

# **Undetectable TOC in UPW Can Influence DUV Photolithography Processes**

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## **Abstract**

On multiple occasions in early 2001, the semiconductor fabrication facilities supplied by the Hillsboro, Oregon municipal city water district experienced high levels of total organic carbon (TOC) in their ultrapure water (UPW) systems. The TOC excursions were either not detected, or measured inaccurately, with a TOC analyzer implementing an older technology, but were successfully measured with a new type of TOC analyzer. The composition of the TOC was initially not known, and worse, it was not removed using conventional UPW purification processes. Manufacturing engineers correlated an influence on the DUV photolithography process to measurements obtained from this new type of TOC analyzer.

In trying to determine what the TOC contaminant was, data from an earlier Intel study showed that its standard TOC analyzers were blind to organic nitrogen compounds at low concentrations, but a new type of TOC measuring instrument was not. By applying an understanding of the different measurement characteristics of on-line TOC analyzers and the possible sources of contamination, we proposed that the TOC contaminate was urea, an organic nitrogen compound. A prototype trace urea analyzer was used to confirm that a substantial portion of the TOC in the water during the excursions consisted of urea. It is now believed the urea originated from agricultural activities in the Hillsboro watershed. Urea naturally decomposes into ammonia. It is well known (6,7,8,9,10,11,12) that

ammonia, at part per billion concentrations, may negatively impact the performance of the acid-catalyzed, chemically amplified photoresists used in today's DUV photolithography processes.

## Introduction

Semiconductor manufacturing facilities that obtained feed water from the City of Hillsboro, Oregon experienced multiple TOC excursions in the final purified ultrapure water supplied to the fab during March and April of 2001. Although the TOC levels in the feed water did not show significant variations above baseline, the TOC concentrations in the UPW polish loops produced a series of four significant excursions. During the TOC excursions, all immediate efforts to remove the contamination by adjusting system parameters of the UPW system failed. The conventional ultrapure water purification techniques of activated carbon, reverse osmosis, ion exchange, electrodeionization, ozonation, degasification, pH adjustment and ultraviolet light were not able to remove the TOC. A new type of on-line UPW TOC analyzer, the Sievers PPT (Analyzer X), was able to accurately measure the TOC spikes. In addition, the response of the Analyzer X correlated with the results of proprietary monitors used in the photolithography processes. However, there was no correlation from the same lithography monitors with the existing TOC analyzer (Analyzer Y). This is due to the fact that Analyzer Y, an industry standard on-line UPW TOC analyzer, was not able to measure the organics until the TOC concentration exceeded approximately 15 ppb as carbon. Once above 15 ppb as carbon for this particular contaminant, Analyzer Y became unstable and bimodal, providing either inflated or very small TOC readings. Compounding the growing concern, conventional laboratory analytical methods are known to be inadequate when trying to measure or identify the specific TOC component at the parts-per-billion levels existing in the UPW before and during the excursions.

## On-line TOC Analyzer Technology

Two different types of TOC analyzers were in service at Intel at the time of the excursions. Both are reagentless ultrapure water analyzers that implement the use of

high-intensity short-wave ultraviolet light to oxidize organic carbon into carbon dioxide. Carbon dioxide will dissolve in deionized water and form the bicarbonate ion, causing the solution conductivity to increase. The analyzers then measure the concentration of carbon dioxide produced prior to and after the oxidation step and convert this differential value into a TOC concentration using different algorithms. Because the two analyzers measure carbon dioxide differently, they respond to TOC differently. Analyzer Y directly measures the conductivity change before and after the UV reactor. Because other ions such as halogens, nitrates and sulfates can be produced in addition to the bicarbonate ion during the UV oxidation step, Analyzer Y does not always accurately measure the actual TOC concentration. Analyzer X, however, measures the carbon dioxide by allowing it to diffuse through a selective permeable membrane into a sample of un-oxidized water and then measures the conductivity of the resulting solution. The membrane blocks the other ions, produced by the oxidation reaction, allowing only carbon dioxide to contribute to the conductivity difference in Analyzer X, resulting in an accurate measurement of TOC concentration.

Rather than recording similar results from the TOC excursion, the two analyzers reported very different results. That being said, each played a unique role in identifying the component that caused the excursions. Analyzer X provided a TOC signal that was stable, accurate, and was sensitive enough to detect the start of the excursions well before Analyzer Y. However, the characteristic lack of response of Analyzer Y to the excursion organics at concentrations less than approximately 15 ppb proved to be an important clue for identifying the contaminant that caused the TOC excursions.

### The TOC Excursions

The TOC data collected from one of the affected UPW systems, showing the differing responses of the two different TOC analyzers, is shown in Figure 1. The solid curve corresponds to the response of Analyzer X, and the dotted curve corresponds to the response of Analyzer Y. Analyzer Y technology failed to detect any signal from the second and fourth TOC peaks while the Analyzer X responded to all of the peaks.

Similar results were obtained at our other factories that were exposed to the same feed water. During the TOC excursions, Analyzer Y provided erratic readings that varied between zeros to levels exceeding 150 ppb. Closer examination of the results from Analyzer Y in the first and third TOC excursions, where both analyzers indicated high levels of TOC, show a rapid vertical increase at the beginning and a sharp vertical decrease at the end of the peaks. The truncation at the beginning and the ending of the TOC peaks indicate Analyzer Y did not respond to the lower concentrations of the organic contamination that caused the TOC excursions. Analyzer Y does not respond at all to the second peak and shows the TOC approaching zero during the 15 ppb TOC spike shown in the fourth peak.

