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The Evolution of Materials Used in Personal Computers

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There is a growing concern about the potential environmental impacts posed by the disposal of waste personal computers (PCs). This concern stems from two factors: the volume of PCs expected to become waste as new, more advanced products enter the market, and the presence and alleged presence of certain substances in PCs, which may be released into the environment upon disposal. This paper will address these concerns. It will also refute claims that PCs contain certain problematic materials and explain which chemicals are in fact found in PCs and which chemicals have been minimized over time. For purposes of this paper, a "personal computer" is defined as consisting of a Central Processing Unit (CPU), a monitor, a keyboard, and a mouse.

Chemicals/Products Not Contained in Personal Computers

There is a misconception that some chemicals or components are used in personal computers when, in fact, they have never been used. Thus, these materials do not pose an environmental risk and do not need to be addressed during end-of-life management.

PCBs

Despite opinions to the contrary, polychlorinated biphenyls (PCBs) have never been used in personal computers and, therefore, will not be found in waste PCs. PCBs were widely used as coolants and lubricants in transformers, capacitors, and other electrical equipment (including household appliances such as televisions and refrigerators). In 1977, the manufacture and use of PCBs in new products were banned in the United States due to evidence that PCBs bioaccumulated in the environment and presented human health risks.

PCBs, however, were never used in personal computers and, therefore, will not be found in waste PCs. This determination is supported by the 1996 Electronics Industry Environmental Roadmap, which contained a chart containing the composition of a Typical Desktop Computer and made no mention of PCBs.[1]

Some commenters have claimed that PCBs may be found in printers. According to industry sources, PCBs have never been used in printers. Furthermore, a printer is not a part of a PC. It is a separate functioning unit and should not be considered in the definition of a PC.

[1] "Composition of Typical Desktop Computer," 1996 Electronics Industry Environmental Roadmap, Microelectronics and Computer Technology Corporation, February 1996, Appendix I.

Mercury

Mercury is not expected to be found in waste PCs. Mercury switches and relays have never been used in personal computers. Although traditionally used in large main frame computers and telephone switching equipment, those uses were phased out before the development of PCs.

Laptop computers make up a unique subset of the computer market and are not considered PCs. However, since others may include laptops in the definition of PCs, we will address them in this paper.

Certain flat screen laptop displays may use mercury-containing back-lit bulbs for illumination; however, the mercury contained in these flat screen displays is in very small amounts. According to laptop manufacturers, the average amount of mercury contained in a laptop computer is 0.12 – 5 milligrams of mercury. By comparison, the amount of mercury contained in a standard 4-foot mercury-containing fluorescent lamp, which is commonly used to light offices and homes, is 25 milligrams.[2] The mercury contained in a normal flat panel monitor is one-fifth the amount of mercury contained in a single household fluorescent lamp, and poses no significant environmental hazard when disposed.

Furthermore, this very small use of mercury in laptop computers provides overall environmental benefits. Mercury-containing lamps reduce the amount of energy used by the laptop and, therefore, decrease the overall contribution of mercury emissions to the environment since a primary source of mercury emissions is fossil-fuel burning power plants.[3]

Chemicals Contained in Personal Computers

In 1996, a computer recycler presented data that illustrated the composition of a typical desktop computer system.[4] The data found that the amount of hazardous materials contained in a typical PC is very small. The analysis revealed that a typical PC consists of the following chemical components (listed in descending order by percentage of weight): silica (24.9%), plastic (23%) iron (20.5%), aluminum (14.2%), copper (7%), lead (6.3%), zinc (2.2%), and tin (1.0%). All other constituents (including cadmium, chromium, antimony and beryllium) were found in *de minimis* percentages of less that 0.1%.

The chemicals that are found in PCs that allegedly pose environmental risk are listed below.

Polyvinyl Chloride (PVC) and Other Plastics

The data, referred to above, found that plastic constitutes approximately 23% of a typical desktop computer.[5] Of that 23%, a residential electronics recycling pilot project found that the most common plastics used in collected PCs were: Acrylonitrile Butadiene Styrene (57%), Polyphenylene Oxide (36%), High-Impact Polystyrene (5%), and Polycarbonate/Acrylonitrile Butadiene Styrene Blend (2%).[6] PVC plastic is not present in PCs in significant amounts.

