Emerging Environmental Contaminants: What's New

Susan D. Richardson

U.S. Environmental Protection Agency,
National Exposure Research Laboratory, Athens, GA

Emerging Contaminants

- Perfluorinated Chemicals (e.g., PFOA and PFOS)
- Pharmaceuticals
- DBPs (including NDMA and nitrosamines)
- Pesticide reaction/degradation products
- Brominated flame retardants (PBDEs)
- Perchlorate
- Nanomaterials
- Sucralose (Splenda !)
- Algal toxins
- Benzotriazoles
- Dioxane
- Sunscreen chemicals (UV filters)
- Gasoline additives
- Naphthenic acids
- Hormones
- Pathogens

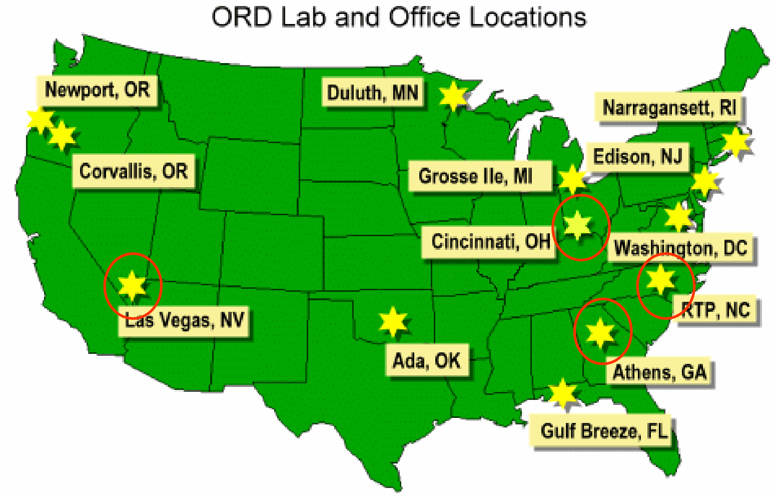
U.S. EPA

Athens, GA

RTP, NC

Most emerging contaminant research described in this presentation is from EPA's Office of Research & Development's four National Exposure Research Laboratories.

Cincinnati, OH



Las Vegas, NV

U.S. Contaminant Candidate List (CCL-3)

- More open process (public could submit contaminants)
- Input from EPA-ORD, National Academy of Science's National Research Council, National Drinking Water Advisory Council, Science Advisory Board
- "Universe" of potential drinking water contaminants considered (7,500)
- Used model to narrow to 560 contaminants
- Used occurrence, toxicity, bioaccumulation, industrial production, and chemical properties to further narrow
- Originally: 11 Microbial contaminants; 95 chemical contaminants
  **Changed now to 12 microbials and 104 chemicals (as a result of SAB review and open comment process)
- CCL-3 JUST FINALIZED Sept. 25, 2009 !

CCL-3: www.epa.gov/safewater/ccl

CCL-3

Microbial Contaminants:

- Adenovirus
- Caliciviruses
- *Campylobacter jejuni*
- Enterovirus
- *Escherichia coli (O157)*
- *Helicobacter pylori*
- Hepatitis A virus
- *Legionella pneumophila*
- *Mycobacterium avium*
- *Naegleria fowleri*
- *Salmonella enterica*
- *Shigella sonnei*

CCL-3: www.epa.gov/safewater/ccl

CCL-3

Chemical Contaminants:

- Pesticides & pesticide degradates (e.g., acetochlor ethanesulfonic acid)
- DBPs (5 nitrosamines, formaldehyde, acetaldehyde, benzyl chloride, chlorate, bromochloromethane)
- Industrial chemicals (e.g., solvents and other chemicals)
- Consumer product chemicals (e.g., urethane)
- Food additives (e.g., butylated hydroxy anisole)
- Gasoline additives (e.g., MTBE)
- Explosives (e.g., RDX)
- Inorganics (e.g., cobalt, molybdenum, tellurium, vanadium)
- Algal toxins (anatoxin-a, cylindrospermopsin, microcystin-LR) !
- PFOA and PFOS !
- Pharmaceuticals and hormones !

CCL-3: www.epa.gov/safewater/ccl

Unregulated Contaminants Monitoring Rule (UCMR-2)

- Allows EPA to collect data for unregulated contaminants suspected to be present in drinking water, but that do not have health-based standards under the Safe Drinking Water Act
- Monitors for no more than 30 contaminants every 5 yrs
- All large water treatment plants and a subset of smaller ones monitored
- UCMR-1 (2001-2005): 28 contaminants on list
- UCMR-2 (2007-2010): new list of 25 contaminants
- **Monitoring for 12-month period between Jan. 2008-Dec. 2010**

www.epa.gov/safewater/ucmr/ucmr2

Unregulated Contaminants Monitoring Rule (UCMR-2)

Assessment Monitoring List 1 (common analytical methods)

All plants serving >10,000 people; subset of other plants

- Dimethoate (OP pesticide)
- Terbufos sulfone (OP pesticide degradate)
- 5 Brominated flame retardants (BDE-47, BDE-99, HBB, BFE-153, BDE-100)
- 3 Explosives (1,3-nitrobenzene, TNT, RDX)

Screening Survey List 2 (specialized analytical methods)

All plants serving >100,000 people; subset of other plants

- 3 Parent acetanilide herbicides (acetochlor, alachlor, metolachlor)
- 6 Acetanilide degradates
- 6 Nitrosamines

www.epa.gov/safewater/ucmr/ucmr2

New Water Quality Criteria Under Development

WHITE PAPER

AQUATIC LIFE CRITERIA FOR CONTAMINANTS OF EMERGING CONCERN

PART I

GENERAL CHALLENGES AND RECOMMENDATIONS

PART II
ILLUSTRATION OF RECOMMENDATIONS USING DATA FOR 17$^{\alpha}$-ETHYNYLESTRADIOL (EE2)

Prepared by the
OW/ORD Emerging Contaminants Workgroup
June 03, 2008

DRAFT DOCUMENT

Ambient water quality criteria are levels of individual pollutants, water quality characteristics, or descriptions of conditions of a water body that, if met, should protect the designated use(s) of the water.

Examples: swimming, drinking water, fishing, fish spawning, and navigation

CMC: Criterion maximum concentration (protects against severe acute effects)

CCC: Criterion continuous concentration (protects against longer term effects on survival, growth, and reproduction)

New Water Quality Criteria Under Development

- WQ criteria will set standards for emerging contaminants
- Starting with pharmaceuticals and personal care products
- EE2 -> Trenbolone -> Triclosan
  - These have different modes of action

The Plan:

- Develop this new Water Quality Criteria
- Get states to adopt criteria
- Criteria would be implemented through National Pollutant Discharge Elimination System (NPDES) permits given

PFOS/PFOA

PFOS:
Perfluorooctanesulfonate

$$CF_3 — (CF_2)_7 — SO_3^-$$

PFOA:
Perfluorooctanoic acid

$$CF_3 — (CF_2)_6 — COOH$$

- Used to make soil-, stain-, grease-, and water-resistant coatings that are widely applied to fabrics, carpets, cookware, paper (microwave popcorn bags)
- Persistent, bioaccumulative, toxic (including developmental), ubiquitous contaminant
- PFOA and PFOS now on new CCL-3
- PFOS not manufactured anymore; environmental levels decreasing
- Eight manufacturers to phase out PFOA by 2010

CCL-3: www.epa.gov/safewater/ccl

PFOA

Ever wonder why grease doesn’t come through paper wrapper?

PFOA

Questions and Concerns

- Why is it in the bloodstream of almost everyone measured?
- Where is it coming from? How is it transported?
- Why is found in biota in the Arctic?
  (Up to 3112 ng/g in polar bears from Arctic—can be at greater levels than PCBs)

Hypothesis: telomer alcohols volatile, transported, oxidized to acid in atmosphere and in the body (Henderson & Smith, *Toxicol. Sci*. 2007, *95*(2), 452).