Figure 2 details the start of the first excursion in Figure 1. Analyzer X responded about 8 hours in advance of Analyzer Y. It was interesting to note that the response curve for Analyzer Y approached zero as the amount of contaminant, as measured by Analyzer X, increased. It is postulated that when the organic was oxidized into carbon dioxide, the carbon dioxide complexed with an organic nitrogen compound to shift the resistivity. This shift would then result in a false reading by the analyzer showing the TOC being reduced or unchanged. Only after the TOC contaminant reached a concentration of approximately 15 ppb did Analyzer Y recognize the presence of the contaminant with the erratic results shown in Figures 1 and 2.

### Identification of TOC Compound(s)

During the summer of 1999, Intel conducted an evaluation (1,2,3) of the performance characteristics of different UPW TOC analyzers with various types of organic compounds, the results of which are shown in Figure 3. For this study we injected 0.03 ppb to 5 ppb (as carbon) of organic compounds that we thought had the potential to contaminate UPW. We observed that Analyzer Y did not respond to urea, trimethylamine, and tetramethylammonium hydroxide (TMAH), each of these a nitrogen-containing carbon compound, while Analyzer X provided close to 100 percent recovery of these compounds. By applying that information during the TOC excursions, it was

concluded that the contaminant was potentially a nitrogen-containing carbon compound. Analysis of the different TOC responses of the two analyzers was essential to identifying an organic nitrogen compound as the probable contamination causing the TOC excursions. One question still remained: Which organic nitrogen compound or compounds caused the excursion?

Trimethylamine is the chemical functional group attached to the anion exchange resin that, with its positive charge, attracts and removes negatively charged ions from UPW. Trimethylamine would be expected to originate from bad ion exchange resin and impact a single facility, but the TOC excursions occurred simultaneously at three different Intel factories as well as several other non-Intel semiconductor manufacturing facilities using the same water supply. Also, one Intel facility that had the capability of changing city water sources was able to switch their sourcing strategy between the third and fourth excursion, and was not impacted by the fourth excursion.

Tetramethylammonium hydroxide (TMAH) is commonly used as a developer during the photolithography processing steps. However, it is unlikely that TMAH was the source of the contamination since the repeated excursions experienced by several semiconductor manufacturers using city water point to a contaminant in the city water supply, and there are no known industries in the watershed that discharge TMAH to the water supply.

Urea is the most commonly used fertilizer, and could very well be present in the city water as a result of rainwater runoff into the streams and rivers from which the city water is sourced. The Hillsboro region of Oregon is primarily agricultural. A mass balance at one Intel facility showed that, depending on the percent of rejection of contaminant by the first pass reverse osmosis arrays, between 100 and 500 pounds of urea could have caused the first excursion shown in Figure 1(4). Note that this is approximately 0.001 to 0.006 percent of the almost 7 million pounds spread annually within the Hillsboro watershed, with almost 6 million pounds being spread between the months of March and June. It was also determined that the timing of the TOC excursions coincided with the start of the annual March-through-June field fertilization cycle.

## Mitigation of TOC Excursions

In hopes of minimizing the impact of the TOC excursions, attempts were made during the start of the excursions to adjust the water treatment process. These attempts to control the TOC excursion included modifications to the reverse osmosis system, increasing the ozone concentration feeding UV reactors, increasing the vacuum in the degasification towers, changing the pH of the RO feed water, and the addition of activated carbon to the makeup loop. None of these attempts resulted in any appreciable reduction of excursion TOC in the UPW polish loops (13). The traditional UPW purification technologies of activated carbon, reverse osmosis, micro-filtration, ion exchange, electrodeionization, ozonation, degasification, and ultraviolet light<sup>1</sup> did not remove the contaminant TOC. This observation indicated that the contaminant was non-volatile, difficult to oxidize, low molecular weight (less than 100), ozone-resistant, and non-ionic (13). The lack of response of Analyzer Y to the TOC spikes strongly suggests an organic nitrogen compound contaminate. Additionally, it was determined the Hillsboro water bureau was not performing any maintenance activities on the water distribution system and there were no known TOC or other anomalies at the water treatment plant. Therefore, the contamination likely entered the water supply in low concentrations that were not detected or removed by the city treatment processes. Meeting all of these criteria, urea was considered the primary cause for the excursions.

One might question why excursions similar to those occurring in 2001 have not occurred in previous years. The rivers and reservoirs in March and April 2001 were at a 20-year low, and at their traditional July and August levels. It is believed that the urea has always been in the watershed, but in past years there was a significant amount of dilution from normal seasonal rainfall to prevent the creation of high concentrations of urea in the city

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<sup>1</sup> UV light oxidized the sample in the TOC analyzers, allowing the TOC to be measured, however the dose the sample received in the analyzer is orders of magnitude higher than experienced in the high volume UV lamps used in UPW systems, thus the reason the UV unit operations were not effective in destroying the TOC.

water supply. Also, prior to the spring of 2001, all ultrapure water TOC measurements at the Intel site were made with Analyzer Y, which has been proven to not see urea at the low-to-moderate levels likely to have been present during possible past urea excursions.

While there was plenty of circumstantial evidence to indicate that urea was the UPW contaminant, there was no way to confirm suspicions since there were no readily available and cost-effective methods to analyze or detect urea at these low concentrations.

### Confirmation of Urea as the Contaminant

There are no laboratory methods available to accurately measure low parts per billion concentrations of urea contamination in water. In 1999, Tetsuo Mizuniwa et al. (5) created an analytical device that combined UV oxidation with ion chromatography to measure organic-combined sulfate, chloride, and nitrate compounds to sub-ppb concentrations. We did not have access to this analyzer during the TOC excursions. Although this analyzer would have been useful to confirm the presence of organic nitrogen compounds in the TOC spikes, it would not have been able to specifically identify urea as the cause of the excursions.

