Potential Priority Metals

March 27, 2014
Meeting of the Scientific Guidance Panel
Biomonitoring California[1]

The metals reviewed in this document include all of the currently designated metals[2] that are not priority chemicals for Biomonitoring California. The Scientific Guidance Panel (SGP) will consider these metals as potential priority chemicals at their March 27, 2014 meeting. A number of the potential priority metals can already be measured by the Environmental Health Laboratory (EHL) of Biomonitoring California, as shown in the following table. Metals measured by the Centers for Disease Control and Prevention (CDC) are also indicated. Three of these metals (cobalt, manganese, and molybdenum) are essential nutrients.

Potential priority metal	**Essential nutrient**	**EHL detection limit (µg/L)**		**CDC detection limit[a] (µg/L)**
		Blood	Urine	Urine
Antimony (Sb)	--	--	--	0.032
Barium (Ba)	--	--	--	0.12
Beryllium (Be)	--	--	--	0.072[b]
Cesium (Cs)	--	--	--	0.066
Cobalt (Co)	✓	--	0.011	0.041
Manganese (Mn)	✓	0.28	0.050	--[c]
Molybdenum (Mo)	✓	--	0.074	0.92
Platinum (Pt)	--	--	--	0.009[b]
Thallium (Tl)	--	--	0.010	0.015
Tungsten (W)	--	0.044	0.005	0.021
Uranium (U)	--	0.001	0.001	0.002

a. Detection limit in urine as reported for 2009-2010 by CDC (2013). None of these metals, except manganese (see footnote c), are currently measured by CDC in blood.
b. Being dropped by CDC due to three survey cycles of non-detects.
c. CDC has added manganese to the blood and urine metals panel; results will be included in the April 2014 release of the Updated Tables for the National Report on Human Exposure to Environmental Contaminants (Mowbray, pers comm, 2014).

[1] California Environmental Contaminant Biomonitoring Program (also known as Biomonitoring California), codified at Health and Safety Code section 105440 et seq.
[2] For the complete list of designated chemicals, visit: http://www.biomonitoring.ca.gov/sites/default/files/downloads/DesignatedChemCurrent_0.pdf

The SGP can recommend priority chemicals based on the criteria specified in the enabling legislation[3]:

- The degree of potential exposure to the public or specific subgroups, including, but not limited to, occupational.
- The likelihood of a chemical being a carcinogen or toxicant based on peer-reviewed health data, the chemical structure, or the toxicology of chemically related compounds.
- The limits of laboratory detection for the chemical, including the ability to detect the chemical at low enough levels that could be expected in the general population.
- Other criteria that the panel may agree to.

Selected information relevant to these criteria is briefly summarized in the following tables. The information was largely drawn from secondary sources and a limited scientific literature search. Additional background materials provided to the SGP included excerpts on the metals from CDC (2009, 2013), where available, and a report by the US Geological Service (USGS, 2014).

Because all of the metals in this document are designated metals, they can already be selected for measurement in a Biomonitoring California study. The purpose of discussing these metals at the March 27, 2014 SGP meeting is to obtain the Panel's recommendations on which, if any, should be *priority* chemicals for measurement in California.

If the Scientific Guidance Panel recommends adding any of these metals to the list of priority chemicals for Biomonitoring California, this listing would cover any form of the metal (e.g., the listing of "antimony" would also include antimony compounds). The Program would determine the most appropriate methods for biomonitoring the priority metals.

[3] SB 1379, Perata and Ortiz, Chapter 599, Statutes of 2006. Available at: http://www.biomonitoring.ca.gov/sites/default/files/downloads/sb_1379_bill_20060929.pdf