Current work:
- exploring microbial degradation of fluorotelomer polymers
- investigating sources & sinks for PFOA (including sorption)
- large worldwide occurrence study in soils
- investigating source from sewage sludge used as soil improver
- measuring PFCs in fish

PFOA

- Most measurements use LC/ESI-MS/MS or GC/MS/MS
- Can be tricky getting clean backgrounds

New EPA Method 537

EPA Document #: EPA/600/R-08/092

METHOD 537. DETERMINATION OF SELECTED PERFLUORINATED ALKYL ACIDS IN DRINKING WATER BY SOLID PHASE EXTRACTION AND LIQUID CHROMATOGRAPHY/TANDEM MASS SPECTROMETRY (LC/MS/MS)

Version 1.0
September 2008

J.A. Shoemaker US EPA, Office of Research and Development, National Exposure Research Laboratory

P.E. Grimmett US EPA, Office of Research and Development, National Exposure Research Laboratory

B.K. Boutin The National Council on Aging, Senior Environmental Employment Program

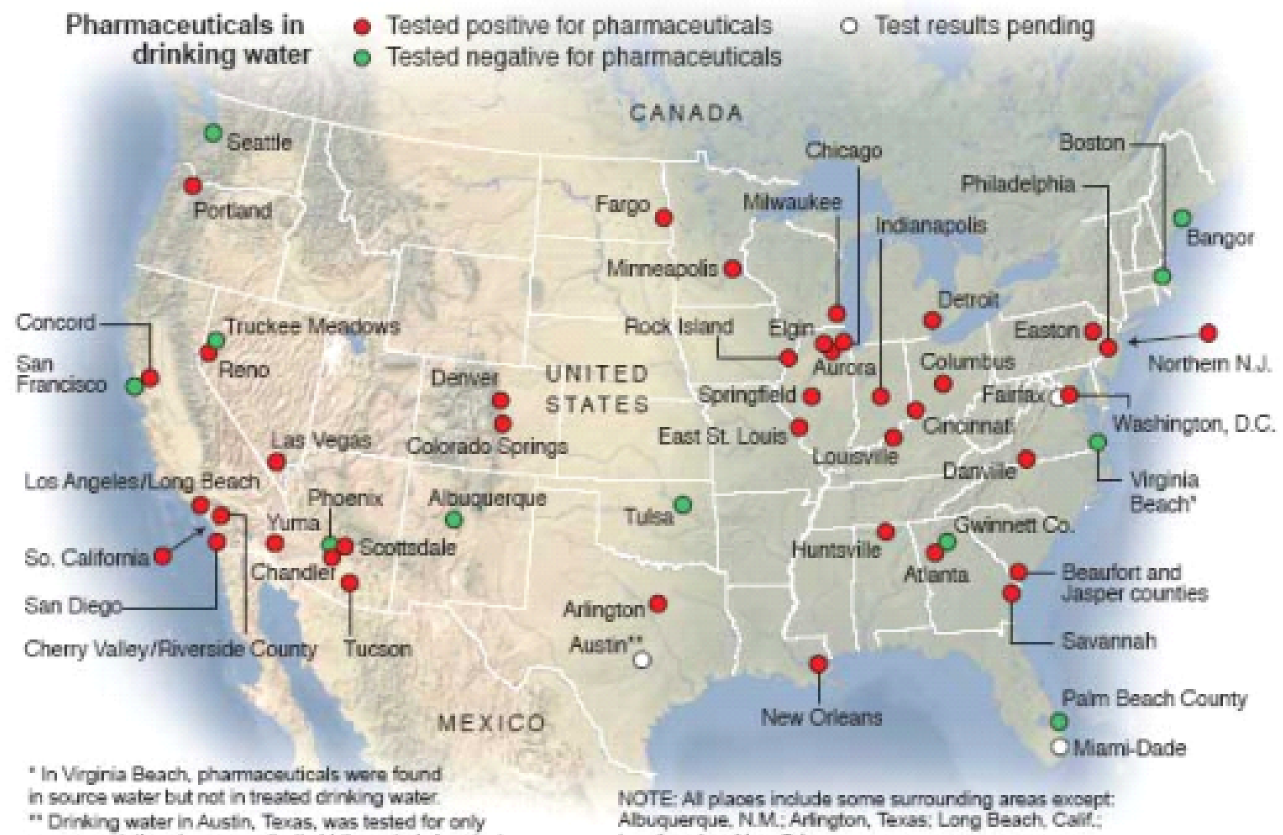
NATIONAL EXPOSURE RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

Available at: www.epa.gov/nerlcwww/ordmeth.htm

Pharmaceuticals

46 million in U.S. have drugs in drinking water

Testing shows traces of meds in water greater than previously reported



updated 4:29 p.m. ET, Thurs., Sept. 11, 2008

Testing prompted by an Associated Press story that revealed trace amounts of pharmaceuticals in drinking water supplies has shown that more Americans are affected by the problem than previously thought — at least 46 million. That's up from 41 million people reported by the AP in March as part of an investigation into the presence of pharmaceuticals in the nation's waterways.

New EPA Method 1694

EPA

Method 1694: Pharmaceuticals and Personal Care Products in Water, Soil, Sediment, and Biosolids by HPLC/MS/MS

December 2007

Available at: www.epa.gov/waterscience/methods/method/files/1694.pdf

Pharmaceuticals

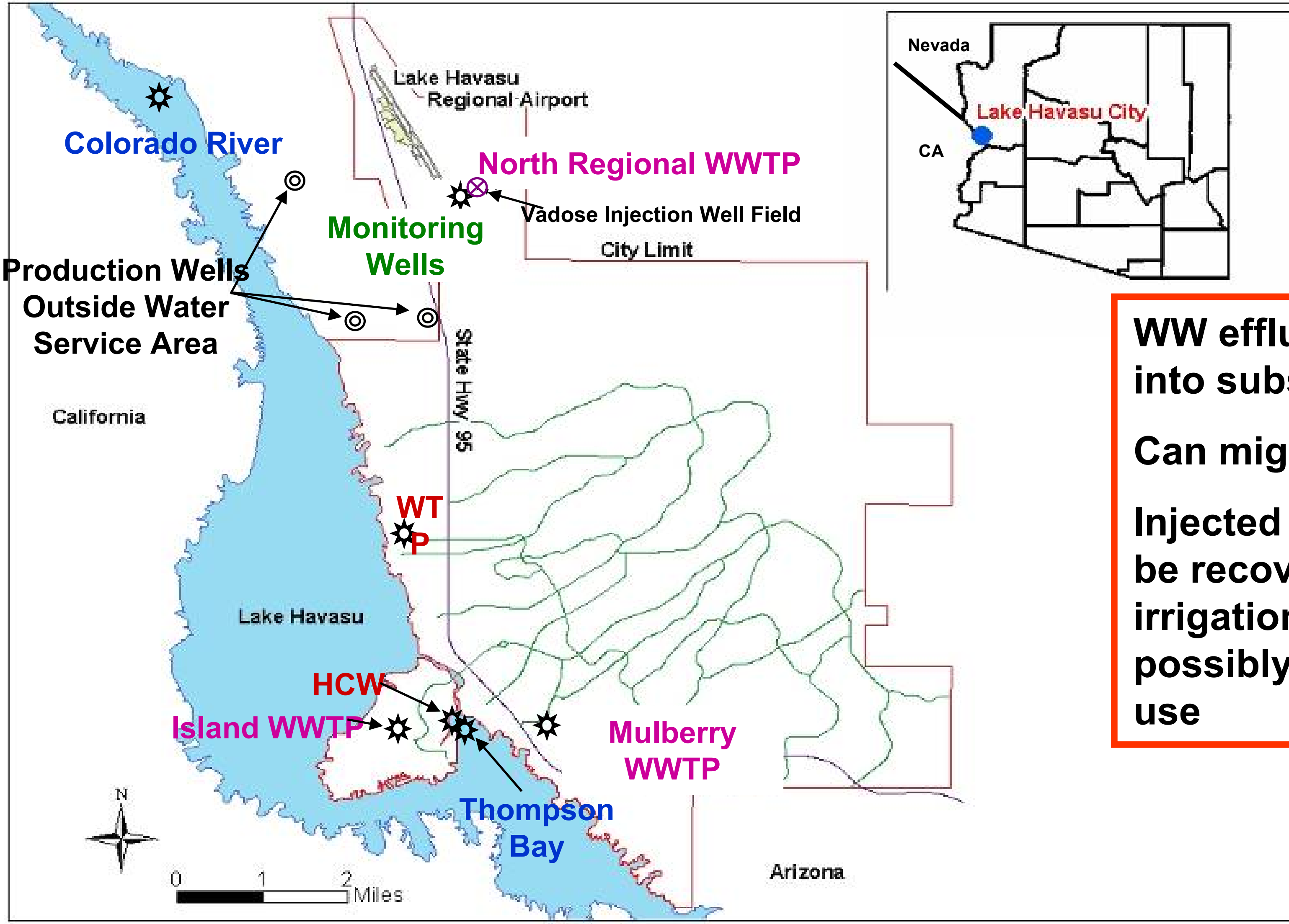
Just included on the CCL-3; will also be included in new Water Quality Criteria

