

The periodic table of danger

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Abstract Society at large often incorrectly thinks that the word ‘chemicals’ implies danger, when of course all matter can be described as a chemical. In this article we define what precisely we mean by ‘hazard’, ‘risk’ and ‘danger’; we then consider selected elements from the periodic table that are noteworthy because of their dangerous characteristics.

The terms ‘hazard’, ‘risk’ and ‘danger’ are commonly used terms that are equally commonly misunderstood, used interchangeably or simply misused. The title of this article, ‘The periodic table of danger’ therefore requires us to offer a short explanation of, and differentiation between, these terms.

The word **hazard** has its origins in the Old French word *hasard*, which means dice game; it is derived from the Arabic *az-zahr*, which means the gaming die (see *Websites* 1). It means a condition or set of circumstances that present a risk or threat to an individual’s life, property or health. It is something that does not exist but is a possibility that an individual will fall victim to an injury or misfortune. Examples might include electricity, chemicals, working up a ladder, noise, a keyboard, a bully at work, stress, and so on.

A **risk** is the chance, high or low, that any hazard will actually cause somebody harm. The relationship between risk and hazard is given by:

$$\text{risk} = \text{hazard} \times \text{likelihood} \times \text{consequence}$$

To put this equation into context, most people are happy to fly by air: the hazard and consequence of an air crash are almost certain death but the likelihood is infinitesimally small and so the overall risk is small – so most of us are willing fliers.

Danger comes from the Middle English word *daunger*, which means power or peril. It is derived from the Old French *dangier* from the Latin *dominus* (master). In the English language it came to refer to the power to cause harm. It is a situation where an individual is susceptible to harm or one wherein they are exposed or put at risk. It may or may not be something that is clearly evident or known. A dangerous incident can be serious, but it can also be as mild as the danger of cutting your finger when slicing onions.

To explain these terms in the context of the elements, take the element arsenic as an example. The hazard associated with arsenic is that it is poisonous if ingested. This is an intrinsic property of the element and cannot

be changed. The risk, or probability, of being exposed to arsenic and therefore poisoned depends on how that risk is controlled. If our arsenic is kept in a sealed container and under lock and key, although it still possesses its hazardous property, there is no probability or risk of exposure and therefore it presents no danger.

Antimony

Antimony is a silver-white, crystalline metalloid and is naturally occurring in the Earth’s crust. It is generally found as the sulfide mineral stibnite. Sitting immediately below arsenic in the periodic table, antimony would be expected to have similar properties and that is the case as far as toxicity goes. Although antimony poisoning has very similar symptoms to arsenic poisoning, the effects are not nearly as strong. Used since the Middle Ages as an emetic to induce vomiting and in the 18th and 19th centuries to discourage over-consumption of alcohol, it was still used as a treatment for some tropical diseases until the 1970s.

Antimony pills were once sold as reusable laxatives. If you were constipated you would swallow one and its toxic action would irritate the intestines, causing them to discharge their contents. The pill was then retrieved and stored for future use and often passed down from generation to generation. Antimony compounds were also popular in other medical treatments. A 5 mg dose of antimony tartrate (known as tartar emetic) would produce profuse sweating which was thought to be beneficial. A larger 50 mg dose would cause vomiting, and this was seen as a cure for a hangover. Alternatively, a solution of this salt would form if wine was left overnight in a cup made of antimony metal and drinking this would have the same effect. Captain James Cook, who achieved the first recorded European contact with the east coast of Australia in 1770, had just such an antimony cup, which was sold for \$400,000 in 2005. The 35-year-old composer Wolfgang Amadeus Mozart may even have died of antimony poisoning in December

1791. He was a heavy drinker and may have taken too much tartar emetic. It was said he died of miliary (not military) fever, an illness we no longer recognise, but whose symptoms were those of antimony poisoning (his doctor even prescribed tartar emetic to treat him during his final fatal illness).

In 1915, antimony became the cure for parasite infections such as bilharzia, also known as snail fever, and leishmaniasis, which is a widespread childhood disease spread by sand flies. Antimony sodium gluconate, also known as Pentostam, was prescribed in doses that would kill the parasite but not poison the patient.

