GREENPEACE Briefing

TOXIC TECH
The dangerous chemicals in electronic products

Electronic products are a complex mixture of several hundred components, many of which contain heavy metals and hazardous chemicals. These dangerous substances cause serious pollution and put workers at risk of exposure when the products are produced or disposed of.

Berylium

Beryllium is a metal with unique properties; it is lighter than aluminium and stronger than steel, as well as being a very good conductor of heat and electricity (Taylor *et al.* 2003). Beryllium is used in electrical and electronic equipment as copper-beryllium alloys typically containing 2% beryllium. This alloy increasing the strength to six times that of copper. It is used in springs, relays and connections, and historically in computer motherboards (OECD 2003, Taylor *et al.* 2003).

During the refining and processing of beryllium and its compounds, fumes and dusts of beryllium and beryllium oxide can be produced. Their inhalation is the main route of beryllium exposure for workers in these industries (Field 2001). Historically many believed that the manufacture and use of beryllium-copper alloys did not pose health risks to workers (see Infante & Newman 2004), however recent studies have shown that people working with such alloys can have a significant risk of exposure to beryllium and suffer health impacts including developing CBD (Balkissoon & Newman 1999, Schuler *et al.* 2005). Workers can also carry beryllium dusts away from the workplace on their clothes and shoes, exposing their family members (Cohen & Positano 1986, Sanderson *et al.* 1999) and there are reported cases of the spouses of beryllium workers developing beryllium sensitivity and chronic beryllium disease (CBD) (Knishkowy & Baker 1986).

While most reported cases of beryllium exposure are related to workers involved in processing and manufacturing activities, exposure may also occur during the recycling of electrical and electronic equipment containing beryllium-copper alloys. Beryllium dusts may be generated during shredding and grinding, or during high temperature processes such as those used at metal refineries (Basel 2004, OECD 2003), which can lead to beryllium sensitivity and CBD in workers (Cullen *et al.* 1987, Infante & Newman 2004).

Beryllium is both acutely and chronically toxic to humans, mainly affecting the lungs. Breathing high concentrations of beryllium dusts or fumes can result in acute beryllium disease (ABD), with a range of effects including shortness of breath, coughing, chest pain, rapid heart rate and death in extreme cases.

Approximately 30% of ABD sufferers will eventually developed chronic beryllium disease (CBD), also known as berylliosis.

Exposure to beryllium, even at very low levels and for short periods of time, can lead to beryllium sensitisation. Some individuals will go on to develop CBD, a debilitating disease with symptoms including emphysema and fibrosis of the lungs that can sometimes be fatal. Although symptoms can be suppressed with steroids, CBD is currently incurable (Field 2001). CBD can develop soon after exposure begins or be delayed for long periods, up to many years after initial exposure (Newman *et al.* 1996). The length of time and amount of exposure that results in sensitisation and subsequent development of CBD is highly variable between individuals. Not all individuals who become sensitised will go on to develop CBD. Some people can develop berylliosis following seeming very low levels of exposure, and health effects have been reported following exposure to levels 20-100 times lower than widely used workplace exposure limits (Kelleher *et al.* 2001). This effect is believed to be a result of a genetic predisposition (Field 2001, Viet *et al.* 2000). In many cases CBD in workers is either undiagnosed or misdiagnosed (Infante & Newman 2004, Newman 1995). Skin contact can also produce dermatitis, and may cause beryllium sensitization, a precursor to CBD development (Tinkle *et al.* 2003).

Furthermore, beryllium and beryllium compounds have been classified as known human carcinogens by the International Agency for Research on Cancer, based upon the increased rates of lung cancer in beryllium production workers (IARC 1993)

In some countries controls exist to address beryllium exposure in the workplace, with maximum allowable air concentrations. Many countries have adopted workplace exposure limits of 1-2 $\mu g/m^3$ (WHO 1990). For example, in the USA a maximum average permissible exposure limit (PEL) is set at 2 $\mu g/m^3$ over 8 hours, with a limit of 5 $\mu g/m^3$ for any 30 minute period and a peak maximum of 25 $\mu g/m^3$ (USCFR 1999).

Workplace exposure limits are typically based upon total beryllium air concentrations. These do not address other factors that can affect exposure such as dust particle size and the chemical form of beryllium. Recent studies indicate that some workers can develop CBD at exposures significantly below such limits (Kelleher *et al.* 2001, Kolanz 2001).

Cadmium

Cadmium and its compounds are used in a number of applications within electronics products. Cadmium is used in some contacts and switches, and many laptop computers contain rechargeable nickel-cadmium (Ni-Cd) batteries. Cadmium compounds have also been used as stabilisers within PVC formulations, such those used as wire insulation. Cadmium sulphide has been also used in older cathode ray tubes (CRTs) as a phosphor coating, a

material used on the interior surface of the screen to produce light (OECD 2003).

Disposal of cadmium containing products can cause releases into the environment. Incineration can release cadmium compounds both to the air and within fly ashes (Allsopp *et al.* 2001). Recycling operation, such as breaking of CRT glass, may also release cadmium to the environment and be hazardous to workers through the inhalation of cadmium sulphide containing dusts (OECD 2003).

Cadmium is a rare metal, found naturally as very low concentrations (Salomons & Forstner 1984). It is persistent in the environment, and in aquatic environments cadmium is more mobile than most other metals (ATSDR 2000). Cadmium is highly toxic to plants, animals and humans, having no known biochemical or nutritional function (ATSDR 2000, WHO 1992). Exposure can result in bioaccumulation of cadmium in humans and animals. Some food crops such as grain, rice and vegetables can also accumulate cadmium, which can provide additional exposures for humans (Elinder & Jarup 1996).

Cadmium exposure can occur occupationally through inhalation (breathing in) of fumes or dusts containing cadmium and its compounds or through environmental exposures, primarily diet. Cadmium is a cumulative toxicant and long-term exposure can result in damage to the kidneys and bone toxicity. For animals as for humans cadmium exposure though diet primarily affects the kidneys (Elinder & Jarup 1996, WHO 1992). Recent studies have demonstrated kidney damage at lower levels of exposure than previously anticipated (Hellstrom *et al.* 2001).

Other effects include disruption to calcium mechanisms in the body and the development of hypertension (high blood pressure) and heart disease (Elinder & Jarup 1996, WHO 1992). The inhalation of cadmium oxide fumes or dusts can affect the respiratory system, with effects including tracheobronchitis and pulmonary oedema (ATSDR 2000, WHO 1992). Furthermore, cadmium and its compounds are known to be human carcinogens, primarily for lung cancer following inhalation (DHSS 2002).

A number of regional controls exist on the use of cadmium in products. EU legislation restricting the use of certain hazardous substances (ROHS) in electrical and electronic equipment, prohibits the use of cadmium in new equipment put on the market from 1 July 2006 (EC 2002a), with a maximum allowable concentration of 0.01% cadmium by weight in homogeneous materials. There are exemptions to this for the use of cadmium in certain plating applications. Under legislation addressing waste electrical and electronic equipment (WEEE), batteries containing more than 0.025% cadmium by weight must be separated from wastestreams and recycled where appropriate (EC 2002b). The use of cadmium in products is addressed under other EU legislation, including restrictions on its use as colouring or plastic stabiliser agents in a wide range of products (including PVC) where the

cadmium content exceeds 0.01 %, with some exceptions for safety reasons (EEC 1991).

In 1998, the Ministerial Meeting of the OSPAR convention for the Protection of the Marine Environment of the North-East Atlantic agreed on the target of cessation of discharges, emissions and losses of all hazardous substances to the marine environment by 2020 - the one generation cessation target - and included cadmium compounds on the first list of chemicals for priority action towards this target (OSPAR 1998).

Chromium Hexavalent

Hexavalent chromium is one chemical form of the metal chromium. It has many uses including as a corrosion inhibitor and in hardening and corrosion protection in metal housings. Hexavalent chromium is far more reactive and soluble in water than other forms of chromium, making it more mobile in the environment (Mukherjee 1998).

Incineration of chromium containing wastes can result in releases to the atmosphere and generate fly ash containing hexavalent chromium, which subsequently can leach from the ash (Allsopp *et al.* 2001, Mangialardi *et al.* 1998).