Potential priority metal Production/import volume (2012, lbs)	**Use**	**Potential exposure** (*examples*)[c]	**Indications of toxicity** (*notes from secondary sources and selected literature reports*)[d]
Antimony USGS*[a]: 58M US EPA[b]: 10-50M (antimony) 5M (antimony trioxide)	Antimony is used as a hardening agent in metal alloys for applications such as batteries and ammunition. It is also used in ceramics, glass and rubber products, and as a catalyst in production of polyethylene terephthalate (PET) food contact materials. Antimony trioxide is used as a flame retardant for plastics and textiles, and is commonly used with tetrabromobisphenol-A in circuit boards. Antimony compounds are also used to treat parasites. Nanoparticles of antimony oxides are used as flame retardant synergists with halogenated compounds for plastics, paints, and textile back coatings; in humidity sensing; and in optical materials in semiconductors.	CDC noted that the general population is primarily exposed through food. Antimony has been shown to migrate from PET materials into food. An analysis of NHANES data found that smokers had higher urinary antimony levels versus non-smokers. Workers in various industries, such as metal smelting, have exhibited elevated blood and urinary levels correlated with antimony levels in air. CARB reported a statewide average ambient air concentration of 2.7 ng/m^3 in 2012.	Antimony trioxide is listed under Proposition 65 as known to cause cancer. Effects on the lungs and the heart have been associated with industrial exposures. OEHHA's PHG of 20 µg/L for antimony is based on slightly reduced longevity and minor clinical signs in a rat study.
Barium USGS: 7.9B (barite) US EPA: 31M (barium sulfide) 9M (barium chloride)	Barium compounds are used primarily in fluids for drilling of oil and gas wells. They are also used in radiography, in pigments, and as fillers in cloth, ink and plastic. Barium has been used for gas scavenging in vacuum tubes and in spark plugs. Barium titanate nanoparticles have many applications in electronics, including electronic ceramics, detectors, capacitors, data storage, and optical computing.	CDC indicated that general population exposure occurs through food, air and water. An analysis of NHANES data found that smokers had higher urinary barium levels versus non-smokers. A study of welders using barium-containing electrodes found urinary levels 60 times higher compared to the general population, but this does not appear to be a common source of occupational exposure. CARB reported a statewide average ambient air concentration of 50.8 ng/m^3 in 2002, the last year with sufficient data to calculate the average.	OEHHA's PHG of 2.0 mg/L is based on the absence of cardiovascular effects (hypertension) in two human studies. Exposure to barium in drinking water caused ototoxicity in mice.
Beryllium USGS: 620K US EPA: Withheld	Beryllium and beryllium alloys (beryllium-copper) are used in consumer and automotive electronics, defense and aerospace applications, energy applications, and appliances. Nanoparticle applications include coatings, nanowire, nanofiber, plastics, and textiles.	Beryllium exposures most commonly occur in the workplace. Beryllium also occurs at low levels in tobacco smoke (0-0.0005 µg/cigarette). In monitoring of California drinking water from 2009 to 2012, beryllium was detected above the PHG (1 µg/L) in only one drinking water source and never above the MCL (4 µg/L). CARB reported a statewide average of 0.019 ng/m^3 in 1993, which was the last year with sufficient data to calculate the average. CDC did not detect beryllium in the general population for three survey cycles and will no longer measure it in urine. A group in the UK developed a more sensitive method (detection limit of 6 ng/L) and could distinguish low levels of beryllium exposures in the general population compared to a worker population.	Beryllium and beryllium compounds are listed under Proposition 65 as known to cause cancer. OEHHA's cREL of 0.007 µg Be/m^3 is based on beryllium sensitization and chronic beryllium disease in workers. The immune system was also identified as a hazard index target. OEHHA's PHG of 1 µg/L is based on gastrointestinal lesions in beagle dogs.

