

Toxicologic Evaluation of Trihalomethanes (THMs)

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[Precursor material] + [Disinfectant] = [Disinfectant byproduct (DBP)]

[Organic matter] + [Chlorine] = [Trihalomethanes (THMs)]

Water Chlorination Process: Addition Points for Chlorine

- prechlorination of raw water (5 mg/l)
- after coagulation/before sedimentation (5 mg/l)
- after sedimentation/before filtration (5 mg/l)
- after treatment but before distribution (0.5-1 mg/l)
- during distribution (0.5-2 mg/l)
- during maintenance activities (up to 50 mg/l)

Chlorine added to Water



Hypochlorous acid / Hydrochloric acid (?Hypochlorite ions)



Reaction with Substances present in Raw Water:

Organic substances (humic & fulvic acids)

Algae, Aquatic plants

Bromide Ion

Inorganic reducing agents

Ammonia

Amino-nitrogen groups



Disinfection Byproducts (DBPs)

Major THM Species

- Chloroform
- Bromoform (tribromomethane)
- Bromodichloromethane (BDCM)
- Dibromochloromethane (DBCM; or chlorodibromomethane, CDBM)

Major Additional DBPs Formed

haloacetic acids

halo ketones

haloacetonitriles

chloral hydrate

chloropicrin

others

Factors Affecting DBP / THM Formation

Water Quality of Raw Water

- Total organic carbon levels
- Bromide levels
- pH (↑ pH, ↑ THM)
- Temperature
- Ammonia levels
- Carbonate alkalinity
- Season of year
- Location & changing conditions of source
- Distance from treatment plant
- Weather conditions

Treatment Conditions

- **Type of disinfectant**
- **Disinfectant dose**
- **Contact time**
- **Prior removal of organic matter**
- **Prior addition of disinfectants**
- **Combination/sequential disinfectant use**
- **Concentration of chlorine residual**
- **Residence and reaction times**
- **Changes in treatment practices over time**

Levels of THMs in Chlorinated Water (ug/l)

THM	Median	Maximum	Range
Chloroform	25	240	Not available
BDCM	9.5	90	1-50
DBCM	1.6	36	1-20
Bromoform	< 0.2	7.1	< 1-10
Total THMs	39	Not available	35-50

Population Daily Exposure Estimates for THMs from drinking water (ug/day)

THM	usual THM water levels	maximum THM water levels
BDCM	20	400
DBCM	7	600
Bromoform	7	600
Chloroform	Not available	Not available

Reduction in THMs After Boiling Water (ug/l)

THM	Before boiling	After boiling
Chloroform	45.6	9.4
BDCM	44.6	10.8
DBCM	42.3	12.3
Bromoform	35.9	13.5
Total THMs	38-104	7-21

Sources and Routes of Human Exposure to Tap Water (potential THM exposure)

- Drinking water (ingestion)
- Bathing (ingestion, inhalation, dermal)
- Showering (ingestion, inhalation, dermal)
- Swimming pool use (ingestion, inhalation, dermal)
- Foods & beverages (ingestion)
- Indoor air (inhalation – chloroform only)

Potential chloroform exposure levels from various exposure routes

Drinking water	9.6-69 ug/l
Shower/bath water	27-86 ug/l
Swimming pool water	3.04-365 ug/l
Shower air	0.4-186 ug/m ³
Indoor pool air	8-380 ug/m ³
Home indoor air	0.3-69 ug/m ³

THM levels in Foods and Beverages

THM	44 food & beverage samples (overall range)	15 bottled water samples (range for maximum values)
Chloroform	0-94 ng/g	Not available
Bromoform	0 ng/g	Not available
BDCM	12 ng/g	Not available
DBCm	2 ng/g	Not available
Total THMs	Not available	15-92 ppb

Levels of THMs in Human Exhaled and Alveolar Air (ug/m³)

Air measured	Total THMs	Chloroform	BDCM	DBCM	Bromoform
Exhaled air after showering	4.0-54	1-134	0.3-13	1-48	0.6-2.3
Exhaled air after swimming	720-1400	Not given	Not given	Not given	Not given
Alveolar air after swimming	9.3-94.1	Mean = 76.5	Mean = 6.5	Mean = 1.4	Not given

Median Human Blood Levels of THMs (pg/ml)

Source	BDCM	Chloroform	DBCM	Bromoform
Showering 10 minutes baseline	3.3	35	0.8	ND = Not detectable
10 min after exp	19.4	125	4.8	ND
30 min after exp	10.3	75	2.2	ND
Bathing 10 minutes baseline	2.3	25	0.7	ND
10 min after exp	17.0	115	3.9	ND
30 min after exp	9.9	80	2.3	ND
Ingesting 1 liter baseline	2.6	40	0.7	ND
10 min after exp	3.8	55	1.2	ND
60 min after exp	2.8	50	1.1	ND