While other forms of chromium can be trace nutrients for animals and humans, hexavalent chromium is highly toxic even at low concentrations, and in some cases carcinogenic (ATSDR 2000). It is also corrosive and can readily cause allergic skin reactions following contact, independent of the amount. Damage to the kidney and liver have also been reported (ATSDR 2000). sIn addition, occupational exposure to airborne hexavalent chromium has been associated with lung cancer, and the International Agency for Research on Cancer has classified hexavalent chromium compounds as known human carcinogens (IARC 1990). Hexavalent chromium is also toxic to animals and plants, and animal studies have also found increased risk of cancer following inhalation (ATSDR 2000).

EU legislation restricting the use of certain hazardous substances (ROHS) in electrical and electronic equipment, prohibits the marketing of new equipment containing hexavalent chromium at a concentration of greater than 0.1% by weight from 1 July 2006 (EC 2002a).

Lead

Lead has two main uses in electronics products. Metallic lead is used in electrical solder primarily on printed circuit boards (commonly as an alloy with tin). Lead oxide is used in cathode ray tubes (CRTs); incorporated within the glass and also in the frit, a type of glass solder used to join the faceplate and funnel sections. CRTs contain approximately 2-3kg of lead in older models

and 1 kg in newer models (OECD 2003). In addition, lead compounds have been used as stabilisers in PVC formulations (Matthews 1996).

Lead can leach from CRTs under landfill conditions (Musson *et al.* 2000). Incineration can also result in release of lead to the air as in the ash produced (Allsopp *et al.* 2001). Lead in CRTs and printed circuit boards may also be released as lead oxide dust or lead fume during glass crushing or high temperature processing, such as smelting or application of heat to loosen the solder (OECD 2003).

Workers using lead in high temperature processes, such as at lead smelters, can be significantly exposed to lead fumes (Schutz *et al.* 2005). Workers using lead based solders may also be exposed to lead-bearing dusts and fumes (ATSDR 2000). Respiratory impairment has been reported amongst workers using lead-tin solders, though the contribution from lead in the solder was not evaluated (Gupta *et al.* 1991).

Lead tends to accumulate when released into the environment, having a long residence time compared with most pollutants. It can remain accessible to the food chain and to human metabolism far into the future. Humans can accumulate lead, as can many plants and animals (Sauve *et al.* 1997, ATSDR 2000). Where soils and dusts are contaminated with lead, children can have increased exposure through behavior such as hand-to-mouth transfer (Malcoe *et al.* 2002)

Lead is highly toxic to humans as well as many animals and plants. It has no known biochemical or nutritional function (ATSDR 2000, Goyer 1996). The toxic effects of lead are the same irrespective of whether it is ingested or inhaled. In humans, exposure to lead has a wide range of effects including damage to the nervous system and blood system, impacts on the kidneys and on reproduction. Of particular concern is the effect of low-level exposure on the development of the brain and central nervous system in children, which can result in intellectual impairment (Canfield *et al.* 2003, Goyer 1993). Lead exposure is cumulative and its effects appear to be irreversible (Bellinger & Dietrich 1994). Similar toxic effects are seen in animals, and lead is also toxic to all aquatic life (WHO 1989a, Sadiq 1992).

A number of regional controls exist on the use of lead in products. EU legislation restricting the use of certain hazardous substances (ROHS) in electrical and electronic equipment, prohibits the use of lead in new equipment put on the market from 1 July 2006 (EC 2002a), with a maximum allowable concentration of 0.1% lead by weight in homogeneous materials. There are certain exemptions including the use of lead in certain solders and in the glass of cathode ray tubes. In addition, legislation addressing waste electrical and electronic equipment (WEEE) specifies that batteries containing more than 0.4% lead by weight must be separated from wastestreams and recycled where appropriate (EC 2002b). In addition, the PVC industry in the EU has a voluntary agreement to phase out lead stabilisers in PVC by 2015 (ENDS 2002).

Mercury

Mercury is used in lighting device that illuminate flat screen displays. It has also been used in switches and relays of older mainframe computers and some older computer may contain batteries containing mercury (OECD 2003).

Releases of mercury can occur during the dismantling of equipment such as flat screen displays. Incineration or landfilling can also result in releases of mercury to the environment (Allsopp *et al.* 2001, OECD 2003). Upon released into the atmosphere, such as from incineration, mercury can travel globally and impact far from the source of its release (UNEP 2002). Subsequent to release, mercury can enter water bodies (either directly or following deposition) and be transformed to methyl mercury, a highly toxic form of mercury that can bioaccumulate and biomagnify (progressively concentrate) to high levels in food chains, particularly in fish. This is the major route of exposure for the general public (WHO 1989b, UNEP 2002). Workers may also be exposed to mercury through inhalation of mercury vapour or dust.

Mercury and its compounds are highly toxic and this metal that has no biochemical or nutritional value (WHO 1989). Inhalation of high levels of mercury vapour may cause a range of effects including impact to the central nervous system (CNS) (ATSDR 2000, Goyer 1996). Long-term exposure to lower levels of mercury vapour can also cause effects on the CNS and kidney damage (Ratcliffe *et al.* 1996, Goyer 1996). These effects have also been reported in animal studies (ATSDR 2000)

For the general population the primary route of exposure is to methyl-mercury through diet (UNEP 2002). This form of mercury can accumulate in the body and the main impact is damage to the nervous system. Methyl-mercury can readily pass through the placental barrier and the blood-brain barrier, and can have adverse effects on the developing brain and central nervous system in foetuses and children, even at levels to which many people are currently exposed (Mahaffey *et al.* 2004, UNEP 2002). Recent research also suggest that exposure can also increase cardiovascular and heart disease (Virtanen *et al.* 2005).

A number of regional controls exist on the use of mercury in products. EU legislation restricting the use of certain hazardous substances (ROHS) in electrical and electronic equipment, prohibits the use of mercury in new equipment put on the market from 1 July 2006 with a maximum concentration of 0.1% by weight in specific materials and components, with certain exceptions for the use of mercury in fluorescent lamps (EC 2002a). Under legislation addressing waste electrical and electronic equipment (WEEE), mercury containing components such as switches or backlighting lamps must be removed from any separately collected WEEE and mercury must be removed from gas discharge lamps (EC 2002b). The use of mercury in products is further addressed under EU legislation, including the prohibiting of marketing batteries and accumulators containing more than 0.0005% of

mercury by weight, other than for button cells with a mercury content of no more than 2% by weight (EC 1998).

In addition, the Ministerial Meeting of the OSPAR convention for the Protection of the Marine Environment of the North-East Atlantic included mercury on the list of chemicals for priority action to achieve cessation of discharges, emissions and losses of all hazardous substances to the marine environment by 2020 - the one generation cessation target (OSPAR 1998).

Brominated flame retardants (BFRs)

Brominated flame retardants (BFRs) are a diverse group of organobromine compounds which are used to prevent combustion and/or retard the spread of flames in a variety of plastics and other materials. Although more than 70 brominated compounds or groups are reportedly in use as BFRs (Lassen *et al.* 1999), three chemical groups dominate current usage; the polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD) and brominated bisphenols, especially tetrabromobisphenol-A (TBBPA). TBBPA is generally used as a reactive component, being chemically bound to the plastic, whereas PBDEs and HBCD are used as additives, simply blended with plastic and therefore more likely to leach out of the products (Alaee *et al.* 2003). In electronics goods TBBPA is used primarily in printed circuit boards that can contain approximately 20% bromine (Alaee *et al.* 2003). PDBEs and TBBPA are also incorporated into plastic casings (OECD 2003). Historically polybrominated biphenyls (PBBs) were also used as flame retardants, though, according to industry, production of these chemicals has now ceased (OSPAR Commission 2004).

Most BFRs are environmentally persistent and some, particularly certain PBDEs, are highly bioaccumulative. However, all those listed above are bioavailable and can be measured in the tissues of wildlife and humans. Indeed, their manufacture has led to their widespread and, in some cases, growing presence in the environment. PBDEs, HBCD and TBBPA have all been detected in indoor air and/or dusts in the workplace (Sjödin *et al.* 2001, Jakobsson *et al.* 2002). PBDEs have also been found in almost all environmental compartments, including sediments (Allchin *et al.* 1999), freshwater and marine fish (Asplund *et al.* 1999a, b), birds eggs (Hites 2004) and even whales from the deep oceans and the Arctic (de Boer *et al.* 1998, Ikonomou *et al.* 2002). Fewer data exist for the other brominated flame retardants in common use.