Arsenic

We all have a little arsenic in our bodies, around 7 mg on average. Some foods, such as prawns, contain higher than average levels, but it is present in the organic form known as arsenobetaine and poses no threat to our health. Inorganic arsenic, however, is another matter. A dose of 250 mg of arsenic oxide, As_2O_3 , will kill a human. Even so, arsenic became popular in medicine from 1780 onwards, when Dr Fowler's Solution first appeared. This was soluble potassium arsenite and was given as a treatment for fevers or as a tonic during convalescence. Prolonged use could result in arsenicosis, in which the skin of the hands and feet becomes covered in ulcers, which eventually become cancerous. This condition reappeared in Bangladesh in the 1980s, caused by drinking water from wells that had high arsenic levels. A simple filter containing iron filings now removes the arsenic by converting it to insoluble iron arsenite.

In 1909, a breakthrough in the treatment of syphilis came in the form of the drug Salvarsan, which was an arsenic derivative. Today, arsenic is back as the drug Trisenox, which is given to treat leukaemia. This is arsenic oxide and acts by stimulating the production of normal blood cells that have become crowded out by cancerous white blood cells.

Accidental arsenic poisoning appeared to be a threat in Victorian times when wallpapers were often printed with the bright green pigment, copper arsenite. When such walls became damp they could give off trimethylarsine gas, AsH_3 , because of the growth of moulds. Breathing the air in such rooms was capable of producing chronic arsenic poisoning, or so it was believed. Then, in 2005, it was shown that this gas is not particularly toxic, and so ended speculation that Napoleon had been poisoned by his wallpaper.

Arsenic is extracted from the arsenic sulfide ores realgar and orpiment. Heated and crushed they produce arsenic oxide, a white powder soluble in water and virtually tasteless in food and drink. For centuries, the ores were used widely as pigments in paints, realgar for red

and orpiment for yellow; the habit of using their lips to achieve a fine brush point caused many a Renaissance artist to suffer the symptoms of arsenic poisoning.

We mention in the introduction the poisonous nature of arsenic. For centuries, arsenic has caused the accidental demise of many famous individuals as well as being used as the agent of murder. Probably the most famous poisoner of Victorian times was Mary Ann Cotton who, in the 1860s, dispatched four husbands and eight children using arsenic. Her husbands, needless to say, were well insured: hence its nickname 'inheritance powder'.

Bromine

Bromine is a dark-brown fuming liquid at room temperature and is highly corrosive, causing severe chemical burns on human flesh. Inhaling bromine gas results in irritation of the respiratory tract, causing coughing, choking, shortness of breath and death if inhaled in large enough amounts. This is in line with its younger brother chlorine, whose deleterious effects on the lungs of the soldiers in the Somme are well known. Bromine is not the easiest of liquids to transport and is usually carried in steel tanks lined with lead.

The bromide anion, Br^- , is not very toxic; however, high levels of bromide chronically impair the membrane of neurons, which leads to a condition called bromism. Symptoms include irritability, hallucinations, psychosis, anorexia, constipation and skin pustules. This is not a common condition these days, but it has been linked to excessive consumption of cola owing to the brominated vegetable oil used to emulsify citrus soft drinks to prevent them separating in storage (Horowitz, 1997).

Cadmium

Mostly known for its use in pigments, cadmium is one of the toxic 'heavy metals'. Cadmium sulfide, when mixed with zinc sulfide, produces a yellow-green colour. First shown at the Great Exhibition in 1851, cadmium yellow is now the most important yellow in artists' palettes. Cadmium is a poison that accumulates in the body, and is on the United Nations' list of top ten pollutants. The World Health Organization says a safe daily intake is 70 μg but most people get less than 25 μg . Cadmium can replace the essential element zinc and it accumulates in the liver and harms it.

Cadmium sulfide was known to the ancient world as a bright-yellow pigment, and is mined in Greece and Bohemia. It was called cadmium yellow and was used in household paints and printing inks and by artists (Monet used it). It was also used to colour rubber, plastics and tiles. Many of these uses have been phased out. Today, cadmium is produced as a by-product of zinc smelters, and

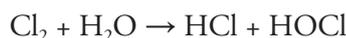
zinc ores can contain 3% cadmium. However, the metal is now used on a scale that is a tenth of that of 50 years ago, when it was widely used to electroplate steel. Cadmium still continues to be used to galvanise the steel of offshore oil facilities and for critical components of aircraft such as the landing gear. Another use for cadmium was in nickel–cadmium batteries, which were seen as environmentally friendly because they can be recharged a thousand times or more. These batteries are being phased out in favour of nickel–metal hydride batteries, which also deliver more current. Cadmium telluride solar panels are another use and these can generate a power output of nearly 100 W.