Toxicokinetics Based on Animal Studies

- Absorption: rapid through oral and inhalation routes
- Distribution: highest concentrations in fat cells, liver, kidneys
- Metabolism: oxidation via cytochrome P450(CYP)2E1
- Excretion: via metabolism to carbon dioxide

Animal Toxicity Studies

critical effects: carcinogenicity, fetotoxicity

target organs: kidney, liver, colon, fetus

Problem: affected by administration route
(increased using oil gavage)

Tolerable Daily Intake (TDI) Estimates for some THMs based on No Observed Adverse Effect Levels and Uncertainty Factor of 1000 (WHO 2000)

THM	Estimate	Species	Dose
Chloroform	Lowest effect level for carcinogenicity	Mice	50 mg/kg/day
	NOAEL	Mice	10 mg/kg/day
	TDI	Humans	10 ug/kg
DBCM	NOAEL	Rats	30 mg/kg/day
	TDI	Humans	30 ug/kg
Bromoform	NOAEL	Rats	25 mg/kg/day
	TDI	Humans	25 ug/kg

Mutagenicity Study Results

Chloroform	Non-genotoxic; carcinogenic promoter
Bromodichloromethane	No consensus; conflicting/inconsistent
Dibromochloromethane	No consensus; conflicting/inconsistent
Bromoform	No consensus; conflicting/inconsistent

Cancer Epidemiologic Studies

Increased risk observed (generally < 2.0) for
bladder (most consistent), rectal, colon cancers

Problems with studies:

- Based on death records (biased due to higher survivorship for these sites)
- Exposure based on residence water source at time of death (does not allow for latency)
- No information on bottled water use, non-home water use, routes of exposure other than ingestion
- Other disinfection byproducts and mixtures not examined
- No information on many other potential confounders

Reproductive Epidemiologic Studies

- Increased risks (<2.0) for spontaneous abortion, stillbirth, preterm birth & (≤ 4.0) for some birth defects
- Exposure indices: water source and type of water treatment in general; routinely collected THM measurements; or THM and other DBP measurements with personal exposure information
- Problems: exposure to low and variable concentrations of THMs; exposure usually based on residence sources only and generally using only ingestion; all relevant potential confounders were not controlled; no controls for moving residence during pregnancy

IARC Carcinogenicity Classifications

BDCM	Group 2b	Possible human carcinogen
Chloroform	Group 2b	Possible human carcinogen
DBCM	Group 3	Not classifiable
Bromoform	Group 3	Not classifiable
Chlorinated drinking water	Group 3	Not classifiable

Issues in Human Exposure Assessment for THMs

- Presence of other DBPs
- Presence of other water contaminants
- Variations in THMs within and across supplies
- Different water usage patterns among individuals
- Various routes of uptake (ingestion, inhalation, dermal)
- THMs exist in other foods and beverages
- Water treatment practices change over time
- Drinking water is a complex mixture

Problems in dealing with drinking water as a complex mixture

- Thousands of chemicals in water (some with unknown composition and effects)
- Animal studies are based on one substance at a time administered at high doses – mixtures are generally not evaluated
- Lack of animal toxicity data using levels similar to real human exposure
- Uncertainty of mixture's effects: synergistic, antagonistic, or additive

Drinking Water Regulations

International standards for THMs vary
from 25-250 ug/l

USEPA current standard for total THMs:
100 ppm

USEPA future standard for total THMs:
80 ppm (beg. 12/01 for large facilities,
12/03 for small facilities)

Alternative water treatment processes

Disinfection alternatives

- Ozonation (produces other types of hazardous DBPs)
- Chloramination (produces THMs at lower levels & cyanogen chloride; generally only used as secondary disinfectant)
- Chlorine dioxide (produces chlorite & chlorate as DBPs)

New technologies being used/investigated:

- Membrane filtration
- Ultraviolet radiation
- Advanced oxidation
- Ion exchange
- Biological filtration

Methods for controlling THM levels in drinking water

- Ensure good quality raw water
- Control levels of precursors in raw water
- Reduce turbidity of raw water
- Minimize disinfection use and prechlorination
- Cease the use of break-point chlorination practices
- Modify disinfection practices

Alternatives in order of financial cost (lowest to highest

- Eliminate prechlorination practices
- Install ammonia feed system to provide chloramines as a secondary disinfectant
- Increase coagulant dose to improve precursor removal
- Switch to ozone/chloramines for disinfection
- Add granular activated carbon or membranes