Mizuniwa et al. (5) demonstrated that organic nitrogen was found in part per billion concentrations in the selected ultrapure water systems in Japan. From their results, it has been suggested that between 0.13 ppb to 1.66 ppb of TOC in the UPW polish loop could result from the presence of organic nitrogen compounds in the studied water systems (1). For factories where surface water sources are used for semiconductor chip production, such as at Hillsboro, it is believed that urea is a common TOC component of the final ultrapure water.

To confirm that urea was the cause of the excursions, a proprietary, on-line, urea-specific analysis method was developed and tested at Intel's Ronler Acres facility. As can be seen in Figure 4, the analyzer recovered urea at a constant 85 percent during initial calibration with standard solutions. Using refrigerated and sealed grab samples from the fourth

excursion, the analyzer was able to identify that urea, as shown in Figure 5, was the primary cause of the fourth excursion.

Standard addition tests using various concentrations of urea were conducted and the behaviors of the two analyzers were consistent with urea contamination. The behaviors of both analyzers (Figure 6 and Figure 7) in the controlled laboratory environment corresponded to the real-time results obtained for the first excursion as seen in Figure 2. Therefore, it is believed that urea was also responsible for the first and subsequent TOC excursions shown in Figure 1, as well as the fourth excursion shown in Figure 5.

One notable aspect of Figure 7 is the extent of the overreaction of the Analyzer Y to urea concentrations greater than 10 ppb. As noted above, both TOC analyzers use an algorithm to convert conductivity differentials resulting from the UV oxidation step into a TOC concentration. However, the Analyzer X measures only the conductivity change caused by the creation of carbon dioxide, while Analyzer Y measures the overall conductivity change of the oxidized sample, which could contain ionic components other than the bicarbonate ion from the dissolved carbon dioxide. When urea is oxidized with UV light, it first converts into ammonia and carbon dioxide, and the ammonia is further oxidized into nitrous or nitric acid. Therefore, the overreaction by Analyzer Y may have resulted when the conductivity differential measured by Analyzer Y was caused by the additional conductivity from the nitrous or nitric acids. However, since we do not know the details of the internal algorithm or completely understand the specifics of the chemical reactions that occur during the UV oxidation step, we can only postulate that undesired chemical reactions are occurring within the single UV reaction/conductivity chamber of Analyzer Y that are changing the measured sample conductivity, causing the TOC readings to approach zero as the urea concentration increases and then overreact and become unstable at even higher concentrations of urea. It is believed that because the Analyzer X uses a membrane to segregate the measured conductivity differential for just the CO<sub>2</sub> component from the extraneous conductivity changes caused by other ions such as nitric acid and other side reactions, it provides more accurate and more stable measurements for urea, like those shown in Figure 6.

## Urea as a Critical UPW Contaminant

Urea may be considered a critical contaminant in UPW because it decomposes to ammonia:



It is the evolution of the ammonia that can adversely affect the acid-catalyzed chemically amplified photoresists that are used with the deep UV (DUV) lithography steps required to achieve today's circuit dimensions near or below 0.5 microns (6).

With the advances in chemically amplified resists come new sensitivities to the ambient environment. The negative effects of low concentrations of airborne molecular contaminants, such as low or sub-ppb levels of organic amines and ammonia, on the control of critical dimensions during the lithography of sub-0.5- $\mu\text{m}$  line widths is widely known throughout in the semiconductor industry (7,8,9).

The primary feature of any chemically amplified resist is the use of a small number of photogenerated acid molecules to initiate a substantial catalytic reaction to convert the exposed portions of the resist (for a positive resist) into a material that is easily removable during the development step (10). If the photoresist comes into contact with ppb-levels of organic bases such as amine and ammonia, the already small quantity of acid generated during the DUV exposure may be reduced even further, significantly impacting subsequent catalytic reactions within the resist. The neutralization of this acid can then result in the partial or deformed features on the wafer, as modeled in Figure 8 (6).

Chemically amplified resists are particularly sensitive to contamination during the interval between after the coated wafer is exposed to the DUV light and when the wafer is baked, which may be less than 3 minutes but could extend to ten minutes or longer depending on the tool loading methods (11). If this pause happens while the wafer is located where the ammonia contamination levels could be as much as 5 ppb, it is possible that a shift of a critical dimension by as much as 10-20 nm may occur (11). Others have reported that some chemically amplified resists may be affected by airborne impurities at concentrations near 1 to 2 ppb (12).

Because airborne ammonia is an issue with DUV lithography, abatement systems using acid impregnated activated carbon filter cartridges to remove the basic organic components from the air are now standard equipment on today's lithography tools. With the acidified carbon filters on the air stream, the tools are protected from an incursion of airborne ammonia. However, it is possible that process streams such as UPW that bypass these filters could provide a source of organic nitrogen that could convert to ammonia. That is, ammonia could get into the litho tool even if acidified carbon filters were used to clean the air.

Lithography tools are generally not a large consumer of UPW in a wafer fab, nor are they usually given the same attention as the big UPW consumers such as wet etch and planar tools. Nonetheless, they are still a user, and the litho process steps can be impacted by contaminants in the UPW. If the contaminant was urea, which decomposed into ammonia and carbon dioxide on the inside of the tool and downstream of the activated carbon air filters, then it is possible that the ammonia could adversely affect the behavior of the chemically amplified photoresist. It is believed that the three most probable scenarios of exposing the lithography process to urea in UPW are as follows: (1) through rinsing steps where UPW is in contact with the wafer or where residual UPW may exist within the tool; (2) through the humidification control for individual tools, which generally use a reservoir of UPW as a source for mini-environment humidification control; or (3) through the humidification systems for the ambient cleanroom, which is generally supplied with UPW.