- Potential estrogenic effects on biota (e.g., feminization of fish)
- Potential antibiotic resistance
- May affect aquatic organism populations (decreased food sources)
- Transformation in drinking water treatment

Recent work:

- Tracing the source of macrolide antibiotics and illicit drugs into the Colorado River Basin (Tammy Jones-Lepp)
- Drinking water: measuring 35 pharmaceuticals and other emerging contaminants in waters from 9 states (so far, levels not a risk for human health effects) (Susan Glassmeyer & USGS researchers)
- Spiking ethinylestradiol in lake in Canada (Jim Lazorchak with researchers from Fisheries and Oceans Canada) (Karen Kidd, Blanchfield, Mills, Palace, Evans)

Lake Havasu, Arizona/California



WW effluent injected into subsurface

Can migrate to lake

Injected effluent will be recovered for irrigation and possibly domestic use

Slide courtesy of Tammy Jones-Lepp, U.S. EPA, Las Vegas, NV and Doyle Wilson, City of Lake Havasu, AZ

Emerging Contaminants Analyzed in this Study

Pharmaceuticals

Atenolol	Ibuprofen
Atorvastatin	Iopromide
Azithromycin	Meprobamate
Caffine	Methamphetamine
Carbamazepine	MDMA
Clarithromycin	Naproxen
Clindamycin	Primidone
Diazepam	Pseudoephedrine
Diclofenac	Roxithromycin
Dilantin	Sulfamethoxazole
Fluoxetine	Triclosan
Gemfibrozil	Trimethoprim

EDCs

Atrazine
Benzophenone
BHA
Bisphenol A
DEET
Musk ketone
Octylphenol
TCEP
TCPP

Steroids

Estradiol
Estrone
Ethinylestradiol
Progesterone
Testosterone

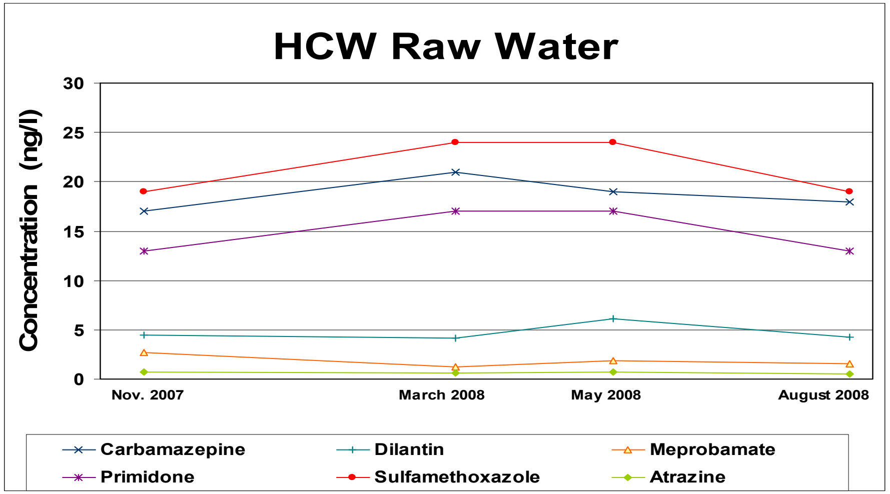
Other

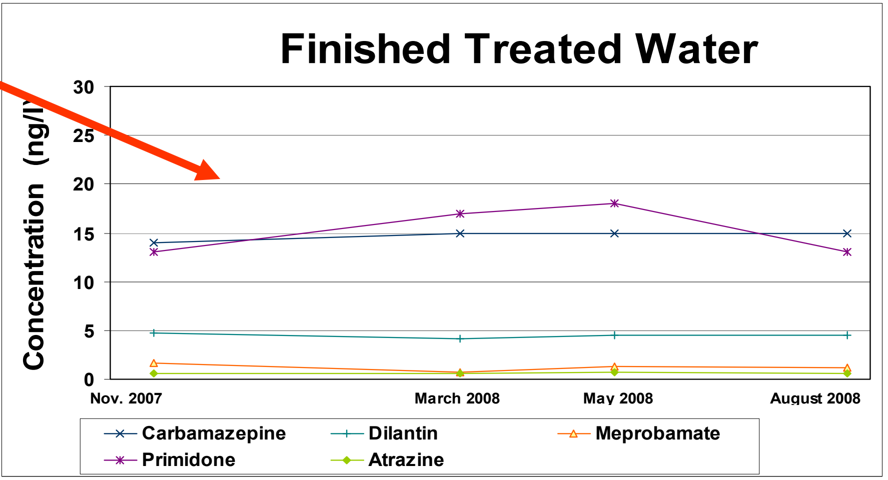
Urobilin
n,n-DMPEA

Slide courtesy of Tammy Jones-Lepp, U.S. EPA, Las Vegas, NV
and Doyle Wilson, City of Lake Havasu, AZ

Horizontal Collector Well and Treated Water Results

Compound (ng/l)	HCW	Treated
Atrazine	0.6	0.6
Carbamazepine	18.8	14.8
Dilantin	4.8	4.5
Meprobamate	1.9	1.2
Primidone	15.0	15.3
Sulfamethoxazole	21.5	ND





Slide courtesy of Tammy Jones-Lepp, U.S. EPA, Las Vegas, NV and Doyle Wilson, City of Lake Havasu, AZ

Emerging Contaminants What are They? Or a Paradigm Shift?

An Example of a Whole Lake Ethynylestradiol Dosing Experiment at Canada's Experimental Lake Area

Jim Lazorchak, U.S. EPA, NERL, Cincinnati, OH

Kidd, Blanchfield, Mills, Palace, Evans, Lazorchak, Flick. 2007. Collapse of a fish population after exposure to a synthetic estrogen. *PNAS* 104, 8897-8901.

