MEMORANDUM

LEGISLATIVE REFERENCE BUREAU

WWW.MILWAUKEE.GOV/LRB

To: Ald. James A. Bohl, Jr.
From: Tea Norfolk, Legislative Fiscal Analyst – Lead
Date: September 26, 2016
Subject: Neurological and other health effects of lead and contaminants in water

This memo is in response to your request to provide information regarding the neurological effects of the following substances in drinking water:

- Lead
- Chlorine
- Copper
- Fluoride

Lead

From the time Romans built the aqueducts, lead has been known to have neurotoxic effects, such as behavioral problems and learning and memory impairments. It damages the brain and peripheral nerves, which connect the brain and spinal cord to the rest of the body.

The primary concern for lead exposure is in children, whose developing brains are more vulnerable to toxic effects of lead exposure than those of adults. The detrimental effects of lead occur at lower levels in children than they do for adults exposed to lead. According to the Centers for Disease Control (CDC), the effects in children include: ataxia (lack of voluntary coordination of muscle movements), attention deficit hyperactivity disorder (ADHD), balance, coma, convulsions, death, encephalopathy (overall brain dysfunction), hearing impairment, hyperirritability, muscle coordination and weakness, muscle and bone development and growth, peripheral nerve function, sense of touch, stupor, synapse formation, and transmission of signals from one location to the next.

According to a study published in the Oxford Journals' Toxicological Sciences (Pabello, Nina G. and Valerie J. Bolifar. "Young Brains on Lead: Adult Neurological Consequences?" Volume 86, Issue 2, June 9, 2005, pp. 211-13), additional effects of lead include apoptosis (programmed cell death), excitotoxicity (nerve cells are damaged or killed by excessive stimulation by neurotransmitters), interference with neurotransmitter storage and release mechanisms, alterations in second messengers, damage to mitochondria, reduced viability of newly generated neurons, and glutamatergic transmission, which is a major player in development and neuronal plasticity and relates to memory impairment. Additionally, lead exposure influences mood, anxiety, and violence / aggression. Lead has been associated with the

development of neurodegenerative diseases later in life, such as Alzheimer's, Parkinson's, and possibly Schizophrenia.

According to one study by Anjali Patel ("How Does Lead Effect the Nervous System?"), lead's ability to substitute for calcium is a factor in its toxic actions because calcium ions help to convert the electrical pulse into a chemical signal. Cells absorb lead through the same channels from which they absorb calcium; accordingly, lead interferes with this electrochemical process. High levels of lead decrease transport of calcium and vice versa, therefore, these two elements function as competitive inhibitors. Lead can enter through the same ion channels as calcium and regulate the activity of those channels to uptake more lead into the cell. Additionally, a child's brain has more synapses than an adult brain, and it is patterned according to the stimuli received during development. If neural activity increases as a result of lead exposure, the development process can be inhibited. This can lead to permanent effects on synaptic anatomy and brain function. It is believed that this is one of the causes of learning and behavioral problems that occur in children. Additional effects of lead include interference on protein kinase C and an increase in the permeability of the blood-brain barrier (BBB), which can allow larger molecules to enter the brain and increase intracranial pressure. Neurological effects in children may begin at low blood lead levels (BPb), at or below 10 micrograms per deciliter (µg/dL). The CDC cites studies that have found that for every 10 µg/dL increase in BPb, children's IQ was found to be lower by 4 to 7 points.

According to the CDC, even without encephalopathy symptoms, lead exposure is associated with increased incidences of lasting neurological and behavioral damage. Some researchers have suggested that lead continues to contribute significantly to socio-behavior problems such as juvenile delinquency and violent crime. According to the National Institutes of Health (NIH), increased blood lead levels before birth and during early childhood were associated with higher rates of arrest for any reason and for violent crimes. For example, for every 5 µg/dL increase in BPb at 6 years of age, the risk of being arrested for a violent crime as a young adult increased by almost 50%. Due to the both the public health risk and the safety risk to the public, it is important to prevent all lead exposure.