Potential priority metal Production/import volume (2012, lbs)	**Use**	**Potential exposure** (*examples*)[c]	**Indications of toxicity** (*notes from secondary sources and selected literature reports*)[d]
Cesium USGS: Estimated a few thousand kg (USGS could not obtain actual data) US EPA: 265K (cesium nitrate) 198K (cesium formate) 46K (cesium carbonate) 44K (cesium sulfate) 33K (cesium chloride)	All cesium used in the U.S. is derived from imported pollucite, although this cesium mineral does occur in Maine and South Dakota. Naturally occurring cesium, cesium-133, is not radioactive ("stable cesium"). Cesium salts are used in fluids for oil and gas drilling, petroleum cracking, pyrotechnics, and as chemical intermediates and catalysts. Cesium is used in atomic clocks, global positioning satellites, and photoemissive devices. Radioactive cesium, such as cesium-137, is used to sterilize food, in gauges, and in medical applications.	CDC stated that most general population exposure to cesium occurs through the diet. Radioactive cesium has been released to the environment in nuclear accidents and explosions.	Radionuclides are listed under Proposition 65 as known to the state to cause cancer.
Cobalt USGS: 29M US EPA: 23M (cobalt) 1M-10M (cobalt[II, III] oxide) 4.7M (cobalt hydroxide) 1.4M (cobalt oxide)	Cobalt is used in metal alloys, such as chromium-cobalt for artificial joints and lithium cobalt oxide in batteries. More than half of the cobalt consumed in the United States is used in "superalloys", mainly for aircraft engines. Cobalt is also used in pigments. Nanoparticle applications include imaging, sensors, and high performance magnetic recording.	Most cobalt exposure is from the diet. Elevated cobalt levels have been measured in blood, urine and other biological samples from patients with artificial joints. CARB reported a statewide average ambient air concentration of 0.92 ng/m^3 in 2012.	Cobalt metal powder and several cobalt compounds are listed under Proposition 65 as known to cause cancer. Elevated levels of cobalt can be toxic to the nervous system, thyroid, and heart.
Manganese USGS: 2.6B (includes Mn, FeMn, SiMn) US EPA: 1B (manganese) 90M (manganese dioxide) 10-50M (manganese oxide) 10-50M (manganese[II,III] oxide) 10-50M (manganese sulfate) 10-50M (manganese alloy)	Manganese is primarily used in steel. Other uses include batteries, fertilizer, matches, and ceramics. Manganese is a component of two fungicides (mancozeb and maneb) widely used in California. Nanoparticle applications include magnetic data storage, imaging, biosensors, textiles, coatings, and plastics.	Most manganese exposure occurs through diet. CDPH reported there were detections above the health-based notification level of 0.5 mg/L for 384 drinking water sources across 46 counties (out of ~12,000 sources statewide) from 2006 to 2011. CARB reported a statewide average ambient air concentration of 17.8 ng/m^3 in 2012. Elevated manganese blood levels have been measured in welders.	Elevated levels of manganese can harm the nervous system in adults, affecting mood and memory, and may affect learning and behavior in children. The OEHHA cREL of 90 ng/m^3 is based on impairment of neurobehavioral function in humans. For more details on the toxicity of manganese, refer to the potential designated chemical document (OEHHA, 2010).

Potential priority metal Production/import volume (2012, lbs)	**Use**	**Potential exposure** (*examples*)[c]	**Indications of toxicity** (*notes from secondary sources and selected literature reports*)[d]
Molybdenum USGS: 177M US EPA: 20M (molybdenum) 184M (molybdenum trioxide) 6M (molybdenum sulfide)	Molybdenum is primarily used in iron, steel and super alloys. It is also used in semiconductors and batteries. Molybdenum trioxide is used as a flame retardant for a wide range of plastics, rubbers, paper and textiles. Nanoparticles of molybdenum compounds are used in lubricants, catalysts, and various space and military applications.	Most molybdenum exposure occurs through food. Elevated levels of molybdenum have been found in serum of patients with hip resurfacing metal implants. Workers at a molybdenum smelter were found to have elevated levels in blood and urine. Welders can also be exposed to molybdenum. CARB reported a statewide average ambient air concentration of 0.87 ng/m^3 in 2012.	NTP found some evidence of the carcinogenicity of inhaled molybdenum trioxide, based on increased incidence of lung tumors in mice. NTP also reported non-neoplastic lung lesions in mice. Elevated molybdenum has been associated with a gout-like disease. Some studies indicate potential reproductive toxicity of molybdenum.
Platinum USGS: 387K US EPA: 67K (platinum) 31K (platinum sulfide) 37K (platinum oxide)	The major use of platinum compounds is in catalysts to decrease vehicle emissions. Platinum compounds are also used in jewelry, dental alloys, and as chemotherapy drugs (cisplatin, carboplatin, nedaplatin, and oxaliplatin). Platinum nanoparticle applications include catalysts, cancer therapy, coatings, and cosmetics.	Gold-platinum dental alloys have been associated with increases in urinary platinum. CDC did not detect platinum in the general population for three survey cycles and will no longer measure it in urine. CARB reported that the 90^{th} percentile of the statewide ambient air concentration was below the detection limit of 0.3 ng/m^3 in 2012.	Platinum has been associated with dermal and respiratory hypersensitivity. The chemotherapeutic agent cisplatin is listed under Proposition 65 as known to the state to cause cancer. Platinum chemotherapy drugs are also ototoxic and neurotoxic.
Thallium USGS: 2.2K US EPA: No records	Thallium is used in alloys for high-temperature superconductors, acousto-optical measuring devices, and low-temperature measurement devices. Thallium is also added to glass to increase refractive index and density and is used as a catalyst for organic compound synthesis. Thallium has been found in cement dust. Radioactive thallium is used for cardiovascular imaging.	CDC concluded that thallium exposure comes primarily from industrial processes such as coal-burning and smelting. Elevated levels up to 15 µg/L were found in mineral water in Germany, which prompted development of a human biomonitoring value (HBM I) of 5 µg/L. In monitoring of California drinking water from 2009 to 2012, thallium was detected infrequently above the PHG (five drinking water sources > 0.1 µg/L) or MCL (one drinking water source > 2 µg/L).	Thallium and thallium compounds are highly toxic. Thallium(I) ions can replace potassium ions in biological systems. Chronic toxicity concerns include neurological effects (central and peripheral), impaired vision, and alopecia. The OEHHA PHG of 0.1 µg/L is based on alopecia in an animal study. Studies in rats showing loss of sperm motility and impairment in development of the autonomic nervous system provided additional support for the PHG.

