The Next Generation of Drinking Water Disinfection By-Products

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Drinking Water DBPs:
How are they formed?

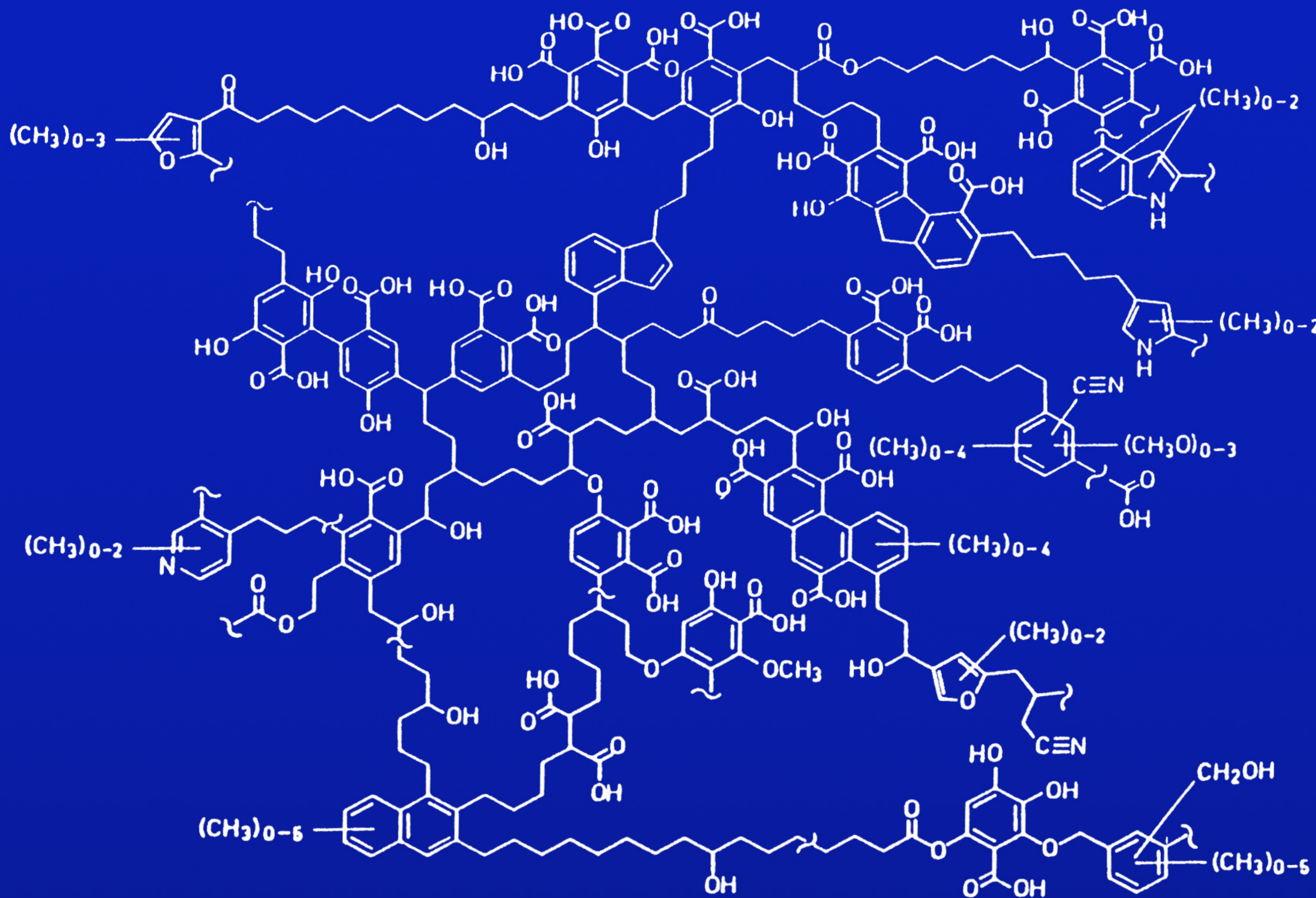


Fig. 12.7 Chemical network structure of humic acids according to Schulten and Schnitzer.[7] Reproduced by permission of Springer-Verlag.

Drinking Water DBPs—What are the Issues?

Concern over possible human health risk:

- Epidemiologic studies: risk of bladder cancer; some cause cancer in laboratory animals
- Recent concerns about possible reproductive & developmental effects (from epi studies)