PBDEs have also been reported as common contaminants in humans, including reports from Sweden, Spain, Finland and North America (Lindstrom *et al.* 1997, Meneses *et al.* 1999, Strandman *et al.* 1999, She *et al.* 2000). Concentrations of PBDEs in human breast milk and blood have shown increasing levels over the last two decades (Alaee *et al.* 2003, Meironyte *et al.* 1999, Thomsen *et al.* 2002), and there is some evidence for a similar trend for TBBPA. In the occupational setting, including electronics recycling, elevated concentrations of PBDEs and TBBPA have been found in the air and

in the blood of workers, which is believed to result from inhalation of contaminated dusts (Sjödin *et al.* 2001, Sjödin *et al.* 2003). For the general population the primary route of exposure is likely to be through foods (especially for the more bioaccumulative PBDEs) though other sources of exposure are also likely to be significant, including direct contact with flame-retarded products through the inhalation of indoor air and/or dusts (Harrad *et al.* 2004).

Knowledge on the long-term, low-dose toxicity for BFRs is generally limited. While the acute toxicity of BFRs is considered to be low, chronic exposure to PBDEs (especially in the womb) has been shown to interfere with brain and skeletal development in animal experiment (Eriksson *et al.* 1999), which may lead to permanent neurological effects such as impaired learning and memory functions, and behavioural effects (Darnerud 2003, Eriksson *et al.* 2001). There is concern over risks for neurobehavioural development in humans through neonatal exposure to PBDEs via mother's milk (Branchi *et al.* 2003). There is also some evidence for PBDE, HBCD and TPPBA being neurotoxic (Mariussen & Fonnum 2003). BFRs can also affect certain hormone systems; metabolites of PBDEs and TBBPA can interfere with thyroid hormones with possible effects on growth and development (Meerts *et al.* 1998, 2001). BFRs are also potential endocrine disruptors of estrogen pathways (Legler & Brouwer 2003). In animal experiments on rodents PDBEs have been found to cause delayed puberty and adverse effects on the liver and on foetal development, as well as effects on the immune system (Birnbaum & Staskal 2004, Darnerud 2003). HBCD also caused adverse effects on the liver in rats (see Alaee *et al.* 2003, Darnerud 2003).

For all BFRs, incineration of wastes containing these compounds contributes to the formation of brominated dioxins and furans, which exhibit equivalent toxicities to their well known chlorinated counterparts (IPCS 1998).

Brominated flame retardants have been included as a group on the list of chemicals for priority action to achieve cessation of discharges, emissions and losses of all hazardous substances to the marine environment by 2020 at the 1998 Ministerial Meeting of the OSPAR convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR 1998). OSPAR has since reviewed opportunities for action for the PBDEs and HBCD, but is awaiting the outcome of assessments within the EU before developing specific measures (OSPAR 2001). No measures in OSPAR have been taken on TBBP-A, though the OSPAR background document recommends substitution with safer chemicals posing less risk to the environment should be encouraged (OSPAR Commission 2004).

EU legislation restricting the use of certain hazardous substances (ROHS) in electrical and electronic equipment prohibits the marketing of new equipment containing PBBs and PBDEs from 1 July 2006 (EC 2002a), with a maximum allowable concentration of 0.1% by weight for each group. An exception for deca-BDE remains under discussion; an EU risk assessment has concluded that controls are not needed, though the EU scientific committee on health and environmental risks (Scher) recently rejected this conclusion and strongly

recommended further risk reduction measures (SCHER 2005). More general EU legislation bans the marketing and use of penta- and octa-BDE in a wider range of products (EU 2003).

Even when national and/or regional bans take effect, however, a substantial legacy of all brominated flame retardants will remain in products still in use and/or in the waste stream. Under EU legislation addressing waste electrical and electronic equipment (WEEE), plastic containing brominated flame retardants have to be removed from any separately collected WEEE (EC 2002b).

Because of its high persistence and propensity to bioaccumulate, penta-BDE is included as a "priority hazardous substance" under the EU Water Framework Directive (EC 2001). Furthermore, in recognition of its "POP-like" properties, penta-BDE is also being considered for addition to the list of persistent organic pollutants (POPs) subject to global control under the 2001 Stockholm Convention developed under the auspices of UNEP (Peltola & Yla-Mononen 2001).

Polyvinyl chloride PVC

Polyvinyl chloride (PVC) is a chlorinated plastic incorporated into some electrical and electronic products, including as insulation on wires and cables (OECD 2003). Both the production of PVC and its disposal by incineration (or simply burning) can result in the generation of chlorinated dioxins and furans. These chemicals are highly persistent in the environment, able to bioaccumulate and many are toxic at very low concentrations (Stringer & Johnston 2001). In addition, many PVC formulations contain additional chemicals; organotin, lead and cadmium based stabilisers, and plasticising (softening) additives in flexible PVC, including phthalates (Matthews 1996). Many additives can be released from PVC during the lifetime of the product and following disposal (Santillo *et al.* 2003). Heavy metals from stabilisers are also released during disposal, particularly through incineration (Allsopp *et al.* 2001).

Phthalates (phthalate esters)

Phthalates are ester derivatives of phthalic acid that are widely used in a range of industrial and consumer applications. Some are marketed and used as discreet chemical products (e.g. the well-known di(ethylhexyl) phthalate or DEHP), while others are complex isomeric mixtures comprising many individual compounds with similar chemical structures (e.g. di-iso-nonyl phthalate, DINP, and di-iso-decyl phthalate, DIDP). As a result of their high volume uses in open applications, they are now among the most ubiquitous man-made chemicals found in the environment (Mayer *et al.* 1972).

Phthalates have a range of applications, dependent on the precise chemical form, although by far their greatest use is as plasticising (softening) additives

in flexible plastics, especially PVC. They are produced in very large quantities, for example in 1997 almost 600 000 tonnes of DEHP were produced in Europe alone (CSTEE 2002). Of the three main phthalates (DEHP, DINP & DIDP), over 90% of use is in a wide range of PVC applications (see e.g. http://www.ecpi.org/plasticisers/index.html). Minor applications include use as components of inks, adhesives, paints, sealants and surface coatings.

All uses of phthalates, especially the major use as PVC plasticisers, result in large-scale losses to the environment (both indoors and outdoors) during the lifetime of products, and again following disposal. Just within the European Union (EU) this amounts to thousands of tonnes per year (CSTEE 2001a). As a consequence, phthalates have long been recognised as one of the most abundant and widespread man-made environmental contaminants (Mayer *et al.* 1972) and human exposure to phthalates is therefore widespread and continuous.

Following release, although some degradation is possible, phthalates are considered to be relatively persistent, especially in soils and sediments. Widespread distribution of phthalates has been documented in all environmental compartments (e.g. see CSTEE 2001b). Because of their extensive use in building materials and household products, phthalates are common contaminants in indoor air (Otake *et al.* 2001), including child day-care centres (Wilson *et al.* 2001, Fromme *et al.* 2004). Phthalates have also been reported as substantial components of house dust, in some cases at more than 1 part per thousand (1g/kg) of the total mass of dust (Butte & Heinzow 2002). PVC products have been shown to emit the phthalates DEHP and DBP (Afshari *et al.* 2004), and in one study the concentration of butyl benzyl phthalate (BBzP) and DEHP in dust samples from homes correlated with the amount of PVC flooring in the homes (Bornehag *et al.* 2004).

Phthalates also have the inherent ability to accumulate in biological tissues, although continuous exposure also contributes to body burden levels. Studies in many countries have found phthalates and their primary metabolites in the human body (Colon *et al.* 2000, Blount *et al.* 2000). In a US study, metabolites of phthalates were found in more than 75% of human urine samples analysed, demonstrating widespread exposure to phthalates, specifically diethyl phthalate (DEP), dibutyl phthalate (DBP) or diisobutylphthalate, benzylbutyl phthalate and DEHP (Silva *et al.* 2004). Another study detected phthalates in samples of urine from pregnant women in New York and Krakow, Poland, and found that inhalation of air was an important route of exposure to phthalates (Adibi *et al.* 2003).