In scenarios (1) and (2), the aqueous urea would completely bypass the activated carbon filters used to remove airborne contaminants, and if exposed to DUV, convert into ammonia and carbon dioxide. In Scenario (3), UPW is supplied to the cleanroom makeup air handlers to control the cleanroom humidity. Since the makeup air handlers are not usually high purity or sterile environments, it is possible that bacteria, which catalyze the decomposition of urea, may do so within the makeup air handlers, resulting in ppb concentrations of ammonia inside the ambient cleanroom. Thus, depending on the nature of the wafer handling mechanisms within the cleanroom, the ppb-concentrations of ammonia from urea may have an adverse affect on the chemically amplified resists.

Therefore, given the widespread use of chemically amplified photoresists in the lithography processes of semiconductor manufacturing, it is now believed that urea and the family of nitrogen-containing organics, should be classified as critical contaminants in UPW systems.

### Additional Dangerous Organic Nitrogen Compounds in UPW

Other organic nitrogen compounds can hide in ultrapure water at part per billion concentrations without being detected by the industry standard analyzers. As urea was not measured by TOC Analyzer Y, organic nitrogen amine compounds are also not measured by the Analyzer Y. As shown in Figure 3, trimethylamine from the anion exchange resin is a prime example of such a compound. The addition of low concentrations of trimethylamine to deionized ultrapure water will initially cause the resistivity to increase above that of deionized water until at a TOC concentration of 2.1 ppb it starts, as expected, to decrease the solution resistivity as shown in Figure 9. This behavior is the result of the titration of the very conductive hydronium ion ( $H^+$ ) by the much less conductive trimethylamine cation. As amines are volatile and basic, they are also known to react with the photoacid in the DUV photoresists and cause the same t-topping problem as ammonia (7,8,9). It is interesting to note that a similar type of the conductivity effect observed in this example may be a possible explanation for the

observed Analyzer Y lack of response to organic nitrogen compounds at low concentrations. If compounds are formed during the UV oxidation of an organic nitrogen compound that cause the conductivity to decrease or not increase, then Analyzer Y would not measure the expected conductivity increase and therefore would report a near-zero TOC concentration

## Conclusions

We have concluded that very low concentrations of urea in ultrapure water can affect the DUV photolithography processes that are used to attain the thinnest of circuit dimensions in today's microchips. The Sievers PPT (Analyzer X) is sensitive and accurate enough to determine when a factory may be at risk of a TOC excursions caused by urea, amine and other organic nitrogen contaminants.

The reality is that most of the current TOC performance specifications used by UPW systems today were developed based on data obtained from Analyzer Y or other similar conductivity based TOC analyzers. These specifications are now questionable for state of the art semiconductor facilities, due to the known lack of response of Analyzer Y to some common organic nitrogen compounds at concentrations less than 15 ppb. The improved ability of the Analyzer X to measure organic nitrogen compounds, previously not measured by Analyzer Y, raises the question of what is the correct UPW TOC specification for an advanced semiconductor facility. The use of the Analyzer X has demonstrated the need to reevaluate water treatment system control limits and to revisit UPW treatment system designs to develop methods to achieve total organic carbon removal. That is, if one implements the improved detection limits of a TOC analyzer such as Analyzer X, which detects previously undetectable nitrogen containing organic compounds, they should no longer expect to be supplied with UPW that meets a 1 ppb specification limit that was derived from Analyzer Y. Something – a change of specification limits, control limits, and/or water treatment system processes – must be implemented in order to accommodate the more sensitive detection by Analyzer X.

With circuit dimensions continuing to decrease, and with more widespread use of chemically amplified DUV resists to achieve these circuit dimensions, we will eventually need to find the answer to the following question: What is the lowest acceptable concentration of nitrogenous TOC contamination in UPW that will not cause negative impacts to current or future manufacturing processes by interfering with chemically amplified DUV photoresists, and how will these contaminants be removed from the UPW system?

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## References

- 1) R. Godec, "The Performance Comparison of Ultrapure Water TOC Analyzers using an Automated Standard Addition Apparatus." Semiconductor Pure Water and Chemicals Conference, pp. 61-112, 2000.
- 2) R. Godec, K. Franklin, "The Verification of Analytical Ultrapure Water Instrumentation Performance using an Automated Standard Dilution Apparatus." Semiconductor Pure Water and Chemicals Conference, pp. 91-110, 1999.
- 3) M.R. Curtis and R.J. McIntosh, "Importance of Analyzers on Stability in UPW Systems," UPW Watertech Conference Proceedings, Portland, Oregon, 1999.

- 4) D.A. Scarpine and C.P. Noling, "Taking Water Quality Outside the Fab; a Case Study on Watershed Analysis and Investigation of a Contaminant Source," UPW Watertech Conference Proceedings, Portland, Oregon, 2001.
- 5) T. Mizuniwa, K. Kitami, M. Ito, R. Miwa, "Analysis of Organic-combined Chloride, Sulfate and Nitrate Ions in Ultrapure Water". Semiconductor Pure Water and Chemicals Conference, pp. 111-124, 1999.
- 6) W. Henke, "Simulation for DUV – Lithography", Semiconductor Fabtech 9th Ed., Section 5 Lithography, March 1999, page 211-218.
- 7) S.A. MacDonald et al., "Airborne Chemical Contamination of a Chemically Amplified Resist," in Proceedings of Advances in Resist Technology and Processing VIII (Bellingham, WA: International Society for Optical Engineering [SPIE], 1991), 1-12.
- 8) J.C. Vigil, M.W. Barrick, and T.H. Grafe, "Contamination Control for Processing DUV Chemically Amplified Photoresists," in Proceedings of SPIE's International Symposium on Microlithography (Bellingham, WA: SPIE, 1995), 210.
- 9) Z. Lin and A.F. VanNatter "Using CD SEM to Evaluate Material Compatibility with DUV Photoresists," <http://www.micromagazine.com/archive/99/02/lin.html>.
- 10) S.A. McDonald et al., "Airborne Contamination of a Chemically Amplified Resist – Identification of a Problem," Chem. Materials, 1993, 5, 348-356.
- 11) B. Demandante, K. Murray, and M. Alexander, "Protect DUV Processes with Real-Time Molecular Monitoring," Semiconductor International, September 2000.
- 12) O. Kishkovich, D. Kinkead, J. Higley, R. Kerwin, and J. Piatt, "Real-time methodologies for monitoring airborne molecular contamination in DUV photolithography facilities," Technical Article from Extraction Systems, Inc.
- 13) J. Rydzewski, "Identification of a Critical UPW Contaminant by Applying an Understanding of Different TOC Measuring Technologies", UPW Watertech Conference Proceedings, Portland, Oregon, 2001.

