Toxic Chemicals in Computers *Reloaded*

Kevin Brigden, Joe Webster,
Iryna Labunska and David Santillo

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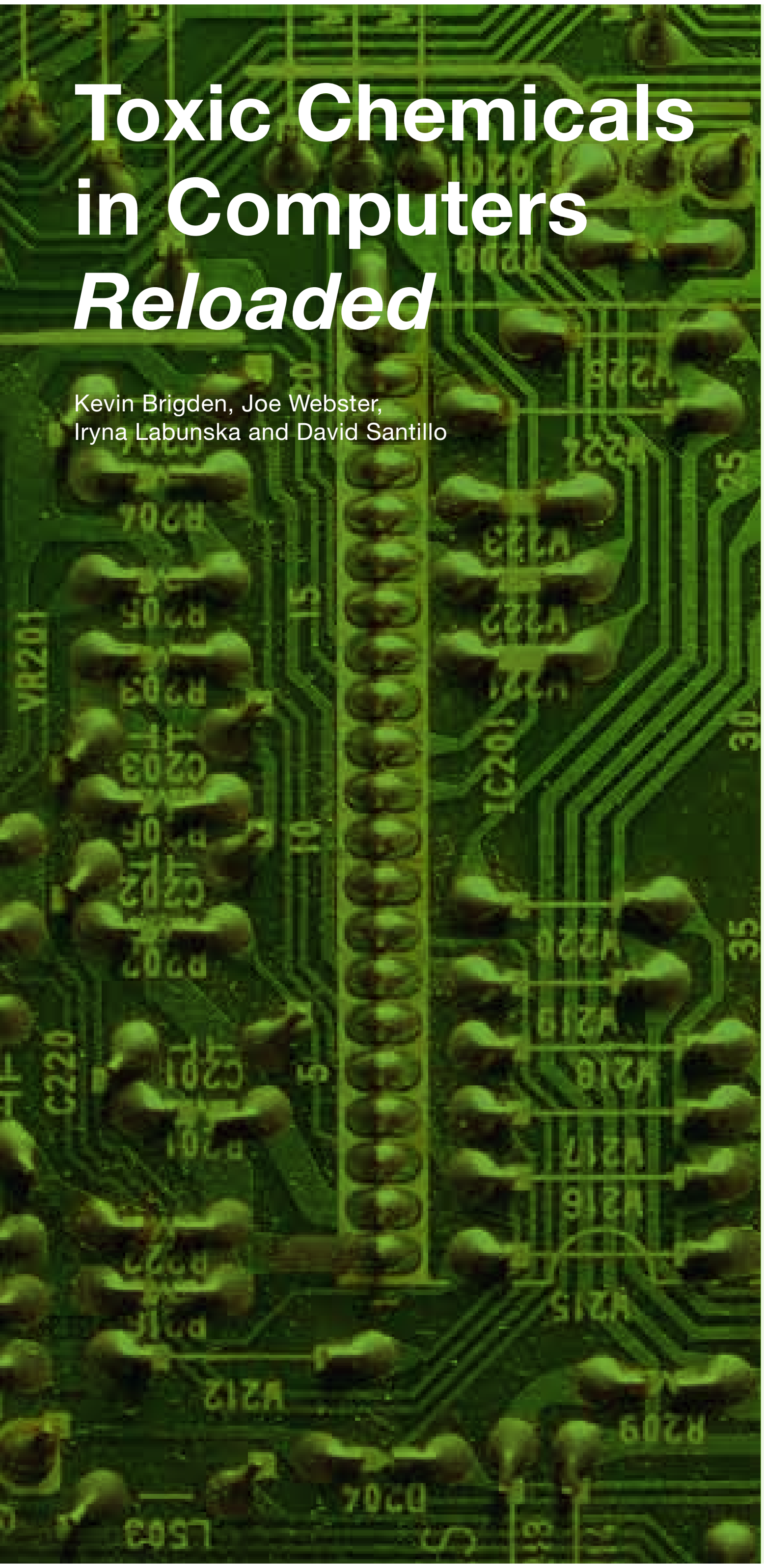

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Executive Summary

There is growing concern over the use of hazardous chemicals in consumer goods, particularly with regard to electrical and electronic equipment. Some of these products, including computers, can contain heavy metals and other hazardous chemicals as constituents of their various components. The ongoing use of such chemicals has the potential to impact on the environment and human health as a result of the manufacture, use and disposal of these products.

In 2006, Greenpeace found a range of hazardous chemicals in laptop computers available for purchase in Europe, prior to the introduction of legislation, known as RoHS, regulating the use of certain hazardous chemicals in electrical and electronic products in the EU. More recently, similar legislation has been introduced in China.

This subsequent study was conducted by Greenpeace following the introduction of these laws, to investigate the presence of certain hazardous substances in a range of laptop computers available for purchase within the EU and other countries in Europe, in North and South America and in Asia.

A total of 18 individual laptops, representing 6 popular brands, were purchased between July and September 2006. Where possible, the same model of laptop for each brand was purchased in different countries, to determine whether place of sale had an influence on the presence of hazardous chemicals. Where identical models were not available, the closest related models were purchased for this investigation. The laptops included in this investigation are listed in the table below (* within the EU).

The presence of certain hazardous substances was investigated in a wide variety of equivalent internal and external materials and components from each laptop. The range of substances were based in part on EU and Chinese legislations that regulate, in different ways, certain hazardous chemicals in electrical equipment, but also included additional chemicals of concern. The specific substances investigated in this study were;

- Heavy metals (lead, mercury, cadmium and hexavalent chromium*)
- Bromine content, to indicate the presence of brominated flame retardants (BFRs)
- Four specific brominated flame retardants (BFRs)**
- PVC (polyvinyl chloride)
- Phthalates esters (phthalates)

**Regulated under EU and Chinese legislation; ** certain of these BFRs regulated under EU and Chinese legislation*

Brand	Model	Countries of purchase
Dell	Latitude D420	China, Germany*, USA
Sony	Vaio TX	Sweden*, Japan
Apple	Macbook 1.83 Ghz	Philippines, Russia, Netherlands*, USA
Acer	Aspire 5562 WXMi Aspire 5672 WLMi	China, Thailand, Poland* Netherlands*
Hewlett Packerd (HP)	Pavilion dv8375LA Pavilion dv8275LA Pavilion dv8365ea Pavilion dv8000t	Mexico Argentina France* USA
Toshiba	Satellite U200	UK*

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For each laptop, approximately 30 materials and components were analysed by X-ray microanalysis (XRF) to determine the concentrations of bromine (Br), cadmium (Cd), mercury (Hg) and lead (Pb). In addition, 10 samples of electrical solder were analysed for lead and other metals, and 8-10 metallic components were analysed for hexavalent chromium (VI), using other standardised techniques. Furthermore, 8-10 plastic materials were tested for the plastic PVC (2-4 internal ribbon cables & the coating of 6 internal wires and external cables), and of these 2 materials (an internal ribbon cable and the plastic coating of an external cable) were further analysed for a range of phthalates. For one laptop from each brand, between 1 and 3 bromine containing components were also analysed for a range of extractable BFRs, namely PBDEs, PBBs, HBCD and TBBPA.

The testing of the various components in these laptops found;

- **Lead, cadmium** and **mercury** were not detected in any of the samples from all laptops tested by XRF (with detection limits of 0.01% for cadmium and 0.05% for lead and mercury).

- **Lead** was not detected in any of the samples of electrical solder analysed from all laptops using other methods (with a detection limit of 0.1%). These solders were composed of various different mixtures of other metals, with composition depending on where they were used within the computer.

- **Hexavalent chromium** was not detected in any of the metallic samples tested for all laptops (with a detection limit of 0.1%).

- **Bromine**, indicative of brominated flame retardants (BFRs), was present in a wide range of different materials and components. Over 40% of the 523 samples tested in total contained bromine (above a detection limit of 0.1%), at concentrations ranging from 0.3% to 10% by weight.

- Of all the brands analysed, the Sony laptops gave by far the lowest number of samples testing positive for bromine (4 per laptop). For all other brands the number of bromine positive samples was higher (between 11 and 16 samples per laptop). There were only small difference between these brands for the frequency with which bromine was detected in components; The Dell models had the highest frequency (14-15 samples per laptop), the HP models had the lowest (11-12 samples per laptop).

- The actual levels of bromine in discrete types of samples (i.e. specific materials or components) tended to vary between laptops of the same brand, as well as between laptops of different brands.

- There were no universal differences between the different brands for the presence and levels of bromine across all components and materials tested. Although differences between brands were apparent for some individual components, these patterns were not consistent across all component types. However, the Sony laptops did stand out from the other brands; bromine was not detected in many types of component that were found to contain bromine in some or all other brands, particularly for circuit boards.

- The elimination of brominated flame retardants from circuit boards is widely seen as a difficult challenge. Bromine was very frequently found in the boards tested, with the exception of the Sony laptops (detected in only 1 of 6 types of board) and to a lesser extent Toshiba (detected in 2 of 5 types of board). For both brands the motherboards did not contain bromine at detectable levels. These results indicate that the use of 'bromine-free' circuit boards is possible across a wide range of applications.

- For all Dell, Apple, Acer and HP laptops, almost all of the tested boards contained bromine, including all the motherboards. Levels were generally high, and for equivalent circuit boards similar ranges of concentrations were seen across these four brands.

- **XRF analysis** is a widely used technique to determine material composition, however the use of this technique is not always straight forward. For some complex non-homogeneous materials, such as circuit boards, this study has demonstrated that XRF analysis inappropriately or incorrectly applied can produce false negative results, indicating the absence of an element such as bromine in a material that does actually contain a high concentration of that element.

- **Brominated flame retardants** were analysed for and quantified in a relatively small number of samples in total (15, limited by the cost of the analyses), and from only one laptop from each brand, other than Apple (for which additional samples were analysed to investigate substantial variations in bromine content within the brand). TBBPA and PBDEs were identified in 4 of these 15 samples (with a limit of detection of 0.5 mg/kg); these compounds were found in three samples from the Apple laptops (two ribbon cables and a mouse touchpad) and in a single sample from the Dell laptop (in a ribbon cable). These BFRs were present at concentrations far lower than could account for the total bromine concentrations found in these samples, indicative of the predominance of other bromine-containing chemicals in these materials. PBBs and HBCD were not identified in any of the 15 samples (with a limit of detection of 0.5 mg/kg).

- Other brominated compounds were also identified in some samples. Though levels were not quantified for these, the data indicates that these were also present at relatively low levels. It seems likely, therefore, that the majority of the bromine in the samples quantified for specific BFRs is bound up in the polymeric material of the samples, or is present as high molecular weight oligomeric flame retardants, such as brominated epoxy oligomers (BEOs), and therefore not amendable to analysis by the methods used.

- **PVC** was present in 44% of all plastic coatings of internal wires and external cables (48 of 108 samples in all laptops), most commonly in the outer coating of the external power cables. For each brand the number of samples that contained PVC varied significantly between individual laptops; none of the brands stood out as clearly containing fewer or greater numbers of PVC containing materials of those tested. PVC was not found in any of the 62 ribbon cables tested across all laptops. Although PVC does not have direct toxicity, this plastic does presents its own waste management problems by acting as a source of organic-bound chlorine to the waste stream, as well as raising additional concerns at other points in its lifecycle. Furthermore, the use of PVC in certain applications requires the use of additive chemicals, such as phthalate esters (phthalates) commonly used as plasticisers (softeners).

- **Phthalates** were found in the outer plastic coating of the external power cable of all laptops at moderate to very high concentrations (up to over a quarter of the total weight of the plastic coating). For every sample, a mixture of two or more phthalates were identified. The plastic coating from the power cables supplied with the Apple laptops, coatings which did not appear to be made of PVC, had by far the lowest total phthalate concentrations (0.2-0.3% by weight). The highest levels were found in cables supplied with the Acer and HP laptops (18-28%). The phthalate mixtures were generally dominated by di isononylphthalate (DiNP) and di isodecylphthalate (DiDP), with lesser amounts of diethylhexylphthalate (DEHP). These chemicals are able to migrate out of the plastic materials over time, and there is evidence for the toxicity of these phthalates, especially DEHP, which is classified as ‘toxic to reproduction’ within Europe.