[2] "Mercury Emissions from the Disposal of Fluorescent Lamps," US Environmental Protection Agency, June 30, 1997, 1-1.

[3] Workshop on Mercury in Products, Processes, Waste and the Environment, U.S. Environmental Protection Agency, March 2000.

[4] Id., Microelectronics and Computer Technology Corporation.

[5] Ibid.

[6] "Plastics from Residential Electronics Recycling: Report 2000," American Plastics Council, April 2000, p. 13.

In the past, PVC was used in monitor and keyboard applications. However, this PVC use represents a low percentage of the plastics used in all PCs. It may also be useful to put electronic PVC applications in perspective. PVC is the most commonly used plastic in the world; however, PVC use in the electronics industry constitutes less than 1% of total PVC use.

Despite allegations that PVC is widely found in waste PCs, the data suggests that PVC is not a major PC plastic. Although PVC is used in computer cable, the amount of PVC used in PC cable by weight is small (see discussion below). Therefore, concerns about dioxin formation during incineration due to PVC from waste PCs appear unfounded.

Lead

According to the MCC Study, lead makes up approximately 6.3% of the typical PC; however, new data suggests that this estimate is high. Lead is used in three primary PC applications: it makes up 37% of the tin-lead solder that connects computer chips to printed circuit boards, it is used as a radiation shielding in monitor glass, and it is sometimes used as a plastic stabilizer in PVC cabling.

Of the amount of lead contained in a PC, the majority is embedded in glass that makes up the monitor's cathode ray tube (CRT). A CRT is comprised of a panel (the monitor face), the funnel, the neck and the frit. The majority of the lead is found in the frit, which is the material used to hold the panel to the funnel. The frit is approximately 65-75% lead. The funnel glass is approximately 22-25% lead. The neck, that holds the electron gun, is 30% lead.

The panel of a CRT varies between 0-2% lead. All but one US-based CRT manufacturer has removed the lead from the panel. Thus, most panel glass is lead-free and not hazardous.

The total lead in a CRT constitutes, on average, 1.1 pounds (0.5 kg) for a 17 inch monitor.[7] Some CRTs made and sold in Japan have a slightly lower percentage of lead, but this is because the human health and safety standards are lower. These monitors cannot be sold in many countries due to concerns that they may not provide sufficient radiation shielding. Shielding is necessary because of the health risks posed by X-rays emitted by the high voltage used to generate the electron beam that create the picture.

The second largest source of lead in a PC is the lead fraction of the tin-lead solder alloy that is used to join chips and components to printed circuit boards. It has been estimated that the total amount of lead on a typical printed circuit board is approximately 0.7% of its total weight.[8] Only 0.5 percent of the lead consumed in the United States is used in solders for electronics assembly.[9]

Finally, lead is used as a plastic stablilizer in some PVC applications. Some PVC cable and wire sheathing contains lead sulfate in small amounts to prevent breakdown of the plastic cable due to

[7] This calculation was determined by the University of Tennessee for the U.S. EPA Design for the Environment Computer Display Life-Cycle analysis. The 1.1 pounds was derived from the following calculation: the glass in a CRT weighs about 4.8 kg (~11 lbs). When the four components are analyzed overall, about 10% of the glass is lead oxide. Thus, there is 1.1 pounds of lead in the entire CRT. For more information on this project see www.epa.gov/dfe.

[8] "Should Metal Recyclables Be Defined As Hazardous Waste?", B. Smith, International Council on Metals and the Environment, 2000, p.6.

[9] "Lead and the Electronics Industry: A Proactive Approach," National Center for Manufacturing Sciences, May 1995.

ultraviolet exposure and high heat. A comparison of the amounts used by cable manufacturers found that the amount of lead used in PVC cable is very small. According to plastic industry experts, there is approximately 19 pounds of vinyl jacket per 1000 feet of cable (.19 pounds of vinyl jacket per 10 -foot cable). Converting this to percentage of lead (by weight), 0.82 % of .19 pounds of jacketing means there is approximately 0.15 pounds of elemental lead per 10 feet of computer cable.[10]

An additional important point is that there is no "free lead" in these compounds. The lead is always bound into the complex of the lead stabilizer and is always tied up into the polymer compound matrix. Due to this chemical reaction, the lead in the PVC is not readily liberated during degradation.