According to the National Institutes of Health (NIH), lead exposure continues to be a major public health problem, particularly in urban centers in the United States. The developmental effects of lead occur during a critical time window, at 2 years of age and younger. Low-level exposure in early childhood has been shown to be inversely associated with neuropsychological development through the first 7 years of life. Additionally, an increase in lead level in breast milk with increasing maternal BPb poses an additional risk to newborn infants.

The NIH cites a study that examined 2 male cousins who were living in the same household. One subject had elevated BPb and the other did not. A comprehensive neuropsychological evaluation revealed difficulties in reading, writing, linguistics, attention, and arithmetic for the lead-exposed child. Additionally, NIH cites another study of adults who grew up around a smelter. The lead-exposed group had poorer

performance on tasks of abstract reasoning, cognitive flexibility, verbal memory, verbal fluency, and fine motor speed as compared to a control group. Dementia, loss of visual acuity, and peripheral neuropathy were also more prevalent.

Although the primary concern for lead exposure in children is neurological, lead exposure can also lead to additional health effects later in life, such as renal problems, hypertension, reproductive difficulties, and developmental issues with offspring. Lead can also affect the following systems: blood, endocrine, gastrointestinal, cardiovascular, and skeletal. Lead is absorbed and stored in bones, blood, and tissue and becomes a source of continual internal exposure. As the human body ages, bones demineralize and internal exposure increases as a result of larger releases of lead from bone tissue. Because of the way lead operates in the skeletal system, post-menopausal women have been found to have higher BPb than pre-menopausal women.

Lead exposure can negatively impact pregnancy outcomes, including premature birth, low birth weight, congenital abnormalities, and post-birth effects on growth and neurological development. Lead readily crosses the placenta and can adversely affect fetus viability as well as fetal and early childhood development. In addition, a retrospective study has shown a higher proportion of learning disabilities among school-aged children whose biological parents were lead-poisoned themselves as children 50 years prior.

In adults, neurological effects of lead include decreased libido, depression / mood changes, diminished cognitive performance, diminished hand dexterity, diminished reaction time, diminished visual motor performance, dizziness, dullness, fatigue, forgetfulness, headache, high blood pressure, impaired concentration, impotence, increased nervousness, irritability, lethargy, loss of memory, malaise, muscular tremor, paresthesia (prickling or tingling sensation), peripheral nerve function, poor attention span, postural balance, reduced IQ scores, slowed nerve function, forearm extensor weakness (wrist drop), and weakness.

Lead poisoning can happen if a person is exposed to very high levels over a short period of time. Symptoms include: abdominal pain, constipation, depression, distraction, fatigue, headache, irritability, loss of appetite, memory loss, nausea, pain or tingling in the hands and/or feet, and weakness.

The World Health Organization (WHO) notes that lead is a cumulative toxicant, which means it does not get eliminated from the body through normal bodily functions. The effects are irreversible. While there is no known safe blood lead concentration, as lead exposure increases, the range and severity of symptoms and effects does as well. Even BPb as low as 5 µg/dl may result in decreased intelligence in children and behavioral difficulties and learning problems.

Chlorine

The main danger of chlorine, according to the NIH, is from inhalation. According to one study cited by the NIH, subjects exposed to undiluted chlorine had impaired balance, delayed simple and choice reaction times, impaired color discrimination, impaired visual field performance, decreased hearing, decreased grip strength, delayed blink reflex, diminished cognitive performance, diminished verbal recall, elevated adverse mood states, reduced vital capacities, and impaired neurophysiologic and neuropscyhologic functions. These effects were noted one to 48 months after exposure and persisted. These effects are likely the reason chlorine gas has been used as a chemical warfare agent, as noted by the CDC.

According to the CDC, infants born to mothers residing in areas where surface water was disinfected with chlorine had smaller cranial circumference than those residing in areas with untreated well water. Additionally, neonatal jaundice occurred more frequently.

According to the New York State Department of Health, the health effects of chlorine are primarily due to its corrosive properties. The oxidizing effect of chlorine produces corrosive tissue damage and destroys cell structure. Ingestion of chlorine can cause corrosive tissue damage of the gastrointestinal tract.