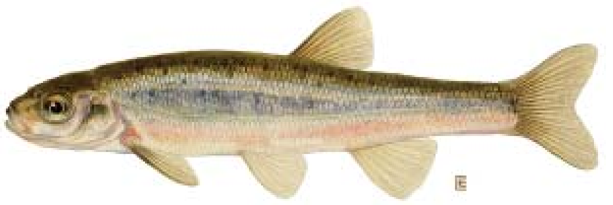
Summary - Fathead Minnow

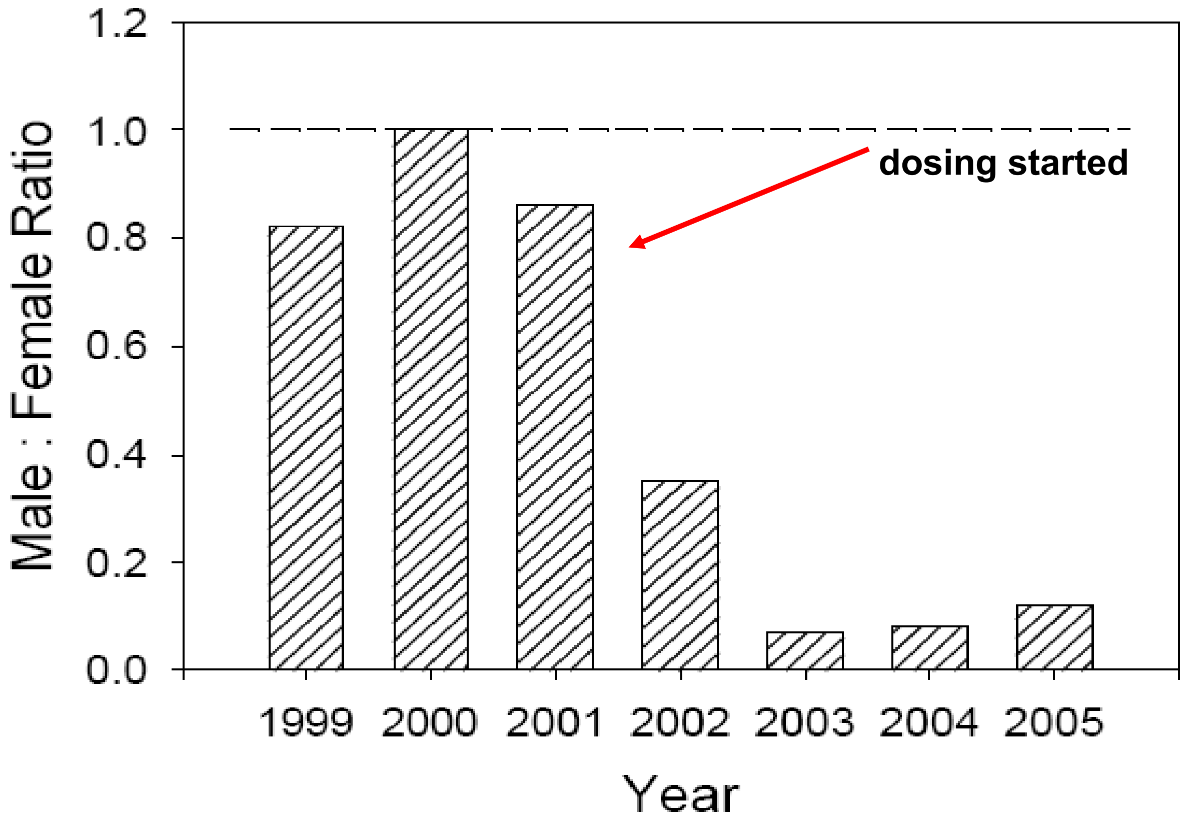
United States Environmental Protection Agency

- Spring 2001 - EE2 additions began
  - Vg gene expression induction in deployed 114 fish in 260 in 24-hrs
  - significant vitellogenin plasma induction after 7 weeks
- Fall 2001 (4 months)
  - proteinaceous accumulation in kidney
  - liver cell size increased
- Spring 2002 (12 months)
  - disorganized testes, immature ovaries
  - decreased spawning aggression, fewer & less-developed eggs
  - reduction in secondary sex characteristics
  - No fish population impacts observed
- Fall 2002 (17 months) - reproductive failure, few age 0 fish
- Spring 2003 (2 years) - only age 2 fish remaining
  - one male found, females with large ovipositors
- 2006 (3 yrs post additions) – Fathead population recovered