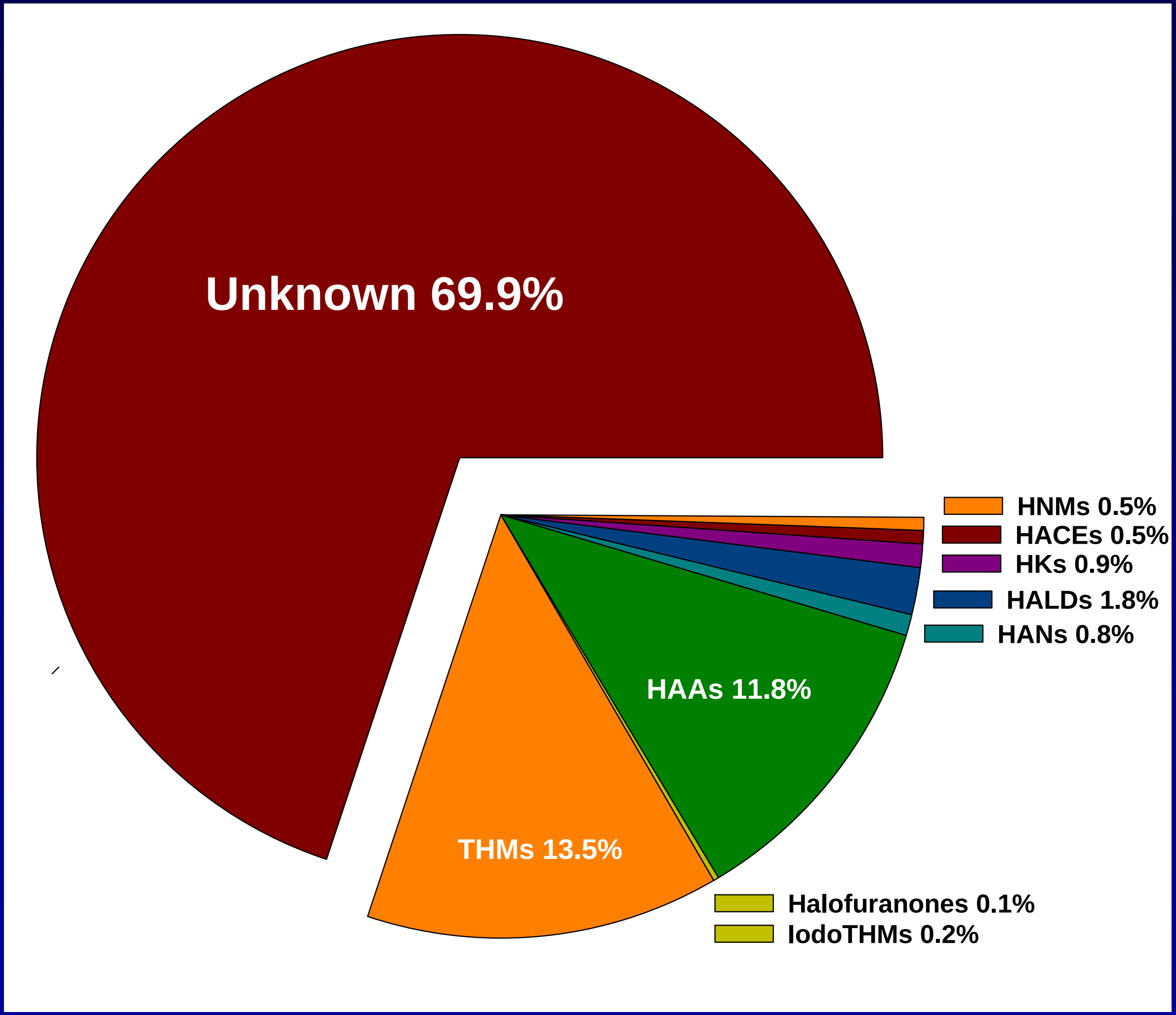
Goal: Comprehensively identify DBPs formed from different disinfectants, test for toxicity, understand their formation, minimize or eliminate in drinking water

Only 11 DBPs Regulated in U.S.

DBP	MCL (µg/L)
Total THMs	80
5 Haloacetic acids	60
Bromate	10
Chlorite	1000

- Little known about occurrence, toxicity of unregulated DBPs
- Regulated DBPs do not cause bladder cancer in animals
- Two unregulated DBPs are carcinogens
- Many unregulated DBPs more genotoxic than regulated ones

>600 DBPs identified, but more than 50% still not known….



Nationwide Occurrence Study, Krasner et al., *Environ. Sci. Technol*. **2006**, *40*, 7175-7185.

~50% of TOX >1000 Da: Khiari, et al., Proc. 1996 AWWA Water Quality Technology Conference