Potential priority metal Production/import volume (2012, lbs)	**Use**	**Potential exposure** (*examples*)[c]	**Indications of toxicity** (*notes from secondary sources and selected literature reports*)[d]
Tungsten USGS: 46M US EPA: 27M (tungsten oxide) 18M (tungsten) 18M (tungsten carbide)	The major use for tungsten is for hard tungsten carbide parts in industries such as construction, metalworking, and oil and gas drilling. Tungsten is in metal alloys, including steel and "superalloys", used to make electronic components, in welding, for various consumer products, and for other applications. Tungsten is replacing lead and depleted uranium in munitions, including armor penetrators. Tungsten compounds are used in ceramic pigments, in fire retardant coatings for fabrics, and in color-resistant dyes for fabrics. Applications for tungsten nanoparticles include coatings, plastics, and nanowires; microelectronics films; and sensors.	CDC indicated that background exposures could occur from soluble tungsten salts in drinking water. A faulty shielding device used in testing of a new radiation treatment for breast cancer patients deposited large numbers of tungsten particles in the breast tissue of the study participants (n = 30). A mine in California produced tungsten concentrates in 2012. Workers can be exposed via inhalation of dust.	NTP is studying the potential carcinogenicity of tungsten and selected tungsten compounds, prompted in part by tungsten's identification as a contaminant of possible concern in two childhood leukemia clusters. Pellets of weapons grade tungsten alloy implanted in rats induced aggressive rhabdomyosarcomas; however this alloy also contained nickel and cobalt, both known carcinogens. Neurobehavioral effects were observed in rats administered pre- and postnatal sodium tungstate via gavage.
Uranium USGS: Not included US EIA[e]: 47M	Naturally occurring uranium is enriched for use as fuel in nuclear power plants, which is the major use for uranium in the U.S. Enriched uranium is also used in nuclear weapons. Depleted uranium, a byproduct of the production of enriched uranium, is used in military applications, transport containers for radioactive materials, and medical applications. Uranium oxide nanoparticles have been used as catalysts.	CDC stated that the general population is primarily exposed to naturally occurring uranium in water and food, especially root crops. Workers, such as uranium miners, can be exposed by inhaling particles. CARB reported a statewide average ambient air concentration of 1.4 ng/m^3 in 2002, the last year with sufficient data to calculate the average.	Radionuclides are listed under Proposition 65 as known to cause cancer. Noncancer effects of uranium include immunotoxicity, neurotoxicity, reproductive toxicity, cardiovascular effects, and kidney toxicity. OEHHA's PHG of 0.5 µg/L (0.43 pCi/L) for natural uranium in drinking water was derived based on a lifetime cancer risk of 1 in a million from exposure to ionizing radiation. This PHG was further supported by a human study showing changes in indicators of kidney function (increased β2-microglobulin and γ-glutamyl transferase levels in the urine).

