BORIC ACID
TECHNICAL FACT SHEET

keywords:
organic, green, environmentally friendly, organophosphate, cockroach, pest control,

npic
NATIONAL PESTICIDE INFORMATION CENTER
1.800.858.7378

NPIC Technical Fact Sheets provide information that is complex and intended for individuals with a scientific background and/or familiarity with toxicology and risk assessment. This document is intended to promote informed decision-making. Please refer to the General Fact Sheet for less technical information.

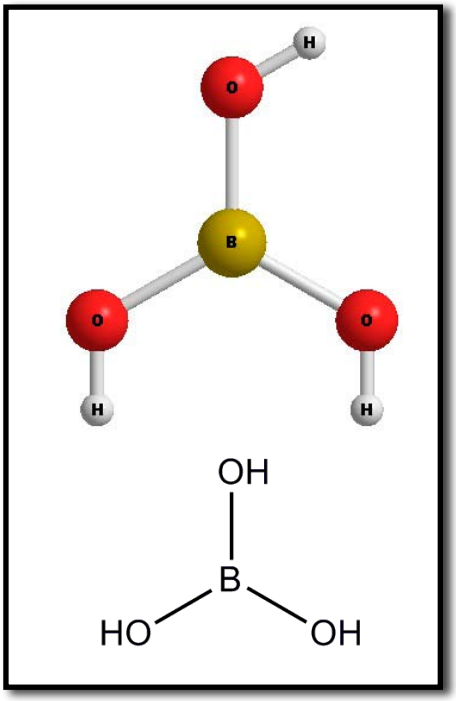
Chemical Class and Type:

- Boric acid and its sodium borate salts are active ingredients in pesticide products used as insecticides, acaricides, algaecides, herbicides, fungicides and as wood preservatives.[1]
- Boric acid and borate salts exist naturally in rocks, soil, plants and water as forms of the naturally occurring element boron.[2,3]

Laboratory Testing: Before pesticides are registered by the U.S. EPA, they must undergo laboratory testing for short-term (acute) and long-term (chronic) health effects. Laboratory animals are purposely given high enough doses to cause toxic effects. These tests help scientists judge how these chemicals might affect humans, domestic animals, and wildlife in cases of overexposure.

- Boric acid and borate salt pesticides were registered for use in 1948 and were reregistered by the United States Environmental Protection Agency (U.S. EPA) in 1993.[1] See the text box on **Laboratory Testing**.
- The borate salts include sodium tetraborate, disodium octaborate and sodium metaborate.[1] Both sodium tetraborate and disodium octaborate occur in several hydration states. Sodium tetraborate decahydrate is also known as borax.[1]

Molecular Structure - Boric Acid



Uses:

- Uses for individual boric acid and borate salt products vary widely. Boric acid and its sodium borate salts are active ingredients in pesticides used against insects, spiders, mites, algae, molds, fungi, and weeds.[1]
- Boric acid and borate salt products are used on a variety of sites including sewage systems, food and non-food crops, outdoor residential areas, and indoor sites such as homes, hospitals, and commercial buildings.[1,2]
- Commercial formulations of boric acid and borate salts include liquids (solutions, emulsifiable concentrates), granules, wettable powders, dusts, pellets, tablets, rods and baits in concentrations ranging from 1% to nearly 100%.[1]
- Signal words for products containing boric acid may range from Caution to Danger. The signal word reflects the combined toxicity of the active ingredient and other ingredients in the product. See the pesticide label on the product and refer to the NPIC fact sheets on ***Signal Words*** and ***Inert or "Other" Ingredients***.
- To find a list of products containing boric acid which are registered in your state, visit the website http://npic.orst.edu/reg/state_agencies.html and search by "active ingredient."
- In addition to pesticidal uses, boric acid and borate salts may be used as soil amendments in boron-deficient soils.[6] Boric acid, anhydrous sodium tetraborate and sodium tetraborate decahydrate (borax) are also used as components of plant fertilizers, household cleaners, laundry detergents and personal care products.[2]
- Boron is present in many foods and drinking water supplies. Estimated human consumption of boron in the U.S. diet ranges from 0.02 mg boron/day to more than 9 mg boron/day with an estimated average intake of 1.17 mg boron/day for men and 0.96 mg boron/day for women.[7] Recent evidence has suggested that boron may be an essential micronutrient.[7,8]
- Boric acid and borates are released into the environment by human activities including the use of borate salt laundry products, coal burning, power generation, chemical manufacturing, copper smelters, rockets, mining operations and industries using boron compounds in the manufacture of glass, fiberglass, porcelain enamel, ceramic glazes, metal alloys and fire retardants.[2,4]

Physical / Chemical Properties:

- The water solubility of boric acid and sodium tetraborate (all hydration states) increases at higher water temperatures.[4]
- Boric acid is a weak acid (pK_a = 9.15), existing in aqueous solutions at or below pH 7 as undissociated boric acid. Above pH 10 the metaborate anion dominates the solution.[3]
- Sodium metaborate is much higher in solubility and alkalinity than the other borates. Sodium metaborate solutions range in pH from 10.5 to 12, while borax solutions typically have a pH of about 9.24.[3]
- To convert doses of boron compounds to boron equivalents, multiply the dose by the compound's boron content in Table 1. For example, multiply the number of mg boric acid by 0.1748 to find the equivalent dose of boron in mg.[3]
- Table 1. Boric acid and its sodium salts[1,2,3,4,5]

Active Ingredient	CASRN	Molecular Formula	% Boron	Physical State	Vapor Pressure (Torr)	Molecular Weight	Solubility in Water (% w/w at 20 °C)	Octanol Water Coefficient (K_{OW})
Boric Acid	10043-35-3 11113-50-1 41685-84-1	H_3BO_3	17.48%	White or colorless solid crystalline powder	$<10^{-4}$ at 20 °C	61.83	4.72%	0.175
Sodium tetraborate decahydrate (borax)	1303-96-4 12447-40-4	$Na_2B_4O_7 \cdot 10\,H_2O$	11.34%	White or colorless crystalline powder	$<10^{-6}$	381.43	4.71%	0.175
Sodium tetraborate pentahydrate	11130-12-04 12178-04-3	$Na_2B_4O_7 \cdot 5\,H_2O$	14.85%	mild white alkaline salt	$<10^{-6}$	291.35	3.6%	No data
Sodium tetraborate anhydrous	1330-43-4 12007-42-0	$Na_2B_4O_7$	21.5%	Solid crystalline or amorphous	$<10^{-6}$	201.22	24.8%	No data
Disodium octaborate tetrahydrate	12008-41-2 12280-03-4	$Na_2B_8O_{13} \cdot 4\,H_2O$	20.96%	Powder	$<10^{-6}$	412.31	9.5% at 20 °C	No data
Disodium octaborate (anhydrous)	12008-41-2 12280-03-4	$Na_2B_8O_{13}$	25.83%	Solid rods	$<10^{-6}$	340.31		No data
Sodium metaborate	15293-77-3 7775-19-1	$NaBO_2$		Solid white pieces or powder	$<10^{-6}$	65.82	Soluble, no values reported	No data

Mode of Action:

Target Organisms

- Boric acid acts as a stomach poison and may also have some toxic effects on the nervous system of insects.[3,9] In addition to being stomach poisons, most borate salts are also abrasive to insect exoskeletons.[1] The effectiveness of boric acid dusts against insects is reduced when dust gets wet.[10]

- Boric acid, sodium tetraborate decahydrate, and disodium octaborate tetrahydrate are used to inhibit the growth of fungi by preventing the production of reproductive spores.[5]
- Boric acid and sodium tetraborate (all hydration states) can be used as herbicides, causing the desiccation of plants.[5] Sodium metaborate works as an herbicide by interrupting the plant's photosynthetic pathway.[5]

Non-target Organisms

- The mechanism of toxicity in animals is not known. Limited studies have suggested that oral boron exposure may play a role in altering gene expression, cell division and/or cell maturation rates.[1,2]

Acute Toxicity:

Oral

- The oral toxicity of boric acid and borate salts relates primarily to the amount of boron ingested as part of the parent compound.[11] Table 1 (page 2) lists the percent of boron in each borate compound that is currently registered as a pesticide.
- Boric acid and sodium tetraborate decahydrate (borax) are low in toxicity for acute oral exposures.[1] Because the other borate salts also exist as boric acid at physiological pH, it is assumed that their acute toxicities are similar.[1,11]

LD_{50}/LC_{50}: A common measure of acute toxicity is the lethal dose (LD_{50}) or lethal concentration (LC_{50}) that causes death (resulting from a single or limited exposure) in 50 percent of the treated animals. LD_{50} is generally expressed as the dose in milligrams (mg) of chemical per kilogram (kg) of body weight. LC_{50} is often expressed as mg of chemical per volume (e.g., liter (L)) of medium (i.e., air or water) the organism is exposed to. Chemicals are considered highly toxic when the LD_{50}/LC_{50} is small and practically non-toxic when the value is large. However, the LD_{50}/LC_{50} does not reflect any effects from long-term exposure (i.e., cancer, birth defects or reproductive toxicity) that may occur at levels below those that cause death.

- The US EPA considers boric acid to be low in acute toxicity based on studies in rats with an oral LD_{50} of 3450 mg/kg for male rats and 4080 mg/kg for female rats.[1] Sodium tetraborate decahydrate (borax) is also low in toxicity based on acute oral toxicity studies in rats with an LD_{50} of 4550 mg/kg for male rats and 4980 mg/kg for female rats.[1] For both compounds the most sensitive toxicological end points are testicular atrophy in males and developmental toxicity in pregnant females. Researchers observed skeletal abnormalities and decreased fetal weight in offspring at oral doses that caused no signs of toxicity to the mother.[1] See the text boxes on **Toxicity Classification** and **LD_{50}/LC_{50}**.