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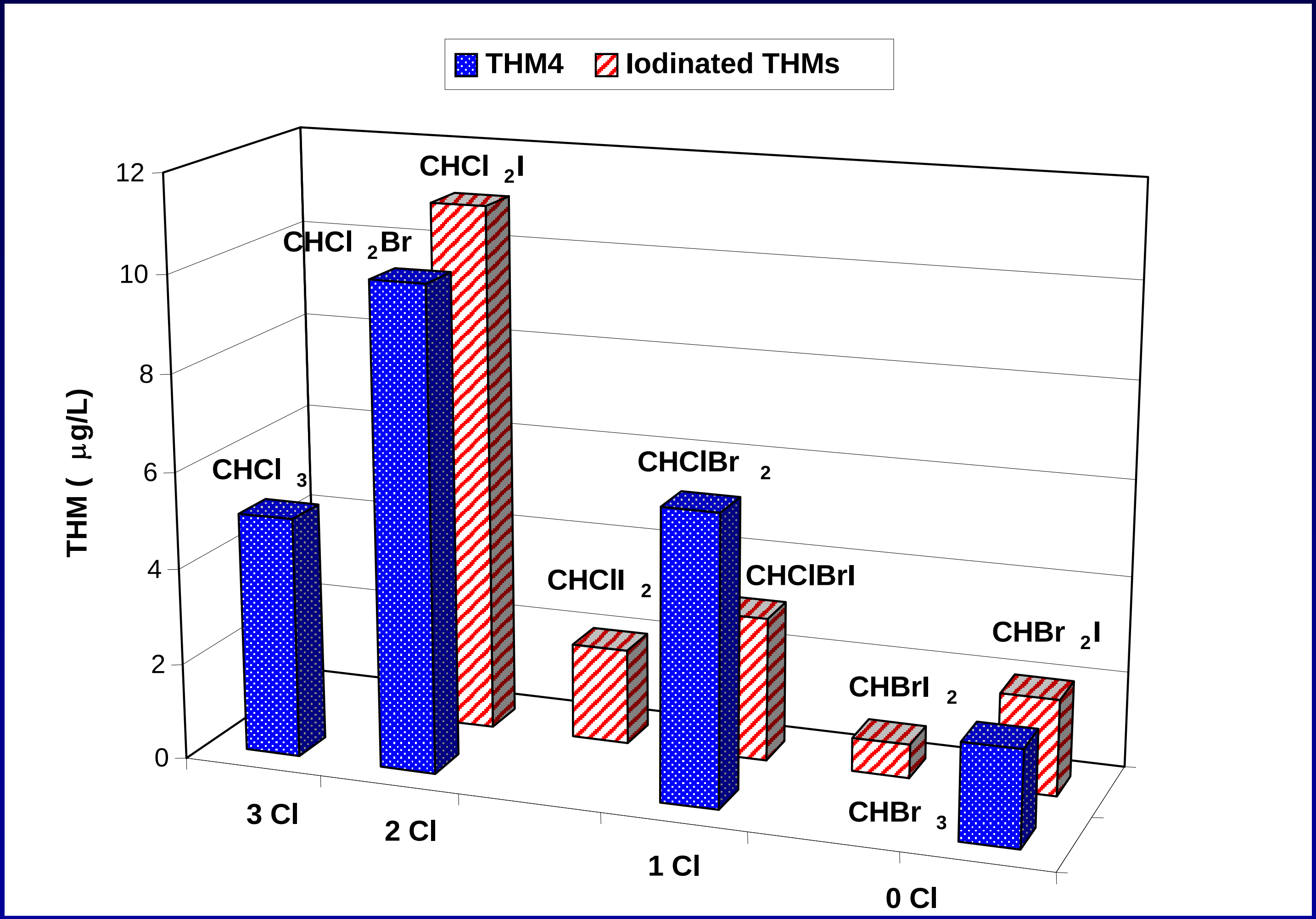
Unlike other contaminants that may or may not be present in drinking water…

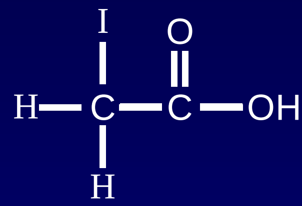
DBPs
are ubiquitous

Iodo-THMs

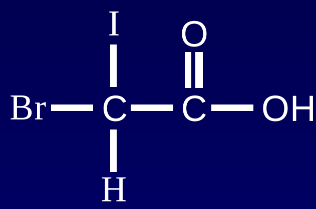


Krasner, Weinberg, Richardson, et al., *Environ. Sci. Technol*. 2006, 40, 7175-7185.