Table Notes

a. Includes domestic production and import volume for 2012 (from USGS, 2014). Data from USGS converted to pounds.
b. Import/production volume reported by US EPA (2012) for the metal and metal compounds. In some cases, such as manganese, many listings were available and only the highest volume metal compounds were included in the table. Import/production volume from earlier years can be accessed at: http://epa.gov/cdr/tools/previouslycollected.html.
c. This column provides examples of ways people in California might be exposed to these metals, to assist with the SGP's discussion. An evaluation of the relative importance of potential exposure sources was beyond the scope of this document.
d. This column provides notes on indications of toxicity, drawn from secondary sources and a limited literature review, to assist with the SGP's discussion. If a metal is formally identified as a particular type of toxicant, such as a carcinogen under Proposition 65, this is noted. However, an evaluation of the toxicity of these metals was beyond the scope of this document. For more details on the indications of toxicity, consult the references provided in the reference section below this table.
e. Data from US EIA (2011).

*Acronyms used in this document

ATSDR - Agency for Toxic Substances and Disease Registry
CARB – California Air Resources Board
CDC – Centers for Disease Control and Prevention
CDPH – California Department of Public Health
cREL – Chronic Reference Exposure Level
NHANES – National Health and Nutrition Examination Survey
NTP – National Toxicology Program
MCL – Maximum Contaminant Level
OEHHA – Office of Environmental Health Hazard Assessment
PET - polyethylene terephthalate
PHG – Public Health Goal
USGS – US Geological Survey
US EPA – US Environmental Protection Agency
UK – United Kingdom
WHO – World Health Organization

K - thousand
M – million
B- billion
lbs – pounds
μg/L – micrograms per liter
ng/m^3 – nanograms per cubic meter
PCi/L – picocuries per liter

References consulted for table and other relevant references

Agarwal S, Zaman R, Tuzcu EM et al. (2011). Heavy metals and cardiovascular disease: Results from the National Health and Nutrition Examination Survey (NHANES) 1999-2006. Angiology 62(5):422-429.

Apostoli P, Catalani S, Zaghini A (2013). High doses of cobalt induce optic and auditory neuropathy. Exp Toxicol Pathol 65:719-727.

ATSDR (1992). Toxicological Profile for Antimony and Antimony Compounds. Available at: http://www.atsdr.cdc.gov/ToxProfiles/tp23.pdf.

ATSDR (2007). Toxicological Profile for Barium and Barium Compounds. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp24.pdf.

ATSDR (2002). Toxicological Profile for Beryllium. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp4.pdf.

ATSDR (2004). Toxicological Profile for Cesium. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp157.pdf

ATSDR (2004). Toxicological Profile for Cobalt. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp33.pdf.

ATSDR (2012). Toxicological Profile for Manganese. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp151.pdf.

ATSDR (1992). Toxicological Profile for Thallium. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp54.pdf.

ATSDR (2005). Toxicological Profile for Tungsten. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp186.pdf.

ATSDR (2013). Toxicological Profile for Uranium. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp150.pdf.

Beyersmann D and Hartwig A (2008). Carcinogenic metal compounds: recent insight into molecular and cellular mechanisms. Arch Toxicol 82:493–512.

Brockhaus A, Dolgner R, Ewers et al. (1981). Intake and health effects of thallium among a population living in the vicinity of a cement plant emitting thallium containing dust. Int Arch Occup Environ Health 48:375-389.

Catalani S, Rizzetti M, Padovani A, Apostoli P (2012). Neurotoxicity of cobalt. Hum Exp Toxicol 31:421-437.

CARB. Annual Toxics Summaries. Statewide. Available at: http://www.arb.ca.gov/adam/toxics/statesubstance.html

CDC, 2009. Fourth National Report on Human Exposure to Environmental Contaminants. Available at: http://www.cdc.gov/exposurereport/pdf/FourthReport.pdf

CDC (2013). Fourth National Report on Human Exposure to Environmental Contaminants. Updated Tables, September 2013. Available at: http://www.cdc.gov/exposurereport/pdf/FourthReport_UpdatedTables_Sep2013.pdf.

CDPH (2013). MCL Review in Response to PHGs. Available at: http://www.cdph.ca.gov/certlic/drinkingwater/Pages/MCLReview2013.aspx

Cesbron A, Saussereau E, Mahieu L et al. (2013). Metallic profile of whole blood and plasma in a series of 106 healthy volunteers. Journal Anal Toxicol. 1-5 doi:10.1093/jat/bkt046. Advance Access published June 21, 2013.