TOXICITY CLASSIFICATION - BORIC ACID

	High Toxicity	Moderate Toxicity	Low Toxicity	Very Low Toxicity
Acute Oral LD_{50}	Up to and including 50 mg/kg (≤ 50 mg/kg)	Greater than 50 through 500 mg/kg (> 50 – 500 mg/kg)	**Greater than 500 through 5000 mg/kg (> 500 – 5000 mg/kg)**	**Greater than 5000 mg/kg (> 5000 mg/kg)**
Inhalation LC_{50}	Up to and including 0.05 mg/l (≤ 0.05 mg/l)	Greater than 0.05 through 0.5 mg/l (>0.05 – 0.5 mg/l)	**Greater than 0.5 through 2.0 mg/l (> 0.5 – 2.0 mg/l)**	Greater than 2.0 mg/l (> 2.0 mg/l)
Dermal LD_{50}	Up to and including 200 mg/kg (≤ 200 mg/kg)	**Greater than 200 through 2000 mg/kg (> 200 - 2000 mg/kg)**	**Greater than 2000 through 5000 mg/kg (>2000 – 5000 mg/kg)**	Greater than 5000 mg/kg (> 5000 mg/kg)
Primary Eye Irritation	**Corrosive (irreversible destruction of ocular tissue) or corneal involvement or irritation persisting for more than 21 days (Borax)**	Corneal involvement or other eye irritation clearing in 8 – 21 days	**Corneal involvement or other eye irritation clearing in 7 days or less (Boric Acid)**	Minimal effects clearing in less than 24 hours
Primary Skin Irritation	Corrosive (tissue destruction into the dermis and/or scarring)	Severe irritation at 72 hours (severe erythema or edema)	Moderate irritation at 72 hours (moderate erythema)	**Mild or slight irritation at 72 hours (no irritation or erythema)**

The highlighted boxes relfect the values in the "Acute Toxicity" section of this fact sheet. Modeled after the U.S. Environmental Protection Agency, Office of Pesticide Programs, Label Review Manual, Chapter 7: Precautionary Labeling. http://www.epa.gov/oppfead1/labeling/lrm/chap-07.pdf

- The reported acute oral LD_{50} for boric acid in mice is 3450 mg/kg.[12] Studies in rats report LD_{50} values for boric acid ranging from 2660-5140 mg boric acid/kg body weight depending on the duration of exposure.[3,12,13] Acute oral LD_{50} for sodium tetraborate decahydrate (borax) in rats ranges from 3493 to 6080 mg borax/kg body weight.[2,3]
- Oral exposure studies in dogs reported LD_{50} values greater than 631 mg boric acid/kg body weight and greater than 974 mg borax/kg body weight, indicating that dogs may be more sensitive to these compounds than rats or mice.[1]
- A review of acute human exposures to boric acid indicated the effects of any particular dose can vary dramatically among individuals. The average dose for asymptomatic ingestion cases, which accounts for 88% of all ingestions, is around 0.9 grams. However, the range of reported asymptomatic doses is wide, from 0.01 to 88.8 g. The average dose causing symptoms was 3.2 grams, but it was also highly variable with individual values ranging from 0.1 to 55.5 g.[14]
- Minimum oral lethal doses of boric acid in humans have been estimated from accidental poisonings to be in the range of 5-20 g for adults, 3-6 g for children and <5 g for infants.[1,3]

Dermal

- Boric acid and sodium tetraborate decahydrate are both low in toxicity when applied to undamaged skin based on dermal LD_{50} >2000 mg/kg when applied to rabbit skin. The U.S. EPA classifies both active ingredients as low in dermal toxicity and neither are considered dermal irritants.[1]
- No information was found regarding the potential for boric acid or any pesticidal borate salts to cause skin sensitization.[1]
- No information was found on the dermal toxicity of any other borate salts used as pesticides.
- Boric acid is low in ocular toxicity.[1] Sodium tetraborate decahydrate (borax) is corrosive, as such it is highly toxic to the eye.[1]

Inhalation

- Boric acid and borate salts can be absorbed following inhalation exposure. However, it is unclear how much is absorbed directly and how much is actually ingested indirectly as a result of mucocillary activity.[4]
- Studies on the inhalation toxicity of boric acid and borate salts are extremely limited. Only one study was found involving rats inhaling a single 0.16 mg/L dose of boric acid. The LC_{50} is thought to be greater than 0.16 mg/L as no deaths were reported in the study. The U.S. EPA considers boric acid to be moderately toxic via inhalation until further studies are performed.[1] The U.S. EPA has required additional inhalation tests of boric acid to be conducted.[1]
- No animal studies on the acute inhalation toxicity of tetraborate decahydrate or any other borate pesticides were found.