Overall, these results provide some further evidence for the feasibility of the substitution of hazardous chemicals and materials within the electronics sector. For almost every distinct type of material that was found to contain either bromine, a specific BFR, or the plastic PVC in one or more laptop, examples of equivalent materials that were free of these chemicals were found in other laptops.

There were no clear and consistent differences in either the prevalence of bromine, the presence of specific BFRs, or the level and composition of phthalates in the tested components according to country of purchase. In other words, laptops that were purchased in countries with national regulations addressing the presence of hazardous chemicals in electronic products showed no systematic difference from those purchased in counties without such regulations. In general, however, the data do suggest that actions to phase-out uses of lead, cadmium, mercury and hexavalent chromium, at least, have been implemented on a wide-spread basis.

For some materials, the elimination of a particular hazardous chemical appears to be universal (for all samples tested), such as lead in electrical solders. This, however, was not the case for all chemicals under investigation, and the results document the continued presence of halogenated (i.e. brominated or chlorinated) materials and of other hazardous chemicals in these popular brands of laptop computers. These include bromine, indicative of brominated flame retardants (BFRs), the use of PVC in plastic coatings for wires and cables, and the use of phthalates as plasticisers in external power cables. Moreover, some alternative materials to those found to be widely used may be of similar concern; in the case of one cable (supplied with an Acer laptop), the apparent use of a material other than PVC was associated with a more hazardous mix of phthalate plasticisers, including DEHP.

It is important to note that the data and conclusions relate only to those materials and components tested, which were a fraction of the very large number of materials and components within each laptop. The absence of a certain chemical in all samples tested from a laptop does not indicate that the laptop is entirely free of that chemical. Thus, it is not possible to state that any of the laptops tested are fully compliant with the EU RoHS legislation, or equivalent regulations in other countries. Furthermore, this study applies to the specific models tested for each brand, and may not reflect the use of certain chemicals in the brand as a whole. These issues highlight the great difficulties in verifying that any individual product, or brand as a whole, is entirely free of a specific chemical.

Although certain BFRs (including most PBDEs) which are regulated in particular countries and regions, as a result of their toxicity and chemical properties, were present at only low levels or not at all in the subset of samples investigated, the results indicate the continued use of other brominated compounds or other bromine-containing materials in these samples. In the context of disposal and/or recycling operations (especially incineration, smelting and open burning), the presence of organically-bound bromine and chlorine in any form is of concern as these can contribute to the formation of various hazardous products of combustion, including hydrogen bromide and brominated dioxins and furans.

It seems likely that the absence of certain hazardous chemicals from the laptops investigated results largely from the influence of legislation recently introduced in some countries, particularly the EU RoHS Directive, which has brought change on this globalised industry even outside the EU region. All of the samples tested from all laptops of all brands were compliant with the EU RoHS directive, whether purchased within the EU or in non-EU countries. Furthermore, even though legislation in China came into force after the purchase date of these laptops, all samples from the laptops purchased in China would comply with the legislation once this type of product is listed as requiring the elimination of the regulated chemicals. Current laws relevant to this sector, however, are only applicable in a fraction of countries where these products are sold. Though they have brought changes outside the EU and China, they do not prevent the sale in other countries of products that contain even the limited number of hazardous chemicals that they regulate, as has been recently demonstrated in other similar investigations. There remains a need for suitable regulation of these and other electrical and electronic products in all countries in which they are placed on the market in order to provide safeguards to consumers and enable safe and consistent recycling practices.

As they stand, even the laws in force in the EU and China do not regulate the use of all hazardous substances that can be present in electrical/electronic equipment. As this study has demonstrated, such products can contain additional hazardous substances to those currently covered under these laws (e.g. other BFRs, PVC and phthalates). Other recent studies have highlighted potential impacts that can arise from the use of BFRs that are currently not included in legislation within the EU or other countries, including the exposure of recycling workers to deca-BDE leading to the highest levels yet reported in humans[13], and potential environmental impacts due to the recycling and disposal of products containing other currently unregulated BFRs[11]. Any legislation seeking to protect human health and the environment by restricting the use of hazardous chemicals in products must ultimately address all hazardous substances.

Elimination of all hazardous chemicals in laptops computers and other electrical and electronic equipment can be achieved through national legislation and/or self imposed commitments by manufacturers. Experience in the EU relating to other hazardous chemicals has recognised that the implementation of voluntary or negotiated measures is most effective when driven by the promise of future regulation. This has certainly been the case for the RoHS Directive, which had an over-riding influence on the use of materials in laptops well beyond the EU even before its formal entry into force in July 2006.

Toshiba CPU and Fan.
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Introduction

Toshiba exterior dismantling.
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There is growing awareness of the use of hazardous chemicals in consumer goods, particularly with regard to electrical and electronic equipment such as computers. Concerns exist over the potential for exposure to hazardous chemicals, as well as impacts on the environment, during the manufacture, use and disposal of such products. Unless the use of hazardous chemicals and materials is phased out, the potential for impacts from their use is likely to rise as worldwide the production of such goods continues to increase, and product lifespans decrease. This is reflected in the already large, and rapidly increasing amounts of electronic waste (e-waste) arising from this sector.

Electronic products such as computers can contain heavy metals and other hazardous chemicals as constituents of their internal components, casings and external wiring. Greenpeace has recently demonstrated[1] workplace and environmental contamination arising from the recycling and disposal of old electrical/electronic equipment containing such chemicals, and also environmental impacts due to the use of hazardous chemicals in the manufacture of new equipment[2].

In 2006, Greenpeace found a range of hazardous chemicals in laptop computers for sale in Europe. In one model (a Hewlett Packard laptop), certain chemicals were found in three materials at levels that would not be allowed under legislation subsequently introduced in the EU[3]. This investigation, however, was carried out prior to the recent introduction of this legislation, the EU RoHS Directive[4], which regulates the use of certain hazardous chemicals in electrical and electronic products. Closely related legislation has been recently introduced in other countries[4]. These laws are discussed further to the right.

Due to the global nature of the electronics manufacturing industry, it is to be expected that the introduction of legislation in one region, or possibly even one country, will have impacts on the nature of products sold in other countries.

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The EU's RoHS Directive and other equivalent legislation[4]

The European Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment, or the RoHS Directive (Directive 2002/95), entered into force on July 1st 2006. The Directive prohibits, with certain exemption, the placing on the market within the EU of such equipment if it contains more than regulated amounts of lead, mercury, cadmium and hexavalent chromium (chromium (VI)), or of two types of brominated flame retardants, namely polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs, other than the decabrominated congener BDE-209). Maximum allowable limit values are set at 0.1% by mass of homogenous materials for all but cadmium, for which the limit is 0.01%. The stated purpose of the Directive includes, inter alia "to contribute to the protection of human health and the environmentally sound recovery and disposal of waste electrical and electronic equipment".

Closely related Chinese legislation, the 'Administration on the control of pollution caused by electronic information products' entered into force on March 1st 2007. This legislation addresses the same chemicals controlled under the EU RoHS directive, but also includes 'other toxic and hazardous substances or elements as specified by the State, though to date (May 2007) no additional substances or elements have been specifically listed under this law. Currently, the legislation requires the labeling of products to describe the presence and quantities of the regulated chemicals. Over time the regulation will include a list of specific types of products that will be required to be entirely free of the regulated chemicals. Additional differences exist between the Chinese and EU legislations. For example, under the Chinese legislation, maximum allowable limit values apply to individual components not to homogenous materials, and there are currently no exemptions under the Chinese legislation.

In Japan, legislation commonly referred to as 'J-MOSS' has required the labelling, since 1st July 2006, of certain electrical products that contain the same substances that are regulated under the EU RoHS Directive.

The national laws identified above do not currently regulate the use of all brominated flame retardants, nor the use of phthalates or PVC in electrical and electronic equipment. In addition to these national regulations, other similar measures have been introduced in other jurisdictions around the world.

This study was carried out to investigate the presence of certain hazardous chemicals in laptop computers sold both in EU countries, and other countries around the world, following the introduction of the EU regulations. The presence of certain hazardous substances was investigated in a wide variety of internal and external components from each laptop. The specific hazardous substances investigated in this study include;

- Heavy metals (lead, mercury, cadmium and hexavalent chromium)
- Bromine content, to indicate the use of brominated flame retardants (BFRs)
- Four specific brominated flame retardants (BFRs)
- PVC (polyvinyl chloride)
- Phthalates esters (phthalates)

The range of substances included in this study were based in part on substances controlled under recently introduced legislation in the EU and China which regulate specific hazardous chemicals in electrical equipment; the EU RoHS Directive and similar Chinese legislation (see Textbox on page 9). In addition to the hazardous chemicals included in these laws, this study included a survey of plastic coatings of cables and wiring for the presence or absence of the plastic PVC. Certain plastic materials were also analysed for phthalate esters (phthalates), chemicals widely used as plasticisers (softeners) in plastics, especially PVC.

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The hazardous chemicals included in this study were;

Lead (Pb) has been widely used as a major component of solders in electronic goods[5] Lead is highly toxic to humans, as well as to animals and plants. It can build up in the body through repeated exposure and have irreversible effects on the nervous system, particularly the developing nervous system in children. Exposure can also have effects on the heart, kidneys and brain. For many effects there is no known safe level of exposure[6].

Hexavalent chromium (Cr VI) is one chemical form of the metal chromium which is far more reactive and mobile in the environment than other forms of chromium. It has been used in electronics primarily for corrosion protection of metallic surfaces. Hexavalent chromium is highly toxic even at low concentrations, and is a known human carcinogen under some circumstances[7].

Mercury (Hg) is a highly toxic metal that has been used in various applications in electrical products. Exposure can cause health effects including damage to the central nervous system and kidneys. Once in the environment, mercury can be converted into compounds which are highly bioaccumulative as well as being toxic, even at very low levels of exposure[8].

Cadmium (Cd) has been used in a number of applications within electronics products, both as a metal and as cadmium compounds. This toxic metal can accumulate in the body over time, with long-term exposure causing damage to the kidneys and bone structure. Cadmium and its compounds are also known human carcinogens[9].

Brominated flame retardants (BFRs); there is potentially a very wide range of brominated chemicals that can be used as BFRs[10]. Commonly used examples include **polybrominated diphenyl ethers (PBDEs)** and **tetrabromobisphenol A (TBBPA)**, as well as brominated polymeric and oligomeric materials. Some BFRs, including certain PBDEs, have known toxic properties, and some are highly persistent in the environment and able to bioaccumulate (build up in animals and humans). In whatever form the bromine is present, impacts can result at the product's end of life as a result of the unintentional formation of toxic brominated byproducts (including dioxins) during some disposal or recycling operations[11].

PVC (Polyvinyl chloride) is a plastic widely used in electrical products, particularly in coatings of wires and cables. Although PVC does not have direct toxicity in the same way as lead or mercury, this plastic does present its own manufacturing and waste management problems due to its organic-bound chlorine content. Furthermore, the use of PVC in certain applications requires that other chemicals be added to the plastic, such as phthalates to plasticise (soften) the plastic.

Phthalates are a group of chemicals possessing similar structures, many of which are widely used as plasticizers (softeners) in plastics, especially PVC. These chemicals are not chemically bound to the plastic, and so are able to migrate out of the material over time into the surrounding environment. Many phthalates are toxic to wildlife and humans, often through their metabolites (chemicals to which they breakdown in the body). Some widely used phthalates are known to be toxic to reproduction, capable of causing changes to both male and female reproductive systems in mammals[12].