Lastly, small amounts of lead may be found in batteries for power supply. There is a misconception that lead acid batteries were used as logic board (or memory board) batteries in PCs. Much larger processors may use lead acid batteries, but not PCs.

Laptops are not considered PCs. However, sealed lead-acid batteries were used as a laptop power supply during the early years of laptop production. They were replaced by nickel cadmium batteries for one product cycle, then nickel metal hydride batteries, and finally lithium ion batteries in 1996. Lithium batteries are a non-toxic battery chemistry.

Antimony

Antimony trioxide, which is a suspected carcinogen, may be used in PCs as a flame retardant and as a chip encapsulant. Estimates for the amount of antimony contained in waste PCs is 0.009%.[11] Sodium antimony is used as a melting agent in CRT glass and provides necessary optical properties. The percent of sodium antimony in a CRT is 0.2% in the funnel and 0.24% in the panel.[12]

Chromium, Cadmium and Lithium

Chromium and cadmium may be found in PC plating applications; however, these uses are rare. The MCC Study found that both chemicals were used in trace amounts (<0.01%) in PCs.[13]

Nickel-Cadmium batteries were traditionally used in personal computers; however, they have been phased-out and replaced with lithium ion batteries, which pose no toxicity concerns. Data from the rechargeable battery industry indicated that, in 1999, approximately 80% of PC batteries were lithium ion. The remainder was largely composed of nickel-metal hydride batteries. Nickel-cadmium batteries made up less than 1% of the PC battery market.[14]

Lithium ion batteries contain no gaseous components or free liquids. They contain an inorganic lithium, cobalt-oxide-based compound as the positive electrode, an organic liquid absorbed in a substrate as the electrolyte, and a carbon graphite-based negative electronic-electrode. They

[10] According to the plastics industry, roughly, 1.0 % tribasic lead sulfate is used in a vinyl coated wire and cable compound to make printer or personal computer cable. The highest estimate is that 82% of tribasic lead sulfate is elemental lead or 0.82% of the vinyl compound. The average thickness of the vinyl jacket for such cable is 14 millimeters.

[11] Id., Microelectronics and Computer Technology Corporation.

[12] Conversation with Steve Wood, Techneglas, CRT glass manufacturer (August 22, 2000).

[13] Id., Microelectronics and Computer Technology Corporation.

[14] Advanced Rechargeable Battery Industry: Final Report, Nomura Research Institute, Ltd., December 1999.

contain no metallic lithium when manufactured. Industry assessments have concluded that lithium ion batteries would not be regulated as hazardous waste under U.S. hazardous waste programs. The only environmental issue raised by lithium ion batteries, during the recycling process; they may pose a fire risk if shredded. This risk can be minimized through proper recycling management.

Halogenated Flame Retardants

Halogenated flame retardants represent an entire class of chemical substances – all with different and varying chemical properties and structures. The highest volume brominated flame retardant used in the electronic industry is tetrabromobisphenol-A (TBBPA). The primary use of TBBPA is a reactive intermediate in the production of flame-retarded epoxy resins used in printed circuit boards. A secondary use for TBBPA is as an additive flame retardant in ABS plastic housings. No free TBBPA exists in the final product. Therefore, it is not considered hazardous when incorporated into plastics.

The halogenated flame retardants typically discussed as being used in electronic products are Polybrominated Biphenyls (PBBs) and Polybrominated Diphenyl Oxides (PBDOs). However, both were largely eliminated from plastic computer housings approximately 7-10 years ago. Halogenated flame retardants used in today's PCs pose no special risk when recycled, landfilled, or burned in properly controlled incinerators.[15]

Although laptop computers are not considered PCs, it is interesting to note that no flame retardants are used in laptop computer casings. Because the heat generated from the mercury bulb is much lower than the heat generated from a CRT monitor, no flame retardants are necessary in the plastic casing.

Beryllium

Traditionally, a small amount of beryllium in the copper beryllium alloy (98% copper, 2% beryllium) was present in a motherboard. Today, however, beryllium is not used on motherboards. It is possible that beryllium copper may have been used in connectors on older PCs. It is also possible that small amounts of beryllium copper is still used in new PCs as finger clips to maintain electrical conductivity in metal housings. Yet, these very small amounts of beryllium copper pose no environmental hazards during disposal.