## Biography

Author John Rydzewski, is a senior facilities UPW engineer in the Facilities Technology Development group at Intel. He has been with Intel for one year, and has been involved with the design and construction of UPW and wastewater treatment systems for the semiconductor industry for seven years while employed as a chemical engineer with the Industrial Design Corporation (IDC) and Harris Group, Inc. In his job at Intel, he is responsible for the design specifications for Intel's high-purity water systems for new plants and plant expansions. Rydzewski holds bachelors and master's degrees in chemical engineering from Clarkson University. He is also a registered professional engineer.

Author Richard Godec, is the Ultrapure Water Product Development Manager at the Ionics Instruments Business Group of Ionics Incorporated. He has over 22 years experience in the design, development and manufacturing of analytical instrumentation for process and laboratory applications in the pharmaceutical, semiconductor, power, petrochemical, and medical industries. He has been solely or jointly responsible for the development of new analyzers for measurement of Total Organic Carbon in water, Trace Boron in water, Organic Sulfur in petrochemicals and Nitric Oxide for asthmatic medical research. Godec holds over 24 US and international patents in these fields. Prior to joining Ionics Instruments (Originally Sievers Instruments) fifteen years ago, was at Anatel Instrument Corporation. He holds a B.Sc. in Chemical Engineering from the University of Colorado.

Figure 1: TOC Excursions Measured at Final UPW to Fab.