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Materials and methods

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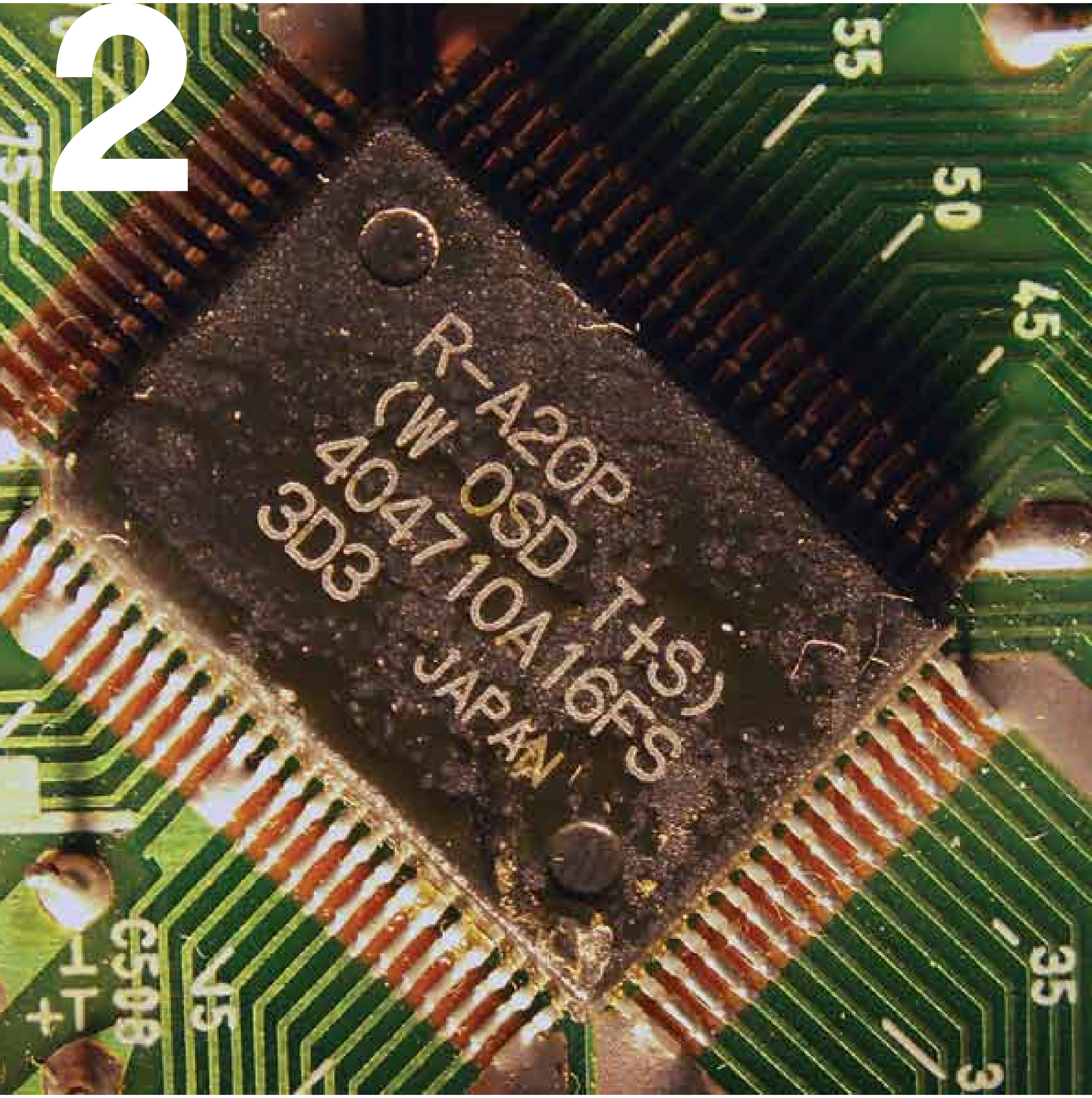
2



Eighteen laptops were purchased by Greenpeace from outlets in a number of countries, between July and September 2006. To enable comparison between equivalent laptops sold by major brands, this study included laptops sold by six manufacturers; Dell, Sony, Apple, Acer, Hewlett Packard (HP) and Toshiba. For each brand, the same model of laptop was purchased in a number of different countries, with certain exceptions. This was carried out in order to determine whether the presence of hazardous materials varied with the country of sale. For Toshiba, only one laptop was purchased, in the UK. For Acer and HP, the same model was not universally available in all countries where the purchases were made. The Acer model purchased in the Netherlands (Aspire 5672 WLMi) was different from, but closely related to, those purchased in other countries (Aspire 5562 WXMi). For the same reason, the four HP laptops were all slightly different, but closely related models. The laptops included in this study, including their models and countries of purchase, are presented in Table 1. For laboratory purposes, the laptops were assigned individual sample codes from LTOP01 to LTOP18.

Laptop	Manufacturer	Model	Country of purchase
LTOP01	Dell	Latitude D420	China
LTOP02	Dell	Latitude D420	Germany *
LTOP03	Dell	Latitude D420	USA
LTOP04	Sony	Vaio TX	Sweden *
LTOP05	Sony	Vaio TX	Japan
LTOP06	Apple	Macbook 1.83 Ghz	Philippines
LTOP07	Apple	Macbook 1.83 Ghz	Russia
LTOP08	Apple	Macbook 1.83 Ghz	Netherlands *
LTOP09	Apple	Macbook 1.83 Ghz	USA
LTOP10	Acer	Aspire 5562 WXMi	China
LTOP11	Acer	Aspire 5562 WXMi	Thailand
LTOP12	Acer	Aspire 5562 WXMi	Poland *
LTOP13	Acer	Aspire 5672 WLMi	Netherlands *
LTOP14	HP	Pavilion dv8375LA	Mexico
LTOP15	HP	Pavilion dv8275LA	Argentina
LTOP16	HP	Pavilion dv8365ea	France *
LTOP17	HP	Pavilion dv8000t	USA
LTOP18	Toshiba	Satellite U200	UK *

*Table 1. Laptops investigated in the study, their manufacturer (brand), model and country of purchase; * EU member state*

Macbook Macro - Motherboard.
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The laptops were dismantled at the Greenpeace Research Laboratories in the UK, taking all possible steps to avoid contamination of materials (including the use of analyte-free materials and antistatic devices in a controlled laboratory environment). A range of different analyses were thereafter carried out on individual components and materials from each laptop. The presence or absence of specific substances was investigated in a wide variety of internal and external components (casing, touch mouse pads, cables, circuit boards, chips, connectors, insulators, etc.). The specific analyses carried out in this study include;

- **Lead in solder:** 10 individual samples of electrical solder were separated from different components within each laptop (e.g. motherboard, DVD drive circuit board) and subsequently analysed for their lead content, as well as the content of other metals reportedly used in electrical solders[5].
- **Hexavalent chromium (VI):** Between 8 and 10 distinct internal metallic components from each laptop were analysed for the presence of hexavalent chromium (VI).
- **Micro-XRF:** Between 28 and 30 individual materials and components were selected from each laptop for X-ray microanalysis (micro-XRF), an analytical technique that allows the detection and quantification (as percent by mass) of major elements in the surface layer of the material analysed. This technique was used to quantify the surface concentrations of the metals cadmium (Cd), mercury (Hg) and lead (Pb), as well as the element bromine (Br) to give an indication of the presence of organobromine compounds used as flame retardants (including brominated polymeric materials).
- **BFR quantification:** For one laptop from each brand, between 1 and 3 individual components were selected for quantification of a range of extractable BFRs; PBDEs, PBBs, HBCD and TBBPA. The selection of components was based on the results of the XRF analyses for the levels of bromine.
- **PVC:** Between 8 and 10 plastic components from each laptop were analysed to determine whether they contained the plastic PVC; these consisted of between 2 and 4 materials analysed by XRF (internal ribbon cables), and a further 6 additional materials (coating of internal wires and external cables)
- **Phthalates:** 2 of the materials from each laptop that were tested for PVC content were further analysed for a range of phthalates. These materials were the plastic coating of an external cable and an internal ribbon cable.

In making the sample selections, every effort was made to include examples of as many as possible of the diverse materials and components present within the laptops. As it was not possible to purchase identical models in all countries for Acer and HP laptops, there were some differences in individual components between models of the same brand. In these cases, the materials and components selected for each brand were chosen to be as similar as possible across all models. A schematic of the components separated and the analyses carried out is presented in Figure 1. A full list of the materials and components tested, along with the results of their analyses, is provided in Tables 2 to 5.

The analysis of the solder samples for their lead content, and analysis of the metallic components for the presence of hexavalent chromium (VI) was carried out at the Greenpeace Research Laboratories. Those materials for analysis by XRF, and those for PVC and phthalate content, were forwarded to the laboratories of Eurofins Environmental A/S in Galten, Denmark, for analysis.

Brief descriptions of each of the individual analytical methods employed are given below, along with the various materials and components tested. Further details of the analytical methods employed are given in Appendix 1.

2.1 Lead content in electrical solder

Samples of electrical solder were removed from components within the laptops. Each sample was fully dissolved in a hydrochloric/nitric acid solution and subsequently analysed by ICP atomic emission spectrometry (AES) for the concentration of lead and other metals reportedly used in solders[5]. The individual solder samples analysed for each laptop and brand are given in Table 2.

Sample	Component
S01	circuit board of DVD drive; solder pad (a)
S02	circuit board of DVD drive; to small component (a)
S03	circuit board of DVD drive to larger component (a)(b)
S04	motherboard; connector to USB socket
S05	motherboard; solder pad
S06	circuit board below mouse touchpad; solder pad (c)(d)
S07	circuit board below mouse touchpad (e)
S08	small circuit board to component (f)
S09	hard drive circuit board to small component
S10	motherboard; to pins of small chip

Table 2. Electrical solder samples, from all laptops, analysed for their concentrations of lead, and other metals. (a) Dell has external DVD drive; (b) Dell-component on PWB; Apple-to ribbon cable socket; Acer-to connector to motherboard; HP & Toshiba-to connector socket; (c) One Acer laptop (LTOP13) had a different circuit board to the other Acer laptops (LTOP10-12); (d) HP-connections to mouse button sensors; (e) Dell & Toshiba-to connector to mouse button PWB; Sony, Acer & HP-to socket for ribbon cable; Apple-to small component; (f) Dell-PWB for slot in memory card; Sony & HP-PWB with headphone socket; Apple-PWB by USB sockets; Acer-to LED; Toshiba-solder pads

2.2 Hexavalent chromium (Cr VI)

Metallic materials were analysed for the presence of hexavalent chromium (VI) using a diphenylcarbazide colorimetric method. The individual materials analysed for each laptop and brand are given in Table 3.

Sample	Component
Cr01	keyboard metal plate
Cr02	mouse touchpad; plate below circuit board (a)(b)
Cr03	removable plate on back casing (c)
Cr04	hard drive case (back plate)
Cr05	hard drive case (main body)
Cr06	case of internal fan (d)
Cr07	plate adjacent to DVD drive (e)(f)
Cr08	DVD drive; external case (e)
Cr09	plate inside rear casing (g)
Cr10	heat sink for fan

Table 3. metallic materials, from all laptops, analysed for the presence of hexavalent chromium (VI). (a) Sony & Toshiba- plastic component so not tested; (b) Acer- LTOP13 different shape plate to other Acer models; (c) Dell & Sony- cover for memory chips; Apple- no such plate, alternative component tested (structural metal around battery); Acer- one laptop (LTOP13) not tested as plastic component; HP- plastic plate, so alternative component tested (PCMCIA slot); (d) Acer- plastic component so not tested; (e) Dell- external DVD drive; (f) Sony- plate attached to circuit board with headphone socket; Acer- no such component for one model (LTOP13); (g) Apple & Acer- plate attached to internal fan

2.3 X-ray microanalysis (XRF)

Each sample for analysis was placed in an EDAX Energy Dispersive X-Ray Fluorescence (XRF) instrument at room temperature, and analysed for the surface concentrations of bromine (Br), cadmium (Cd), lead (Pb) and mercury (Hg). The instrumentation employed offers greater accuracy and precision than use of related hand-held XRF instruments.