United States Environmental Protection Agency

Pearl Dace Sex Ratio



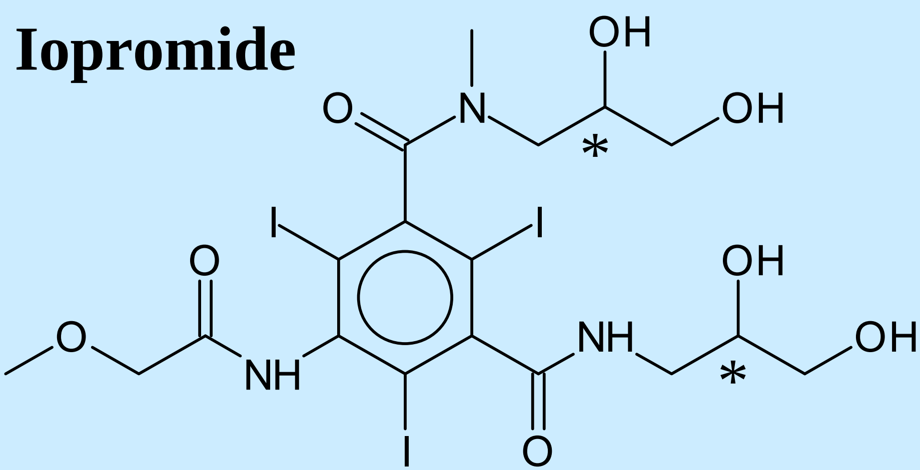


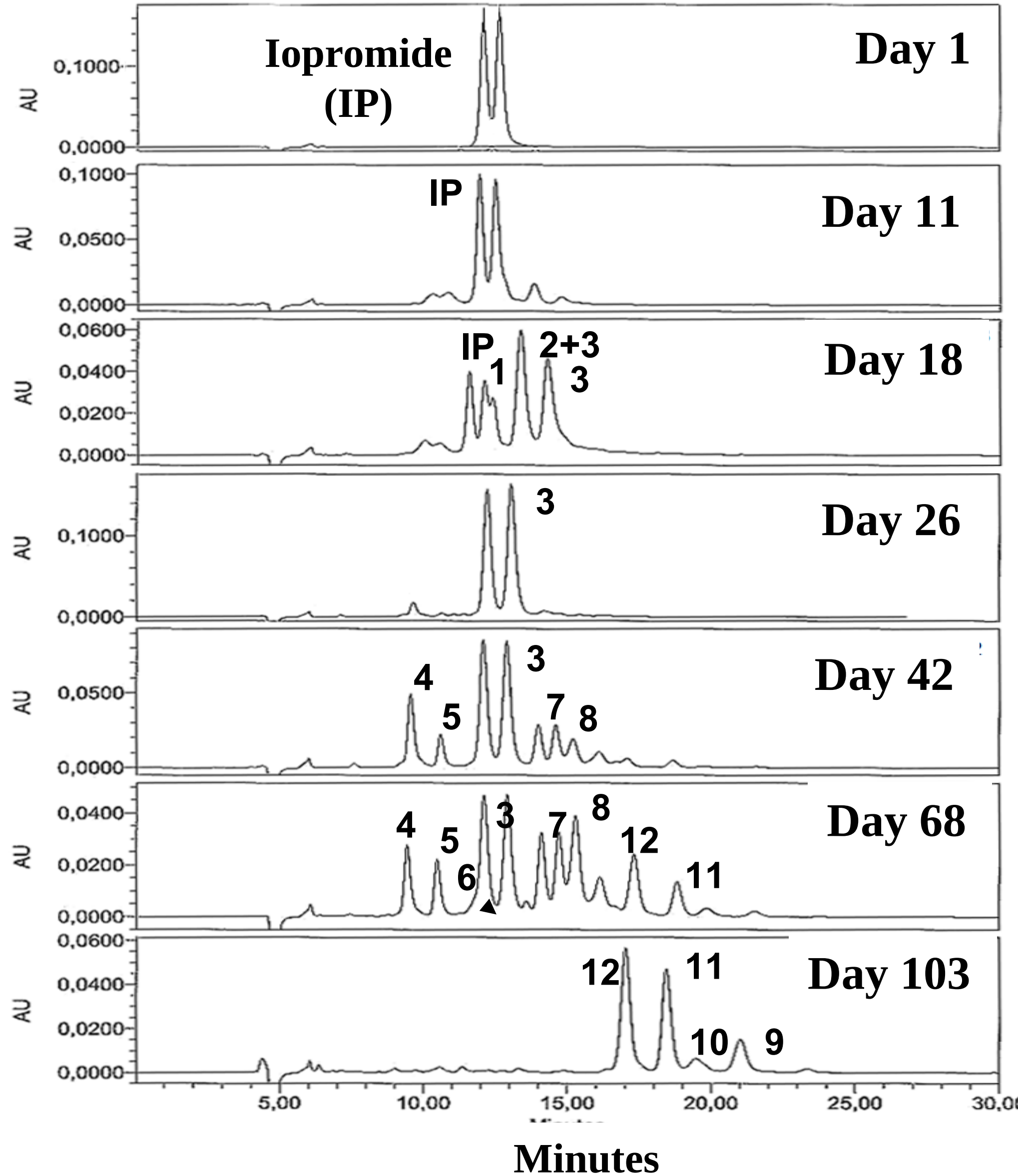
K Mills – FW Inst

X-Ray Contrast Media

Formation of 12 iopromide transformation products (TP)
detection via HPLC/UV

Iopromide



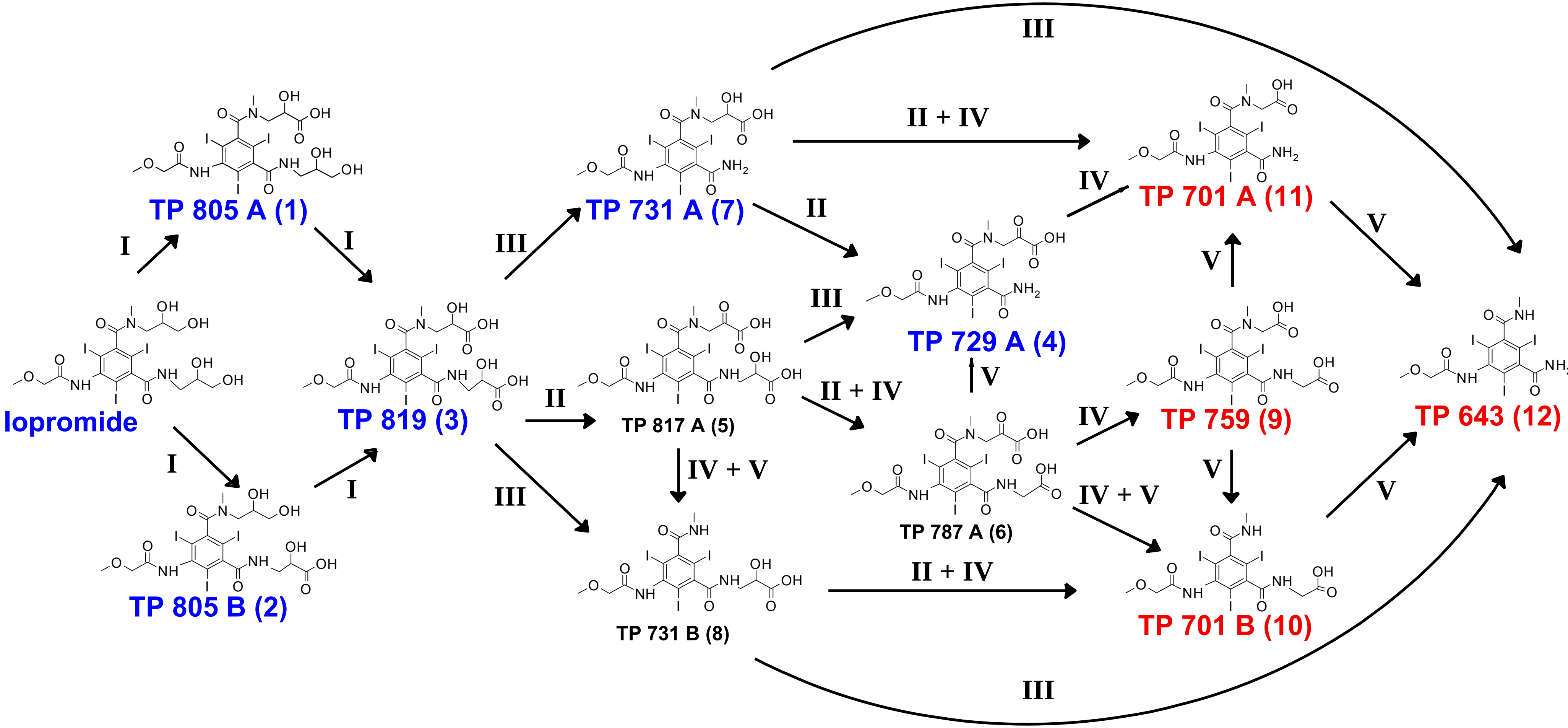


Slide courtesy of Thomas Ternes, Federal Inst. Hydrology, Koblenz, Germany

bfg Bundesanstalt für Gewässerkunde

Potential aerobic degradation pathway of Iopromide

Reaction products identified using LC/MS/MS and NMR



Source: Schulz et al., ES&T 2009.

Slide courtesy of Thomas Ternes, Federal Inst. Hydrology, Koblenz, Germany

Drinking Water DBPs

- Formed by the reaction of disinfectants with natural organic matter

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)

- Huge movement toward alternative disinfectants
- Use of UV and membranes increasing dramatically
- By 2025, 70% of drinking water plants expected to use membranes

DBPs Regulated by the U.S. EPA

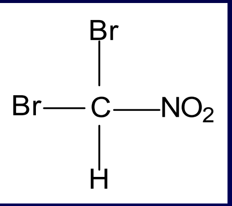
DBP	MCL (µg/L)
Total THMs	80
5 Haloacetic acids	60
Bromate	10
Chlorite	1000

But more than 600 DBPs have been identified

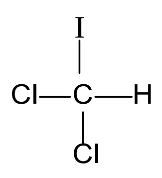
Little known about occurrence & toxicity of unregulated DBPs

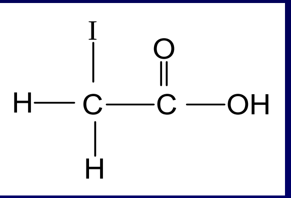
Emerging DBPs

- Halonitromethanes (up to 3 ppb; highly genotoxic); new *in vivo* effects; increased with preozonation

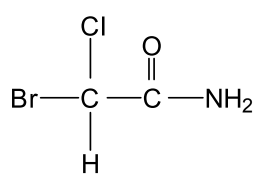


- Iodo-THMs and Iodo-Acids (iodo-THMs up to 15 ppb; iodo-acids up to 1.7 ppb; both classes highly cytotoxic or genotoxic); increased with chloramination
  Richardson et al., *ES&T*, 2008, 42, 8330.

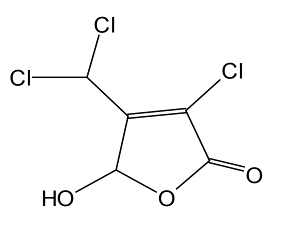




- Haloamides (up to 14 ppb; highly genotoxic) may be increased with chloramination

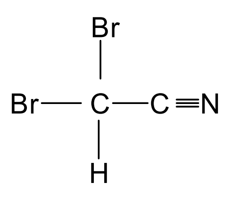


- Halofuranones (up to 2.4 ppb for total MX analogues; genotoxic, carcinogenic); chloramination can also form

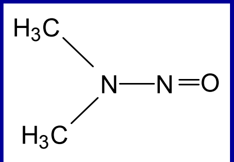


MX

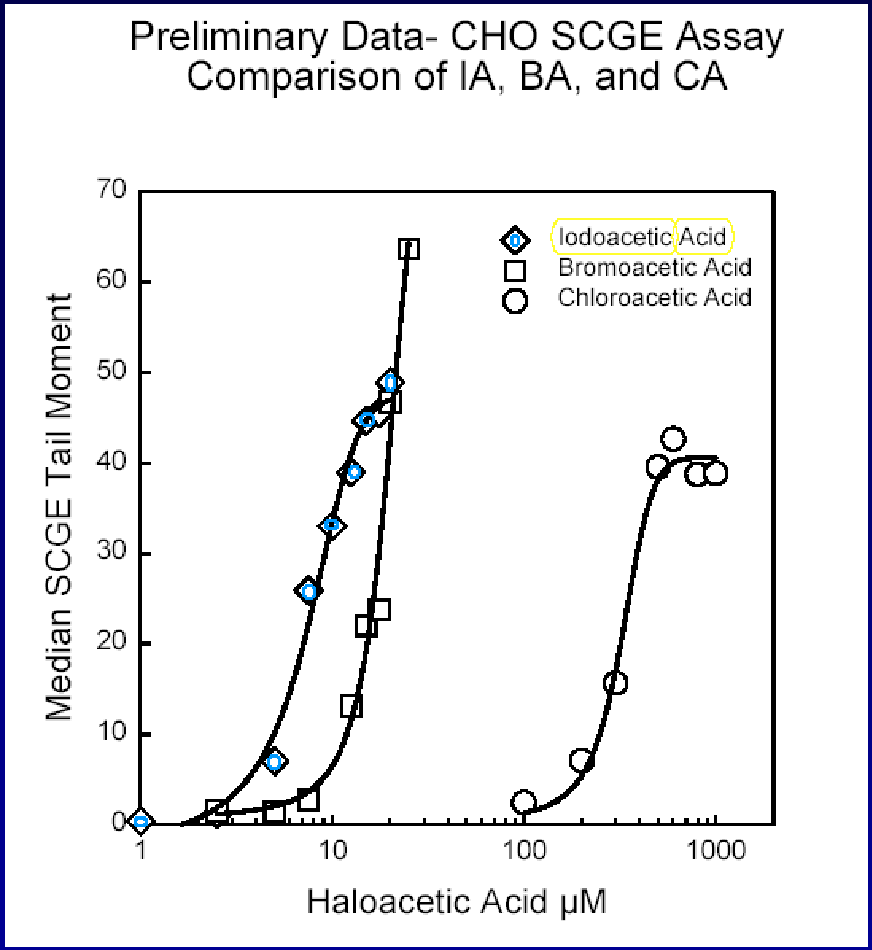
- Haloacetonitriles (up to 41 ppb; ~10% of THM4; genotoxic, cytotoxic); may be increased with chloramination