In the summer of 2010, fast-food giant McDonald's recalled more than 12 million *Shrek*-themed glasses because of cadmium contamination, and US retail chain Walmart was criticised for an entire line of Miley Cyrus branded jewellery containing high levels of cadmium. Exposure to cadmium occurs in industrial processes such as the manufacture of pigments, coatings, plastics and NiCd batteries. Smoking is also a significant source of cadmium exposure, so yet another argument to give up or indeed not to start.

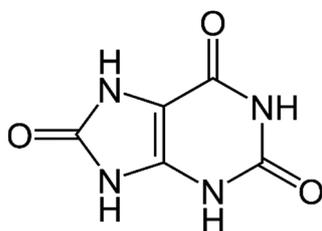
The symptoms of cadmium poisoning include inflammation of the lungs, renal failure, liver damage and softening of the bones. In extreme cases the bones are so weak that mere body weight can cause fractures.

Chlorine

Chlorine (Cl₂) is a yellow-green gas at room temperature. It is an extremely reactive element and a very strong oxidising agent; chlorine gas is a stronger oxidising agent than oxygen gas. Elemental chlorine is poisonous to all living things and has been used as far back as the 1820s as a disinfectant, when the French scientist Labarraque used sodium hypochlorite solution to destroy the smell of putrefaction and retard tissue decomposition (see *Websites 2*). Chlorine's use in swimming pools is well known. The reason that your swimming costume may appear drabber and faded over time is that it is being bleached; the hypochlorous acid produced by the dissolution of chlorine bleaches the pigments by removing electrons:



The eye irritation suffered by some at swimming pools has a less-than-lovely cause. Clean pool water should not irritate swimmers' eyes. Red eyes are caused by the reaction product between chlorine and urine; the urea in urine can decompose to ammonia and ammonia reacts with chlorine to produce



Uric acid

chloroamines NH₂Cl, NHCl₂ and NCl₃. Moreover, the uric acid in urine can produce small amounts of cyanogen chloride (N≡C–Cl), another irritant (Bailar *et al.*, 1984):

Elemental chlorine at high concentrations is extremely dangerous and poisonous for all living organisms; it was used in the First World War as the first gaseous chemical warfare agent. Developed as a chemical weapon by the Nobel Prize winning chemist, Fritz Haber, chlorine was used on a huge scale in the battle of Ypres in April 1915, when 150 tonnes of chlorine gas were released over two days into the Allied lines. In May 1915 there were three devastating attacks on the Eastern Front where the Russians lost around 25 000 men killed or wounded. Haber's wife, Clara, committed suicide after he refused to stop his chemical warfare work (Harris and Paxman, 2011). The gas works by dissolving in the moisture in the unlucky recipient's lungs and causing the pH to drop as per the same equation as the swimming pool disinfection equation above. The body attempts to mitigate the drop in pH by flooding the lungs with plasma and the subject dies by drowning in their own lung exudate.

Fluorine

The lightest of the halides, fluorine is the most reactive element of the periodic table. Fluorine reacts with every other element except helium, neon and argon, and has such a strong affinity for electrons it will even oxidise oxygen. Being so reactive, fluorine is hard to isolate and several 19th century attempts at generating the element resulted in the deaths and maiming of several scientists. These brave scientists are often referred to as the 'fluorine martyrs'.

To put fluorine's reactivity into daily context, it quickly reacts with glass fragments, asbestos fibres and powdered steel. Water spontaneously combusts in the presence of a jet of fluorine gas. The Royal Institution has published a *YouTube* video showing fluorine reacting with caesium (see *Websites 3*).

Perhaps the biggest risk to human well-being that fluorine contributes to is through its non-reactive fluorocarbon compounds. Hydrofluorocarbon (HFC), chlorofluorocarbon (CFC) and bromofluorocarbon (BFC) compounds are used in the manufacture of a range of products including aerosol propellants, coolants, refrigerants, fire extinguishers and synthetic polymers. Most are non-reactive, have low toxicity, are non-flammable and are stable at high temperatures. Their long lifetimes in the atmosphere mean that some end up in the higher atmosphere (stratosphere) where they contribute to the depletion of the ozone layer. Although the amounts emitted are relatively small, they have a very high global

warming potential. Carbon dioxide is used as the reference comparator and has a global warming potential value of 1, whereas many fluorocarbon compounds have values of several thousand (see *Websites* 4, 5).