Signs of Toxicity - Animals

- Ingestion of small amounts of boric acid or borate salts by animals has resulted in clinical signs that include excessive salivation, thirst, fever, vomiting, retching, depression, loss of appetite, diarrhea, and abdominal pain. The vomit or stools of exposed animals may contain blood or have a blue-green color.[15,16]
- The onset of clinical signs following boric acid or borate salt ingestions is usually within 2 hours.[16]
- Following ingestion of large amounts of boric acid or borate salts, animals have also shown signs of ataxia, tremors, seizures, decreased urination, and can develop reddish-violet colored skin. Suppressed growth, reproductive sterility and testicular degeneration in males have also been observed. Seizures from massive oral ingestions of boric acid can be followed by depression, metabolic acidosis, coma and death.[12,15,16]
- Signs reported in animals following the chronic ingestion of boric acid include anorexia, weight loss, vomiting, diarrhea, rashes, hair loss, anemia, kidney damage resulting in difficulties urinating and death.[15]
- Dermal exposure to borax has resulted in redness or inflammation of the skin.[16]

- Boric acid and disodium octaborate produce mild eye irritation but sodium tetraborate (borax) is highly irritating to the eyes.[11]
- Older animals or young animals may be more sensitive to boric acid and borate salts than adult animals.[15]

Signs of Toxicity – Humans

- Acute ingestion of boric acid or borate salts in humans has rarely led to severe toxicity. Commonly reported symptoms include nausea, vomiting (often with blue-green coloration), abdominal pain and diarrhea (which may contain blood or have a blue-green color). Other less commonly reported symptoms include headaches, lethargy, weakness, restlessness, tremors, unconsciousness, respiratory depression, kidney failure, shock and death.[14,17,18]
- Large oral exposures have resulted in an intense red skin rash within 24 hours of exposure, followed by skin loss in the affected area 1-2 days after the skin coloration first appears. These skin rashes typically affect the face, palms, soles, buttocks and scrotum.[17]
- Infants ingesting small amounts of boric acid in acute exposures displayed irritability, vomiting, erythema, exfoliation, diarrhea and nervous system affects.[11,19] Chronic exposure to borax in infants has led to seizures, vomiting and diarrhea.[11]
- People processing borax at work have reported temporary respiratory irritation including dry mouth, nose and throat, coughing, sore throat, shortness of breath and nose bleeds after exposure to airborne particles of sodium tetraborate decahydrate.[2,4] One such study found that a single 20 minute exposure to 10 mg sodium borate decahydrate/m^3 (0.7 mg boron/m^3) had no effect on workers, while another study found over a 6 hour shift, the lowest average concentration causing respiratory effects (LOAEL) was 5.72 mg particulate borax/m^3 (0.44 mg boron/m^3).[2] See the text box on **NOAEL, NOEL, LOAEL**, and **LOEL**.

NOAEL: No Observable Adverse Effect Level
NOEL: No Observed Effect Level
LOAEL: Lowest Observable Adverse Effect Level
LOEL: Lowest Observed Effect Level

- Employees working for more than five years around borax or boric acid dust found that exposure to 4.4 mg/m^3 of borax or more caused respiratory and nasal irritation. Other workers exposed to particulate boric acid reported respiratory and nasal irritation at concentrations less than 10 mg boric acid/m^3.[20]
- Always follow label instructions and take steps to minimize exposure. If any exposure occurs, be sure to follow the First Aid instructions on the product label carefully. For additional treatment advice, contact the Poison Control Center at 1-800-222-1222. If you wish to report an incident to the National Pesticide Information Center, please call 1-800-858-7378.

Chronic Toxicity:

Animals

- Chronic oral exposure studies with either boric acid or sodium tetraborate decahydrate (borax) yield similar toxicity values in studies performed in both dogs and rats. Long-term studies on oral exposure to these compounds in dogs has shown a NOAEL of 8.8 mg boron/kg-day with testicular atrophy and spermatogenic arrest being seen at the LOAEL of 29.2 mg boron/kg-day. In similar studies in rats, the NOAEL was found to be 17.5 mg boron/kg-day and testicular effects were noted at 17.5 mg boron/kg-day.[4,13]
- Mice exposed over their lifetime to 0.95 mg boron/kg-day as sodium metaborate in their drinking water had no changes to their body weight or life span when compared to control mice receiving deionized water.[4]

Humans

- Humans breathing sodium tetraborate decahydrate while employed at a borax processing plant have reported temporary respiratory irritation from exposures equal to or above 4.5 mg borax/m^3, but no chronic respiratory effects were found.[3]