Substantial concerns exist with regard to the toxicity of phthalates to wildlife and to humans, although the precise mechanisms and levels of toxicity vary from one compound to another. In many cases it is the metabolites of the phthalates which are responsible for the greatest toxicity (e.g. Dalgaard *et al.* 2001). For humans, although substantial exposure can occur through food, direct exposure to phthalates from consumer products and/or medical devices

is likely to be very significant. Perhaps the best-known example is the exposure of children to phthalates used in soft PVC teething toys (see e.g. Stringer *et al.* 2000), now subject to controls within Europe (see below).

DEHP, one of the most widely used phthalates, is a known reproductive toxin, interfering with testes development in mammals, and is classified in the EU as "toxic to reproduction". Indeed, its toxicity to the developing male reproductive system has been recognised for more than 50 years (Park *et al.* 2002). In animal studies DEHP has also been found to have adverse effects on female reproduction in adult rats, and has adverse impacts on development of the young (Lovekamp-Swan & Davis 2003). Observed toxicity is due mainly to the compound MEHP, formed in the body as a metabolite of DEHP, and appears to impact on many aspects of development and liver function, including hormone metabolism and immune function (Dalgaard *et al.* 2001, Wong and Gill 2002). Other animal studies have reaffirmed the reproductive toxicity of DEHP and several other commonly used phthalates, including butyl benzyl phthalate (BBzP) and dibutyl phthalate (DBP) (Ema & Miyawaki 2002, Mylchreest *et al.* 2002). Animal data also indicate that BBzP, DBP, DEHP and MEHP can damage the testes and decrease sperm production (Duty *et al.* 2003). As for DEHP, DBP is classified in the EU as "toxic to reproduction".

Reproductive toxicity is generally thought to be of lower concern for the other widely used phthalates DINP and DIDP, although there is evidence for abnormal sexual development in rats exposed to DINP (Gray *et al.* 2000) and that this phthalate is weakly oestrogenic (Harris *et al.* 1997). Other concerns for DINP and DIDP relate primarily to toxic effects on the liver and kidney.

In the indoor environment, correlations have been reported between incidence of bronchial obstruction (asthma) in children and the abundance of phthalate-containing materials in the home (Oie *et al.* 1997). Levels of phthalates in house dust, in the range normally found in the indoor environment, have also been associated with allergic symptoms in children including rhinitis, eczema and asthma (Bornehag *et al.* 2004). In adults, exposure to certain phthalates (DBP and DEP) has been reported to be associated with adverse impacts on some measures of pulmonary (lung) function in men, though not women (Hoppin *et al.* 2004).

At present, there are few controls on the marketing and use of phthalates, despite their toxicity, the volumes used and their propensity to leach out of products throughout their lifetime. Of the controls which do exist, probably the best known is the EU-wide emergency ban on the use of six phthalates in children's toys designed to be chewed (first agreed in 1999 and then continuously renewed to date, EC 2004). While this ban addressed one important exposure route, exposures through other consumer products remain unaddressed.

In 1998, the Ministerial Meeting of OSPAR convention for the Protection of the Marine Environment of the North-East Atlantic agreed on the target of cessation of discharges, emissions and losses of all hazardous substances to the marine environment by 2020 (the "one generation" cessation target), and

included the phthalates DBP and DEHP on the first list of chemicals for priority action towards this target (OSPAR 1998). DEHP is also proposed as a "priority hazardous substance" under the EU Water Framework Directive (EU 2001), such that action to prevent releases to water within 20 years will be required throughout Europe.

Organotins

Organotins are organic compounds containing at least one bond between carbon and the metal tin. By far the best known is tributyltin (TBT) which, as a result of its widespread use in antifouling paints on ships and boats, has led to widespread changes in sexual development in marine snails. However, several other organotin compounds are in common use, most notably mono- and dibutyltin (MBT, DBT), mono- and dioctyl tin (MOT, DOT) and triphenyltins (TPT).

Although antifouling paints have accounted for the majority of TBT used, this compound is also used as an antifungal agent in some consumer products, including certain PVC (vinyl) flooring (Allsopp *et al.* 2000, Oeko-Test 2000). In consumer products the most abundant organotins are MBT and DBT, used as heat stabilisers in rigid PVC (pipes, panels) and soft (wall-coverings, furnishings, flooring, toys) PVC products and in certain glass coating applications (Matthews 1996). Use in PVC represents about two-thirds of the global consumption of these compounds (Sadiki & Williams 1999), which can comprise up to 2% by weight of the finished product. Mono- and dioctyl tins (MOT, DOT) are also used as PVC stabilisers, primarily in food contact applications, with levels up to the g/kg range reported for MOT in PVC containers (Kawamura *et al.* 2000).

Much of the research describing the environmental distribution of organotin compounds has, understandably, focused on the spread of TBT and its break-down products (including DBT) in the marine environment. The global use of TBT antifouling paints has resulted in contamination on a global scale with devastating impacts on populations of oysters and other marine molluscs (Santillo *et al.* 2001a). The relative persistence of butyl tins, combined with their affinity for biological tissues, has led to their widespread occurrence in fish, seals, whales and dolphins in all major sea areas (Iwata *et al.* 1995, Kannan *et al.* 1996, Ariese *et al.* 1998). Much less information is available concerning the distribution of organotins in other environmental compartments. In one of the few studies which have been conducted, Takahashi *et al.* (1999) reported butyltin residues in the livers of monkeys and other mammals in Japan, as well as in human livers, and suggested that uses in consumer products may represent an important exposure route. It has been recognised for some time that butyltin stabilisers can migrate from PVC used in such products during normal use (Sadiki & Williams 1999) and such uses undoubtedly contribute to the widespread presence of organotin compounds in dusts from the indoor environment (see e.g. Santillo *et al.* 2001b).

Organotins are known to be toxic at relatively low levels of exposure, not only to marine invertebrates but also for mammals. In marine invertebrates, TBT is generally more toxic than DBT, which is in turn more toxic than MBT (Cima *et al.* 1996). However, this is by no means always the case; DBT is more toxic than TBT to certain marine organism enzyme systems (Al-Ghais *et al.* 2000) and is frequently a more potent toxin than TBT in fish (O'Halloran *et al.* 1998), with the immune system the primary target.

Organotins have also been demonstrated to have immunotoxic and teratogenic (developmental) properties in mammalian systems (Kergosien & Rice 1998), again with DBT frequently more toxic than TBT (Ema *et al.* 1995). DBT and TBT have been reported to inhibit cells of the immune system (natural killer cells) *in vitro*, at concentrations similar to levels that have been detected in human blood (Jenkins *et al.* 2004). DBT is neurotoxic to mammalian brain cells (Eskes *et al.* 1999). Recently neurotoxicity has been reported at levels lower than those that have been detected in human blood samples (Jenkins *et al.* 2004), suggesting that chronic exposure to low levels of DBT in the human population may be neurotoxic. DBT was also found to cause an increased incidence of cell death (apoptosis) in certain brain tissues of rats exposed during development (Jenkins *et al.* 2004). Exposure of animals to trimethyltin (TMT) during development can cause impaired learning and memory (Jenkins & Barone 2004). Toxic effects on testes development in mice have also been reported (Kumasaka *et al.* 2002).

Both animal studies and human studies have demonstrated that acute exposure to organotins can result in neurotoxicity or immunotoxicity. For example, acute human exposure to high doses of trimethyltin due to accidental poisoning has resulted in memory deficits, seizures, hearing loss, disorientation and death (Jenkins *et al.* 2004). While seafood probably remains the predominant source of organotin exposure for many consumers, exposure to consumer products which contain them, or to dusts in the home, may also be significant.

To date, legislative controls on organotin compounds have focused primarily on TBT in antifouling paints. In the European Union (EU) the use on vessels less than 25m has been banned since 1991 (Evans 2000). More recently, the International Maritime Organisation (IMO) agreed on a global phase-out of all TBT applications (from January 2003) and TBT presence on ships (from 2008) under its Convention on Harmful Anti-fouling Systems (see www.imo.org).

However, despite the toxicity to mammals noted above, TBT continues to be used as an additive in some consumer products, as do uses of other butyltins and octyltins. For example, within the EU organotin compounds must not be used for certain textiles to qualify for an "eco-label" (EU 2002), but there are otherwise no restrictions on their use unless the treated materials or products are used in contact with water. This is despite the fact that TBT is classified under the EU's labelling Directive as "harmful in contact with skin, toxic if swallowed, irritating to the eyes and skin" and as presenting a "danger of

serious damage to health by prolonged exposure through inhalation or if swallowed".