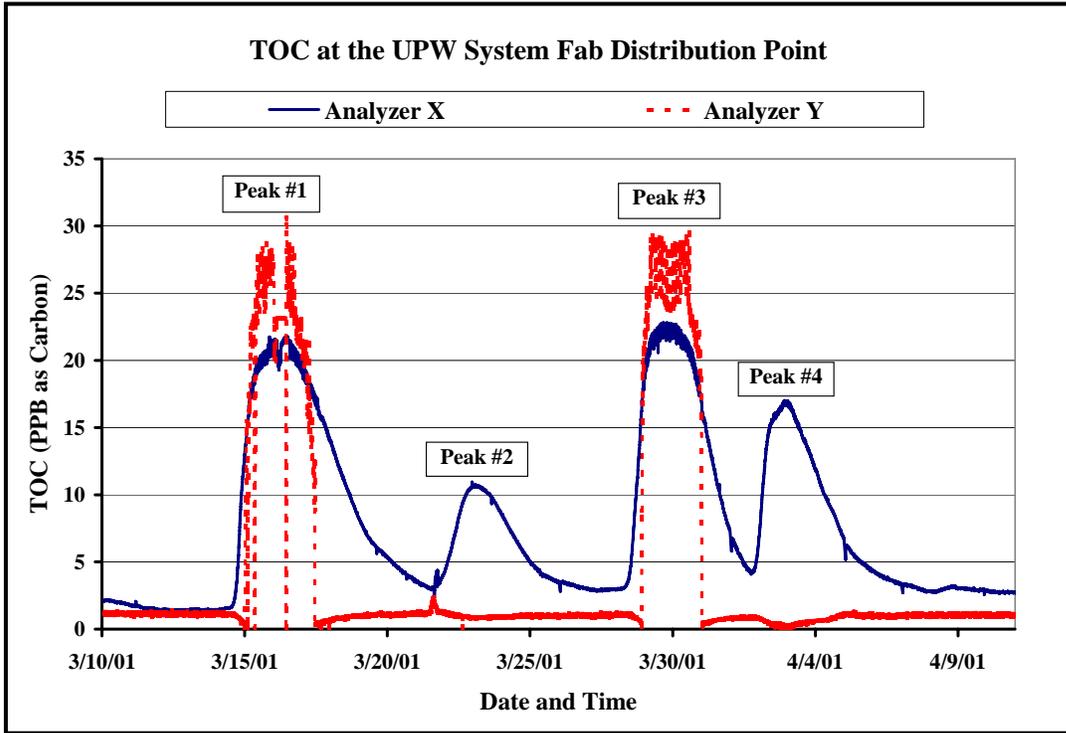
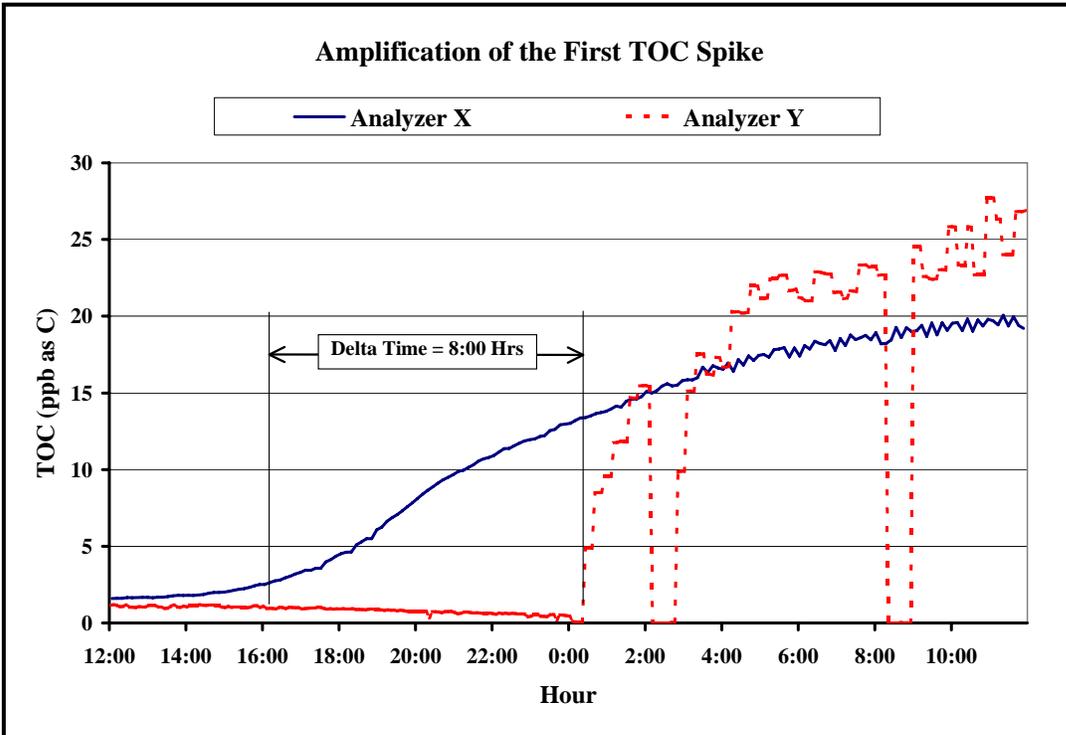
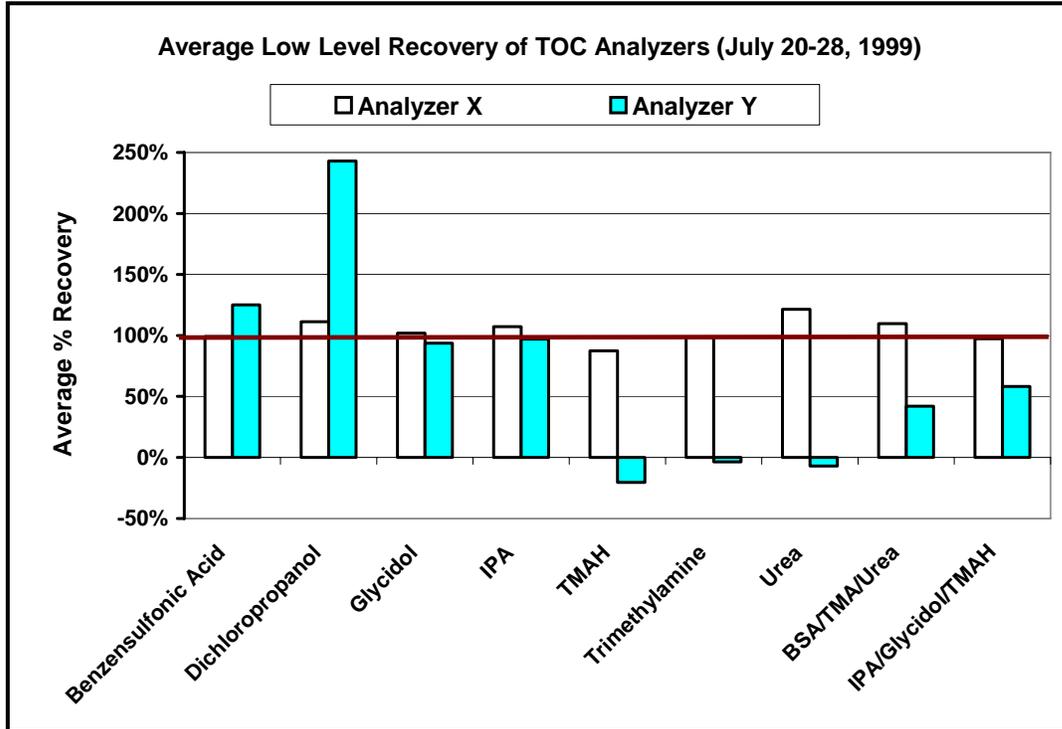


Figure 2: Details of Peak #1.