- Chronic oral exposure to boric acid has resulted in symptoms that include vomiting, nausea, diarrhea, and stomach pain that are often followed by headache, fever, tremors, twitching, lethargy, and weakness as well as dermal erythema, desquamation and ulceration. Severe cases of chronic exposure have caused coma, seizures, circulatory collapse, liver and kidney dysfunction, anemia and death. Seizures and death are more commonly reported in infants chronically exposed to boric acid than adults.[11,21]

Endocrine Disruption:

- No studies were found on the endocrine disruption potential of boric acid, borate salts or boron in humans.
- Boric acid and borates are not currently on the list of compounds being screened by the U.S. EPA as part of the Endocrine Disruptor Screening Program (EDSP).[22]

Carcinogenicity:

Animals

- When mice were fed boric acid at doses of 0, 275, or 549 mg/kg/day (0, 48 or 96 mg/kg/day boron) for 2 years, no evidence of carcinogenicity was found.[1]
- Rats fed sodium tetraborate decahydrate (borax) for 2 years at doses of 0, 65, 154, or 515 mg/kg/day (0, 7.3, 17, or 58 mg boron/kg/day) showed no increases in tumor incidence at any dose tested.[1]

Humans

- Boric acid and borate salts are classified by the U.S. EPA as "not likely to be carcinogenic to humans" under the 2005 carcinogen assessment guidelines.[1]
- No data were found from occupational exposures or epidemiological studies indicating the carcinogenicity of boric acid, borate salts or boron.[2,3]
- Recent studies have shown that boric acid may have a protective role with regard to both prostate and breast cancer. Boric acid has been shown to inhibit the growth of human prostate and breast cancer cells, although the mechanism of growth inhibition is not understood.[23,24] See the text box on **Cancer**.

Cancer: Government agencies in the United States and abroad have developed programs to evaluate the potential for a chemical to cause cancer. Testing guidelines and classification systems vary. To learn more about the meaning of various cancer classification descriptors listed in this fact sheet, please visit the appropriate reference, or call NPIC.

Developmental Effects:

Animals

- In a study with pregnant rats exposed to boric acid in their diet, researchers found no maternal toxicity at 78 mg boric acid/kg-day (13.6 mg boron/kg-day) but offspring had decreased fetal body weights. Higher doses resulted in increased rates of skeletal malformations in offspring. Maternal animals showed changes in organ weights at 163 mg boric acid/kg-day (28.5 mg boron/kg-day). Follow-up studies in pregnant rats dosed with boric acid reported no effects in offspring at doses ranging from 55 – 74 mg boric acid/kg-day (9.6 – 12.9 mg boron/kg-day).[4,25,26,27]
- Mice exposed to boric acid in their diet during pregnancy were less sensitive to developmental toxicity than rats. The reported NOAEL in mice for both mothers and offspring was 248 mg boric acid/kg-day (43.4 mg boron/kg-day) with decreased fetal body weights occurring at the LOAEL of 452 mg boric acid/kg-day (79 mg boron/kg-day).[4,26]

- Developmental studies on pregnant rabbits reported a NOAEL of 125 mg boric acid/kg-day (21.9 mg boron/kg-day) with fetal malformations being noted after exposure to 250 mg boric acid/kg-day (43.7 mg boron/kg-day).[4,26,28]

Humans
- No data were found on the potential developmental effects of boric acid or borates in humans.

Reproductive Effects:

Animals
- The reproductive toxicity of boric acid and sodium tetraborate decahydrate (borax) has been studied extensively in animals including rats, mice, and dogs exposed to these borates in their diet. In both short and long-term reproductive studies, boric acid and borax have been found to act as reproductive toxins to males and females exposed to sufficient doses.[1,2,11,29,30]

- Studies in dogs have shown testicular atrophy and spermatogenic arrest at the LOAEL of 29.2 mg boron/kg-day. In similar studies in rats, testicular effects were noted at 17.5 mg boron/kg-day.[3,4,14]

- Male mice exposed to boric acid in their diet for 27 weeks showed degeneration of the seminiferous tubules, decreased sperm production and motility when exposed to doses above 27 mg boron/kg-day. When these animals were then mated with untreated females, they produced fewer live pups per litter than control mice. In another mouse study, testicular toxicity similar to that described above was noted in male mice at a dose of 288 mg boron/kg-day in the diet for 13 weeks.[2,30]

Humans
- Data from occupational exposures, accidental poisonings and epidemiological studies have not provided any conclusive information on the reproductive toxicity of boric acid in humans.[2]

Fate in the Body:

Absorption
- Studies in both humans and other animals has shown that the absorption of boric acid is rapid following oral exposure, with 81-95% of the boric acid absorbed within 24-96 hours of ingestion.[2] More than 98% of all forms of boron ingested (boric acid, sodium tetraborate, or boron in plant and animal tissues) are absorbed as undissociated boric acid.[31]