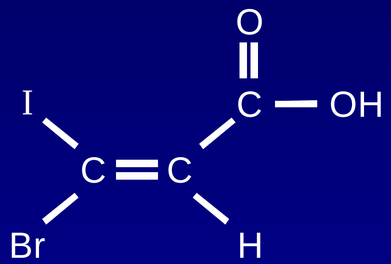
New Iodo-Acids



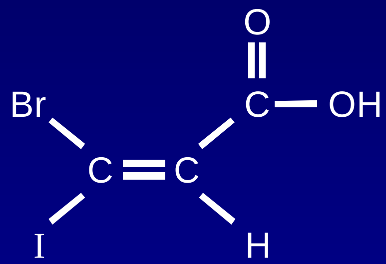
Iodoacetic acid



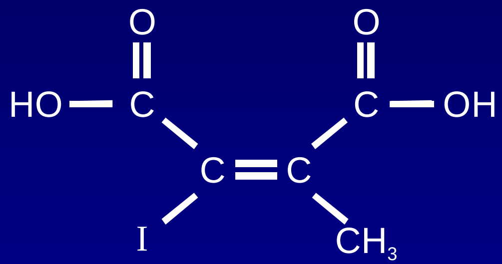
Bromoiodoacetic acid



(Z)-3-Bromo-3-iodopropenoic acid



(E)-3-Bromo-3-iodopropenoic acid



(E)-2-Iodo-3-methylbutenedioic acid

Initially discovered using GC/MS

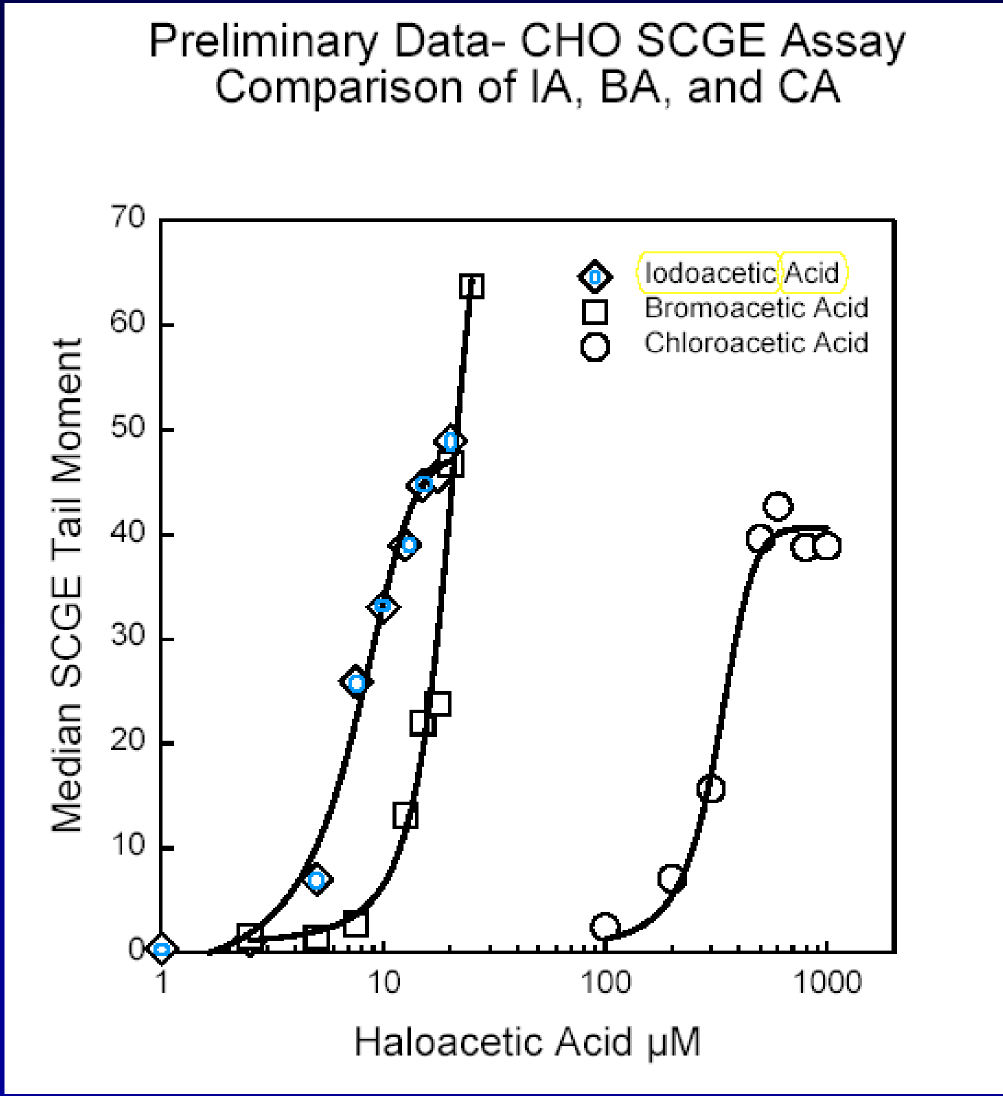
Highly genotoxic

Increase in formation with NH_2Cl vs. Cl_2

Occurrence Study published in Nov. 2008 (23 cities in U.S. & Canada)

Richardson et al., *Environ. Sci. Technol.* 2008, 42, 8330-8338.