Chan P, Herbert R, Roycroft J, Haseman J et al. (1998). Lung tumor induction by inhalation exposure to molybdenum trioxide in rats and mice. *Toxicol Sci* 45:58 - 65

Chin H, Cheong K, Razak K (2010). Review on oxides of antimony nanoparticles: synthesis, properties, and applications. J Mater Sci 45:5993–6008.

Choe S, Kim S, Kim H et al. (2003). Evaluation of estrogenicity of major heavy metals. Sci Total Environ 312:15-21.

Christensen KLY (2013). Metals in blood and urine, and thyroid function among adults in the United States 2007–2008. Int J Hyg Envir Heal 216:624– 632.

Cristaudo A, Sera F, Severine V, et al. (2005) Occupational hypersensitivity to metal salts, including platinum, in the secondary industry. Allergy 60:159-164.

Ding D, Allman B, Salvi R. (2012). Ototoxic characteristics of platinum antitumor drugs. Anatom Record 297:1851-1867.

Edelman P, Osterloh J, Pirkle J et al. (2003). Biomonitoring of chemical exposure among New York City firefighters responding to the World Trade Center fire and collapse. Environ Health Perspect 111(16):1906-1911.

Gajek R, Barley F, She J (2013). Determination of essential and toxic metals in blood by ICP-MS with calibration in synthetic matrix. Anal Methods 5(9):2193-2202.

Gbaruko BC and Igwe JC (2007). Tungsten: Occurrence, chemistry, environmental and health exposure issues. Global J Environ Res 1(1):27-32.

Haldimann M, Blanc A, Dudler V (2007). Exposure to antimony from polyethylene terephthalate (PET) trays used in ready-to-eat meals. Food Addit Contam 24(8):860-8.

Heitland P and Koster H (2006). Biomonitoring of 30 trace elements in urine of children and adults by ICP-MS. Clinica Chimica Acta 365:310–318.

Heitland P and Koster H (2006). Biomonitoring of 37 trace elements in blood samples from inhabitants of northern Germany by ICP–MS. J Trace Elements Med Biol 20:253‑262.

Jantzen C, Jorgensen HL, Duus BR et al. (2013). Chromium and cobalt ion concentrations in blood and serum following various types of metal-on-metal hip arthroplasties. A literature overview. Acta Orthopaedica 84 (3):229–236.

Kalinich JF, Emond CA, Dalton TK et al. (2005). Embedded weapons-grade tungsten alloy shrapnel rapidly induces metastatic high-grade rhabdomyosarcomas in F344 rats. Environ Health Perspect 113(6):729-734.

Kazi H, Perera J, Gillott E, et al. (2013). A prospective study of a ceramic-on-metal bearing in total hip arthroplasty- Clinical results, metal ion levels and chromosome analysis at two years. Bone Joint J 95-B:1040–44.

Kelly A, Lemaire M, Young Y, et al. (2013) In vivo exposure alters B-call development and increases DNA damage in murine bone marrow. Toxicol Sci 131(2):434-446

Leikin J, Karydes H, Whiteley P, et al. (2013). Outpatient toxicology clinic experience of patients with hip implants. Clin Toxicol 51:230-236

Lesser S and Weiss S. (1995) Art hazards. Am J Emerg Med 13(4): 451-458

Martin M, Reiter R, Pham T et al. (2003). Estrogen-like activity of metals in MCF-7 breast cancer cells. Endocrinol 144:2425-2436.

Mazoochian F, Schmidutz F, Kiefl J et al. (2013). Levels of Co, Cr, Ni and Mo in erythrocytes, serum and urine after hip resurfacing arthroplasty. Acta Chir Belg 113:123-128.

McInturf S, Bekkedal M, Wilfong E et al.(2011). The potential reproductive, neurobehavioral and systemic effects of soluble sodium tungstate exposure in Sprague–Dawley rats. Toxicol Appl Pharmacol 254:133-137.

Meeker J, Rossano M, Protas B et al. (2008). Cadmium, lead, and other metals in relation to semen quality: Human evidence for molybdenum as a male reproductive toxicant. Environ Health Perspect 116:1473-1479.

Meeker J, Rossano M, Protas M et al. (2010). Environmental exposure to metals and male reproductive hormones: Circulating testosterone is inversely associated with blood molybdenum. Fertil Steril 93:130-140

Mendy A, Gasana J, Vieira ER (2012). Urinary heavy metals and associated medical conditions in the US adult population. Int J Environ Health Res 22(2):105-118.