Iodine

Elemental iodine is a lustrous, almost black solid that gives off a purple vapour. This vapour irritates the eyes and lungs and its harmful effects should not be underestimated. The short-term exposure limit for Iodine vapour is just 1 ppm (1.1 mg m^{-3}) (see *Websites* 6). Iodine poisoning by ingestion is rare, as it requires a large dose; however, the effects are exceedingly unpleasant and include burning of the mouth, throat and stomach.

Iodine is one of those elements that is essential for human health. A deficit of iodine can cause the thyroid gland to overwork and enlarge leading to a pronounced swelling of the neck, called goitre. This condition is caused by a lack of dietary iodine and in extreme cases can lead to fetal development problems, including severely stunted physical and mental growth. Goitre used to be called 'Derbyshire neck', as, during the 19th century and earlier, it was prevalent in rural communities in the Derbyshire Dales (Slavin, 2005).

The radioactive isotope I-131 is the most feared fission product released into the atmosphere following an atomic explosion or nuclear accident like Chernobyl. Iodine is concentrated in the thyroid gland when inhaled or ingested in food, particularly milk, and can lead to thyroid cancer.

Lead

Today we know of lead's slow and deadly threat to human health and we need to minimise human contact with this metal. Yet it continues to be mined on a large scale at 4 000 000 tonnes per year. It is refined to remove the silver it contains, which can be as much as 1.2 kg per tonne, and then it is used for lead-acid batteries for vehicles, for lead sheeting for roofs, for ammunition, for cable sheathing, for exercise weights and for radiation protection. So-called chemical-grade lead, which contains small amounts of silver and copper, is used in the chemical industry because it resists the action of corrosive liquids.

Lead-based semiconductors such as lead selenide and lead telluride are part of infrared detectors. Lead-based perovskites, such as methylammonium lead bromide ($\text{CH}_3\text{NH}_3\text{PbBr}_3$), are likely to play a role in solar panels because they make them more efficient at converting light to electrical energy.

Lead is poisonous because it is absorbed into the bloodstream where it interferes with the enzymes that make haemoglobin. This leads to a build-up of

aminolaevulinic acid from which haemoglobin is made, and it is the excess aminolaevulinic acid that poisons the body and accounts for the symptoms of lead poisoning, namely general weakness, constipation, headaches, insomnia and even infertility.

In the last century, new uses were found for lead, such as the insecticide lead arsenate and the petrol-additive tetraethyl lead, which was used to boost fuel performance. Eventually lead was contaminating the whole planet as shown by its rising level in the snows of the Arctic in the 1970s. Unleaded petrol is now the only kind allowed and many other domestic uses of lead have also disappeared, such as lead water pipes, pottery glazes and hair dyes for men. The last of these used lead acetate.

Lead can measure time on a geological scale using the uranium-lead dating method. Its atoms are the end product of the radioactive decay of uranium and thorium, so by comparing the amount of these metals to lead it is possible to calculate the age of a rock.

If one is to judge the danger of an element by the number of fatalities, then perhaps lead comes out on top. It is estimated that in 2016, lead poisoning resulted in 540 000 deaths worldwide (see *Websites* 1, 7).

Lead is a cumulative poison that affects the brain, liver, kidneys and bones and accumulates over time in the teeth and bones. During pregnancy, lead is released into the bloodstream and can have a detrimental effect on the developing fetus.

Sources of lead exposure include leaded petrol and aviation fuel, pigments, glassware and ammunition.

High levels of lead in the body attack the brain and central nervous system and can lead to coma, convulsions and even death. Young children and babies absorb lead much more easily than adults as their brains are developing and exposure can lead to behaviour problems, low IQ, hearing problems and growth delays.

Queen Elizabeth I used a makeup foundation on her face to cover up her smallpox scars. This consisted of a mixture of white-lead ore, vinegar, lead hydroxide and lead carbonate and gave the skin a silvery white sheen. Unfortunately, lead is absorbed through the skin so the price paid to follow this particular fashion was headaches, hair loss, tooth loss, muscle paralysis and mood swings. Indeed, Maria, Countess of Coventry, died in 1752 at the age of 28 as a 'victim of cosmetics' according to the press at the time.