XRF analysis determines the concentration of bromine, and other elements, in the surface layer of a material. The thickness of the surface that is analysed by this method depends on the nature of the material being tested. For some materials (e.g. metallic surfaces) only a very thin surface layer will be analysed, while for other materials, including many plastics, the analysis will penetrate to a greater depth. For some non-homogeneous materials, such as circuit boards with multiple different layers, it is possible that metallic components within the material can block the analysis of other materials below. For each circuit board sample, XRF analysis was carried out at a site that did not contain copper, which might block the analysis of material below.

For circuit boards, an additional investigation was carried out into the potential for copper at the XRF test site to inhibit analysis of the bromine concentration in the material. Four circuit board samples were analysed by both surface XRF testing and also by analysis of the ground and homogenized material (each sample was ground to a fine powder which was thoroughly mixed and then subjected to XRF analysis). This analysis was carried out on 2 circuit boards at sites where copper was present (confirmed by surface XRF analysis), and 2 circuit boards at sites where copper was not present (confirmed by surface XRF analysis).

Toshiba Circuit Board being dismantled.
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	Analysis	XRF Analysis						PVC	Phthalate
Sample	Component Brand	Dell	Sony	Apple	Acer	HP	Toshiba	All	All
	LTOP#	01-03	04-05	06-09	10-13	14-17	18	01-18	01-18
1	Mouse touchpad	y	y	y	y	y	y	-	-
2	Mouse button (left)	y	y	y	y	y	y	-	-
3	Keyboard space bar	y	y	y	y	y	y	-	-
4	Screen surface	y	y	y	y	y	y	-	-
5	External casing: plastic casing surrounding mouse touchpad & buttons	y	y	y	y	y	y	-	-
6	Ribbon cable (internal); connected to keyboard	y	y	y	y	y	y	y(p)	y(t)
7	External casing: plastic casing surrounding screen	y	y	y	y	y	y	-	-
8	External casing: outside top casing (reverse of screen)	y	y	y	y	y	y	-	-
9	External casing: plastic casing inside battery compartment	y	y	y(a)	y	y	y	-	-
10	Cooling fan (internal)	y	y	y	y	y	y	-	-
11	External casing: casing immediately around keyboard	y	-(b)	-(b)	y	y	y	-	-
12	Electrical insulating sheet by cooling fan	y	y	y(c)	y(c)	y	y	-	-
13(d)	Electrical insulation sheet	y	y	y	y	y	y	-	-
14	Circuit board, base board; motherboard	y	y/-	y	y	y	y	-	-
15	Circuit board, base board; memory chips	-/y(e)	-/y(e)	y	y	y	y	-	-
16(f)	Ribbon cable between motherboard and component (flex. circuit board)	y	y	y	y	y	y	y	-
17	Circuit board, base board; hard drive	y	y	y(g)	y(g)	y	y	-	-
18	Circuit board, base board; under mouse touchpad	y (h)	y	y	y	y	-	-	-
19(i)	Circuit board, base board; DVD drive	y	y	y	y	y	y	-	-
20(j)	Circuit board, base board; laptop dependant	y	y	y	y	y	y	-	-
21	Socket on motherboard for external battery	y	y	y	y	y	y	-	-
22	External battery casing	y	y	y	y	y	y	-	-
23(k)	Ribbon cable; connected to mouse touchpad PWB, or PWB sample #20	y	y	y	y	y	y	y	-
24(l)	Ribbon cable to component	y	y	-	y	y	y	y	-
25	Plastic socket for pin connector, on motherboard (see #28)	y	y	y	y	y	y	-	-
26	Plastic socket for memory chip circuit board	y(m)	y	y	y	y (m)	y	-	-
27	Plastic connector socket for DVD drive	y(n)	y(n)	y	y	y	y	-	-
28	Plastic pin connector, fitting into #25	Y	y(o)	y	y	y	y	-	-
29	External power transformer plastic casing	y	y	y	y	y	y	-	-
30	Surface of main chip on motherboard	y	y	y	y	y	y	-	-
31	Plastic coating of internal power wire to screen	-	-	-	-	-	-	y	-
32	Plastic coating of internal wire to fan	-	-	-	-	-	-	y	-
33	Plastic coating of internal wire attached to dc input socket	-	-	-	-	-	-	y (r)	-
34	Plastic coating of internal wire to internal BIOS battery, else to speaker	-	-	-	-	-	-	y (s)	-
35	Outer plastic coating; external cable from dc power transformer to laptop	-	-	-	-	-	-	y	y
36	Inner plastic coating; external cable from dc power transformer to laptop	-	-	-	-	-	-	y	

Table 4. Samples analysed by X-ray microanalysis (XRF), as well as those samples analysed for the presence of PVC, and those samples analysed for phthalate composition; y – sample analysed; - sample not present or not analysed. For two Brands (Acer, HP), some laptops were slightly different models of, and therefore some individual components differ between laptop models of the same make. (a) Apple models-large rear plastic casing (battery compartment is metal); (b) no such material for Sony and Apple models; (c) Apple models-sheet attached to rear plastic casing (#9); Acer models-black sheet inside front casing; (d) no universal material; tested similar materials within different laptop makes & models; (e) no such material for 2 Dell (LTOP01, LTOP03) and 1 Sony (LTOP05) models; (f) Dell; flexible PWB motherboard to HDD; Sony flexible PWB motherboard to small PWB; Apple flexible PWB motherboard-DVD drive; Acer thin white ribbon on motherboard; HP thin white ribbon on motherboard; Toshiba white ribbon motherboard to small PWB; (g) Apple; different hard drives used (LTOP07-Seagate; LTOP08-09-Toshiba); Acer LTOP12 has different hard drive to other Acers tested; (h) not analysed for LTOP01 (i) Sony-PWB with USB sockets; Apple-small PWB linked to motherboard; HP- PWB linking DVD drive to motherboard; (j) Dell-PWB for flash memory card; Sony-PWB for ethernet socket; Apple-small PWB linked to motherboard; Acer-small PWB with LEDs; HP-PWB with USB sockets; Toshiba-small PWB linked to motherboard (via #16); (k) to mouse touchpad PWB (Sony, Apple, HP, Toshiba); PWB sample #20 (Dell, Acer); (l) Dell-to PCMCIA card slot; Sony-to headphone socket PWB; Acer-to motherboard; HP-to PWB attached to keyboard plate; Toshiba - to small separate PWB; (m) Dell-LTOP01 black plastic, LTOP02-03 white plastic; HP-LTOPO14 white plastic, LTOP15-17 black plastic; (n) Dell and Sony models; plastic connector socket for WLAN CARD; (o) Sony-no pin connector to #25 (direct cable input), different pin connector tested; (p) not tested for LTOP01 (Dell), LTOP06, 09 (Apple), LTOP13 (Acer), LTOP14 (HP), LTOP18 (Toshiba); (q) no such material for all Apple laptops LTOP06-09; (r) Dell-wire to internal on switch; Acer-wire to WiFi PWB; (s) Sony & HP models - wire to speaker, as no wire to BIOS battery; (t) Phthalate analysis for all makes, with the exception of all Apple laptops (sample #23).

Macbook DVD Drive dismantling.
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2.4 Extractable BFR quantification

For one laptop from each brand, between 1 and 3 individual components were analysed for a range of extractable BFRs. The only exception was Apple, where samples were analysed from 2 separate Apple laptops for reasons given below. The selection of components was based on the results of the XRF analyses for the levels of bromine.

Of all samples tested by XRF, three materials consistently contained high levels of bromine; the internal cooling fan (#10), the internal attachment for the detachable battery (#21), and a plastic pin connector socket on the motherboard (#25). Due to limited resources it was only possible to analyse one of these three materials from one laptop of each brand. Of the three, the pin connector socket (#25) was selected for detailed BFR analysis.

For laptops of all brands, with the exception of Sony, internal ribbon cables also commonly contained bromine at moderate to high levels. Furthermore, these components were composed of visibly different material from the pin connectors. One ribbon cable (#16) was common to all laptops, and XRF analysis demonstrated that this component very frequently contained bromine. This ribbon cable was therefore selected for quantitative BFR analysis from one laptop of each brand, other than Sony.

XRF analysis had also shown that, for two of the Apple laptops studied, this ribbon contained substantially higher levels of bromine (6.6-6.8%) than in the equivalent component from the other two Apple laptops studied (2.2-2.3%). To investigate this difference, detailed BFR analysis was carried out on 1 sample (LTOP09/16) containing the higher level of bromine, and 1 sample (LTOP06/16) containing the lower level of bromine.

In addition, one further material was analysed from Apple, Dell and Toshiba laptops for extractable BFRs, namely the mouse touchpad. This component was selected for further study as it was the only component tested by XRF that had consistently high bromine levels in all laptops of only one brand (Apple). In one of the three Dell laptops (LTOP01), and the Toshiba laptop (LTOP18), the mouse touchpads also contained bromine at a detectable level by XRF analysis, though at much lower levels than in the Apple components. The touchpads from these two laptops were also analysed for comparison.

As noted above, due to resource limitations, it was not possible to analyse the selected samples from all laptops, and so one laptop was selected from each brand (with the one exception being the analysis of the ribbon cable in a second Apple laptop described above). Individual laptops from each brand were selected based on their country of purchase, in order to give a wide geographical spread across all laptops analysed.

The BFRs quantified in each sample included PBDEs (tri- to deca-brominated congeners), PBBs (tetra- to deca-brominated congeners), HBCD (hexabromocyclododecane) and TBBPA (tetrabromobisphenol A). The individual materials analysed are given below in Table 5.

In addition, the samples that were analysed for the specific BFRs listed above (PBDEs, PBBs, TBBPA and HBCD) were also screened for the presence of other brominated compounds using gas chromatography/mass spectrometry (GC/MS, operated in SCAN mode). This screening analysis method provides useful indications of the identity of other compounds present in each sample, but does not quantify the concentrations of individual compounds identified.

Sample	Component	Brand Laptop	Dell LTOP01	Sony LTOP05	Apple LTOP06	Apple LTOP09	Acer LTOP13	HP LTOP14	Toshiba LTOP18
1	Mouse touch pad		y	-	-	y	-	-	y
16	Ribbon cable (flexible circuit board)		y	-	y	y	y	y	y
25	Pin connector socket on motherboard		y	y	-	y	y	y	y

Table 5. Materials and components quantified for a range of extractable BFRs; y, sample analysed; - sample not present / bromine not detected by XRF