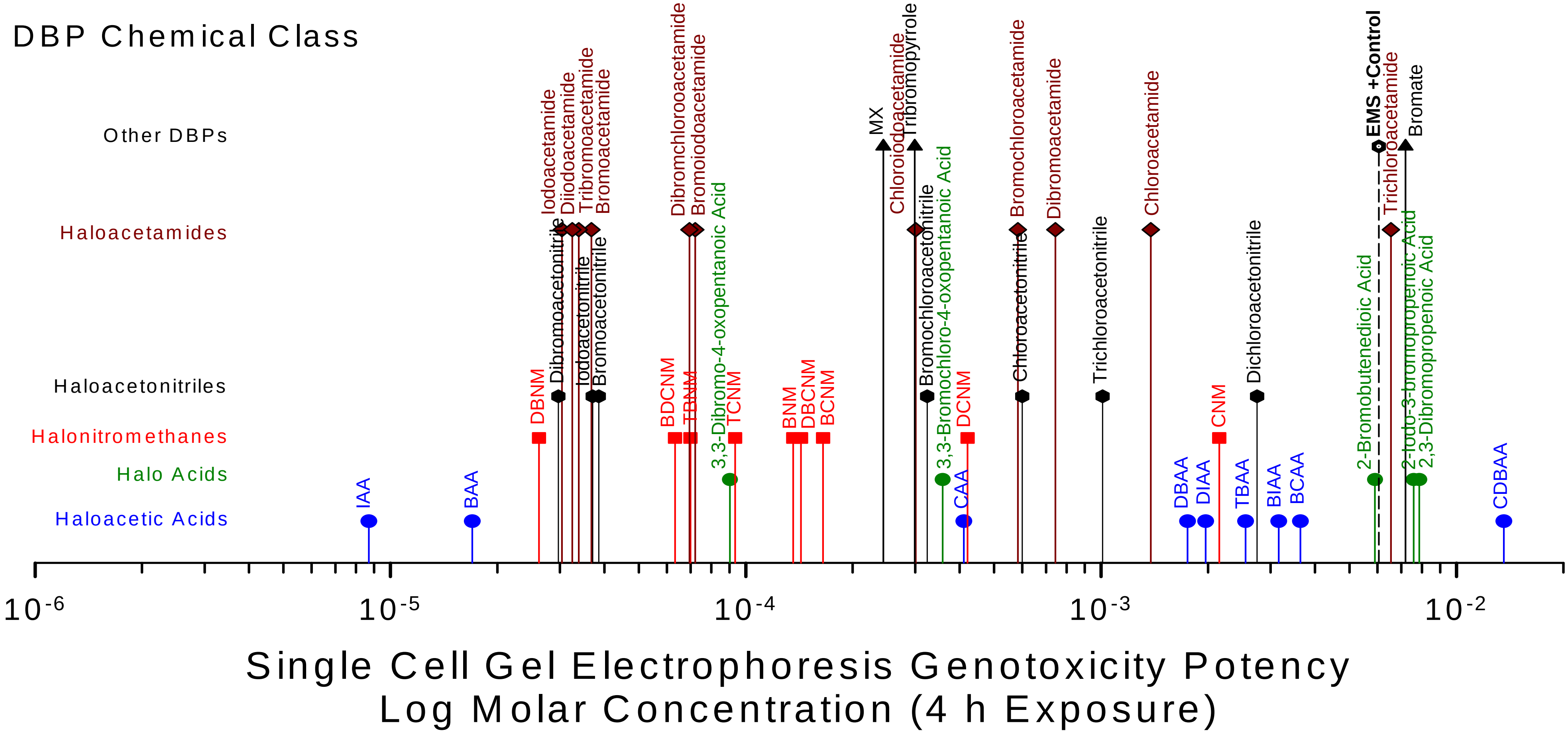
Genotoxicity of Iodoacetic acid



Plewa et al., *Environ. Sci. Technol.* 2004

IA also caused developmental effects in mouse embryos (Hunter et al., 1995)

Genotoxicity of Emerging DBPs

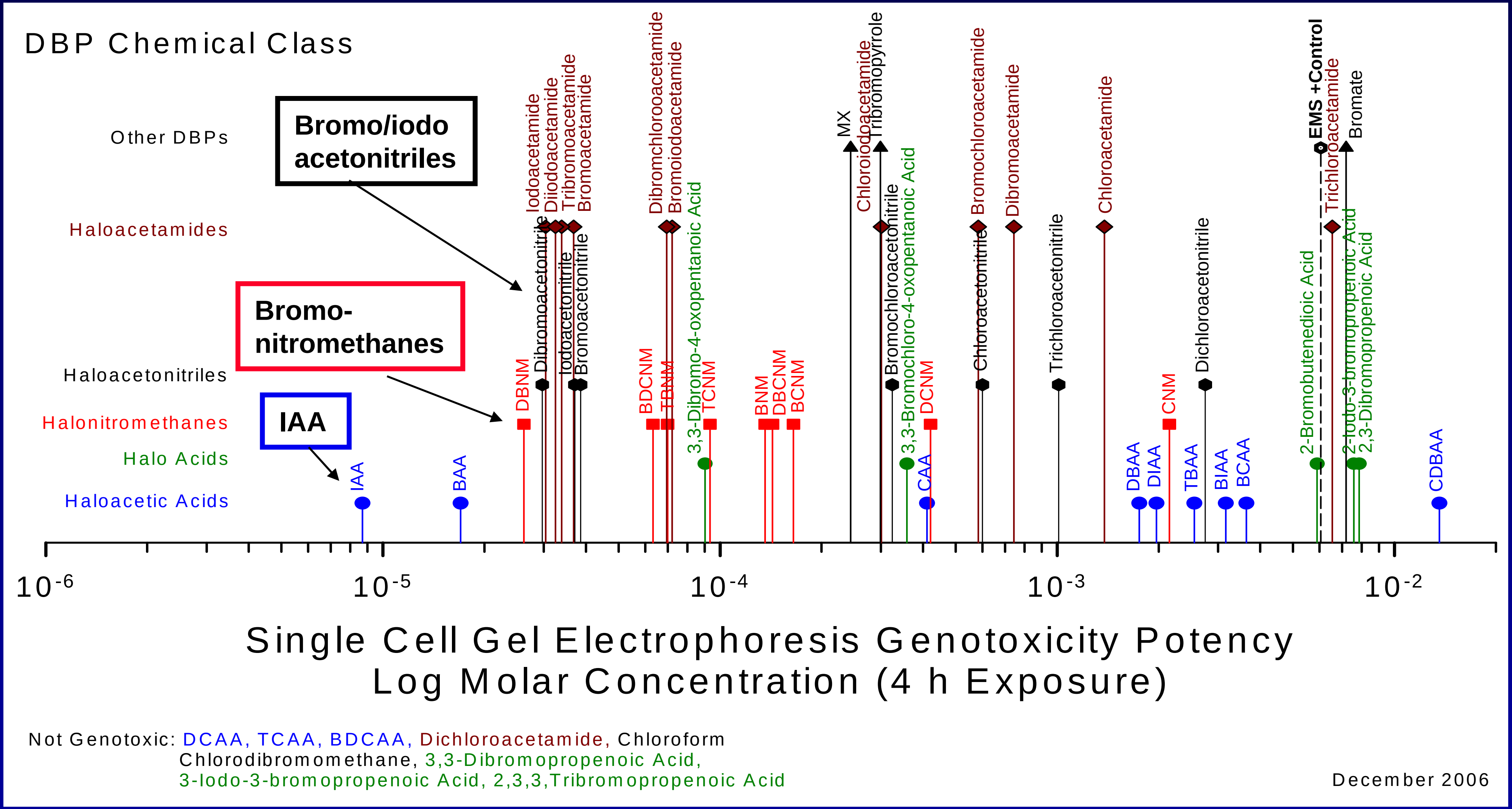


Not Genotoxic: DCAA, TCAA, BDCAA, Dichloroacetamide, Chloroform
Chlorodibromomethane, 3,3-Dibromopropenoic Acid,
3-Iodo-3-bromopropenoic Acid, 2,3,3,Tribromopropenoic Acid