- Studies in humans and rabbits have shown that boric acid, borax and disodium octaborate tetrahydrate are poorly absorbed across intact skin. However, animals and humans with damaged skin, including those with psoriasis, eczema or urticaria (hives), can absorb significant amounts of boric acid.[4]

- When 5% boric acid or sodium tetraborate decahydrate (borax) or 10% disodium octaborate were applied to intact human skin for 24 hours, adsorption ranged from 0.12 – 9.23% of the applied dose, regardless of the form of boron applied. Using these figures, the authors estimated a human immersed in saturated boric acid solution for 24 hours would absorb less boron through their skin than is ingested on a daily basis in food and water.[32]

- Investigators evaluated infants 1-10 months old who received dermal applications of talcum powder containing 5% boric acid 7-10 times/day for at least one month for diaper rash. The calculated exposure dose for the infants was 2.33 g boric acid/day. Only trace amounts of boric acid penetrated the skin.[3,33]

- Workers inhaling dust from borate salts at concentrations ranging from 3.3 – 18 mg/m^3 (sodium tetraborate decahydrate, sodium tetraborate pentahydrate and anhydrous sodium tetraborate) showed increased urinary boron levels at the end of their work shift.[34] Rats inhaling 77 mg/m^3 of boron oxide (not a pesticide ingredient) also showed increased urinary boron levels suggesting the boric oxide was absorbed by the respiratory system.[35] However, in both studies the exposure may have included ingestion of boron compounds following mucociliary transport from the respiratory system.[4]

Distribution

- Boric acid and borate salts exist in the body as undissociated boric acid that is evenly distributed among all tissues except bone which can accumulate boron.[4,36]
- Rats fed 9000 ppm boric acid (93-96 mg boron/kg body weight/day) for up to 7 days distributed the boron fairly evenly between plasma, liver, kidney, muscle, colon, brain, testes, epididymis, seminal vesicles, prostate and adrenal glands (12-30 mg boron/kg tissue). Adipose tissues contained 20% less boron than plasma and other tissues, while 2-3 fold increases in boron were found in bone. Tissue concentrations peaked within 3-4 days while bone concentrations continued to increase for the duration of the study.[37]
- Rats fed boric acid at doses up to 9000 ppm in their diet for 9 weeks all accumulated boron in their bones. Boron levels in bone reached steady state concentrations four times greater than serum levels within 1-4 weeks, with higher doses requiring more time to achieve steady state. Bone boron concentrations remained three times higher than control animals 32 weeks after the cessation of treatment.[38]

Metabolism

- There is no evidence that boric acid is metabolized in plants or animals, perhaps due to the large amount of energy required to break the bond between the oxygen and elemental boron molecules in biological systems.[1,39]
- Borate salts convert to boric acid in mucosal tissues prior to absorption because of the pH of the overlying aqueous layer. In studies of humans and animals, over 90% of the inorganic borates occur as boric acid once absorbed.[3]
- Boric acid can attach to some biological molecules including hydroxyl, amino and thiol groups in a reversible but concentration-dependent fashion.[3,4]

Excretion

- Boric acid is rapidly excreted, primarily in the urine.[1] Approximately 89-98% of boric acid and inorganic borates were eliminated in the urine as boric acid over a 96-hour period.[3]
- Studies of excretion in humans ingesting boric acid indicated an average urinary elimination half-life of approximately 21 hours.[40] Case reports of accidental or intentional exposure to boric acid in humans have calculated urinary half-lives ranging from 4 to 28 hours.[14,19]
- Renal clearance rates for boric acid are approximately 4.9 times higher in rats than the clearance rates measured in humans. The renal clearance in pregnant rats was found to be 3.6 times higher than those measured in pregnant women.[4]
- The plasma half-life and renal clearance of boric acid has been studied in rats ingesting boric acid. In these studies, the plasma half-life of boric acid was estimated to be about three hours. None of the measured parameters differed significantly between pregnant and non-pregnant rats with low dose exposures. At high doses, pregnant females excreted more boron.[41]
- Humans ingesting boron as part of their normal diet excreted boron at rates that were similar in both pregnant and non-pregnant subjects. The rates ranged from 0.68-2.82 mg boron/day.[31]

Medical Tests and Monitoring:

- Boric acid and borate salt exposure can be measured as boron in the blood, tissue or urine of exposed individuals using high-temperature atomic spectrometric or colorimetric methods. However measured levels do not correlate well with any particular clinical manifestations.[17]

Environmental Fate:

Soil

- Boric acid and borate salts are present in soils throughout the earth's crust. Many of the naturally occurring minerals in the earth's crust contain boron, including sodium metaborate decahydrate (borax).[2,3] In soils, inorganic boron compounds can react with moisture to form borates.[2]
- Soil boron concentrations vary with soil type, organic matter and rainfall.[3] In the U.S., mean soil boron concentrations are 33 mg boron/kg soil. Levels range from less than 20 to over 300 mg boron/kg soil.[2]
- Boric acid's mobility in soil is a function of soil pH, with the greatest adsorption occurring at pH 7.5-9.0.[2] Other factors affecting soil mobility include the presence of aluminum or iron oxide in soils. Soil adsorption can be irreversible or not, depending on soil characteristics.[2,3] As such, soil-water partitioning coefficients (K_{oc}) must be determined experimentally for each soil type.[2]
- Boric acid and borate salts are soluble in water. They are removed from soils by leaching and uptake by plants.[2]

Water

- Boric acid and borate salts are soluble in water. Most boron will exist in aqueous solution as boric acid or borate ion.[2]
- Out of 1577 water samples collected from surface freshwater in the U.S., 97% contained boron ranging from 0.001 to 5 mg/L, with an average concentration of about 0.1 mg/L. Seawater boron concentrations tend to be much higher, averaging 4.5 mg/L.[5,42,43] Boron concentrations in drinking water have been reported as high as 3.28 mg/L.[2]
- Boric acid and borate salts may reach groundwater because of their relatively high water solubility and their variable soil sorption.[3]

Air

- The low volatility of boric acid and borates results in only small amounts these compounds being widely distributed in the Earth's atmosphere.[3]
- Particulate borates are expected to be removed from the atmosphere through precipitation and dry deposition.[2] Airborne borate particles are estimated to have an atmospheric half-life of a few days depending on the size of the particle and the atmospheric conditions.[2]
- There is no data to show that borates or boric acid are transformed or degraded in the atmosphere through photolysis, oxidation or hydrolysis.[2,3]

Plants

- Boron is an essential nutrient for plant growth, but too much boron is toxic to plants.[3,44] Symptoms of excess boron uptake include cessation of root and leaf growth and yellowing of the leaf tip. Bark splitting and necrosis at the tips of roots and leaves may also occur. Damage from excess boron can reduce the overall productivity of the plant and lead to death. However, plants have been shown to recover when soil boron is reduced.[3]
- Plant roots take up soil boron mainly as undissociated boric acid through active transport when soil boron levels are low. Passive diffusion occurs at higher soil boron levels. Boron is transported unchanged to the leaves where water evaporates, leaving the boron behind to accumulate in the leaves. Because boron is virtually immobile in the phloem of plants, little moves to other tissues, such as the stems and fruits.[3,45]
- In general, most vegetable crops are fairly tolerant of high concentrations of boron in soils or irrigation water. However, tuber and cereals crops are considered semi-tolerant. Citrus, stone fruits and nut trees are most sensitive to boron.[3]
- Sodium metaborate acts as a non-selective herbicide that can inhibit plant growth in treated soils for a year or more.[5]

Indoor

- No data were found on the indoor fate of boric acid or borate salts.

Food Residue

- Boron exists naturally in edible plants. Boric acid and sodium borate salts are exempt from the requirement of a tolerance when used on agricultural crops. Residues present at the time of harvest are expected to be relatively small compared to naturally occurring boron compounds in the food items.[1,5,46,45]
- The naturally occurring boron found in plants varies with the crop but tends to be highest in fruits and nuts. For example, pears and strawberries have been found to contain about 160 ppm boron, and red cabbage has been reported to have residues as high as 200-300 ppm boron.[5] Peanut butter has been found to contain about 15 ppm boron, avocados about 11 ppm, grapes about 5 ppm, and bananas about 1 ppm.[1]
- The average daily dietary boron intake in the United States varies, but is generally thought to be in the range of 0.5 to 3.1 mg/day (0.007 – 0.044 mg/kg/day). The FDA estimates an average boron intake of 1.52 mg/day(0.025 mg/kg/day) for adult males.[1]

Ecotoxicity Studies:

Birds

- Studies in both Bobwhite quail (*Colinus virginianus*) and Mallard ducks (*Anas platyrhynchos*) have indicated that boric acid is very low in toxicity to birds.[5]
- The acute LD_{50} for bobwhite quail exposed to boric acid is greater than 2510 mg/kg. The dietary LC_{50} for boric acid in the feed of Bobwhite quail was found to be greater than 10,000 ppm.[5]
- Dietary intake of boric acid may adversely affect the reproduction and development of birds. Mallards exposed to 30 mg boron/kg body weight (as boric acid) had ducklings with reduced growth rates. Higher concentrations in the range of 100-400 mg boron/kg body weight resulted in increased duckling mortality, altered behavior, and decreased growth and hatching success.[47,48]