In 1998, the Ministerial Meeting of the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic agreed on the target of cessation of discharges, emissions and losses of all hazardous substances to the marine environment by 2020 (the "one generation" cessation target) and included organotin compounds on the first list of chemicals for priority action towards this target (OSPAR 1998). While initial action focused on the achievement of the IMO Convention on Harmful Antifoulants (OSPAR 2000), in 2001 OSPAR began to consider the scope for action on other uses and other organotin compounds, including the widespread use of butyltin stabilisers, though so far, no further measures are proposed.

References

Adibi J.J., Perera F.P., Jedrychowski W., Camann D.E., Barr D. & Jacek R. (2003) Prenatal exposure to phthalates among women in New York City and Krakow, Poland. Environmental Health Perspectives 111 (14): 1719-1722

Afshari A., Gunnarsen L., Clausen P.A. & Hansen V. (2004) Emission of phthalates from PVC and other materials. Indoor Air 14 (2): 120-128

Alaee M., Arias P., Sjödin A & Bergman A. (2003). An overview of commercially used brominated flame retardants, their applications, their use patterns in different countries/regions and possibly modes of release. Environment International 29 (6): 683-689

Al-Ghais, S.M. & Ahmad, A.B. (2000) Differential inhibition of xenobiotic-metabolizing carboxylesterases by organotins in marine fish. Ecotoxicology and Environmental Safety 46(3): 258-264

Allchin, C. & Morris, S. (2002) The determination and occurrence of three groups of brominated flame retardants (polybrominated diphenyl ethers, tetrabromobisphenol A and hexabromocyclododecane) in samples of aquatic origin from the UK. In: Readman, J.; Worsfold, P., eds. Proceedings of ISEAC 32, International Symposium on the Environment and Analytical Chemistry, Plymouth, 17-20 June 2002: 15

Allsopp, M., Santillo, D. & Johnston, P. (2000). Hazardous chemicals in PVC flooring. Greenpeace Research Laboratories Technical Note 14/00, November 2000: 10 pp. [published under cover title "Poison Underfoot: Hazardous Chemicals in PVC Flooring and Hazardous Chemicals in Carpets, ISBN 90-73361-68-0]

Allsopp, M., Costner, P. & Johnston, P. (2001). Incineration and Human Health: State of knowledge of the impacts of waste incinerators on human health. Publ. Greenpeace International, Amsterdam, ISBN 90-73361-69-9: 81 pp.

Ariese, F., van Hattum, B., Hopman, G., Boon, J. & ten Hallers-Tjabbes, C. (1998) Butyltin and phenyltin compounds in liver and blubber samples of sperm whales (*Physeter macrocephalus*) stranded in the Netherlands and Denmark.. Institute for Environmental Studies, Vrije Universiteit, Amsterdam, Report W98-04, March 1998

Asplund, L., Athanasiadou, M., Sjödin, A., Bergman, Å. & Borjeson, H. (1999b) Organohalogen substances in muscle, egg and blood from healthy Baltic salmon *(Salmo salar*) and Baltic salmon that produced offspring with the M74 syndrome. Ambio 28(1): 67-76

Asplund, L., Hornung, M., Peterson, R.E, Turesson, K. & Bergman, Å. (1999a) Levels of polybrominated diphenyl ethers (PBDEs) in fish from the Great Lakes and Baltic Sea. Organohalogen Compounds 40:351-354

ASTDR (2000) Toxicological profile for cadmium on CD-ROM. Agency for Toxic Substances and Disease Registry

Balkissoon, R. C. & Newman, L. S. (1999) Beryllium copper alloy (2%) causes chronic beryllium disease. Journal of Occupational & Environmental Medicine 41(4): 304-308

Basel (2004) Technical guidelines on the environmentally sound recycling/reclamation of metals and metal compounds (R4). Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, UNEP/CHW.7/8/Add.3. Available www.basel.int/meetings/cop/cop7/docs/08a3e.pdf

Belfroid, A.C., Purperhart, M. & Ariese, F. (2000) Organotin levels in seafood. Marine Pollution Bulletin 40(3): 226-232

Bellinger, D. & Dietrich, K.N. (1994) Low-level lead exposure and cognitive functioning in children. Pediatric Annals 23: 600-605

Birnbaum L.S & Staskal D.F. (2004). Brominated flame retardants: cause for concern? Environmental Health Perspectives 112 (1): 9-17

Blount, B.C., Silva, M.J., Caudill, S.P., Needham, L.L., Pirkle, J.L., Sampson, E.J., Lucier, G.W., Jackson, R.J. & Brock, J.W. (2000) Levels of seven urinary phthalate metabolites in a human reference population. Environmental Health Perspectives 108(10): 979-982

Bornehag C-G., Sundell J., Weschler C.J., Sigsgaard T., Lundgren B., Hasselgren M. & Hägerhed-Engman L. (2004) The association between asthma and allergic symptoms in children and phthalates in house dust: a nested case-control study. Environmental Health Perspectives 112 (14): 1393-1397

Branchi I., Capone F., Alleva E. & Costa L.G. (2003). Polybrominated Diphenyl ethers: neurobehavioural effects following developmental exposure. NeuroToxicology 24 (3): 449-462

Butte, W. & Heinzow, B. (2002) Pollutants in house dust as indicators of indoor contamination. Reviews in Environmental Contamination and Toxicology 175: 1-46

Canfield, R.L., Henderson, C.R., Cory-Slechta, D.A., Cox, C., Jusko, T.A., Lanphear, B.P. (2003) Intellectual impairment in children with blood lead concentrations below 10 mu g per deciliter. New England Journal of Medicine 348(16): 1517-1526

Cima, F., Ballarin, L., Bressa, G., Martinucci, G. & Burighel, P. (1996) Toxicity of organotin compounds on embryos of a marine invertebrate (*Styela plicata*; Tunicata). Ecotoxicology and Environmental Safety 35(2): 174-182

Cohen, B.S. & Positano, R. (1986) Resuspension of dust from work clothing as a source of inhalation exposure. American Industrial Hygiene Association Journal 47(5): 255-258

Colon, I., Caro, D., Bourdony, C.J. & Rosario, O. (2000) Identification of phthalate esters in the serum of young Puerto Rican girls with premature breast development. Environmental Health Perspectives 108(9): 895-900

CSTEE (2001a) EC Scientific Committee on Toxicity, Ecotoxicity and the Environment, Opinion on the results of the Risk Assessment of: 1,2-Benzenedicarboxylic acid, di-C8-10-branched alkyl esters, C9-rich and di-"isononyl" phthalate - Report version (Human Health Effects): Final report, May 2001. Opinion expressed at the 27th CSTEE plenary meeting, Brussels, 30 October 2001: 7 pp. http://europa.eu.int/comm/food/fs/sc/sct/out120_en.pdf

CSTEE (2001b) EC Scientific Committee on Toxicity, Ecotoxicity and the Environment, Opinion on the results of the Risk Assessment of: 1,2-Benzenedicarboxylic acid, di-C8-10-branched alkyl esters, C9-rich and di-"isononyl" phthalate - Report version (Environment): Final report, May 2001. Opinion expressed at the 27th CSTEE plenary meeting, Brussels, 30 October 2001: 5 pp. http://europa.eu.int/comm/food/fs/sc/sct/out122_en.pdf

CSTEE (2002) EC Scientific Committee on Toxicity, Ecotoxicity and the Environment, Opinion on the results of the Risk Assessment of Bis (2-ethylhexyl) phthalate (DEHP). Report version: Human Health, September 2001. Opinion expressed at the 29th CSTEE plenary meeting, Brussels, 09 January 2002: 8 pp. http://europa.eu.int/comm/food/fs/sc/sct/out141_en.pdf

Cullen, M.R., Kominsky, J.R., Rossman, M.D., Cherniack, M.G., Rankin, J.A., Balmes, J.R., Kern, J.A., Daniele, R.P., Palmer, L., Naegel, G.P., McManus, K. & Cruz R. (1987) Chronic beryllium disease in a precious metal refinery: clinical, epidemiologic and immunologic evidence for continuing risk from exposure to low level beryllium fume. American Review of Respiratory Disease 135:201-209

Dalgaard, M., Nellemann, C., Lam, H.R., Sorensen, I.K. & Ladefoged, O. (2001) The acute effects of mono(2-ethylhexyl)phthalate (MEHP) on testes of prepubertal Wistar rats. Toxicology Letters 122: 69-79

Darnerud P.O. (2003). Toxic effects of brominated flame retardants in man and in wildlife. Environment International 29 (6): 841-853

de Boer, J., Wester P.G., Klamer H.J.C., Lewis, W.E. & Boon J.P. (1998) Do flame retardants threaten ocean life? Nature 394 (2 July): 28-29 DHHS (2002) 10th Report on Carcinogens.

