/25	4:47 PM	0:59:00	H	9	1.24	75.8	7.84	527	0.09
10/1/25	2:18 PM	21:31:00	H	10	3.54	75.2	7.96	258	0.09
10/2/25	2:05 PM	23:47:00	H	11	3.65	75.6	7.99	246	1.51

Table 13: All Phase III Readings

Date	Time	Duration	Pool	Sample	UVA	Temp	pH	ORP (mv)	BrO3 PPM
10/3/25	1:01 PM	22:56:00	H	12	3.91	75.2	7.76	272	2.61