During the recycling process, there is a small health and human safety concern if beryllium becomes airborne and is inhaled. This is only a factor during the preparation of a sample and can be controlled through proper management practices.

Phosphers

Zinc sulfide, which is non-hazardous, is used in the interior of a CRT screen to convert the kinetic energy of an electron beam to light. Cadmium sulfide and rare earth metals may have also been used in the past. These chemicals were used in very small amounts and only in very old technology.

[15] Report on Incineration of Products Containing Brominated Flame Retardants, OECD Waste Management Policy Group, August 14, 1998.

Liquid Crystal Display

Although laptop computers are not PCs, a 15" flat panel display monitor contains approximately 0.42 grams of liquid crystal compound.[16] This is only a trace amount of material. Moreover, numerous studies on the toxicological properties of compounds have been carried out[17]. These studies show that commercial liquid crystal compounds are not toxic either to humans or to fish or to bacteria[18]. Results of eco-toxicological investigations also revealed no toxicity to daphnia and algae. Therefore, there is no reason to consider LCDs as hazardous waste. Although some commenters have stated that LCDs are carcinogens, there is currently no evidence that supports this claim.

Chemicals That Have Been Minimized

Manufacturers of personal computers actively design for the environment and great strides have been made in reducing the amount and toxicity of chemicals used in personal computers. At this time, the chemicals that are used in PCs are used because they provide unique functionality and because less hazardous alternatives that would achieve the same functionality are not yet available.

All but one U.S.-based manufacturer of CRT glass has removed the lead from CRT panel glass. This has greatly reduced the amount of lead used in CRTs. The remaining lead that is used is contained in the frit, funnel and neck glass. This lead is necessary to shield users from the electron ray, which would otherwise be damaging to the human eye. Overall the amount of lead used in all parts of the CRT have been greatly reduced. Other chemicals that have been reduced in PCs include the following:

- Sodium antimony has replaced arsenic, which was originally used in CRT glass. Sodium antimony is used because it is much less hazardous than arsenic.

- Cadmium sulfide was originally used for phosphorescence in CRT coatings. Current manufacturers use zinc sulfide, which does not pose environmental risks.

- Lead acid and nickel-cadmium batteries were once briefly used in PCs and have largely been replaced with lithium ion batteries, which are non-toxic.

- Beryllium is no longer used in motherboards.

- Some companies have stopped using flame retardants in their products.

The materials used in current technology are used because they are necessary to the functionality of the personal computer. The industry is actively conducting research and development to improve and reduce the use, while maintaining technological efficiency, of materials of concern.

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[16] Data from Computer Display Industry and Technology Profile, U.S. Environmental Protection Agency, December 1998.

[17] Merck KGaA "Toxicological Investigations of Liquid Crystals," 28th Freiburg Workshop, Liquid Crystals," March 24-26,1999; Comité Valortube -Ademe & FIEEC, "Final Report of the Flat Panel Displays Committee," January 1999; Merck KGaA, "Toxicological Investigations of Liquid Crystals and Disposal of Liquid Crystal Displays," 4th Annual Conference of EUROFORUM, July 06-07,1999.

[18] Some of the liquid crystals (LCs) showed irritating or sensitizing properties. However, these effects are prevented in practice by reducing the concentrations of the respective LCs in the LC mixtures (e.g. LCDs) to levels where no harmful properties are expected.

Conclusion

The PC industry continues to develop products that contain fewer and less harmful chemicals. The two drivers largely responsible for this outcome are the increased functionality of components, which enable the same job to be accomplished with fewer resources, and the reduced size of components and products, which is being driven by technological advancements. The PC of the future will continue to evolve into a "cleaner" and more environmentally friendly device.

Moreover, studies have shown that the PCs of today and yesterday do not pose significant environmental risks. PCs are mainly composed of non-hazardous constituents. Hazardous constituents that may be present are usually contained in *de minimis* concentrations – usually lower than the concentrations found in other household items managed as municipal solid waste. Many potentially problematic compounds can be easily removed and recycled at properly equipped facilities with trained personnel.

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