- Nitrosamines (up to 180 ppt; probable human carcinogens); increased with chloramination
  EPA Method 521: www.epa.gov/nerlcwww/m_521.pdf



Genotoxicity of Iodoacetic acid



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

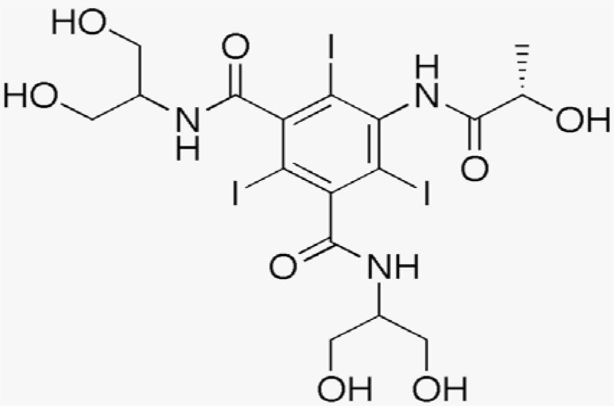
IA also caused developmental effects in mouse embryos (Hunter et al., 1995)

New iodo-acid/iodo-THM occurrence study published: Richardson et al., *ES&T*, 2008, 42, 8330.
Also reports genotoxicity & cytotoxicity of other iodo-acids and iodo-THMs

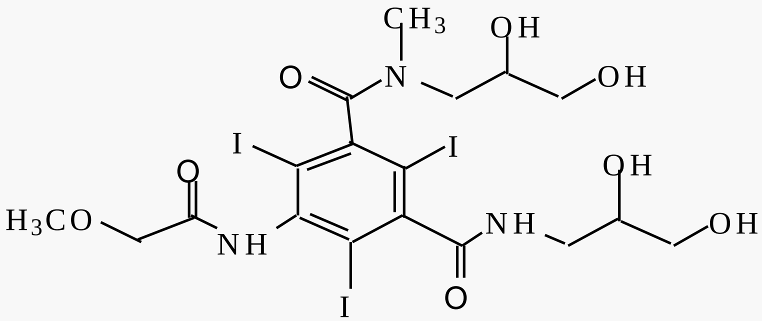
Emerging DBPs

- EPA Method 521 for nitrosamines (GC/MS/MS); sub-ng/L detection
- Also an LC/MS/MS method for 9 nitrosamines:
  Zhao, Boyd, Hrudey, Li, *Environ. Sci. Technol*. 2006, 40 (24): 7636-7641.
- NDMA and other nitrosamines on CCL-3 and UCMR-2

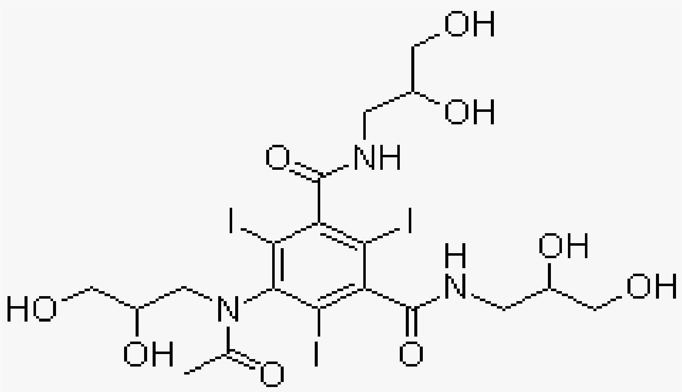
Iodinated X-ray Contrast Media (ICM)



Iopamidol

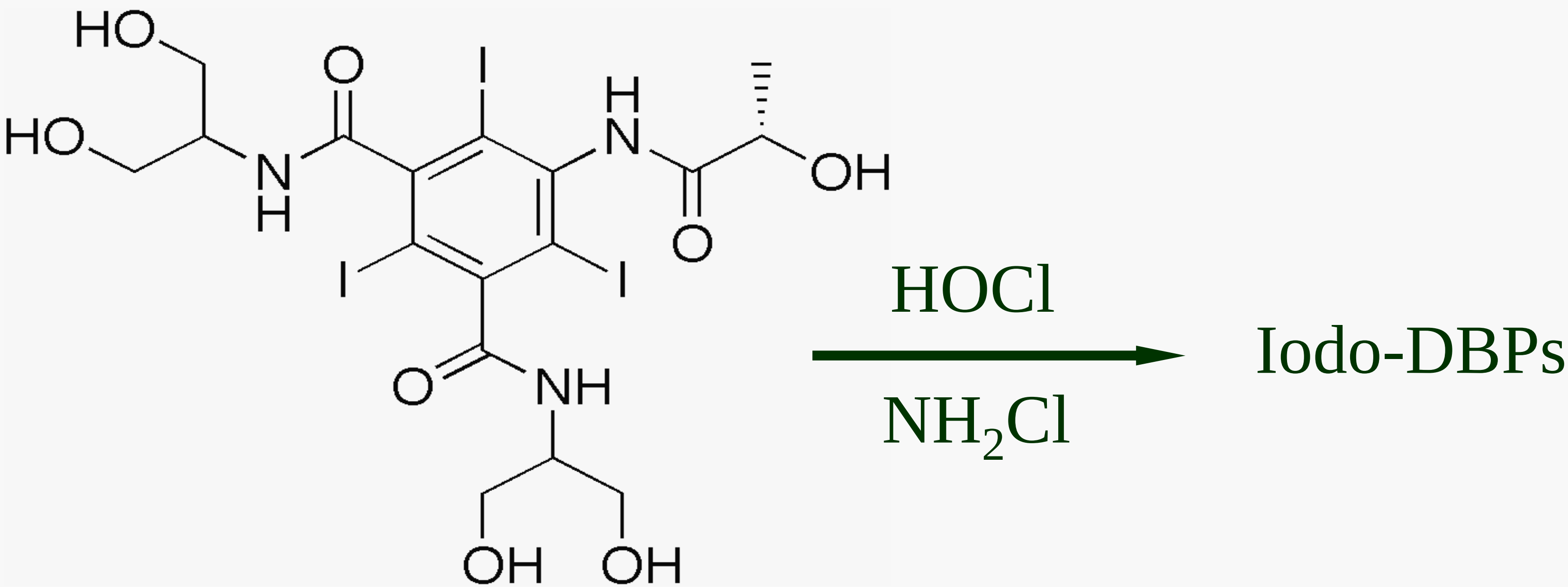


Iopromide



Iohexol

Iodinated X-Ray Contrast Media Transformation by Chlorine and Chloramines



Iopamidol

GC/EI-MS and GC/NCI-MS used to measure iodo-THMs and iodo-acids

LC/ESI-MS/MS used to measure disappearance of iopamidol

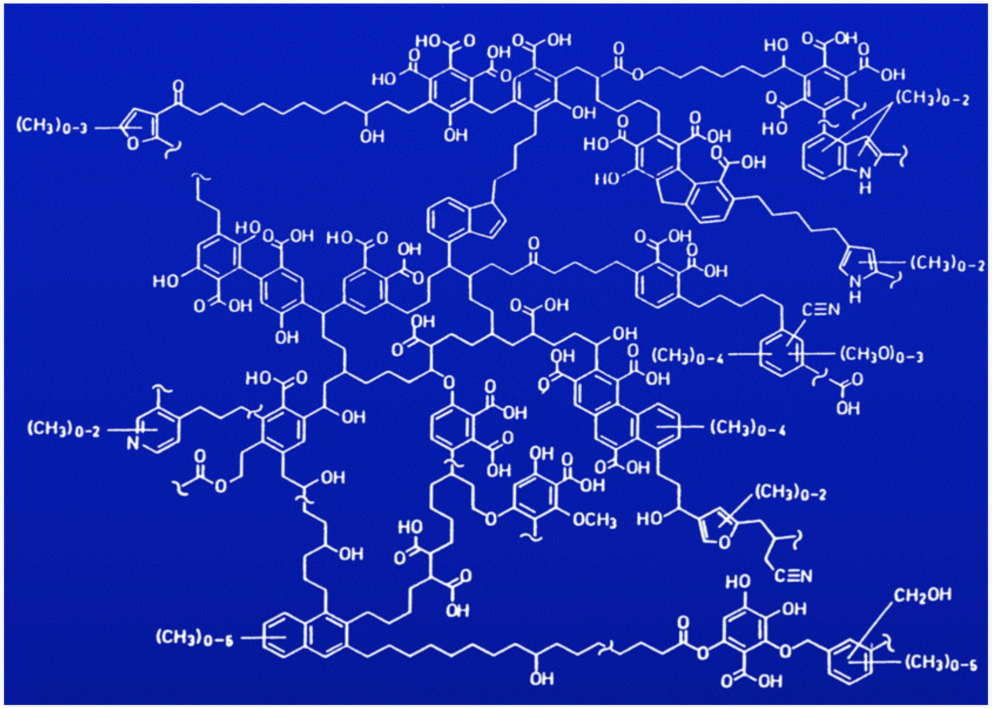
Iodo-DBP Occurrence Study

	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.