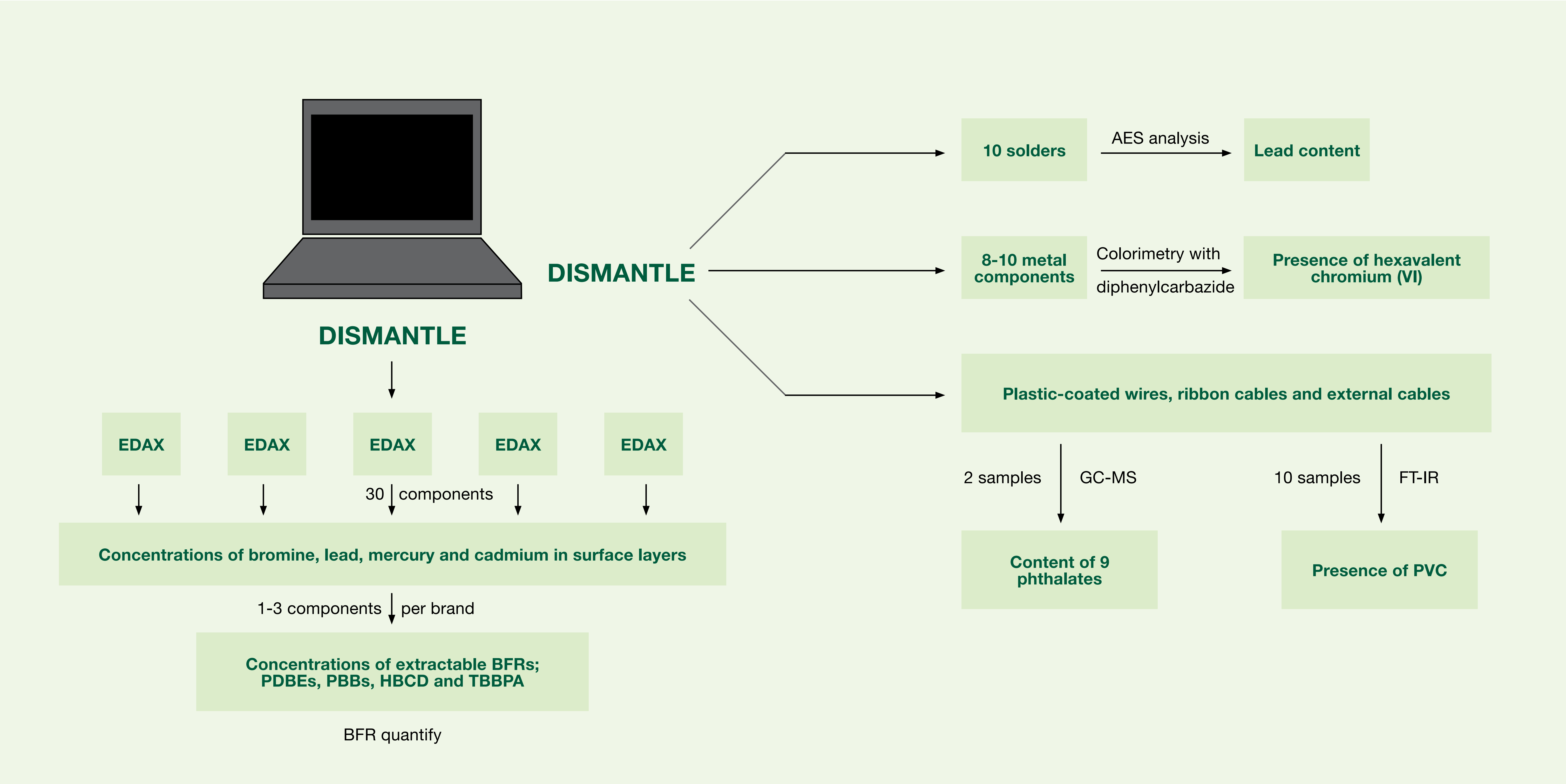
2.5 PVC

For each component analysed, the insulating plastic coating was analysed for the presence or absence of the plastic PVC by Fourier Transform Infrared (FT-IR) analysis. The individual materials analysed are given above in Table 4.

2.6 Phthalates

For each component tested (of either an external cable or an internal ribbon cable), the insulating plastic coating was analysed for the concentration of 9 phthalate esters; di-n-butylphthalate (DBP), butylbenzylphthalate (BBP), diethylhexylphthalate (DEHP), di-n-octylphthalate (DOP), dimethylphthalate (DMP), diethylphthalate (DEP), di-iso-butylphthalate (DiBP), di-isononylphthalate isomers (DiNP), di-isodecylphthalate isomers (DiDP). Unlike the other phthalates listed, both DiNP and DiDP are not individual chemicals but are groups of very closely related chemicals (isomers). The individual component analysed are given above in Table 4.

Dismantling of the components from each laptop and their subsequent analyses



3 Results and discussion

Toshiba main motherboard macro - cables, ram, motherboard. ©Greenpeace/Rose

The results from the range of analyses carried out on the various components from the 18 laptops are discussed in the following sections. It is important to note that these data relate only to those materials and components tested, which were a fraction of the very large number of materials and components within each laptop. The absence of a certain chemical in all samples tested from a laptop does not indicate that the laptop is entirely free of that chemical.

3.1 Lead content in electrical solder

None of the samples of electrical solder analysed contained lead at concentrations above 0.1 % (1000 mg/kg). In addition to other quality control methods, the ability of the analytical method to quantify lead in such materials was verified by the analysis of similar metal alloys known to contain lead, tin and other metals. The EU RoHS Directive and equivalent Chinese legislation4 set maximum concentration values of 0.1% lead in solder, with certain exceptions for the EU RoHS Directive. Thus all samples tested for lead from all laptops were compliant with EU and Chinese regulations.

Lead based solders have historically been widely used in electrical solders (commonly an alloy of tin and lead; 63% tin to 37% lead), though these materials have increasingly been substituted in recent years with lead-free alternatives[5]. To gain an understanding of the various alternative materials in use, all samples of solder were also analysed for concentrations of other metals reportedly used in electrical solders[5], namely antimony, bismuth, copper, indium, nickel, silver, tin and zinc. The data from the quantification of these metals in all samples is given in Appendix 2. These data show that the solders tested have a wide range of different compositions. In many cases, solder from equivalent locations within each laptop have similar compositions to each other, though some differences do exist. The presence of these metals in the solder alloy mixtures poses far less potential for impacts to human health and the environment than the presence of the highly toxic metal lead in traditional solders.

3.2 Hexavalent chromium (Cr VI)

Qualitative colorimetric analysis of between 8 and 10 internal metallic components from each laptop did not detect hexavalent chromium (VI) in any of the samples. The analytical method employed is able to detect the presence of hexavalent chromium at levels significantly below 0.1% by weight. All samples tested for hexavalent chromium from all laptops were therefore compliant with EU and Chinese regulations.

3.3 X-ray microanalyses (XRF); bromine, cadmium, lead & mercury

The following XRF data relate to concentrations in the surface layer of each material tested, at the site of measurement. The thickness of the surface layer analysed will vary between materials. For each material, there may be some variation between the surface concentration of an element, and the average concentration for the bulk of the material.

For the complex non-homogeneous circuit board samples, initial XRF analysis revealed the potential for copper within the surface layers to interfere with the analysis of other materials in the circuit board, including bromine containing materials, and thereby incorrectly indicate the absence of bromine where it was in fact present (See 3.3.1). As XRF is able to determine the presence of copper at the site of analysis, for each sample it was possible to identify a site on the base board that was free of copper, and obtain a measurement of bromine in the polymeric material of the base board. The data presented below for all circuit boards was measured at copper free sites.

None of the components tested by XRF contained cadmium, lead or mercury in surface layers at concentrations above method detection limits of 0.01% for cadmium and 0.05% for lead and mercury.

Bromine was detected in just over 40% of all samples tested from all laptops, i.e. in 221 of the 523 samples (with a detection limit of 0.1%). With the exception of the Sony laptops, of the 30 samples tested from each laptop, bromine was detected in between 11 and 16 samples. Of these, there was little difference between brands for the frequency with which bromine was detected in components; the Dell models had the highest frequency (14-15 samples per laptop), the HP models had the lowest (11-12 samples per laptop). For the Sony laptops, bromine was detected in far fewer of the equivalent materials tested, in only 4 samples from each laptop.

For all brands, a similar range of bromine concentrations was generally found in the various samples that tested positive, typically ranging from approximately 0.3% to 10% by weight. A summary of the number of samples found to contain bromine in each brand, and the range of concentrations found, is presented in Table 6. A breakdown of the data for different components is given in Table 7, showing the range of concentrations for each brand, and the brand with the highest bromine level. A complete list of data from the XRF analyses for all samples from each laptop is provided in Appendix 3.

Model	Laptops	No. of samples where bromine was detected for each laptop (a)	Range of bromine surface concentrations
Dell	LTOP01-03	14-16	0.30-10%
Sony	LTOP04-05	4	0.38-9.4%
Apple	LTOP06-09	13-15	0.15-9.9%
Acer	LTOP10-13	12-15	0.18-10%
Hewlett Packard	LTOP14-17	11-12	0.26-9.5%
Toshiba	LTOP18	12	0.32-9.2%

Table 6. Number of samples found to contain bromine above the detection limit of 0.1% by XRF analysis, and the range of surface concentrations in all laptop models; (a) the range of numbers containing bromine for a brand reflects the differences found between models of the same brand.

For some components, a very similar pattern was found for all laptops irrespective of the brand. For example, bromine was consistently present in the cooling fan (#10), with high surface concentrations in the range 4.4-6.6%. Somewhat lower levels were commonly found for the surface of the main chip (#30), in the range 0.28-0.42% (with one exception, as bromine was not detected in a Sony laptop purchased in Japan; LTOP05). A pin connector socket (#25) on the motherboard consistently contained high bromine levels in the range 6.0-10% (though with two exceptions in which bromine was not detected; one Sony laptop purchased in Sweden; LTOP04, and one Dell laptop purchased in the USA, LTOP03). For two other pin connector sockets (#26, #27), bromine was not detectable in any of the laptops, other than at relatively low levels in one Apple and one HP laptop.

Component or material type	Highest value[a]	Number of samples with bromine (total number of samples analysed) concentration range (%) [b]					
		Dell	Sony	Apple	Acer	HP	Toshiba
Circuit boards	**Acer 8.2%**	**15 (15)** 1.8-6.2%	**1 (10)** 6.0%	**22 (24)** 0.15-7.4%	**20 (24)** 2.0-8.2%	**21 (24)** 1.9-7.5%	**2 (5)** 6.6-7.7%
Ribbon cables[c]	**HP 7.0%**	**9 (12)** 0.58-2.7%	**- (8)** -	**8 (12)** 1.1-6.8%	**11 (15)** 0.2-3.0%	**7 (16)** 2.2-7.0%	**3 (4)** 1.7-2.2
Insulation sheets	**Dell 5.8%**	**6 (6)** 1.4-5.8%	**- (4)** -	**4 (8)** 2.8-2.9%	**1 (8)** 1.9%	**- (8)** -	**- (2)** -
Internal plastic pin connectors	**Dell/Acer 10%**	**5 (12)** 3.7-10%	**3 (8)** 9.3-9.4%	**5 (16)** 0.2-7.4%	**8 (16)** 4.5-10%	**5 (16)** 0.26-7.0%	**2 (4)** 4.8-8.7%
Fans	**Apple 6.6%**	**3 (3)** 5.9-6.4%	**2 (2)** 4.6-6.1%	**4 (4)** 5.3-6.6%	**4 (4)** 4.5-6.4%	**4 (4)** 4.4-5.3%	**1 (1)** 5.9%
Socket for external battery	**Apple 9.9%**	**3 (3)** 7.9-8.5%	**- (2)** -	**4 (4)** 6.9-9.9%	**4 (4)** 8.4-8.8%	**4 (4)** 8.1-9.5%	**1 (1)** 9.2%
Main chip surface	**HP 0.42%**	**3 (3)** 0.30-0.38%	**1 (2)** 0.38%	**4 (4)** 0.30-0.38%	**4 (4)** 0.28-0.36%	**4 (4)** 0.29-0.42%	**1 (1)** 0.36%
External battery casing	**Acer/HP 1.4%**	**1 (3)** 0.64%	**- (2)** -	**- (4)** -	**1 (4)** 1.4%	**1 (4)** 1.4%	**- (1)** -
Power transformer casing	**Sony 2.8%**	**1 (3)** 0.30-0.35%	**1 (2)** 2.8%	**- (4)** -	**1 (4)** 0.18%	**- (4)** -	**1 (1)** 0.32%
Touch mouse pads	**Apple 5.0%**	**1 (3)** 2.2%	**- (2)** -	**4 (4)** 4.6-5.0%	**- (4)** -	**- (4)** -	**1 (1)** 0.54%
Mouse button	**Dell 1.5%**	**1 (3)** 1.5%	**- (2)** -	**- (4)** -	**- (4)** -	**- (4)** -	**- (1)** -
Plastic housing/casing	**Apple 0.68%**	**- (15)** -	**- (8)** -	**1 (16)** 0.68%	**- (20)** -	**- (20)** -	**- (5)** -

Table 7. Summary of bromine content in samples from all models from each brand, for key component groups analysed. (a) brand yielding the highest surface bromine concentration for each component type; (b) of all values above detection limit of 0.1%; (c) no surface bromine detected in sample 6 (ribbon cable connected to keyboard) for all laptops

Toshiba exterior dismantling.
©Greenpeace/Rose

For all brands other than Sony, all laptops contained a number of other components with significant bromine contents, and with some similarities between models. These components (and the range of surface bromine concentrations) were the attachment on the motherboard for the external battery (#21; 6.6-9.9%), and two different ribbon cables (#16; 1.8-3.5% and #24; 1.3-3.0%). For one of the ribbon cables (#16), particularly high levels were seen in two of the Apple laptops (L08/L09; 6.6-6.8%). The other ribbon cable tested (#24) was not present in any Apple laptop, nor in one Acer laptop (LTOP13) and there are therefore no data for these models. In the two Sony laptops, no bromine was detected in any of the above components.