Children may be more susceptible than adults to the health effects of chlorine, but the damage may not be evident until a later stage of development, according to the CDC. Neurodevelopmental delays and postnatal changes in serum thyroid hormone levels have been observed in animals following exposure of their mothers to chlorine dioxide or chlorite during gestation and/or lactation.

In addition to the health effects of chlorine and corrosiveness on bodily tissues, chlorine's corrosive properties have been found to leach lead from pipes into water, according to the American Society of Civil Engineers (ASCE). However, one study conducted by ASCE also revealed that chloramines were more likely to result in lead release from pipes than free chlorine, which the study found to not be as corrosive. In the study, lead solder provided the only source of lead in a system with pipe loops and copper pipe rigs. The water quality of the treated water had a low alkalinity, neutral pH, and low hardness. Additionally, the study used a corrosion control program that consisted of dosing with zinc orthophosphate.

In a study conducted by the Midwest Technology Assistance Center (MTAC), the researcher concluded that chlorine was of little importance to the galvanic corrosion process in lead pipes. (Cantor, Abigail F., et. al. "The Effect of Chlorine on Corrosion in Drinking Water Systems". November, 2000.) However, chlorine appeared to increase the corrosivity of water in copper pipes. Additionally, phosphate further increased the corrosivity by the end of a year of operation. Several researchers dislike adding phosphorus to the water system, as it stimulates microbial counts, which can increase corrosion in a water system.

Copper

According to the CDC, one study reported neurological effects from acute copper dust exposure as including headache, vertigo, and drowsiness. Other effects from copper include respiratory, hepatic, endocrine, and ocular effects. Children and infants exposed to excess levels of copper, at approximately 30 times higher than the dietary requirement for copper, have suffered liver damage. Idiopathic copper toxicosis has been linked to exposure to high levels of copper in drinking water.

According to the National Academies Press, acute copper toxicosis is manifested by hemolysis (rupture of red blood cells), headache, febrile reactions (fever), prostration (placing body in a prone position), and gastrointestinal symptoms. One child was observed to have these symptoms after a solution containing copper sulfate was applied to burned skin during a debridement procedure.

Fluoride

The neurotoxicity and corrosive effects of fluoride are controversial.

According to the CDC, “the concern that using fluorosilicate additives to fluoridate drinking water causes water system pipes to corrode is not supported by science.” The most common forms of fluoride for approximately 92% of the drinking water comes as either fluorosilicic acid or sodium fluorosilicate.

On the other hand, the National Academy of Sciences (NAS) has published a 2012 study by a group of Harvard scientists and researchers linking low levels of fluoride in drinking water with decreased thyroid function and depressed childhood IQ. Philippe Grandjean, adjunct professor of environmental health at Harvard School of Public Health, has stated that fluoride is in the same class as lead and mercury with respect to causing chemical “brain drain.” He noted that the effect of each toxicant may seem small, but that the combined damage on a population scale can be serious. Additionally, Grandjean noted that fluoride acts topically and need not be ingested for its dental benefits.

In 2006, the National Research Council (NRC) stated that “it is apparent that fluorides have the ability to interfere with the functions of the brain.” In addition to calling for U.S.-based research on fluoride’s IQ effects, the NRC expressed concern about fluoride’s possible contribution to dementia. According to the NRC: “Studies of populations exposed to different concentrations of fluoride should be undertaken to evaluate neurochemical changes that may be associated with dementia. Consideration should be given to assessing effects from chronic exposure, effects that might be delayed or occur late-in-life, and individual susceptibility.”

In 2011, the U.S. Department of Health and Human Services (DHHS) called for a 40% reduction in maximum fluoridation levels, pursuant to the findings in the NAS report. The CDC and the American Dental Association (ADA) has stated that mixing infant

formula with fluoridated water puts infants at risk of excessive fluoride intake. Dr. Hardy Limeback, DDS, a member of NAS Committee on Fluoride and former head of Preventive Dentistry at the University of Toronto, has identified risks of excessive fluoridation as including impaired brain and endocrine functions.