U.S. Department of Health and Human Services, US Public Health Service, National Toxicology Program

Duty, S.M., Singh, N.P., Silva, M.J., Barr, D.B., Brock, J.W., Ryan, L., Herrick, R.F., Christiani, D.C. & Hauser, R. (2003) The relationship between environmental exposures to phthalates and DNA damage in human sperm using the neutral comet assay. Environmental Health Perspectives 111 (9): 1164-1169

EC (1998) Commission Directive 98/101/EC of 22 December 1998 adapting to technical progress Council Directive 91/157/EEC on batteries and accumulators containing certain dangerous substances. Official Journal L 001, 05/01/1999: 1-2

EC (2001) Decision No 2455/2001/EC of the European Parliament and of the Council of 20 November 2001 establishing the list of priority substances in the field of water policy and amending Directive 2000/60/EC, Official Journal L 249, 17/09/2002: 27-30

EC (2002a) Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. Official Journal L 037, 13/02/2003: 19-23

EC (2002b) Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE) - Joint declaration of the European Parliament, the Council and the Commission relating to Article 9. Official Journal L 037, 13/02/2003: 24–39

EC (2003) Directive 2003/11/EC of the European Parliament and of the Council of 6 February 2003 amending for the 24th time Council Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations (pentabromodiphenyl ether, octabromodiphenyl ether), Official Journal L 42, 15/02/2003: 45-46

EC (2004) Commission Decision 2004/781/EC amending Decision 1999/815/EC concerning measures prohibiting the placing on the market of toys and childcare articles intended to be placed in the mouth by children under three years of age made of soft PVC containing certain phthalates. Official Journal L 344, 20.11.2004: 35-36

EEC (1991) Directive 91/338/EEC of 18 June 1991 amending for the 10th time Directive 76/769/EEC on the approximation of the laws, regulations and administrative provisions of the Member States relating to restrictions on the marketing and use of certain dangerous substances and preparations. Official Journal L 186, 12/07/1991: 59-63

Elinder, C.G. and Jarup, L. (1996) Cadmium exposure and health risks: recent findings. Ambio 25, 5: 370-373

Ema, M., Kurosaka, R., Amano, H. & Ogawa, Y. (1995) Comparative developmental toxicity of butyltin trichloride, dibutyltin dichloride and tributyltin chloride in rats. Journal of Applied Toxicology 15(4): 297-302

Ema, M. & Miyawaki, E. (2002) Effects on development of the reproductive system in male offspring of rats given butyl benzyl phthalate during late pregnancy. Reproductive Toxicology 16: 71-76

ENDS (2002) PVC Industry agrees to phase out lead stabilisers by 2015. The ENDS Report No. 328, May 2002, 31-32

Eriksson, P., Viberg, H., Ankarberg, E., Jakobsson, E., Örn, U. & Fredriksson, A. (2001) Polybrominated diphenylethers (PBDEs): a novel class of environmental neurotoxicants in our environment. In: Asplund, L.; Bergman, Å.; de Wit, C., *et al.* eds. Proceedings of the Second International Workshop on Brominated Flame Retardants, BFR 2001, Stockholm, May 14-16 2001: 71-73

Eskes, C., Honegger, P., Jones-Lepp, T., Varner, K., Matthieu, J.M. & Monnet-Tschudi, F. (1999) Neurotoxicity of dibutyltin in aggregating brain cell cultures. Toxicology *In Vitro* 13(4-5): 555-560

Evans, S.M. (2000) Marine antifoulants. In: C. Sheppard [Ed.], Seas at the Millenium: An Environmental Evaluation, Volume III: Global Issues and Processes, Elsevier Science Ltd, Oxford, ISBN: 0-08-043207-7, Chapter 124: 247-256

Field S. (2001) Toxic Beryllium: New Solutions for a chronic problem. Environmental Health Perspectives 109(2): A74-A79

Fromme H., Lahrz T., Piloty M., Gebhart H., Oddoy A. & Rüden H. (2004) Occurrence of phthalates and musk fragrances in indoor air and dust from apartments and kindergartens in Berlin (Germany). Indoor Air 14 (3): 188-195

Goyer, R.A. (1993) Lead toxicity: current concerns. Environmental Health Perspectives 100: 177-187

Goyer, R.A. (1996) Toxic effects of metals. In Casarett & Doull's Toxicology. The Basic Science of Poisons, Fifth Edition, Klaassen, C.D. [Ed]. McGraw-Hill Health Professions Division, ISBN 0071054766

Gray, L.E., Ostby, J., Furr, J., Price, M., Veeramachaneni, D.N.R. & Parks, L. (2000) Perinatal exposure to the phthalates DEHP, BBP and DINP, but not DEP, DMP or DOTP, alters sexual differentiation of the male rat. Toxicological Sciences 58(2): 350-365

Gupta, B.N., Rastogi, S.K., Husain, T., Mathur, N., Pangtey, B.S. (1991) A study of respiratory morbidity and pulmonary-function among solderers in the electronics industry. American Industrial Hygiene Association Journal 52(2): 45-51

Harrad S., Wijesekera R., Hunter S., Halliwell C. & Baker R. (2004). Preliminary assessment of UK human dietary and inhalation exposure to polybrominated dipehyl ethers. Environmental Science and Technology 38 (8): 2345-2350

Harris C.A., Henttu, P., Parker, M.G. & Sumpter, J.P. (1997) The estrogenic activity of phthalate esters in vitro Environmental Health Perspectives 105 (8): 802-811

Hellstrom, L., Elinder, C.G., Dahlberg, B.,Lundberg, M., Jarup, L., Persson, B., & Axelson, O. (2001) Cadmium Exposure and End-Stage Renal Disease. American Journal of Kidney Diseases, 38(5), 1001-1008

Hites R.A. (2004). Polybrominated Diphenyl ethers in the environment and in people: A meta-analysis of concentrations. Environment, Science and Technology 38 (4): 945-956

Hoppin J.A., Ulmer R. & London S.J. (2004) Phthalate exposure and pulmonary function. Environmental Health Perspectives 112 (5): 571-574

Ikonomou, M.G., Rayne, S. & Addison, R.F. (2002) Exponential increases of the brominated flame retardants, polybrominated diphenyl ethers, in the Canadian Arctic from 1981 to 2000. Environmental Science and Technology 36(9): 1886-1892

Infante, P.I. & Newman, L.S. (2004) Beryllium exposure and chronic beryllium disease. The Lancet 363: 415-416

International Agency for Research on Cancer, IARC (1990) Chromium. In International Agency for Research on Cancer (IARC) monograph; Chromium, Nickel and Welding. IARC monograph, Vol. 49, 677pp ISBN 9283212495

International Agency for Research on Cancer, IARC (1993) Beryllium and Beryllium Compounds. In International Agency for Research on Cancer (IARC) monograph; Beryllium, Cadmium, Mercury, and Exposures in the Glass Manufacturing. IARC monograph, Vol. 58, 444pp ISBN 9283212584

IPCS (1998) Polybrominated dibenzo-p-dioxins and dibenzofurans, Environmental Health Criteria, No. 205, International Programme on Chemical Safety, UNEP/ILO/WHO, ISBN 92 4 157205 1: 303 pp.