December 2006

Data courtesy of Michael Plewa, University of Illinois

Genotoxicity of Other DBPs



Data courtesy of Michael Plewa, University of Illinois

But, all of this toxicity testing is for separate, individual DBPs…

DBPs
are really present as MIXTURES

>300 DBPs probably present in glass of water

Four Lab Study

Integrated Disinfection By-products Mixtures Research: Toxicological and Chemical Evaluation of Alternative Disinfection Treatment Scenarios

A collaborative effort between:

NHEERL (National Health and Environmental Effects Research Laboratory), RTP

NERL (National Exposure Research Laboratory), Athens

NRMRL (National Risk Management Research Laboratory), Cincinnati

NCEA (National Center for Environmental Assessment), Cincinnati

Purpose:

To address concerns related to potential health effects from exposure to DBPs that cannot be addressed directly from toxicological studies of individual DBPs or simple DBP mixtures

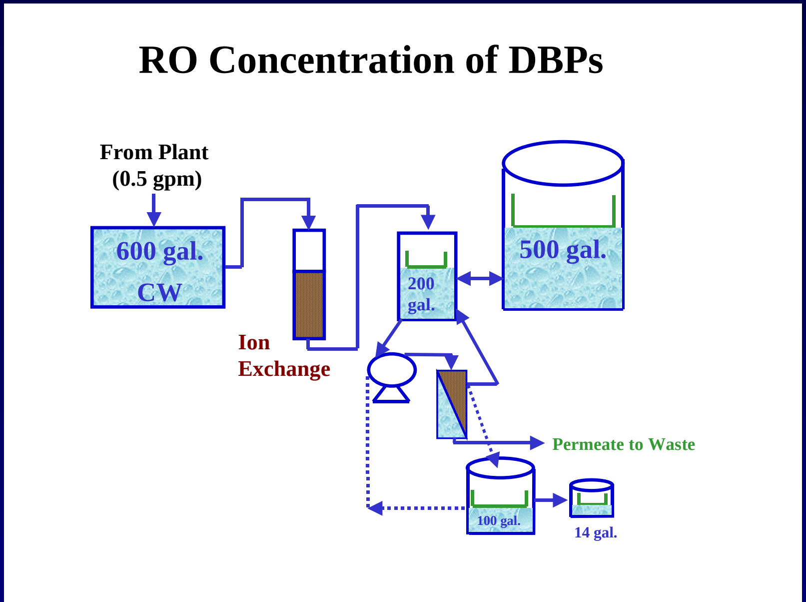
In Vitro and *In Vivo* Toxicological Assays

***In vitro*:**

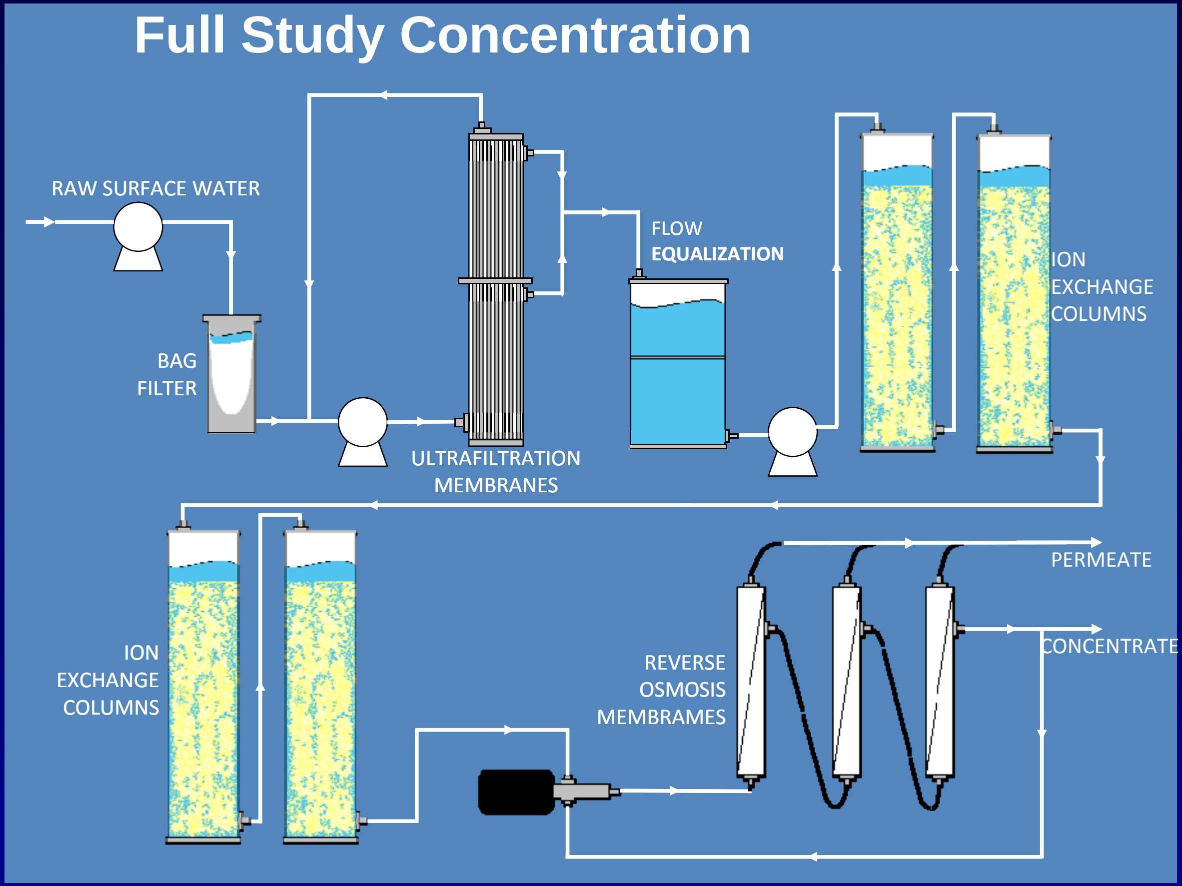
- Reproductive/developmental
- Mutagenicity
- Carcinogenicity
- Neurotoxicity
- Metabolism