According to an NRC study, researchers noted that rats exposed to fluoride exhibited histopathological (microscopic tissue) changes similar to those traditionally associated with Alzheimer's. Additionally, links to diminished reasoning capabilities, problem-solving, IQ, and short-term and long-term memory were found as was a connection to dementia.

In a news story reporting on Israel's ban on fluoridation, Newsweek reported that high levels of fluoride can cause pitted teeth, bone defects, and thyroid problems. The story also cited to a study published in the medical journal The Lancet, which labeled fluoride as a developmental neurotoxin due to a link between high levels of exposure and reduced IQ in children. The study in The Lancet identified several industrial chemicals as neurotoxicants, including lead and fluoride, and noted that a fetus is not well protected against industrial chemicals, including fluoride. The placenta does not block the passage of these environmental toxicants from maternal to fetal circulation. An analysis of 27 cross-sectional studies of children exposed to fluoride in drinking water in China suggested an average IQ decrease of about seven points in children exposed to elevated fluoride concentrations.

A 2006 report from the National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council noted that the EPA's drinking water standard for fluoride at the time (4 milligrams per liter (mg/L) of water) did not protect against the adverse health effects of fluoride. The report concluded that not only were children at risk of severe tooth enamel fluorosis, which causes tooth enamel loss and pitting, but that people who drink water containing 4 mg/L or more of fluoride over a lifetime are likely at increased risk for bone fractures. Children and infants experience 3 to 4 times greater exposure to fluoride than adults due to their bodyweight. Even at 2 mg/L of fluoride, the risk of moderate enamel fluorosis is increased. While skeletal fluorosis is uncommon, fracture risks are present from increased fluoride intake.

According to the National Center for Biotechnology Information, U.S. National Library of Medicine / National Institutes of Health (NIH), fluoride additives in water fluoridation are a potential vehicle for metal ingestion of cadmium, arsenic, lead, chromium, mercury, nickel, uranium, and other metals. Data from 2000 to 2006 and 2007 to 2011 showed detectable levels of up to 13 metal contaminants in finished drinking water samples as a result of water fluoridation procedures. The study warned that the controlled dilution process does not protect public safety in the case of accidents. The study further indicated that gaps in regulation could allow for unreported metal content to enter the public drinking water. The metal contaminant content of raw fluoride additives varies from batch to batch. Fluoride often contains arsenic, and while fluoride is typically monitored daily, arsenic is typically checked only quarterly or annually.

Additionally, combinations of contaminants can trigger chemical degradation, as fluoride tends to act as a corrosive to metals. For example, the NIH has previously reported that rats exposed to lead and sodium fluoride accumulate higher concentrations of lead in their blood and bone tissue than rats that had been exposed to only lead. In a study by University of North Carolina researchers, co-directors of the Environmental Quality Institute at the University of North Carolina – Ashville stated that fluoride chemicals combined with other water additives pull lead from plumbing systems into drinking water, especially a combination of chloramines and fluorosilicic acid.

Dr. J. William Hirzy, Chemist in Residence at American University's College of Arts and Sciences in Washington, D.C., and former EPA senior scientist, wrote a letter in 2013 to the acting administrator of EPA, petitioning EPA to prohibit the use of hydrofluorosilicic acid (HFSA) as a fluoridation agent, instead urging the use of pharmaceutical grade sodium fluoride. He identified HFSA as a hazardous waste by-product of industrial processes, and noted HFSA meets the criteria for classification as a hazardous waste under 42 U.S.C. § 6901 et. seq. More specifically, sodium fluoride is largely derived from by-products of the aluminum smelting industry, and HFSA is a waste by-product of the phosphate fertilizer manufacturing industry. Approximately 90% of drinking water systems that add fluoride use HFSA, which contains arsenic. In combination with chloramine, HFSA leaches lead from pipes and plumbing fixtures into drinking water.