Iwata, H., Tanabe, S., Mizuno, T. & Tatsukawa, R. (1995) High accumulation of toxic butyltins in marine mammals from Japanese coastal waters. Environmental Science and Technology 29: 2959-2962

Jakobsson, K., Thuresson, K., Rylander, L., Sjödin, A., Hagmar, L. & Bergman, Å. (2002) Exposure to polybrominated diphenyl ethers and tetrabromobisphenol A among computer technicians. Chemosphere 46(5): 709-716

Jenkins, S.M. & Barone, S. (2004) The neurotoxicant trimethyltin induces apoptosis via capase activation, p38 protein kinase, and oxidative stress in PC12 cells. Toxicology Letters 147 (1): 63-72

Jenkins, S.M., Ehman, K. & Barone, S. (2004) Structure-activity comparison of organotin species: dibutyltin is a developmental neurotoxicant in vitro and in vivo. Developmental Brain Research 151 (1-2): 1-12

Kannan, K., Corsolini, S., Focardi, S., Tanabe, S. & Tatsukawa, R. (1996) Accumulation pattern of butyltin compounds in dolphin, tuna and shark collected from Italian coastal waters. Archives of Environmental Contamination and Toxicology 31: 19-23

Kawamura, Y., Machara, T., Suzuki, T. & Yamada, T. (2000) Determination of organotin compounds in kitchen utensils, food packages and toys by gas chromatography/atomic emission detection method. Journal of the Food Hygienic Society of Japan 41(4): 246-253

Kelleher, P.C., Martyny, J.W., Mroz, M.M., Maier, L.A., Ruttenber, A.J., Young, D.A. & Newman, L.S. (2001) Beryllium particulate exposure and disease relations in a beryllium machining plant. Journal of Occupational & Environmental Medicine 43(3): 238-249

Kergosien, D.H. & Rice, C.D. (1998) Macrophage secretory function is enhanced by low doses of tributyltin-oxide (TBTO), but not tributyltin-chloride (TBTCl). Arc. Environ. Contam. Toxicol. 34: 223-228

Knishkowy, B. & Baker, E.L. (1986) Transmission of occupational disease to family contacts. American Journal of Industrial Medicine 9(6): 543-550

Kolanz, M.E. (2001) Introduction to Beryllium: Uses, Regulatory History, and Disease. Applied Occupational and Environmental Hygiene 16(5): 559-567

Kumasaka, K., Miyazawa, M., Fujimaka, T., Tao, H., Ramaswamy, B.R., Nakazawa, H., Makino, T. & Satoh, S. (2002) Toxicity of the tributyltin compound on the testis in premature mice. Journal of Reproduction and Development 48(6): 591-597

Lovekamp-Swan T. & Davis B.J. (2003) Mechanisms of phthalate ester toxicity in the female reproductive system. Environmental Health Perspectives 111 (2): 139-145

Lassen, C., Lokke, S. & Hansen, L.I. (1999) Brominated Flame Retardants: substance flow analysis and substitution feasibility study. Danish Environmental Protection Agency Environmental Project No. 494, Copenhagen, ISBN 87-7909-415-5: 240 pp.

Legler J. & Brouwer A. (2003). Are brominated flame retardants endocrine disruptors? Environmental International 29 (6): 879-885

Lindstrom, G., van Bavel, B., Hardell, L. & Liljegren, G. (1997) Identification of the flame retardants polybrominated diphenyl ethers in adipose tissue from patients with non-Hodgkin's lymphoma in Sweden. Oncology Reports 4(5): 999-1000

Mahaffey, K.R., Clickner, R.P. & Bodurow, C.C. (2004) Blood Organic Mercury and Dietary Mercury Intake: National Health and Nutrition Examination Survey, 1999 and 2000. Environmental Health Perspectives 112(5): 562-570

Malcoe, L.H., Lynch, R.A., Kegler, M.C. & Skaggs, V.J. (2002) Lead sources, behaviors, and socioeconomic factors in relation to blood lead of native American and white children: A community-based assessment of a former mining area Environmental Health Perspectives 110 (Supplement 2): 221-231

Mangialardi, T., Piga, L., Schena, G. & Sirini, P. (1998) Characteristics of MSW incinerator ash for use in concrete. Environmental Engineering Science 15(4): 291-297

Mariussen E. & Fonnum F. (2003). The effect of brominated flame retardants on neurotransmitter uptake into rat brain synaptosomes and vesicles. Neurochemistry International 43 (4-5):533-542

Matthews, G. (1996) PVC: production, properties and uses. Publ: The Institute of Materials, London.

Mayer, F.L., Stalling, D.L. & Johnson, J.L. (1972) Phthalate esters as environmental contaminants. Nature 238: 411-413

Meerts, I.A.T.M., Marsh, G., van Leeuwen-Bol, I., Luijks, E.A.C., Jakobsson, E., Bergman, Å. & Brouwer, A. (1998) Interaction of polybrominated diphenyl ether metabolites (PBDE-OH) with human transthyretin *in vit*ro. Organohalogen Compounds 37: 309-312

Meerts, I.A.T.M., Letcher, R.J., Hoving, S., Marsh, G., Bergman, Å., Lemmen, J.G., van der Burg, B. & Brouwer, A. (2001) *In vitro* estrogenicity of polybrominated diphenyl ethers, hydroxylated PBDEs and polybrominated bisphenol A compounds. Environmental Health Perspectives 109(4): 399-407

Meironyte, D., Noren, K. & Bergman, Å. (1999) Analysis of polybrominated diphenyl ethers in Swedish human milk. A time-related trend study, 1972-1997. Journal of Toxicology and Environmental Health - Part A 58(6): 329-341

Meneses, M., Wingfors, H., Schuhmacher, M., Domingo, J.L., Lindstrom, G. & von Bavel, B. (1999) Polybrominated diphenyl ethers detected in human adipose tissue from Spain. Chemosphere 39(13): 2271-2278

Mukherjee, A.B. (1998) Chromium in the environment of Finland. The Science of the Total Environment 217: 9-19

Musson, S.E., Jang, Y.C., Townsend, T.G., Chung, I.H. (2000) Characterization of lead leachability from cathode ray tubes using the toxicity characteristic leaching procedure. Environmental Science & Technology 34(20): 4376-4381

Mylchreest, E., Sar, M., Wallace, D.G. & Foster, P.M.D. (2002) Fetal testosterone insufficiency and abnormal proliferation of Leydig cells and gonocytes in rats exposed to di(n-butyl) phthalate. Reproductive Toxicology 16: 19-28

Newman, L.S. (1995) Beryllium disease and sarcoidosis: clinical and laboratory links. Sarcoidosis 12: 7-19

Newman, L.S., Lloyd, J. & Daniloff, E. (1996) The natural history of beryllium sensitization and chronic beryllium disease. Environmental Health perspectives 104 (Supplement 5): 937-943

Oie, L., Hersoug, L.G. & Madsen, J.O. (1997) Residential exposure to plasticizers and its possible role in the pathogenesis of asthma. Environmental Health Perspectives 105 (9): 972-978

O'Halloran, K., Ahokas, J.T. & Wright, P.F.A. (1998) Response of fish immune cells to *in vitro* organotin exposures. Aquatic Toxicology 40(2-3): 141-156

OECD (2003) Technical guidance for the environmentally sound management of specific waste streams: used and scrap personal computers. Organisation for Economic Co-operation and Development (OECD) Working Group on Waste Prevention and Recycling. ENV/EPOC/WGWPR(2001)3/FINAL.

Oeko-Test (2000) Sondermüll im Haus. öko-test magazine 5/2000: 74-79

OSPAR (1998) OSPAR Strategy with Regard to Hazardous Substances, OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, OSPAR 98/14/1 Annex 34

OSPAR (2000) OSPAR Background Document on Organic Tin Compounds, OSPAR Priority Substances Series, OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, OSPAR Commission, London, ISBN 0-946956-56-1: 16pp.

OSPAR (2001) Certain Brominated Flame Retardants – Polybrominated Diphenylethers, Polybrominated Biphenyls, Hexabromocyclododecane, OSPAR Priority Substances Series, OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, OSPAR Commission, London: 25pp.

OSPAR (2004) OSPAR Commission 2001 (updated 2004). Background document on certain brominated flame retardants – polybrominated diphenylethers, polybrominated biphenyls, hexabromo cyclododecane. ISBN 0 946956 78 2

Otake, T., Yoshinaga, J. & Yanagisawa, Y. (2001) Analysis of organic esters of plasticizer in indoor air by GC-MS and GC-FPD. Environmental Science and Technology 35(15): 3099-3102

Park, J.D., Habeebu, S.S.M. & Klaassen, C.D. (2002) Testicular toxicity of di-(2-ethylhexyl)phthalate in young Sprague-Dawley rats. Toxicology 171: 105-115

Peltola, J. & Yla-Mononen, L. (2001) Pentabromodiphenyl ether as a global POP. TemaNord 2001:579, Nordic Council of Ministers, Copenhagen, ISBN 92-893-0690-4: 78 pp.