Mercury

The Earth's atmosphere contains about 2500 tonnes of mercury and it is increasing. Some of this is natural, coming from volcanoes, soil erosion and microbial release of methyl mercury, but most comes from human activity, mainly from burning coal. In ages past, mercury

and its compounds were used in medicines, in thermometers, barometers, seed protection and dental fillings. These applications have been replaced by alternatives.

The human intake of mercury is about 3 µg per day and every mouthful of food we eat contains some. Fish such as tuna can concentrate mercury, but not to a level that poses any threat to the health of those who eat it.

The deadliest form of mercury is methyl mercury (CH_3Hg^+) and is produced by bacteria from inorganic mercury. It disrupts the central nervous system and it can cause a deformed fetus. This is what happened to the people who lived around Minamata Bay in Japan in the 1950s. A chemical company had polluted the bay with mercury, where it was converted into methyl mercury by various organisms, thereby ending up in local fish, which could have high levels. It was many years before the illness afflicting residents around the bay was traced to the eating of mercury-contaminated fish.

Karen Elizabeth Wetterhahn was an American professor of chemistry at Dartmouth College, New Hampshire, who specialised in toxic metal exposure (see *Websites* 8). She died of mercury poisoning at the age of 48 owing to accidental exposure to the organic mercury compound dimethylmercury ($\text{Hg}(\text{CH}_3)_2$).

The use of mercury has declined significantly in recent years and is now mainly confined to the chemical industry, which uses it as a catalyst, and to some electrical applications such as switches and rectifiers, which need to be reliable. A little mercury goes into cell batteries for hearing aids and into fluorescent lights, but even these amounts have declined significantly and are being phased out.

Mercury and its compound are insidious poisons causing neurological damage. Symptoms of mercury poison include tremors, mood swings and aggressive and antisocial behaviour. Mercury salts were used in 19th-century hat making and there is some evidence that this is where the saying 'mad as a hatter' originates. In medicine, mercury salts have been used to treat a wide range of ailments from constipation to syphilis. In the latter case the treatment was extremely long, which led to the phrase '*A night with Venus before a lifetime with mercury*'.

Plutonium

All radioactive isotopes present some type of hazard. We shall focus on two that are dangerous in slightly different ways. The first, plutonium, is used in nuclear weapons as it undergoes fission when hit by neutrons of a certain energy. This element was used in the nuclear device called *Fat Man*, which was the first-ever use of a nuclear weapon in a time of war. This device was equivalent to around a reported 15 000 tonnes of TNT. That

to one side, there are some surprising facts about the two bombs dropped on Japan: *Little Boy* and *Fat Man*. They were different inasmuch as *Little Boy* was a fission bomb that used fissile U-236 and only 1.5% of the fissile material actually underwent fission (see *Websites* 9). *Fat Man* used Pu-239 as the fissile material. This bomb was dropped onto Nagasaki, and is an example of the awful randomness of life or death in war. The intended target had been Kokura, but Kokura was cloud-bound on the day in question, so the B-29 Superfortress, named *Bockscar*, which carried it diverted to the fallback target that was Nagasaki. Upon witnessing the destructive power of the first detonation of a nuclear device in the Trinity test in the New Mexico desert earlier in 1945, J. Robert Oppenheimer, the 'father' of the atomic bomb, was reported to recall verses from the Hindu scripture *Bhagavad Gita*:

If the radiance of a thousand suns were to burst at once into the sky, that would be like the splendour of the mighty one ... I am become Death, the destroyer of worlds.

Selenium

Every cell of the body contains a million atoms of selenium, and levels are highest in hair, kidneys and, especially, the testicles. Selenium is part of various enzymes, and we have about 14 mg in our body in total. If we take in too much, we may develop selenosis, which is typified by breath that smells of garlic and offensive body odour. This is caused by excess selenium being excreted as dimethyl selenide, $(\text{CH}_3)_2\text{Se}$. Selenium's big brother, tellurium, has even worse consequences of overdosing as can be seen in the tellurium section.