The following countries have banned or stopped using fluoride in their drinking water:

- Austria
- Belgium
- Denmark
- Finland
- Germany
- Hungary
- Israel
- The Netherlands
- Norway

Some communities in the following countries have banned or stopped using fluoride:

- Australia
- Canada
- England
- Ireland
- Japan
- New Zealand

In the United States, hundreds of communities have banned or stopped using fluoride, including communities in the following:

- Alabama
- Alaska
- Arizona
- Arkansas
- California
- Colorado
- Florida
- Georgia
- Hawaii
- Idaho
- Indiana
- Iowa
- Kansas
- Louisiana
- Maine
- Maryland
- Massachusetts
- Michigan
- Mississippi
- Missouri
- Montana
- Nebraska
- New Mexico
- New York
- North Carolina
- Ohio
- Oregon
- Pennsylvania
- South Carolina
- Tennessee
- Texas
- Utah
- Vermont
- Virginia
- Washington
- West Virginia
- Wisconsin
- Wyoming

In Wisconsin, the following communities do not fluoridate their water:

- Balsam Lake
- Bloomer

- Blue River
- Chippewa Falls
- Granstburg
- Holmen
- Milltown
- Montello
- Prairie du Chien
- Saukville
- Shawano
- Shell Lake
- St. Croix Falls
- Village of Orfordville

Some of the communities that do not fluoridate their water provide the following reasons:

Albuquerque, New Mexico – Discontinued supplemental fluoridation because fluoride occurs naturally in water.

Chippewa Falls, WI – The cost of adding fluoride was too much for the budget.

Davis, California – Community members lobbied the city to stop fluoridating. In the city's decision, the mayor stated that the vast majority of fluoride added to city water would end up on lawns and down drains, calling instead for more focused efforts to combat dental decay. Adding fluoride at the water project's planned treatment plant would have cost the city as much as $301,000 before yearly operating costs, according to preliminary city estimates. Fluoridation costs would have added about $2 per month to residential customers' water bills, according to a city staff report.

Grantsburg, Wisconsin -- "If people want fluoride, they can get it anywhere — toothpaste, mouthwash, even gum," trustee Glenn Rolloff said. "I don't think we should continue injecting it in the water — the people should have the right to decide."

Montello, Wisconsin – Dentists opined that while there are some benefits to having fluoride put in municipal water, a person would get more fluoride from brushing his or her teeth daily than by drinking a gallon of city water.

Portland, Oregon –Portland's clean water campaign was spearheaded by Clean Water Portland (CWP). CWP gathered over 40,000 signatures to halt the mandate of fluoridation. Opposition to fluoridation included the regional Sierra Club, the Portland branch of the NAACP, Oregon's Department of Environmental Quality employees union, and more than 200 local medical professionals. Voters who rejected fluoridation were concerned by research showing low-income communities to be at highest risk of fluoride's adverse effects, with virtually no offsetting benefit.

Santa Fe, New Mexico – “What’s happening is you are fluoridating 100 percent of the water, and anywhere from 95 to 99 percent of it does not get ingested,” said Councilor Chris Calvert. “So you are basically dumping most of it into the environment one way or the other.”

Saukville, Wisconsin – Cost was a major factor in discontinuing fluoride treatment. Utility committee members questioned whether the added cost was justified, since just 4% of municipal water was consumed as drinking water, and the remaining 96% was used for other things. After considering the overall annual operational and maintenance expenses, including testing, the committee decided it was not worth the expense to continue fluoridating the water for such a small added value, especially taking into consideration that fluoride is widely available through other sources.

Shell Lake, Wisconsin – Council decided by unanimous vote to stop fluoridating based on employee safety and cost to properly ventilate the two city pump houses that contain the fluoridation equipment.

Tacoma, Washington – After discontinuing fluoride during a drought, lead concentration in drinking water dropped by almost 50%.

Thurmont, Maryland – Lead levels in the public drinking water system decreased significantly after the utility stopped adding fluoride.

Wichita, Kansas – Voters voted against fluoridation.

The City of Milwaukee fluoridates its water at a level not exceeding 0.7 mg/L and notes that the CDC recommends that parents use a low-fluoride alternative water source for formula-fed infants up to 6 months of age.

LRB 166425