Similarly, another ribbon cable (#23) contained bromine at surface concentrations similar across all brands, with the exception of the two Sony laptops and all four HP laptops for which bromine was not detected in the equivalent components. In two of the Apple laptops (L07/L08) this material contained notably higher bromine levels than in the other two Apple laptops. Differences that were found between laptops of the same brand are further discussed below.

For circuit boards, the elimination of brominated flame retardants is widely seen as a difficult challenge. For the circuit boards tested, bromine was widespread, being detected in all but a very few samples in laptops from all brands, with the exception of the Sony and Toshiba models. Where present, bromine was generally found at high concentrations.

In the Sony laptops, only 1 of the 6 different types of circuit board that were tested was found to contain bromine; the memory chip board (6.0%). No bromine was detected in all other circuit boards, including the large motherboard. Similarly, for the one Toshiba laptop tested, bromine was detected in only 2 of the 5 circuit board that were tested; in the memory chip board (6.6%) and also one other circuit board (from the DVD drive, 7.7%). No bromine was detected in the 3 other circuit boards tested, including the large motherboard.

For the Dell, Apple, Acer and HP laptops, the presence of bromine in circuit boards was widespread, ranging from 20 out of the 24 samples tested in the 4 Acer laptops, to every sample tested in the 3 Dell laptops. Similarities were seen for equivalent circuit boards across all four brands, though a small number of differences were seen between brands as well as between laptops of the same brand.

While not found in the motherboards of the Sony and Toshiba laptops, the motherboards (#14) from all other laptops (Dell, Apple, Acer and HP) contained bromine, with a similar range of levels across all brands (1.8-4.3%). The same pattern was seen for other circuit boards (#20). For the circuit board situated under the mouse touchpad (#18), all Apple laptops had far lower bromine levels (0.15-0.37%) compared to equivalent boards in all laptops from the Dell, Acer and HP models (3.9-7.5%).

The memory chip circuit board (#15) contained bromine across every brand including Sony and Toshiba, being detected in all laptops with the exception of 1 of the 4 Acer laptops and 2 of the 4 HP laptops. Again, where present, a similar range of levels was found across all brands (4.0-8.1%). The Acer laptop (LTOP13) and HP laptops (LTOP15 & LTOP16) in which bromine was not detected were different models from those Acer and HP laptops in which bromine was found. A similar pattern was seen for other circuit boards; One (#19) contained bromine in all laptops other than the Sony models. A similar range of levels was found across all brands (3.8-7.7%), with the exception of 1 Acer laptop (LTOP13, 2.2%) and 2 HP laptops (LTOP14 & LTOP15, 2.1-2.7%). Again, the Acer and HP laptops with lower levels were different models from those laptops in which higher levels were found.

Unlike the other circuit boards discussed above, those within the hard drives (#17) had a far lower frequency of bromine detection, with bromine being present in only 6 of the 18 equivalent components tested; in 2 of 4 Apple laptops, 1 of 4 Acer laptops and 3 of 4 HP laptops. No bromine was detected in this component from any of the Dell, Sony or Toshiba models.

There were other examples where components in all laptops of certain brands were found to contain bromine, while equivalent components from other brands did not contain detectable levels of bromine. However, no universal differences were seen between brands for these components; the brands in which bromine was consistently detected in one component were different from the brands in which bromine was consistently detected in another component. However, Apple and Dell laptops were commonly amongst those brands in which bromine was detected.

All Dell and Apple laptops contained electrical insulating sheeting with detectable levels of bromine. In the Dell models, bromine was present in both such materials tested (1.8-5.8%), while in the Apple models, bromine was detected in only 1 of the 2 materials tested from each laptop (2.8-2.9%). For the laptops from the other brands, no bromine was detected in these materials, with the exception of one sample from an Acer laptop (LTOP13) containing 1.9% bromine.

One component, a pin connector (#28), consistently contained high levels of bromine in all Dell, Sony, Acer and Toshiba laptops. For this component, the Sony laptops had the highest surface concentrations of bromine of all brands (9.3-9.4%). This pattern contrasts that of many other components, where bromine was frequently detected in one or more brand but was not detected in the components from the Sony models (see above).

Finally, the mouse touchpad of all Apple laptops contained bromine, all at similar levels (4.6-5.0%). This component in the one Toshiba model that was tested also contained bromine, though at a far lower level (0.54%). Bromine was also detected in the mouse touchpad of 1 of the 3 Dell models tested (LTOP01; 2.2%), though not in the 2 other Dell laptops, nor those of the other brands.

A variety of other materials were found to contain bromine in individual laptops, though in no more than one laptop from each brand. One such material was the casing of the laptop battery, which contained bromine at surface concentrations ranging from 0.64 to 1.4% in one Dell (LTOP03), one Acer (LTOP10) and one HP laptop (LTOP15). A second example was the casing of the external power supply transformer, with bromine surface concentrations ranging from 0.18 to 2.8% in one Dell (LTOP03), one Sony (LTOP05), one Acer (LTOP10) and the one Toshiba laptop tested (LTOP18). In this latter sample, the level in the Sony laptop (2.8%) was far higher than those in the other 3 models (0.18-0.57%).

For two components, bromine was detected in only 1 of the 18 laptops tested, namely the mouse button (Dell, LTOP02) and the laptops' plastic housing (Apple, LTOP06).

3.3.1 Copper within circuit boards can affect analysis of other elements

For the 4 circuit boards that were tested by both XRF surface analysis and also by XRF analysis of the ground sample, the data revealed the ability of copper within the mixed material to block the analysis of bromine in the material, and give a false negative reading (Table 8). The surface XRF analysis of the 2 samples that were measured at sites where copper was present did not detect bromine. However, for these samples the analysis of the ground material showed that bromine was present, at 2.7% and 4.3% in the 2 samples. These data indicate that, for the testing of circuit boards and other heterogeneous materials, there is a need to verify the absence of copper or other materials that can affect the analysis. Incorrectly applied XRF testing can incorrectly indicate that a component is bromine free even where it contains a significant concentration of bromine.

For the 2 circuit boards that were analysed at sites where copper was not present, the data from the surface XRF analysis (1.8% and 2.2%) did vary from the data from the ground sample (both 3.0%). However, both testing methods indicated significant bromine concentrations in both materials. For each sample, the difference in the data from the different testing methods more probably demonstrates the potential for variation between the measured surface bromine concentration and the average bromine concentration for the bulk of the material, particularly for heterogeneous multilayered components such as circuit boards.

Sample	Copper at test site	Surface analysis (Br %)	Ground sample (Br %)
LTOP001/14	No	2.2	3.0
LTOP002/14	No	1.8	3.0
LTOP010/14	Yes	<0.1	2.7
LTOP012/14	Yes	<0.1	4.3

Table 8. Bromine concentrations in four circuit board samples. For each, the concentration was measured in the surface layer by surface XRF analysis, and separately in the bulk of the material by analysis of the ground sample

3.3.2 Differences between laptops of the same brand; occurrence and levels of bromine

For each brand, individual laptops were purchased in different countries and regions. At the time of purchase, legislation had recently been introduced in the EU to regulate the use of certain hazardous chemicals in these products. The range of laptops investigated in this study included examples in which a specific model sold within the EU could also be purchased in a country outside the EU. In such cases, regulations that apply to the model sold within the EU do not apply to the laptop sold outside the EU.

For example, the three Dell laptops tested were all model Latitude D420. One was purchased in Germany (LTOP02) where EU legislation applies. The other two laptops were purchased in China (LTOP01) and the USA (LTOP03), and therefore their sale was not controlled under the EU regulations.

For all brands, the data reveal differences between identical models that were purchased in different countries (with the exception of Toshiba, given that only 1 laptop was tested). Some patterns are apparent between the country of purchase and the presence and/or levels of bromine in certain components, though the differences are by no means universal. Likewise, while there are some differences between laptops purchased within EU countries compared to those purchased outside the EU, there are also cases where the differences do not follow these patterns. Specifically for circuit boards, no consistent differences were seen between laptops purchased within the EU compared to those purchased outside the EU. The same situation was seen between laptops purchased in China compared to those purchased in other countries.

Where patterns existed, the clearest examples were for the Acer brand. For these laptops, two components from the model purchased in China (LTOP10) contained bromine; an external battery casing (#22; 1.4% bromine) and the casing of the external power supply transformer casing (#29; 0.18%), while equivalent components from the other three Acer laptops (purchased in Poland, the Netherlands and Thailand) did not. Uniquely amongst the Acer laptops, a sample of electrical insulating sheet (#12) in the laptop purchased in the Netherlands (LTOP13) contained bromine at 1.9%, though this model was different from the models purchased in other countries (Aspire 5672 WLMi versus Aspire 5562 WXMi).

For the Dell and Apple laptops, the patterns are less clear.

For Dell, only the model purchased in China (LTOP01) had a mouse touchpad which contained a detectable level of bromine (#01; 2.2%). For another component, a pin connector socket (#25), bromine was detected in only the model from China (LTOP01) and the model from Germany (LTOP02). Furthermore, the model from Germany was the only Dell laptop in which bromine was detected in the mouse button (#02; 1.5%). An opposite trend was seen for other components; the model purchased in the USA (LTOP03) had an external battery casing (#22) and an external power supply transformer casing (#29) that contained detectable levels of bromine, at 0.64% and 0.57% respectively. Bromine was not detected in these components in either the model purchased in China nor the model purchased in Germany. An insulation sheet (#12) in the USA model also contained approximately twice the surface level of bromine compared to this same material in both the Chinese and German models.

For the Apple laptops, only the model purchased in the Philippines (LTOP06) contained a housing material (#08) with bromine at a detectable level (0.68%). Significantly different levels of bromine were found in equivalent ribbon cables from models purchased in different countries. For one ribbon cable (#16), the models purchased in the Netherlands and the USA contained surface bromine levels 3 times higher than in the models purchased in the Philippines and Russia. However, for a different ribbon cable (#23), the models purchased in the Netherlands and Russia contained the higher levels (3-4 times those found in the other models).

For the HP laptops, differences also existed between individual laptops. However, the four HP models tested were all different, though closely related, models from each other. For the model purchased in Argentina (LTOP15), the casing of the battery (#22) contained bromine (1.4%), which was not seen for the other models. For each model, however, the batteries had different part numbers. Similarly the circuit board joining the motherboard to the DVD drive (#19) in the HP laptops, all with the same identification code, contained higher levels of bromine in the models purchased in France and the USA (6.4 & 4.8% respectively) compared to those purchased in Mexico and Argentina (2.1-2.7%).

Comparisons for the Sony laptops are less clear as the study included only 2 Sony laptops, while for other brands laptops purchased in up to 4 countries were tested. For the Sony laptop purchased in Japan (LTOP05), two components contained bromine (a pin connector socket (#25; 9.3% bromine) and the external power supply transformer casing (#29; 2.8%), while bromine was not detected in these components from the other Sony laptop, purchased in Sweden (LTOP04).

Brominated flame retardants (BFRs); there is potentially a very wide range of brominated chemicals that can be used as BFRs10 Commonly used examples include polybrominated diphenyl ethers **(PBDEs)** and tetrabromobisphenol A **(TBBPA)**, as well as brominated polymeric and oligomeric materials. Historically, some electrical/electronic equipment contained polybrominated biphenyls **(PBBs)**, though these BFRs have now been widely phased out for some time. Hexabromocyclododecane **(HBCD)** is another commonly used additive brominated flame retardant, especially in expanded polystyrene, which can be readily extracted if present.