The most common clinical signs of selenosis, are hair and nail loss or brittleness. Other symptoms include lesions of the skin and nervous system, nausea, diarrhoea, skin rashes, mottled teeth, fatigue, irritability and nervous system abnormalities. Before you decide to delete all selenium from your diet you should be aware that selenium affects DNA repair so may play a part in preventing cancer, and low selenium levels result in lazy or non-existent sperm, since it is involved in enzyme in the mitochondria that propel sperm cells. Selenium supplements could also reduce the risk of cardiovascular disease and cognitive decline in old age. The maxim of selenium intake is to always read the label and stick to the advised dose.

Most people get their selenium from breakfast cereals and bread. Other selenium-rich foods are tuna, salmon, Brazil nuts and peanuts. Selenium can protect against other metal toxins, especially cadmium and mercury. Tuna accumulates high levels of mercury, but is safe to eat because this fish protects itself by taking in an

atom of selenium for every mercury atom it absorbs. Some farmed soils are rich in selenium, such as the great plains of America. In other parts of the world they are deficient in selenium so this is added to fertilisers in small amounts.

Selenium is used for glass manufacture, for metallurgical purposes – especially for manganese production – and for electronic devices. When light falls on selenium it becomes electrically conducting and so it can be used in light-sensitive photoelectric cells, light meters, solar cells and photocopiers. The largest user of selenium is the glass industry, which adds a little of it to decolourise the glass. Cadmium selenide is added in larger amounts to produce a rich ruby colour. Selenium pigments provide ceramics, paint and plastics with a range of orange, red and maroon colours. Cerium selenide acts as a striking and permanent red pigment.

Selenium is produced as a by-product of copper refining, and the total amount produced is about 1500 tonnes a year. Some selenium is reclaimed from industrial waste.

Tellurium

Tellurium is an element to avoid because of its socially isolating effects, although it has its uses. If even small amounts (10 µg) of tellurium get into the body, we expel it via the lungs or the sweat glands as foul-smelling dimethyl telluride ($\text{Te}(\text{CH}_3)_2$) and we quite literally stink. When tests were carried out on volunteers, they were given tiny doses of 15 mg, and they still suffered from ‘tellurium breath’ eight months later. This was a sure sign in the chemistry research lab that someone was a tellurium researcher. Indeed, the discoverer of tellurium, Glenn Seaborg, delegated his tellurium chemistry to his student, who found it almost impossible to shed the awful stink. It was even possible to tell which textbooks he had handled as they absorbed the offensive odour and slowly released it over time. (In passing, Glenn Seaborg was the first-ever living person, and one of only two people, to have an element, seaborgium, named after him. The only other is Yuri Tsolakovich Oganessian, after whom element 118, oganesson, is named. There are of course many elements that were named after deceased scientists, such as fermium, curium, rutherfordium, mendelevium, lawrencium, roentgenium, copernicium, einsteinium and nobelium, to name but nine.)

There are some tellurium minerals but none is mined as a source of the element. Commercial tellurium is obtained as a by-product of copper refining. World production is around 200 tonnes per year. Tellurium is alloyed with copper and stainless steel to improve their machinability, and a little is added to lead to make it

harder and more acid-resistant, especially that which is used in batteries. At various times, tellurium has been used to vulcanise rubber, to tint glass and ceramics, in electronic devices, and as an industrial catalysts in oil refining.

When added to rubber, tellurium speeds up the curing process and makes the rubber less likely to be affected by oil, which softens normal rubber. Tellurium is also used in photoreceptors and other microelectronic devices, in the form of bismuth telluride. Cadmium telluride is used to make solar panels and, indeed, it has one of the highest efficiencies for solar cell electricity generation. Zinc cadmium telluride is used in X-ray detectors.

Thallium

Thallium is a heavy metal used in the cement, optics, photographic and electronics industries. Thallium salts were once used as a hair remover. The dose was 500 mg, which was a near-lethal dose of what is in fact a slow poison. Thallium sulfate was used to kill rats, cockroaches and ants, but is now banned in most developed countries. Some murders have been carried out with it.

Thallium is chemically like potassium and can replace it at all sites in the body but does most damage to the central nervous system. Thallium also affects hair follicles and the hair slowly drops out. The antidote for the poison is Prussian blue, the dye of blue ink. It can trap the thallium and carry it out of the body.

Thallium minerals are rare, and it is mainly obtained as the by-product of copper, zinc and lead smelting. World production is around 30 tonnes per year. Most is used by the electronics industry as thallium sulfide, thallium selenide and thallium arsenide for photoelectric cells. Thallium is also used to make special glass for lenses and thallium bromide-iodide is used for infra-red detectors.