**Figure 3: Average TOC Recovery of the Analyzer X and Analyzer Y with Various Organic Components.**



**Figure 4: Plot showing response of urea specific measurement technique to urea standard injections.**

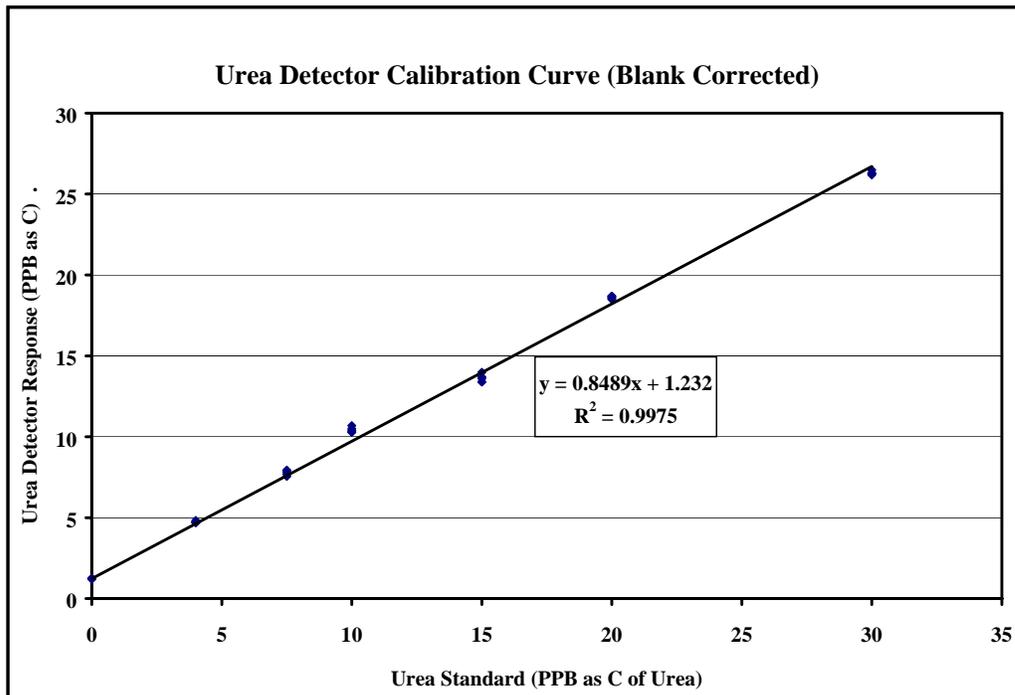


Figure 5: Correlation between the urea analyzer and the TOC concentration measured by the Analyzer X during the fourth excursion.

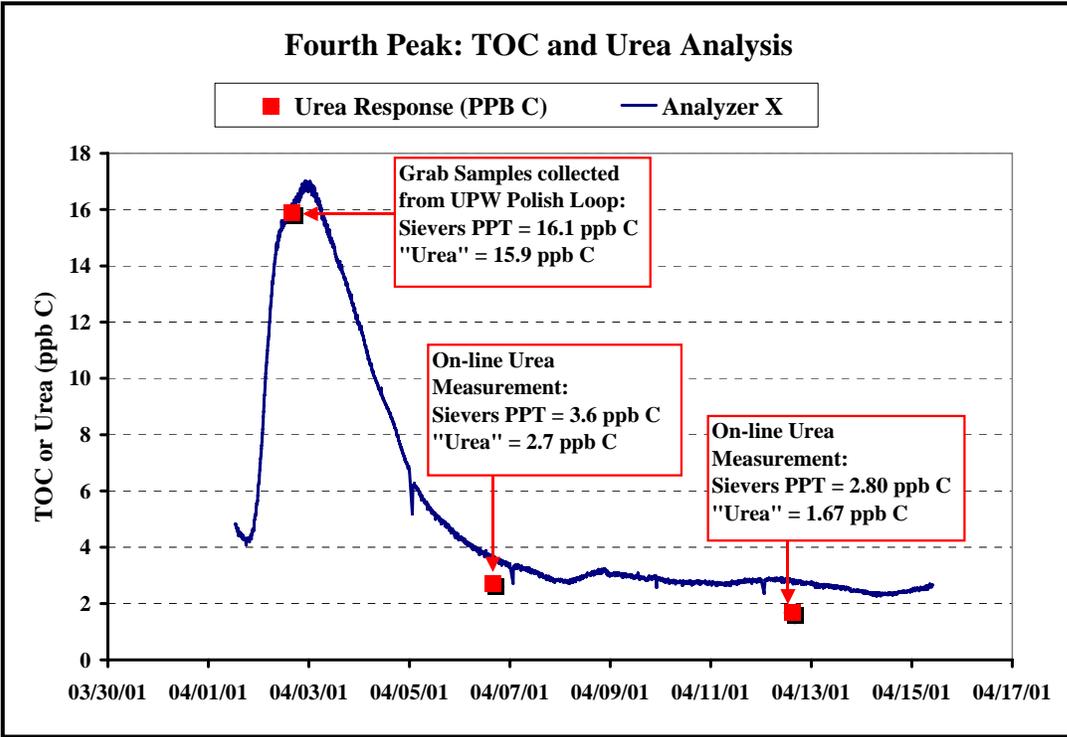


Figure 6: A plot of the response of the Sievers PPT (Analyzer X) to various concentrations of urea standard solutions.

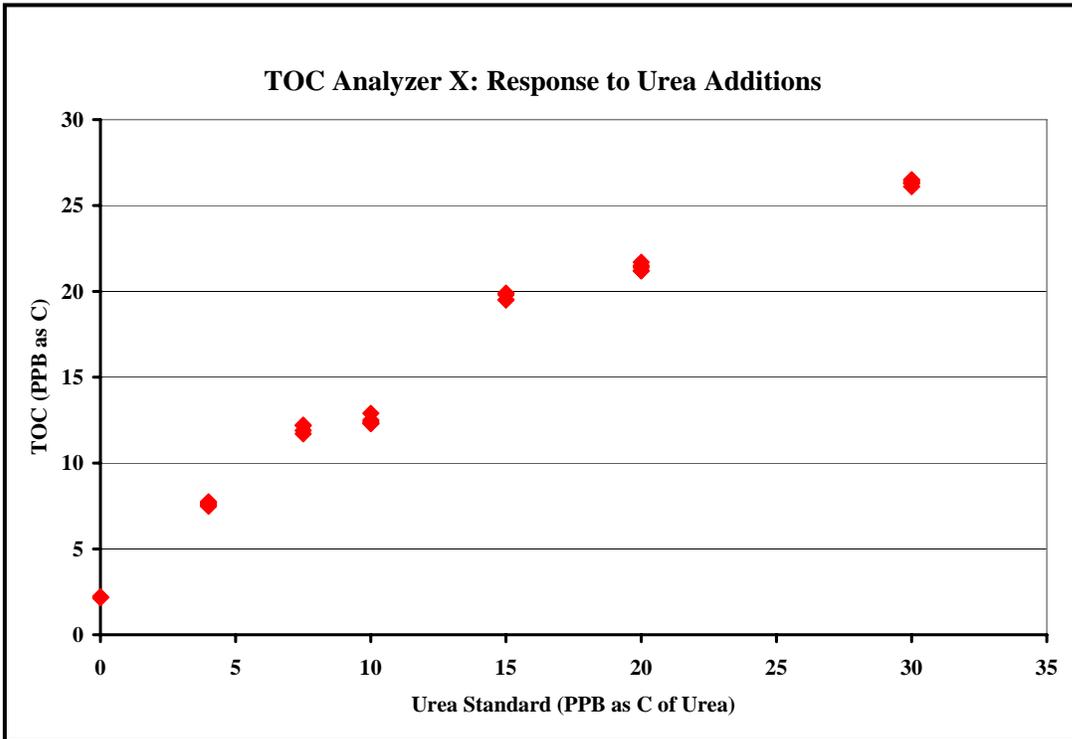


Figure 7: A plot of the response of TOC Analyzer Y to various concentrations of urea standard solutions.