Ratcliffe, H.E., Swanson, G.M. and Fischer, L.J. (1996). Human exposure to mercury: a critical assessment of the evidence of adverse health effects. Journal of Toxicology and Environmental Health 49: 221-270

Sadiki, A-I. & Williams, D.T. (1999) A study on organotin levels in Canadian drinking water distributed through PVC pipes. Chemosphere 38 (7): 1541-1548

Sadiq, M. (1992) Toxic metal chemistry in marine environments. Marcel Dekker Inc., New York, Basel, Hong Kong. ISBN 0824786475

Salomons, W. and Forstner, U. (1984) Metals in the hydrocycle. Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, ISBN 3540127550

Sanderson, W.T., Henneberger, P.K., Martyny, J., Ellis, K., Mroz, M.M. & Newman L.S. (1999) Beryllium contamination inside vehicles of machine shop workers. Applied Occupational and Environmental Hygiene 14(4): 223-230

Santillo, D., Johnston, P. & Langston, W.J. (2001a) Tributyltin (TBT) antifoulants: a tale of ships, snails and imposex. Chapter 13 in: P. Harremoës, D. Gee, M. MacGarvin, A. Stirling, J. Keys, B. Wynne, S.G. Vaz [eds], *Late Lessons from Early Warnings: the precautionary principle 1896-200*0, European Environment Agency Environmental Issue Report No 22, Office for Official Publications of the European Communities, Luxembourg, ISBN 92-9167- 323-4: 135-148

Santillo, D., Johnston, P. & Brigden, K. (2001b) The presence of brominated flame retardants and organotin compounds in dusts collected from Parliament buildings from eight countries. Greenpeace Research Laboratories Technical Note 03/2001, March 2001: 24 pp.

Santillo, D., Labunska, I., Davidson, H., Johnston, P., Strutt, M. & Knowles, O. (2003). Consuming Chemicals: Hazardous Chemicals in house dust as an indicator of chemical exposure in the home: Part I - UK. Greenpeace Research Laboratories Technical Note 01/2003, April 2003: 74 pp.

Sauve, S., McBride, M.B. & Hendershot, W.H. (1997) Speciation of lead in contaminated soils. Environmental Pollution 98(2): 149-155

Schuler, C.R., Kent, M.S., Deubner, D.C., Berakis, M.T., McCawley, M., Henneberger, P.K., Rossman, M.D. & Kreiss, K. (2005) Process-related risk of beryllium sensitization and

disease in a copper-beryllium alloy facility. American Journal of Industrial Medicine 47(3): 195-205

Schutz, A., Olsson, M., Jensen, A., Gerhardsson, L., Borjesson, J., Mattsson, S., Skerfving, S. (2005) Lead in finger bone, whole blood, plasma and urine in lead-smelter workers: extended exposure range. International Archives of Occupational and Environmental Health 78(1): 35-43

Scientific Committee on Health and Environmental Risks, SCHER (2005) Opinion on "Update of the risk assessment of bis(pentabromophenyl) ether (decabromodiphenyl ether)", 18th March 2005. Available; http://europa.eu.int/comm/health/ph_risk/committees/04_scher/docs/scher_o_012.pdf

She, J., Winkler, J., Visita, P., McKinney, M. & Petreas, M. (2000) Analysis of PBDEs in seal blubber and human breast adipose tissue samples. Organohalogen Compounds 47: 53-56

Silva M.J., Barr D.B., Reidy J.A., Malek N.A., Hodge C.C., Caudill S.P., Brock J.W., Needham L.L. & Calafat A.M. (2004) Urinary levels of seven phthalate metabolites in the U.S. population from the National Health and Nutrition Examination Survey (NHANES) 1999-2000. Environmental Health Perspectives 112 (3): 331-338

Sjödin, A., Carlsson, H., Thuresson, K., Sjolin, S., Bergman, Å. & Ostman, C. (2001) Flame retardants in indoor air at an electronics recycling plant and at other work environments. Environmental Science and Technology 35(3): 448-454

Sjödin A., Patterson D.G. and Bergman A. (2003). A review on human exposure to brominated flame retardants – particularly polybrominated diphenyl ethers. Environment International 29: 829-839

Strandman, T., Koistinen, J., Kiviranta, H., Vuorinen, P.J., Tuomisto, J. & Vartiainen, T. (1999) Levels of some polybrominated diphenyl ethers (PBDEs) in fish and human adipose tissue in Finland. Organohalogen Compounds 40:355-358

Stringer, R., Labunska, I, Santillo, D., Johnston, P., Siddorn, J. & Stephenson, A. (2000) Concentrations of phthalate esters and identification of other additives in PVC children's toys. Environmental Science and Pollution Research 7(1): 27-36

Stringer, R.L. & Johnston, P.A. (2001) Chlorine and the Environment: An Overview of the Chlorine Industry. Publ. Kluwer Academic Publishers, Dordrecht, Netherlands. ISBN 0-7923-6797-9, 429pp

Takahashi, S., Mukai, H., Tanabe, S., Sakayama, K., Miyazaki, T. & Masuno, H. (1999) Butyltin residues in livers of humans and wild terrestrial mammals and in plastic products. Environmental Pollution 106: 213-218

Taylor, T.P., Ding, M., Ehler, D.S., Foreman, T.M., Kaszuba, J.P. & Sauer, N.N. (2003) Beryllium in the environment: A review. Journal of Environmental Science and Health Part A-Toxic/Hazardous Substances & Environmental Engineering 38(2): 439-469

Thomsen, C., Lundanes, E. & Becher, G. (2002) Brominated flame retardants in archived serum samples from Norway: A study on temporal trends and the role of age. Environmental Science and Technology 36(7): 1414-1418

Tinkle, S.S., Antonini, J.M., Rich, B.A., Roberts, J.R., Salmen, R., DePree, K. & Adkins, E.J. (2003) Skin as a route of exposure and sensitization in chronic beryllium disease. Environmental Health Perspectives 111(9): 1202-1208

UNEP (2002) Global Mercury Assessment, United Nations Environment Programme (UNEP) Chemicals, Geneva, Switzerland. Available at; www.chem.unep.ch/mercury

United States Code of Federal Regulations, USFCR (1999) Title 29, Labor, Part 1910. Occupational Safety and Health Standards, Subpart Z, Toxic and Hazardous Substances, Title 29, Volume 6, parts 1910.1000, Washington, DC

Viet, S.M., Torma-Krajewski, J. & Rogers J. (2000) Chronic beryllium disease and beryllium sensitization at Rocky Flats: A case control study. American Industrial Hygeine Association Journal 61: 244-254

Virtanen, J.K., Voutilainen, S., Rissanen, T.H., Mursu, J., Tuomainen, T., Korhonen, M.J., Valkonen, V., Seppa¨nen, K., Laukkanen, J.A., Salonen, J.T. (2005) Mercury, Fish Oils, and Risk of Acute Coronary Events and Cardiovascular Disease, Coronary Heart Disease, and All-Cause Mortality in Men in Eastern Finland. Arteriosclerosis, Thrombosis and Vascular Biology 25: 228-233

Wilson, N.K., Chuang, J.C. & Lyu, C. (2001) Levels of persistent organic pollutants in several child day care centres. Journal of Exposure Analysis and Environmental Epidemiology 11(6): 449-458

Wong, J.S. & Gill, S.S. (2002) Gene expression changes induced in mouse liver by di(2-ethylhexyl) phthalate. Toxicology and Applied Pharmacology 185(3): 180-196
World Health Organisation (1989a) Lead; environmental aspects. Environmental Health Criteria 85. ISBN 9241542853
World Health Organisation (1989b) Mercury. Environmental Health Criteria 86. ISBN9241542861
World Health Organisation, WHO (1990) Beryllium. Environmental Health Criteria 106. ISBN 9241571063
World Health Organisation (1992) Cadmium. Environmental Health Criteria 135. ISBN 9241571357