Mikulski M, Leonard S, Sanderson W et al. (2010). Risk of beryllium sensitization in a low-exposed former nuclear weapons cohort from the Cold War era. Am J Ind Med. DOI10.1002/ajim.20913. Published online in Wiley Online Library.

Morton J, Leese E, Cotton R et al. (2011). Beryllium in urine by ICP-MS: a comparison of low level exposed workers and unexposed persons. Int Arch Occup Environ Health 84:697–704.

Mowbray A (pers comm, 2014). Electronic mail from Amy Mowbray, Centers for Disease Control and Prevention to Robin Christensen, California Department of Public Health. January 14, 2014.

Muennig P, Song X, Payne-Sturges D (2011). Blood and urine levels of long half-life toxicants by nativity among immigrants to the United States. Sci Tot Environ 412-413:109-113.

Murray J, Sullican F, Tiwary A, Carey S. (2013). 90-Day subchronic toxicity study of sodium molybdate dihydrate in rats. Regul Toxicol Pharmacol http://dx.doi.org/10.1016/j.yrtph.2013.09.003.

Ortiz A, Fernandez E, Vicente A, et al. (2011) Metallic ions released from stainless steel, nickel-free, and titanium orthodontic alloys: Toxicity and DNA damage. Am J Orthod Dentofacial Orthop 140:e115-e122.

NTP (2003). Tungsten and Selected Tungsten Compounds. Review of Toxicological Literature. Prepared by Integrated Laboratory Systems, Inc. Available at: http://ntp.niehs.nih.gov/ntp/htdocs/Chem_Background/ExSumPdf/tungsten_508.pdf.

NTP (2005). Antimony Trioxide. Brief Review of Toxicological Literature. Prepared by Integrated Laboratory Systems, Inc. Available at: http://ntp.niehs.nih.gov/ntp/htdocs/Chem_Background/ExSumPdf/Antimonytrioxide_508.pdf

OEHHA (1997). Public Health Goals for Chemicals in Drinking Water. Antimony. Available at: http://www.oehha.ca.gov/water/phg/pdf/anti3_c.pdf

OEHHA (1999). Public Health Goals for Chemicals in Drinking Water. Thallium. Available at: http://www.oehha.ca.gov/water/phg/pdf/thal_f.pdf

OEHHA (2001). Public Health Goals for Chemicals in Drinking Water. Uranium. Available at: http://www.oehha.ca.gov/water/phg/pdf/uranium801.pdf

OEHHA. Table of all Reference Exposure Levels. Available at: http://www.oehha.ca.gov/air/allrels.html

OEHHA (2003). Public Health Goals for Chemicals in Drinking Water. Barium. Available at: http://www.oehha.ca.gov/water/phg/pdf/Ph4Ba092603.pdf

OEHHA (2003). Public Health Goals for Chemicals in Drinking Water. Beryllium and Beryllium Compounds. Available at: http://www.oehha.ca.gov/water/phg/pdf/BePHG92303.pdf

OEHHA (2004). Update of PHG - Thallium. Available at: http://www.oehha.ca.gov/water/phg/pdf/Thall1104.pdf

OEHHA (2010). Manganese. Potential Designated Chemical. Materials for the November 2010 Biomonitoring California Scientific Guidance Panel Meeting. Available at: http://www.biomonitoring.ca.gov/sites/default/files/downloads/102110Manganese.pdf

Ohgami N, Hori S, Ohgami K, et al. (2012). Exposure to low-dose barium by drinking water causes hearing loss in mice. Neurotox 33(5):1276-83. 3.

Padilla MA, Elobeid M, Ruden DM, Allison DB (2010). An examination of the association of selected toxic metals with total and central obesity indices: NHANES 99-02. Int J Environ Res Public Health 7:3332-3347.

Pandey R and Singh S. (2002) Effects of molybdenum on fertility of male rats. BioMetals 15:65-72.

Petera A and Viraraghavan T. (2005). Thallium: a review of public health and environmental concerns. Environ Int 31:493– 501.

Richter P, Bishop E, Wang J, and Swahn M. (2009). Tobacco smoke exposure and levels of urinary metals in the U.S. youth and adult population: The National Health and Nutrition Examination Survey (NHANES) 1999–2004. Int J Environ Res Public Health 6:1930-1946.