When it comes to poisonous elements, thallium is in a class of its own. It holds the title of the most toxic non-radioactive element. Although known as the poisoner’s poison – odourless, colourless and tasteless, with less than a gram as a fatal dose – cases of thallium poisoning are quite rare. In 2008, 11 individuals from two Iraqi families were poisoned (several fatally) through eating cake from a local bakery (Al Hammouri *et al.*, 2011). Initial symptoms manifest themselves within a few hours and include vomiting, haematemesis (vomiting blood) and abdominal pain. Within a few hours to days after the initial symptoms, victims suffer tremors, pain in the arms and legs, facial palsy, ataxia, psychosis and severe weakness. Two weeks into the poisoning the victim suffers complete hair loss, their skin becomes dry and scaly and white lines appear on their fingernails. Death is usually by cardiac arrest or respiratory failure.

Tin

Cases of poisoning from tin metal, its oxides and its salts are almost unknown. Tin(II) fluoride is even used in some dental products as it is effective against gum disease. So, what makes it dangerous? Certain organotin compounds are almost as toxic as cyanide. Organotin compounds are often used for their biocidal properties and find use as fungicides, pesticides, algacides, wood preservatives and antifouling agents. Tetraethyltin was used as an antifouling agent to prevent the growth of marine organisms on ship hulls and it was very effective. However, it leached into seawater and became a persistent organic pollutant, proving deadly to some marine species. The European Union banned the use of organotin compounds in 2003 and this was followed by a worldwide ban by the International Maritime Organization.

Websites

1. www.differencebetween.net/language/words-language/difference-between-hazard-and-danger
2. https://en.wikipedia.org/wiki/Antoine_Germain_Labarraque
3. Reacting fluorine with caesium: www.youtube.com/watch?v=TLOFaWdPxBo
4. <https://chemical-materials.elsevier.com/new-materials-applications/global-warming-fluorocarbons-montreal-protocol-2016>
5. www.environment.gov.au/protection/ozone/ozone-science/students-teachers-resources
6. *EH40/2005 Workplace Exposure Limits*: www.hse.gov.uk/pUbns/priced/eh40.pdf
7. www.who.int/en/news-room/fact-sheets/detail/lead-poisoning-and-health
8. https://en.wikipedia.org/wiki/Karen_Wetterhahn
9. *Little Boy*: https://en.wikipedia.org/wiki/Little_Boy#Assembly_details

Zinc

Zinc is an important trace metal in our diet. Without it we experience a loss of appetite, decreased sense of taste and smell and our wounds heal more slowly. Lack of zinc can even cause birth defects. Like a lot of things, zinc is good for us in moderation. Too much zinc is definitely bad.

Exposure to excess zinc comes from industrial processes such as galvanising steel, but it is also found as a pigment in paints, plastics, photocopier paper, wallpaper, inks and even cosmetics. An argument to look after your teeth is that zinc is used in some denture fixatives, which, when used too generously, can be swallowed and lead to zinc poisoning (Afrin, 2010). The symptoms of zinc poisoning include damage to the nerves that control breathing and swallowing and movement in the arms and legs. In extreme cases the effects can prove fatal.

References

- Afrin, L. B. (2010) Fatal copper deficiency from excessive use of zinc-based denture adhesive. *American Journal of Medical Sciences*, **340**(2), 164–168.
- Al Hammouri, F., Darwazah, G., Said, A. and Ghosh, R. A. (2011) Acute thallium poisoning: series of ten cases. *Journal of Medical Toxicology*, **7**, 306–311. Available at: <https://link.springer.com/article/10.1007/s13181-011-0165-3>.
- Bailar, Jnr, J. C., Moeller, T., Kleinberg, J., Guss, C. O., Castellion, M. E. and Metz, C. (1984) *Chemistry*. London: Harcourt Brace Jovanovich.
- Harris, R. and Paxman, J. (2011) *A Higher Form of Killing*. London: Random House.
- Horowitz, B. Z. (1997) Bromism from excessive cola consumption. *Journal of Toxicology: Clinical Toxicology*, **35**(3), 315–320.
- Slavin, G. (2005) Derbyshire neck and iodine deficiency. *Mercian Geologist*, **16**(2), 79–88.

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