PBDEs are a group of related chemicals differing in the amount and arrangement of bromine within each molecule. The most commonly used in modern electronics is deca-BDE (BDE-209), often referred to as simply 'deca'. A recent study[13] has demonstrated the potential for human exposure to deca-BDE and other PBDEs as a result of the recycling and disposal of electronic wastes, resulting in the highest levels of deca-BDE to be reported in humans. PBBs are a similar group of chemicals based on a different molecular backbone. HBCD is also a group of related chemicals, each with the same degree of bromination but arranged differently within the molecule. TBBPA is a single individual chemical.

Some BFRs, including certain PBDEs and PBBs, have known toxic properties, and some are highly persistent in the environment and able to bioaccumulate (build up in animals and humans). In whatever form the bromine is present, impacts can result at the product's end of life as a result of the unintentional formation of toxic brominated byproducts (including dioxins) during some disposal or recycling operations[11].

13 Bi, X., Thomas, G.O., Jones, K.C., Qu, W., Sheng, G., Martin, F.L., Fu, J. (2007) Exposure of Electronics Dismantling Workers to Polybrominated Diphenyl Ethers, Polychlorinated Biphenyls, and Organochlorine Pesticides in South China. Environmental Science and Technology 41: 5647-5653

3.4 Brominated flame retardants

Although XRF can provide a reliable method for determining the bromine content of the surface layer of a material, it does not yield information on the chemical form in which the bromine is present. High bromine content is likely to result from the use of a brominated flame retardant formulation, whether in additive or reactive (polymer-bound) forms.

There is potentially a very wide range of brominated chemicals that can be used as brominated flame retardants. This investigation focussed on certain classes of brominated chemicals due to their common usage as flame retardants, namely PBDEs, PBBs, TBBPA and HBCD (see text box to the left).

Due to resource limitations, it was possible to only quantify these brominated flame retardants in a relatively small number of the materials that were found to contain bromine. Where available, a ribbon cable (#16) and a pin connector socket from the motherboard (#25), were analysed from one laptop of each brand. These materials were selected in recognition of their consistently high bromine content across all brands. Samples from two separate Apple laptops (LTOP06 and LTOP09) were analysed due to the very different levels of bromine that were found in the ribbon cables (sample 16) of the identical laptop models that had been purchased in different countries.

In addition, BFRs were quantified in three mouse touchpads. This component was selected as it was the only component tested by XRF that had consistently high bromine levels in all laptops of only one of the brands investigated (Apple). In one of the three Dell laptops (LTOP01), and the Toshiba laptop (LTOP18), this component also contained bromine at a detectable level by XRF analysis, though at much lower levels, particularly for the Toshiba laptop.

The samples that were quantified for extractable BFRs, and those samples in which extractable BFRs were found are presented in Table 9, along with the surface levels of bromine as determined by XRF analysis. For those samples in which extractable BFRs were identified, a breakdown of the type of BFRs identified and their concentrations in the samples is given in Table 10.

Sample	Component	Dell LTOP01	Sony LTOP05	Apple LTOP06	Apple LTOP09	Acer LTOP13	HP LTOP14	Toshiba LTOP18
01	Mouse touch pad	X (2.2% Br)	-	- (4.6% Br)	BFR (4.8% Br)	-	-	X
16	Ribbon cable (flex. circuit board)	BFR (2.2% Br)	-	BFR (2.2% Br)	BFR (6.8% Br)	X (2.4% Br)	X (2.3% Br)	X
25	Pin connector socket	X (10% Br)	X (9.3% Br)	- (6.3% Br)	X (7.4% Br)	X (6.5% Br)	X (6.0% Br)	X (6.9% Br)

Table 9. Components in which extractable BFRs were quantified; BFR=extractable BFRs identified; X=BFRs not present above method detection limits; - sample not quantified for BFRs. (%) indicates the surface level of bromine by XRF analysis, for those samples where bromine was detected

Sample type	Mouse touch pad			Ribbon cable (flexible circuit board)		
Sample #	01	01	01	16	16	16
Laptop	LTOP01 DELL	LTOP09 APPLE	LTOP18 Toshiba	LTOP01 DELL	LTOP06 APPLE	LTOP09 APPLE
Surface bromine by XRF (%)	2.2	4.8	0.54	2.2	2.2	6.8
Surface bromine by XRF (mg/kg)	22000	48000	5400	22000	22000	68000
Extractable BFR concentrations (mg/kg) of;						
PBDEs;						
All tetra- to octa-BDEs	-	-	-	-	-	-
NonaBDEs	-	**1.87**	-	-	-	-
DecaBDE (BDE-209)	-	**12.2**	-	-	-	-
TBBP-A	-	**125**	-	**242**	**13.1**	**87.1**
HBCD	-	-	-	-	-	-
PBBs (all)	-	-	-	-	-	-

Table 10. Summary of the groups of extractable BFRs, and their concentrations, in those samples in which extractable BFRs were identified; '-' indicates no BFRs identified above method detection limits

Of the three mouse touchpads (#01) analysed, extractable BFRs were identified in only the component from the Apple laptop (LTOP09). PBDEs were present at low levels in this sample, including deca-BDE (BDE-209) at 12.2 mg/kg and nona-BDEs at 1.87 mg/kg. This component also contained the brominated chemical TBBPA at a higher concentration of 125 mg/kg.

Of the ribbon cables (#16) analysed, the compound TBBPA was identified in the Dell laptop (LTOP01) and both Apple laptops (LTOP06 & LTOP09). No extractable BFRs were identified in this component for the Acer, HP or Toshiba laptops. The highest level of TBBPA was found in this component from the Dell laptop, at 242 mg/kg. Of the two Apple laptops, a higher level of TBBPA was present in the laptop purchased in the USA (LTOP09) compared to that purchased in the Philippines (LTOP06). The same pattern was seen for the total bromine levels in these materials as determined by XRF analysis; 6.8% and 2.2% respectively.

For all laptops tested, the pin connector socket (#25) did not contain detectable levels of the extractable BFRs quantified.

Deca-BDE and TBBPA are not included amongst the BFRs regulated under the EU RoHS directive. This Directive does restrict the use of PBDEs, though deca-BDE is specifically exempted. Other BDEs, including nona-BDEs, are regulated under this legislation. However, a maximum allowable limit for BFRs, including nona-BDE, is set at 1000 mg/kg (0.1%) in homogeneous materials, far higher than the levels detected in the mouse touchpad from the Apple laptop.

Where present in the components tested, the low concentrations of both PBDEs and TBBPA are highly unlikely to provide sufficient flame retardancy alone for the plastic material from which the components are constructed. Furthermore, XRF analysis has demonstrated that these components contained far higher total surface bromine levels (between 0.54% and 6.8% , or 5400–68000 mg/kg) than could be explained by the concentrations of these extractable chemicals alone. Therefore the bulk of the bromine content (assuming surface concentrations are indicative of concentrations throughout the material) must result from the presence of brominated chemicals other than those specifically quantified in this study.

Macbook Ribbon.
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PBDEs are incorporated into polymers in 'additive' mode. The PBDEs are simply mixed with the polymer during production, but are not chemically bound to the polymer. When incorporated in this way, many BFRs can be extracted from the plastic and therefore are able to be identified by analysis. A further consequence of the incorporation of PBDEs in additive mode is that these chemicals can migrate out of the material over time, and this can result in substantial losses during the lifetime of products, and also following disposal. This has lead to their widespread presence in the environment.

TBBPA can also be incorporated into polymers in additive mode, though it is far more common for TBBPA to be used in reactive (polymer-bound) mode. The use of TBBPA in reactive mode in brominated epoxy resin circuit boards represents one of the major uses of this compound worldwide. In reactive mode, the majority of the TBBPA chemically reacts to become part of the polymer and is no longer present as the TBBPA monomer. Even when used in this mode, however, a small proportion of the total TBBPA that has been used remains as unreacted TBBPA monomer, and this can be isolated by solvent extraction.

As the use of TBBPA in reactive mode is a far more common process, it seems likely that the concentrations of extractable TBBPA in the three pin connector sockets and the Apple mouse touchpad are due to the inevitable presence of a small proportion of unreacted TBBPA resulting from its use in reactive mode. In this case, the majority of the bromine would be bound up in the polymeric material and could not be extracted and quantified by the methods employed. This alone could account for the large differences between the levels of extractable TBBPA and the total levels of bromine in these materials, though the possible presence of other oligomeric or polymeric forms of organic bromine cannot be ruled out.

3.4.1 Other BFRs

Those samples quantified for the specific BFRs discussed above (PBDEs, PBBs, TBBPA and HBCD) were also screened for the presence of other extractable brominated compounds. Some additional compounds were identified in extracts from samples from the Acer, HP and Toshiba laptops. The samples that contained these additional brominated chemicals, were different to those samples that contained the BFRs discussed above (PBDEs, PBBs, TBBPA, HDCD).

Two brominated chemicals, pentabromotoluene and 3,4-dibromostyrene, were identified in 3 samples, namely the pin connector sockets from the Acer, HP and Toshiba laptops (Samples #25 from LTOP13, LTOP14 & LTOP18). Pentabromotoluene is known to be used as a flame retardant in some applications10. 3,4 dibromostyrene is most likely to be present as a result of the use of brominated styrene polymer, a known flame retardant10. This polymer is manufactured from brominated styrene, and the residues of 3,4-dibromostyrene could arise as unreacted monomer or from the partial decomposition of the polymer over time.

One sample, the ribbon cable from the Toshiba laptop (LTOP18), also contained tribromophenol. Again, this compound may be present as a result of the use of brominated polymer10 which can contain trace amounts of the tribromophenol used in its manufacture. Some other samples contained brominated compounds, though it was not possible to identify these chemicals fully.

For all the above compounds, though the levels in the samples were not quantified, data indicate that they were present at relatively low concentrations, of a similar or lower magnitude to the levels of TBBPA and PBDEs identified in other samples. It is unlikely, therefore, that they too could account for the majority of the bromine content detected in these samples by the XRF analyses.

Indeed, it seems likely that the majority of the bromine in the samples that were analysed for individual BFRs is bound up in the polymeric material of the samples tested, and therefore not amenable to solvent extraction and analysis by the methods used. These materials may also contain high molecular weight oligomeric flame retardants, such as brominated epoxy oligomers (BEOs), which are not amenable to solvent extraction and/or analysis by GC-MS.

A number of such polymeric and oligomeric materials are available, and commercial information indicates that they are becoming widely used in electronics applications. However, it is not possible to obtain any further information on the exact chemical forms of the majority of the detectable bromine content of the materials analysed using the methods employed in this study. To obtain such information by analysis is likely to remain very difficult, such that the only option may ultimately be to request such information from the component manufacturers themselves.

3.5 PVC

The results of the analysis of certain plastic components from each laptop for the presence of the plastic PVC are presented in Table 11. Of these materials, between 2 and 4 samples from each laptop (#6, #16, #23, #24) were also analysed by XRF, as discussed above. Furthermore, 2 of the samples (samples #6 & #35) were also analysed quantitatively for the presence of 9 phthalate esters.

Of the 170 materials from all laptops subject to PVC analysis, a total of 48 tested positive for the presence of PVC. For all laptops of all brands, none on the 62 plastic materials of the different internal ribbon cables analysed tested positive for PVC. In addition, the plastic coatings of the internal power wire to the screen (#31) tested negative for PVC in all cases. Of the remaining 5 materials tested in each laptop (all plastic coatings of internal and external wires and cables), one or more tested positive for PVC in every laptop.

Of all internal wires and external cables tested (#31 #36) for all laptops, 44% tested positive for PVC in the plastic coating (48 out of 108 materials).

For each brand, the average number of materials that tested positive for PVC per laptop was similar; between 2 and 3 materials for the Dell, Sony, Apple and Acer brands, while the HP and Toshiba brands had an average of 4 materials per laptop. However, within each brand, the number of materials that tested positive varied between individual laptops, with the exception of the two Sony laptops. For example, in one HP laptop (LTOP17) only two materials tested positive, while in another HP laptop (LTOP15) five materials tested positive.