Schroeder H and Mitchener M. (1971). Toxic effects of trace elements on the reproduction of mice and rats. Arch Environ Health 23(2):102-106.

Schulz C, Wilhelm M, Heudorf U, et al. 2011. Update of the reference and HBM values derived by the German Human Biomonitoring Commission. Int J Hyg Envir Heal 215:26– 35.

Schultze B, Lind P, Larsson A, Lind L. (2013). Whole blood and serum concentrations of metals in a Swedish population-based sample. Scand J Clin Lab Inv [early online].

Schuster B, Roszell L, Murr L, et al. (2012). In vivo corrosion, tumor outcome, and microarray gene expression for two types of muscle-implanted tungsten alloys. Toxicol Appl Pharm 265:128-138.

Shimkin M, Stoner G, Theiss J. (1978). Lung tumor response in mice to metals and metal salts. In Inorganic and nutritional aspects of cancer. Proceedings of the First Conference of the International Associations of Bioinorganic Scientists, Inc. Ed. Schrauzer G Plenum Press, New York and London. pp 85-91.

Shiue I. (2013). Urinary environmental chemical concentrations and vitamin D are associated with vision, hearing, and balance disorders in the elderly. Environ Int 53:41-46.

Sundar S and Chakravarty J (2010). Antimony toxicity. Int J Environ Res Pub Health 7:4267-4277.

Titenko-Holland N, Shao J, Zhang L, et al. (1998) Studies on the genotoxicity of molybdenum salts in human cells *in vitro* and in mice *in vivo*. Environ Mol Mutagen 32:251-259

Tower S (2010). Arthroprosthetic cobaltism: Identification of the at-risk patient. Alaska Med 52:28-32.

Tyrell J, Galloway TS, Abo-Zaid G et al. (2013). High urinary tungsten concentration is associated with stroke in the National Health and Nutrition Examination Survey 1999–2010. PLOS One 8 (11):1-7.

US EIA (2011). Today in Energy. July 11, 2011. Available at: http://www.eia.gov/todayinenergy/detail.cfm?id=2150

US EPA (US Environmental Protection Agency, 2012). Non-confidential 2012 Chemical Data Reporting Rule information. Available at: http://java.epa.gov/oppt_chemical_search/.

U.S. EPA (2009). Toxicological Review of Thallium and Compounds. (CAS No. 7440-28-0). In Support of Summary Information on the Integrated Risk Information System (IRIS). EPA/635/R-08/001F. U.S. Environmental Protection Agency. Washington, DC. Available at: http://www.epa.gov/iris/toxreviews/1012tr.pdf

USGS (2014). Mineral Commodities Summary. Available at: http://minerals.usgs.gov/minerals/pubs/mcs/2014/mcs2014.pdf

Vyskočil A AND Viau C. (1999). Assessment of molybedum toxicity in humans. J Appl Toxicol. 19:185-192.

Wei H-J, Luo X-M, and Yang S. (1985). Effects of molybdenum and tungsten on mammary carcinogenesis in SD rats. JNCI 74:469-473.

Witten M, Sheppard P, and Witten B. (2012). Tungsten toxicity. Chem-Biol Interact 196:87–88.

WHO (2003). Depleted Uranium. Sources, Exposure and Health Effects. Department of Protection of the Human Environment, Geneva. Available at: http://www.who.int/ionizing_radiation/pub_meet/Depluraniumintro.pdf

WHO (2011). Molybdenum in Drinking Water. Background document for development of WHO Guidelines for Drinking-water Quality. Available at: http://www.who.int/water_sanitation_health/dwq/chemicals/molybdenum.pdf

Yoshida M, Sachie O, Fukunaga K, Nishiyama T (2006). Serum molybdenum concentration in healthy Japanese adults determined by inductively coupled plasma-mass spectrometry. J Trace Elem Med Biol 20:19–23.

Zeng Q, Zhou B, Feng W et al. (2013). Associations of urinary metal concentrations and circulating testosterone in Chinese men. Repro Toxicol 41:109-114.

Zhai X-W, Zhang Y-L, Qi Q, et al. (2013). Effects of molybdenum on sperm quality and testis oxidative stress. Sys Biol Repro Med 59:251-255.

Zhang Y-L, Liu F-J, Chen X-L, et al. (2013). Dual effects of molybdenum on mouse oocyte quality and ovarian oxidative stress. Sys Biol Repro Med 59:312-318.