***In vivo*:**

- Reproductive/developmental
- Mutagenicity/carcinogenicity
- Immunotoxicity
- Hepatic/renal toxicity
- Neurotoxicity/developmental neurotoxicity
- Kinetics/metabolism



1st Phase (1999-2001):
Cl_2 & O_3; treated water first
Concentrated after



Full Study (2006-2008):
Concentrated NOM first
Treated with Cl_2 after

1st Phase of study published: Richardson et al., *J. Toxicol. Environ. Health* 2008, 71, 1165-1186.
2nd Phase (chemistry): in press with *Environ. Sci. Technol.*

Results

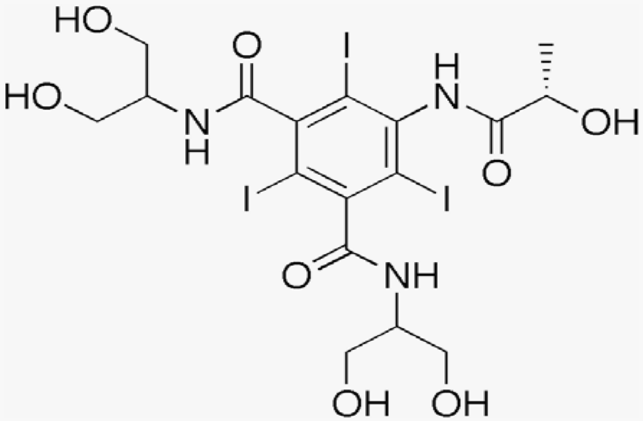
- Good mix of Cl/Br DBPs produced
- 75 Priority and regulated DBPs quantified
- >100 DBPs comprehensively identified
- Most DBPs fairly consistently produced among chlorination events
- Concentration offered by RO a bonus for detecting DBPs present at very low levels (e.g., MX, which is present in drinking water at ng/L levels)
- Most DBPs are stable over time on the rats' cages
- No major repro/developmental effects observed, but some subtle effects (decreased sperm count, etc.)

Conclusions

- A thorough examination of reproductive/developmental and other endpoints was predominantly negative
- Some small, subtle effects for chlorinated water concentrate (136x concentration factor may be “on the edge” of ability to see effects)
- Concentration offered by RO a bonus for detecting DBPs present at very low levels (e.g., MX, which is present in drinking water at ng/L levels)
- Combination of comprehensive, qualitative identification work and quantification of 75 DBPs allowed comprehensive assessment of DBPs present in water
- Most DBPs stable on rats’ cages and chlorination events were reproducible

Planning a follow-up study that includes Chlorine vs. Chloramines

Formation of iodo-DBPs from X-ray contrast media



Iopamidol

+ NOM $\xrightarrow[NH_2Cl]{HOCl}$ Iodo-DBPs

Richardson, Duirk, Lindell, Cornelison, Ternes, presented at Micropol Conference, June 2009

Iodo-DBP Occurrence Study

	Iodide (µg/L)	Sum iodo-acids (µg/L)	Sum iodo-THMs (µg/L)
Plant 2	1.0	0.37	4.9
Plant 4	ND	0.10	1.2
Plant 11	1.5	0.21	2.3
Plant 15	ND	0.17	2.4

Detection limit = 0.13 µg/L

Richardson et al., *Environ. Sci. Technol.* 2008, 42, 8330-8338.

ICM in U.S. Drinking Water Sources (ng/L)

	Iopamidol	Iomeprol	Iopromide	Iohexol	Diatrizoate
Plant 1	11	ND	ND	ND	ND
Plant 2	510	ND	24	120	93
Plant 4	110	ND	6	49	ND
Plant 10	ND	ND	ND	ND	ND
Plant 11	100	ND	ND	85	ND
Plant 12	280	ND	ND	120	ND
Plant 13	ND	ND	ND	ND	ND
Plant 15	2700	ND	25	ND	ND
Plant 17	ND	ND	ND	ND	ND
Plant 19	ND	ND	ND	ND	ND

Courtesy of Thomas Ternes, Federal Institute of Hydrology, Germany
ICM measured using LC/ESI-MS/MS; DLs = 5-20 ng/L

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Controlled Laboratory Reactions

Cristal and Steve

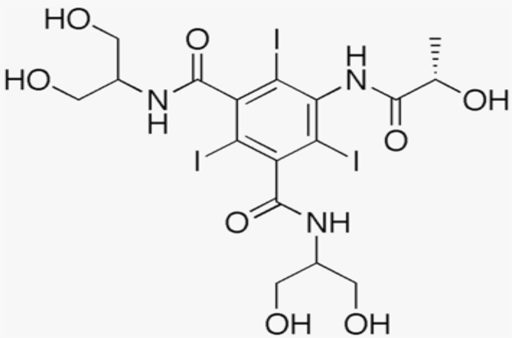
Experiments

- React ICM with HOCl, NH_2Cl (with and without NOM)
- 3 pHs
- Follow formation of iodo-DBPs
- Identify reaction products and intermediates
- Measure genotoxicity