Fish and Aquatic Life

- Short-term exposure studies (24-hours) in rainbow trout (*Oncorhynchus mykiss*) have reported LC_{50} values of 65-88 mg Boron/L when exposed to borax, and 100-150 mg boron/L when exposed to boric acid.[3]
- Bluegill fish (*Lepomis macrochirus*) were the most sensitive in acute studies with a 24-hour LD_{50} equal to 41 mg borax/L (4.6 mg boron/L). Mosquitofish (*Gambusia affenis*) were the least sensitive with 24-hour LC_{50} values of 12,002 mg borax/L (1361 mg boron/L) and 17998 mg boric acid/L (3146 mg boron/L).[3]
- Among several species of fish that were exposed to boric acid or borate salts on a chronic basis, LC_{50}s ranged from 12.2 to 235 mg boron/L. Based on these results, the World Health Organization (WHO) determined that none of the tested species were especially sensitive to boron.[3]
- The concentration of borates in water shown to inhibit the growth of single-celled organisms varies dramatically. No effects were noted in bacteria (*Pseudomonas putida*) exposed to 291 mg boron/L for 72 hours in one study. However, in another study with the same species, growth was inhibited at doses as low as 7.6 mg boron/L.[3]
- Borax has been shown to inhibit the growth of green algae (*Chlorella vulgaris*) over 3-4 months when concentrations in water were at or above 10.6 mg borax/L (1.2 mg boron/L).[3]
- Boric acid and borate salts have been shown to be toxic to aquatic crustaceans (*Daphnia magna*) exposed to concentrations above 54 mg boron/L for two days. Forty-eight hour LC_{50} values ranged from 133-226 mg boron/L. In longer-term exposures over 21 days, *Daphnia magna* had decreased reporductive success when exposed to boric acid at doses above 13.6 mg boron/L.[3]

- The 24-hour NOAEL for aquatic worms (*Tubifex* sp.) was estimated to be 750 mg borax/L (85 mg boron/L) and 7500 mg boric acid/L (1311 mg boron/L).[3]
- Boric acid has been shown to be toxic to frogs and toads with reported LC_{50} values ranging from 704 – 847 mg boric acid/L (123-148 mg boron/L) depending on the age and species tested. Similar studies have found borax to be slightly higher in toxicity than boric acid to frogs and toads with LD_{50} values ranging from 414-529 mg borax/L (47-60 mg boron/L).[3]

Terrestrial Invertebrates

- Boric acid is low in toxicity to bees. Syrup containing 50 mg/L boric acid fed to bees had no effect on bee survival (NOAEL) but syrup containing 100 mg/L boric acid was lethal to 50% of the bees tested.[3]
- The U.S. EPA reported a contact LD_{50} of greater than 362 ppm and classified boric acid as "relatively nontoxic" to bees.[5]
- Cockroaches exposed to sub-lethal amounts of boric acid may produce more allergens than non-exposed roaches.[49]

Regulatory Guidelines:

- The cancer classification of boric acid is "not likely to be carcinogenic to humans".[1] See the text box on **Cancer** (page 6).
- The U.S. EPA has set the reference dose (RfD) for boron compounds at 0.2 mg boron/kg/day.[20] No RfC could be determined due to the lack of adequate data.[1,4,20] See the text box on **Reference Dose (RfD)**.

Reference Dose (RfD): The RfD is an estimate of the quantity of chemical that a person could be exposed to every day for the rest of their life with no appreciable risk of adverse health effects. The reference dose is typically measured in milligrams (mg) of chemical per kilogram (kg) of body weight per day.

U.S. Environmental Protection Agency, Technology Transfer Network, Air Toxics Health Effects Glossary, 2009. http://www.epa.gov/ttnatw01/hlthef/hapglossaryrev.html#RfD

- A 12-hour Restricted Entry Interval (REI) has been established under the Worker Protection Standard (WPS) to protect workers following agricultural applications of boric acid and borate salts.[5]
- Boric acid and borates were evaluated as potential drinking water contaminants and the U.S. EPA determined there was no need to develop primary drinking water standards for boron compounds.[50] The Health Advisory level (HA) for a 10 kg child is 4 mg boron/L for one-day exposures and 0.9 mg boron/L for 10-day exposures. The drinking water equivalent level (DWEL) is 7 mg boron/L.[2]
- For occupational exposures to inorganic borates, the Threshold Limit Value (TLV) has been established at 2 mg/m^3 for exposures that could occur eight hours each day, five days each week for a lifetime. For exposures that are likely to last about 15 minutes, the TLV is higher at 6 mg/m^3.[51]
- The Recommended Exposure Limits (REL) for exposures over a 40-hour workweek are 1 mg sodium tetraborate (anhydrous)/m^3 and 5 mg borax/m^3.[52]
- Boric acid and borate salts are exempt from the requirement of a tolerance under CFR 180.1121.[1] No maximum residue levels (MRLs) have been established for boric acid or borates in foods.
- The tolerable daily intake (TDI) estimated by the National Academy of Sciences Food and Nutrition Board is 0.32 mg/kg/day, whereas the TDI estimated by the World Health Organization (WHO) is 0.4 mg/kg/day.[1]

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