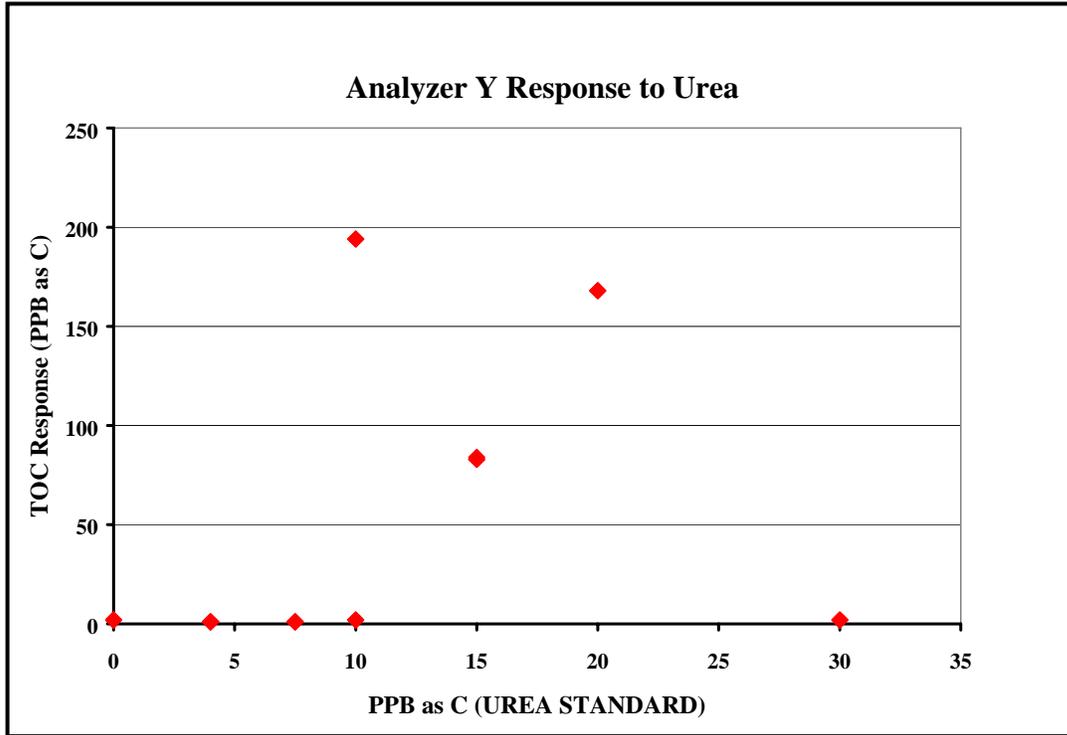
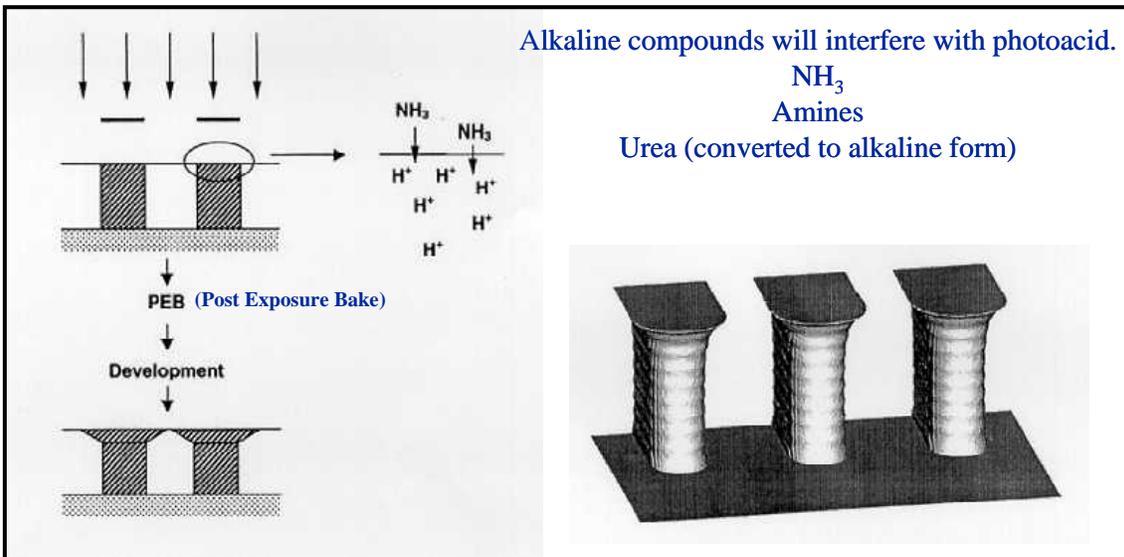


Figure 8: Computer simulated T-topping effect resulting from the exposure of an exposed chemically amplified resist to a basic gas. The left hand schematic shows how exposure to airborne ammonia or amine can impact the resist, shown in three dimensions in the right hand graphic (6).



**Figure 9: The addition of low concentrations of trimethylamine to ultrapure water can cause an initial unexpected increase in resistivity.**