Typically, DBPs formed by reaction of disinfectants with NOM and Br/I



NOM

$$+\ I^- \xrightarrow[NH_2Cl]{HOCl} \text{Iodo-DBPs}$$

Iodo-DBP Occurrence Study

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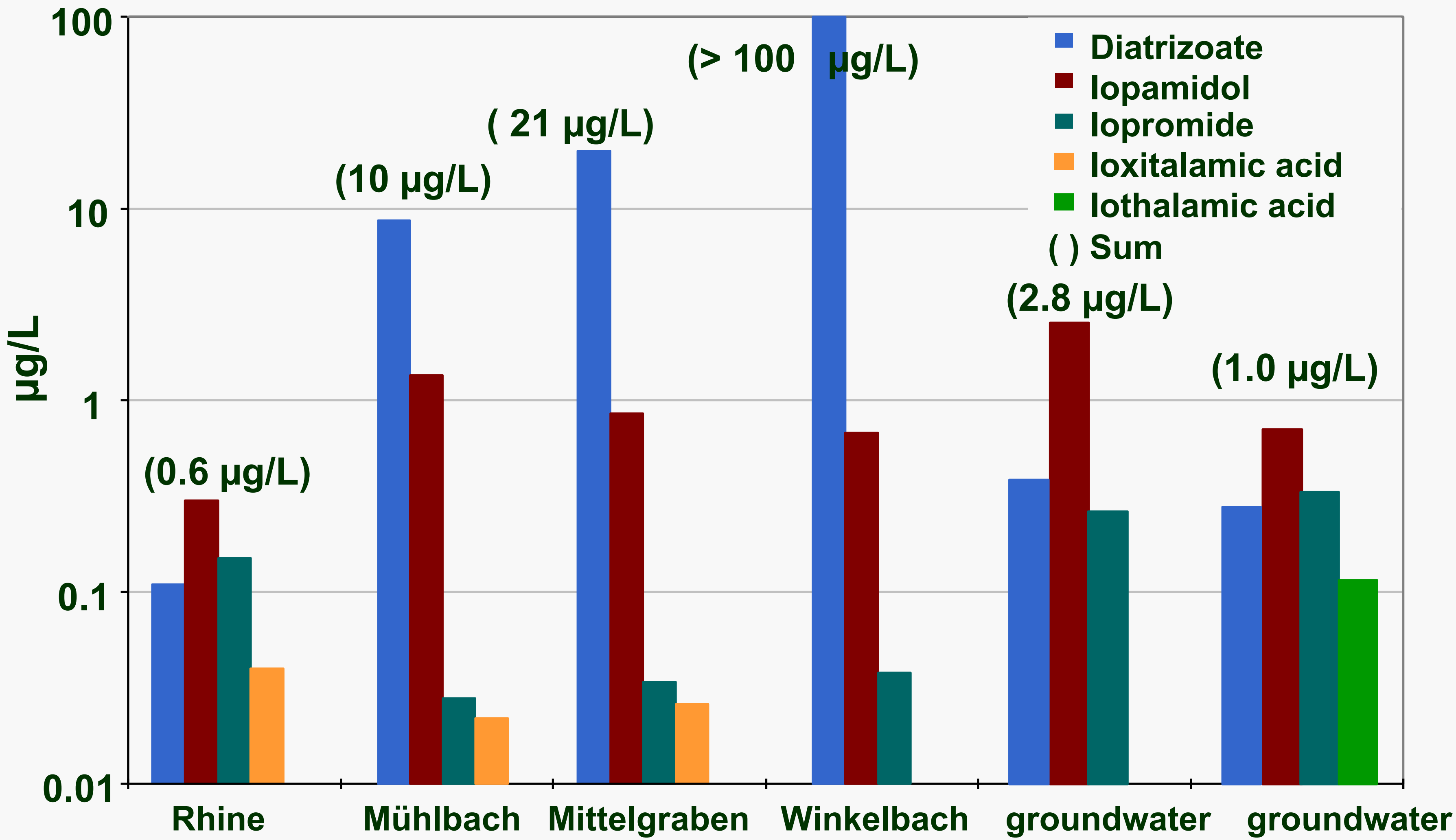
What about other sources of iodine?

ICM concentrations: rivers, creeks and ground water



Ternes & Hirsch, *Environ. Sci. Technol*. (2000) 34, 2741-2748

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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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

Pesticide Degradation Products

- May be more environmentally relevant than parent species (and some more toxic than parent)
- Previously overlooked
- Most highly polar; require LC/MS or LC/MS/MS
- Some on the CCL-3:
  - Alachlor ESA & OA
  - Acetochlor ESA & OA
  - Metolachlor ESA & OA

CCL-3: www.epa.gov/safewater/ccl

Perchlorate (ClO_4^-)

- On CCL-3
- Contaminant in groundwater, surface water, foods, milk
- Used in solid rocket propellants (rockets, missiles, fireworks); some natural sources (e.g., nitrate)
- Originally found in U.S.
  **now found in many countries

  El Aribi et al., Anal. Chim. Acta 2006, 567, 39-47.

  Present in almost all 350 food and beverage products measured from >50 countries
- Accumulates in plants
- Perchlorate affects thyroid function—which affects normal metabolism, growth, development

TAINTED **The Coachella Canal appears pristine as it branches off the All-American Canal in Southern California, but it carries perchlorate.** ***C&E News, 2003*****.**

CCL-3: www.epa.gov/safewater/ccl

Perchlorate (ClO_4^-)

Recent EPA Methods

- Developed to overcome matrix interferences in high ionic strength waters and to lower detection limits
- EPA Method 314.0: IC-conductivity (MRL 4 µg/L)
- EPA Method 330.0: IC/ESI-MS (MRL 0.02-0.05 µg/L)
- EPA Method 331.0: LC/ESI-MS/MS (MRL 0.02 µg/L)

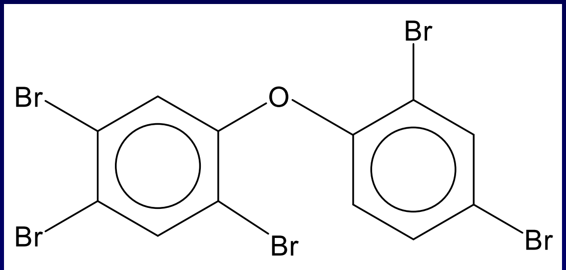
www.epa.gov/safewater/methods/sourcalt.hrml
www.epa.gov/nerlcwww/ordmethod.htm

CCL-3: www.epa.gov/safewater/ccl

Polybrominated diphenyl ethers (PBDEs) Flame Retardants

on the UCMR-2

www.epa.gov/ogwdw/ucmr



- Found in human samples—worldwide
- Potential adverse developmental effects, cancer
- Global production: 200,000 metric tons (most used in U.S. and Canada)
- Added to plastics, textiles, particularly furniture, consumer electronics
- Environmentally persistent; ubiquitous
- Octa- and penta- phased out in North America in 2004, but deca- still made
- EPA Method 527 (GC/MS; mid-ng/L detection limits)

  www.epa.gov/safewater/methods/analyticalmethods_ogwdw.html
- New method developed at EPA-RTP to measure 9 BDE congeners in dust samples (ASE-SPE cleanup-GC/NCI-MS; Maribel Colon, Walt Weathers et al.)