Methods

- Iodo-THMs: GC/EI-MS
- Iodo-Acids: GC/NCI-MS (with derivatization)
- Iopamidol (and other ICM): LC, LC/MS/MS
- Larger MW products and intermediates: LC/MS/MS
- Genotoxicity: Chinese hamster ovary cells, single cell gel electrophoresis

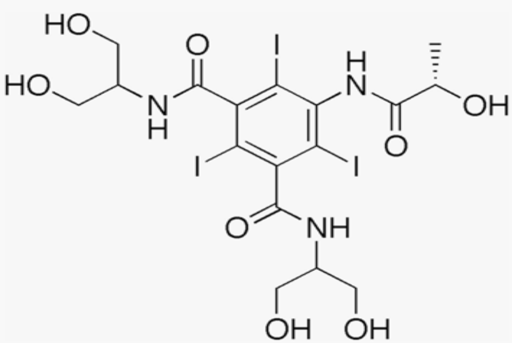
Results



Iopamidol

$\xrightarrow[NH_2Cl]{HOCl}$ Iodo-DBPs

Only trace levels

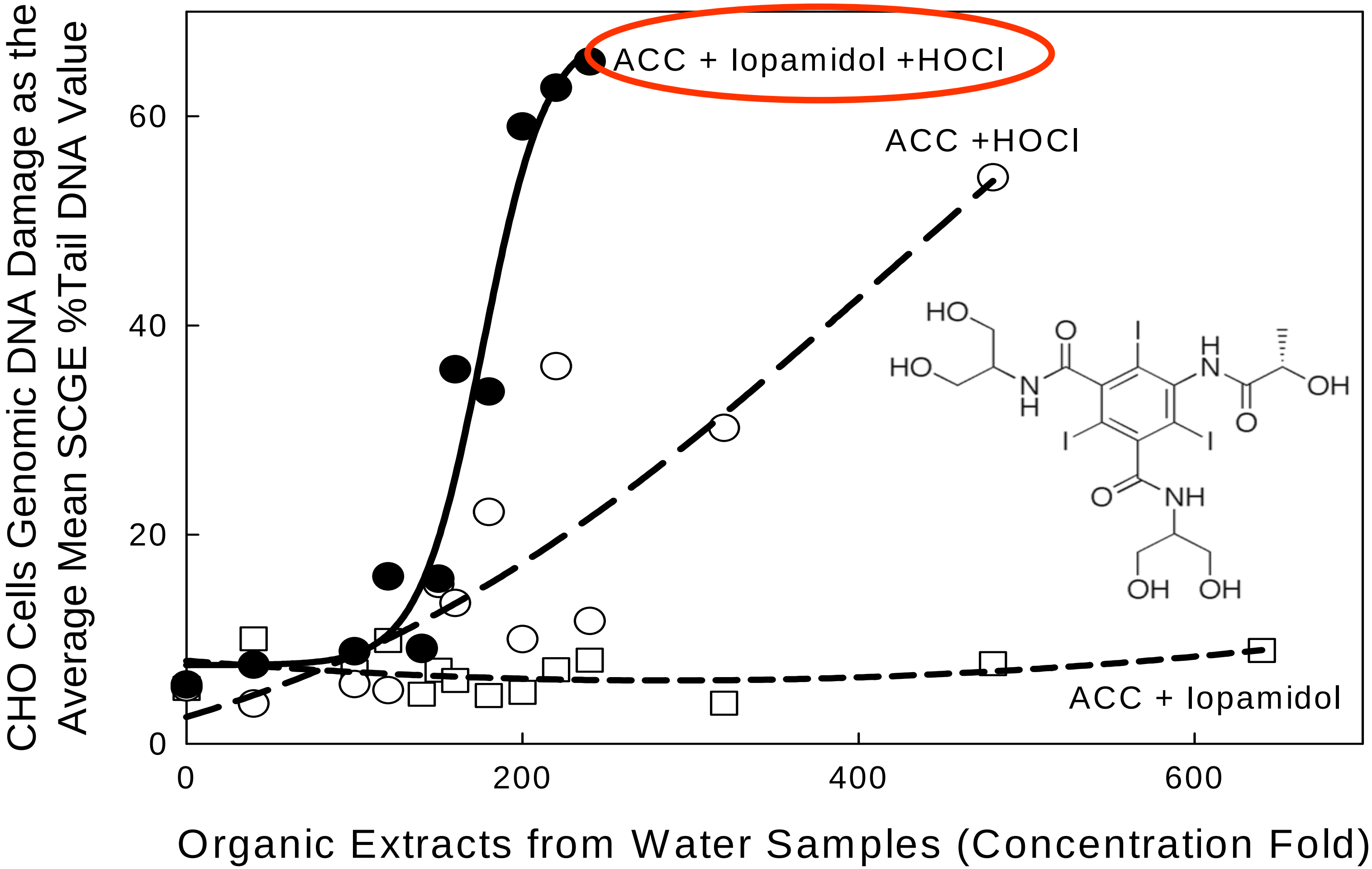


Iopamidol

\+ NOM $\xrightarrow[NH_2Cl]{HOCl}$ Iodo-DBPs ✓

Iodo-THMs
&
Iodo-Acids

Genotoxicity of Chlorinated Waters Containing Iopamidol



Acknowledgments

Michael Plewa

Jane Ellen Simmons

Tony DeAngelo

David DeMarini

A few fabulous toxicologists who have helped push this field forward….

Also, Mike Narotsky, Sid Hunter, Rex Pegram, ….