Algal Toxins

- Included on the new CCL-3
  (microcystin-LR, anatoxin-a, cylindrospermopsin)
- EU: guideline (0.1 µg/L)
- WHO: provisional guideline (1.0 µg/L)
  for microcystin-LR
- Responsible for large fish kills, poisoning of
  shellfish, illness in people

Examples:

- Microcystins, nodularins, saxitoxins, anatoxins, brevetoxins
- Some found in finished drinking water from Florida (2003)

CCL-3: www.epa.gov/safewater/ccl

Nanomaterials

- Big new area for research
- New initiative at U.S. EPA to study occurrence, fate, and health effects
- 1-100 nm in size; unique properties
- Examples: Fullerenes (C_{60}), zero-valent iron, TiO_2, nano-silver, functionalized fullerenes (in hollow spheres, ellipsoids, tubes), quantum dots, metal oxanes
- Already used in many consumer products (cosmetics, sunscreens, clothing, paints, tires, tennis rackets, lubricants, electronics, soaps, shampoos, detergents; zero-valent iron used to remediate groundwater)
- Many more products under development (e.g., medical diagnostics, cancer treatment)

EPA-Athens looking at fate & transport of fullerenes using LC/**APPI**-MS/MS (Carl Issacson and Dermont Bouchard)

Development of Genomic Indicators of Nanoparticle Exposure in Invertebrates

Helen Poynton, James Lazorchak, Christopher Impellitteri, Joel Allen, Mark Smith, and Katherine Hammer

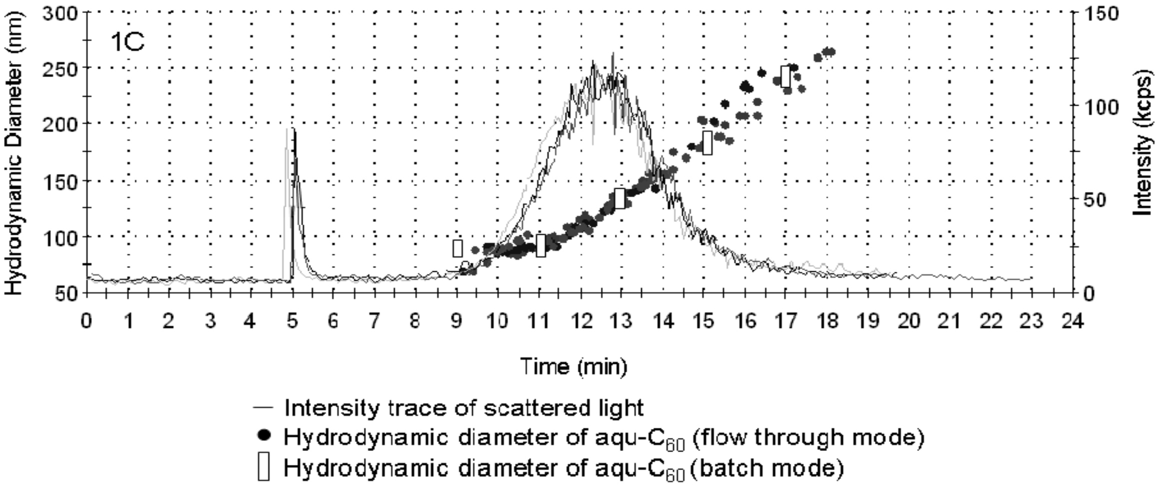
National Exposure Research Laboratory, National Risk Management Research Laboratory, The McConnell Group

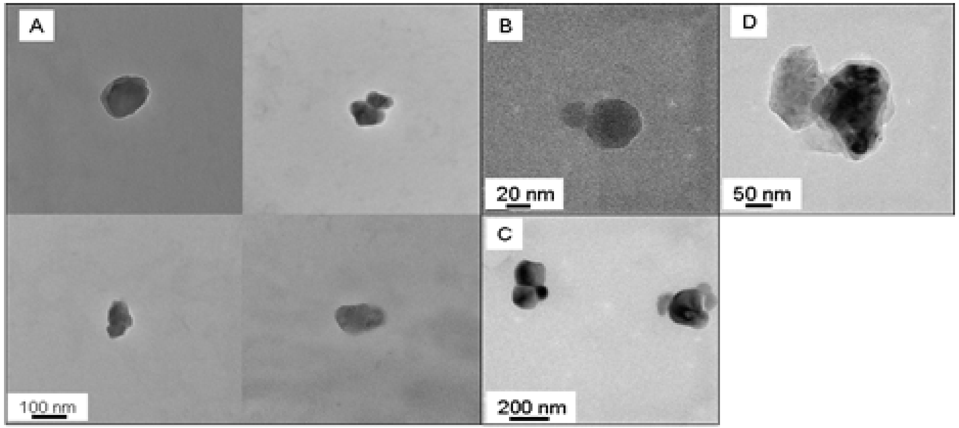
Developing biomarkers of exposure for ZnO and Ag nanoparticles to *D. magna*

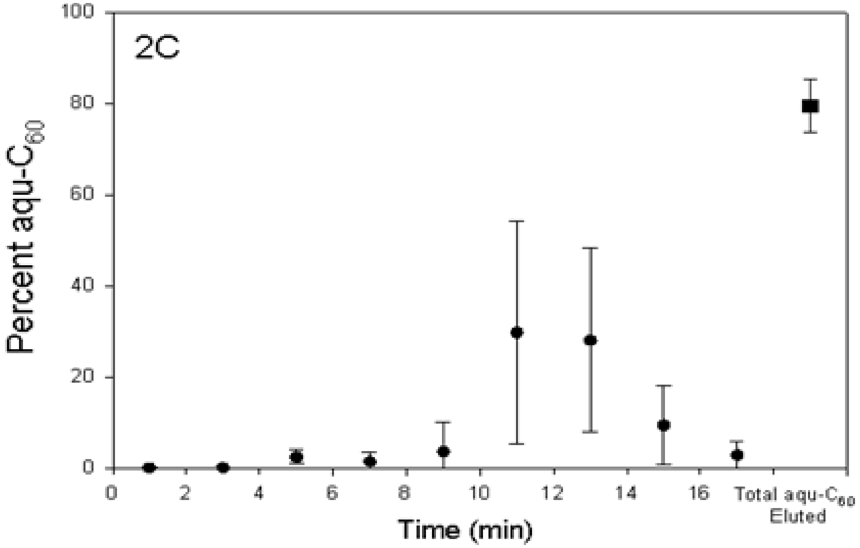
EPA-Athens looking at fate & transport of fullerenes

Characterization of Fullerenes with Asymmetric Flow Field-Flow Fractionation (AF4) and LC/MS

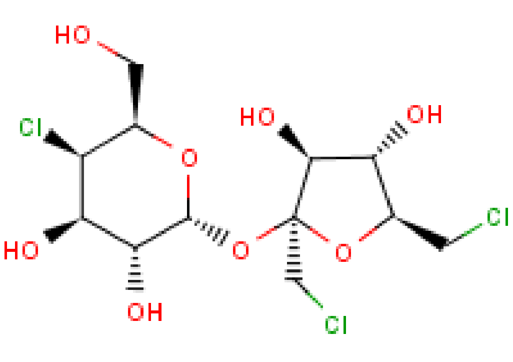
- Aqu/C_{60} aggregate ranged in size from 80-260 nm
- Mass of C60 determined in each fraction by LC/APPI-MS
- Mass balance of 77 ± 5.8 %
- Sizes corroborated by dynamic light scattering in batch mode and transmission electron microscopy
- Use of LC/MS important for specificity—to know which nanoparticles are being measured







Sucralose (Splenda) !



- Artificial sweetener; widely used
- Very stable (can bake with it)
- New publication:
  Loos et al., *J. Chromatogr., A* 2009, 1216, 1126-1131.

- Large European study (120 samples from 27 countries)
- Up to 1 µg/L in river waters
- Extremely persistent
- Predominantly in samples from UK, Belgium, the Netherlands, France, Switzerland, Spain, Italy, Norway, Sweden
- SPE-LC/negative ion-ESI-MS/MS method used
- Potential for ecological effects not known

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Jim Lazorchak

Thomas Ternes

Carl Isaacson