There were generally no clear and consistent patterns in the number and type of materials that tested positive for PVC between different brands, or even between laptops of the same brand. The only exception was the Sony brand; in both laptops the same two materials contained PVC (inner and outer coatings of the cable from the dc power transformer), while all other materials did not.

The material that most commonly tested positive for PVC was the outer plastic coating of the cable from the DC power transformer (in all laptops other than the Apple laptops and one Acer laptop). However, for this Acer laptop and 3 of the 4 Apple laptops, the inner plastic coating of this cable did test positive for PVC. This inner coating material also tested positive in many of the other laptops.

Individual laptops were purchased in different countries and regions. Considering all laptops of all brands together, there were no clear relationship between the country or region in which the laptop was purchased and the number / type of materials that tested positive for PVC. For example, the Dell laptop purchased in Germany contained the most PVC positive results for all Dell laptops, while the Apple laptop also purchased in an EU country (the Netherlands) contained the least PVC positive results for all Apple laptops.

However, for each of the materials of which samples from some laptops showed the presence of PVC, equivalent samples from other laptops showed a non-PVC containing material being used. This illustrates that, for these applications, it is not essential for PVC to be used.

Although PVC does not have direct toxicity, this plastic does presents its own manufacturing and waste management problems by acting as a source of organic-bound chlorine to the waste stream, as well as raising additional concerns at other points in its lifecycle. Furthermore, the use of PVC in certain applications requires the use of additive chemicals, such as phthalate esters (phthalates) used as plasticisers (softeners).

Macbook exterior.
©Greenpeace/Rose

Sample	Component		Dell		Sony			Apple				Acer				HP			Toshiba
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
6(a)(b)	Ribbon cable to keyboard	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
16(a)	Ribbon cable from motherboard	-	nd	nd	nd	nd	-	nd	nd	-	nd	nd	nd	-	-	nd	nd	nd	-
23(a)	Ribbon cable to a PWB	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
24(a)	Ribbon cable to component	nd	nd	nd	nd	nd	-	-	-	-	nd	nd	nd	nd	nd	nd	nd	nd	nd
31	internal power wire to screen	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
32	internal wire to fan	nd	PVC	nd	nd	nd	nd	PVC	nd	PVC	PVC	PVC	PVC	nd	nd	PVC	PVC	PVC	PVC
33	internal wire to dc input socket	nd	PVC	nd	nd	nd	PVC	PVC	nd	PVC	nd	nd	nd	nd	PVC	PVC	nd	nd	nd
34	internal wire to BIOS battery/speaker	PVC	PVC	nd	nd	nd	nd	nd	nd	nd	nd	PVC	PVC	nd	PVC	PVC	PVC	nd	PVC
35(b)	external cable to transformer (outer)	PVC	PVC	PVC	PVC	PVC	nd	nd	nd	nd	PVC	PVC	nd	PVC	PVC	PVC	PVC	PVC	PVC
36	external cable to transformer (inner)	nd	PVC	PVC	PVC	PVC	nd	PVC	PVC	PVC	nd	PVC	PVC	nd	nd	PVC	nd	nd	PVC

Table 11. Results of the analysis of components for PVC content in all laptops (LTOP01-18); PVC, presence of PVC confirmed; nd, not detected; -, not analysed. (a) also analysed by XRF; (b) also analysed for phthalate content.

Sample 35		Dell		Sony			Apple				Acer				HP			Toshiba
	L01	L02	L03	L04	L05	L06	L07	L08	L09	L10	L11	L12	L13	L14	L15	L16	L17	L18
Di-n-butylphthalate (DBP)	< 20	22	< 20	< 10	< 10	30	< 10	< 20	20	< 20	< 10	< 10	< 10	< 9	< 10	< 10	< 20	< 20
Butylbenzylphthalate(BBP)	< 20	< 20	< 20	< 10	< 10	< 20	< 10	< 20	< 20	< 20	< 10	< 10	< 10	< 9	< 10	< 10	< 20	< 20
Diethylhexylphthalate (DEHP)	450	630	130	750	330	340	47	72	86	2600	2800	200000	1300	100	11	1200	58	190
Di-n-octylphthalate (DOP)	190	25	< 20	< 10	< 10	< 20	< 10	< 20	< 20	< 20	< 10	< 10	< 10	< 9	< 10	< 10	< 20	< 20
Dimethylphthalate (DMP)	< 20	< 20	< 20	< 10	< 10	< 20	< 10	< 20	< 20	< 20	< 10	< 10	< 10	< 9	< 10	< 10	< 20	< 20
Diethylphthalate (DEP)	< 20	< 20	< 20	< 10	< 10	< 20	< 10	< 20	< 20	< 20	< 10	< 10	< 10	< 9	< 10	< 10	< 20	< 20
Diisononylphthalates (DiNP)	<100	(d)	95000	55000	(d)	3100	2000	2000	2300	22000	180000	2800	180000	200000	260000	280000	190000	130000
Di-iso-butylphthalate (DiBP)	<20	< 20	< 20	< 10	< 10	< 20	< 10	< 20	< 20	< 60	19	30	< 10	20	21	< 10	30	20
Di-isodecylphthalates (DiDP)	86000	33000	(n)	(n)	73000	(nd)	< 50	< 90	< 90	(n)	(n)	(nd)	(n)	(n)	(n)	(n)	< 90	(nd)
TOTAL (mg/kg)	86640	33677	95130	55750	73330	3470	2047	2072	2406	24600	182819	202830	181300	200120	260032	281200	190088	130210
TOTAL (%)	8.7	3.4	9.5	5.6	7.3	0.3	0.2	0.2	0.2	2.5	18.3	20.3	18.1	20.0	26.0	28.1	19.0	13.0

Table 12. Concentrations of nine phthalates in sample #35, the outer plastic coating of the cable from the power transformer, in mg/kg;
** summed data for diisononylphthalates (DiNP) and diisodecylphthalates (DiDP); (n) DiNP dominates, (d) DiDP dominates, (nd) Approximately equal contribution from DiNP & DiDP.*

3.6 Phthalates

The concentrations of the nine phthalates quantified in the two plastic materials from each laptop are given in Table 12 and 13. In addition to the two components analysed from each laptop (samples #6 and #35), two of the purposefully designed storage bags used to store and transport all samples was also analysed for phthalate content to determine whether the use of these bags could have contributed to the levels of phthalates in the materials tested. Neither storage bag contained phthalates above method detection limits, demonstrating that the use of these was not a potential source of phthalate contamination.

Sample 6	SONY LTOP04	All other laptops	storage bag (2 samples)
Di-n-butylphthalate (DBP)	< 20	<10 - <30	< 20
Butylbenzylphthalate(BBP)	< 20	<10 - <30	< 20
Diethylhexylphthalate (DEHP)	< 20	<10 - <30	< 20
Di-n-octylphthalate (DOP)	< 20	<10 - <30	< 20
Dimethylphthalate (DMP)	< 20	<10 - <30	< 20
Diethylphthalate (DEP)	< 20	<10 - <30	< 20
Diisononylphthalate Isomers (DiNP)	100	<50 - <200	< 20
Di-iso-butylphthalate (DiBP)	< 20	<10 - <30	< 80
Di isodecylphthalate Isomers (DiDP)	< 90	<50 - <200	< 80

Table 13. Concentrations of nine phthalates in samples of ribbon cable (#6) from all laptops and from two sample storage bags, in mg/kg.

None of the internal ribbon cables (#6) analysed contained detectable levels of any of the nine phthalates (Table 13). The only exception to this was the material in one of the Sony laptops (LTOP04) which contained DiNP at a relatively low level (100 mg/kg). This is most likely to be a result of unintentional trace contamination, rather than the intentional addition of this phthalate to the material. For all laptops, the plastic coating of these ribbon cables did not test positive for PVC.

In contrast, for all laptops of all brands, the outer plastic coating of the cable from the power transformer (#35), contained two or more of the nine phthalates. For each sample, the total concentration of phthalates far exceeded levels that might be due to trace contamination, indicating the intentional addition of phthalates to these materials.

For this material, the Apple laptops had by far the lowest total concentrations of phthalates of all laptops (0.2-0.3%). For the other brands, the highest total concentrations were seen in the HP and Acer laptops (18-28%), with a similar range of concentrations in both brands. Somewhat lower was the level in the material from the Toshiba laptop (13%). In the Dell and Sony laptops, the levels were lower still (3.4-9.5%), with both brands having a similar range of concentrations.

In all but one laptop (LTOP12), the predominant phthalates in this material were di isononylphthalate (DiNP) and di isodecylphthalate (DiDP). All such materials also contained lesser amounts of diethylhexylphthalate (DEHP). Trace amounts of certain other phthalates were present in samples from individual laptops, though the concentrations of these phthalates suggest they are present from unintentional trace contamination, rather than having been added intentionally to the materials.

The main phthalates quantified in these samples all have known toxicity to greater or lesser degree. Particular concerns exist for DEHP which is known to be toxic to reproduction[12]. The predominant phthalate identified in the cable coatings, DiNP, also has potential toxicity to reproductive systems in mammals, though to a lesser degree[12], and potential toxicity to other organs (see the text box on page 42).

As noted in Section 3, the phthalates DiNP and DiDP are not individual chemicals. Each one is a group of very closely related chemicals, or isomers, with the same overall molecular formula but slightly different structures. The chemical similarity of DiNP and DiDP, combined with the large numbers of individual isomers present in each formulation, inevitably leads to a degree of overlap between the two during analysis when high overall concentrations are present. Consequently, complete separation of DiNP and DiDP congeners was not possible for the majority of samples.

In four laptops, the material contained DiNP, but not DiDP. The remainder of the samples contained mixtures of DiNP and DiDP that could not be fully separated. However, the data indicated that the mixture was predominantly DiNP in 8 of the samples where overlap occurred. In each of 3 other samples DiNP and DiDP were present in similar amounts, and in only 3 samples was DiDP the predominant phthalate. No clear pattern existed between the ratio of DiNP to DiDP and either the brand or the country of purchase.

Of all brands, the materials in the Acer laptops contained the highest concentrations of DEHP. In one of the Acer laptops (LTOP12), the phthalate composition was very different to that found in the other 3 Acer laptops. In particular, the cable from LTOP12 contained a very high level of DEHP (20%), compared to DEHP levels (0.1-0.3%) in the equivalent cable from the other Acer laptops (which predominantly contained DiNP/DiDP).

There was no clear pattern between the country or region in which laptops were purchased and the total level of phthalates, or the phthalate composition in the cable coating. For the Dell, Sony and Apple brands, models purchased within the EU had somewhat lower total phthalate levels than equivalent models purchased in non-EU countries. However, for the HP and to a lesser extent the Acer laptops, the models purchased within the EU had somewhat higher total phthalate levels than equivalent models purchased in non-EU countries.

Phthalates that are incorporated into plastic materials are not chemically bound to the plastic, but are able to migrate out of the material over time. This can result in substantial losses to the environment during the lifetime of products, and again following disposal. Therefore, it is of particular concern that phthalates were found in external components of all laptops (the plastic coating of the cable from the DC power transformer, sample #35), and in very high levels for the majority.

Within the EU, the phthalate DEHP is classified as "toxic to reproduction"[14]. Phthalates are not currently included in the European RoHS directive that restricts the use of certain other hazardous substances in electrical and electronic products specifically. However, due to concerns over human exposure to toxic and potentially toxic chemicals, the use of certain phthalates is restricted in toys and childcare articles within the European Union[14]. This Directive prohibits the sale of toys and childcare articles that include plastic containing more than 0.1 % by weight of phthalates including DiNP and DiDP (for products that can be placed in the mouth by children), as well as those with more than 0.1 % of DEHP or DBP (for all such products).

Moreover, though not applicable to electrical equipment, the classification of certain phthalates (including DEHP) in the EU as 'toxic to reproduction' results in their prohibition for use in certain other product groups, including cosmetics [15].

Phthalates are widely used as plasticizers (softeners) in plastics, especially PVC (e.g. in cables and other flexible components), though many other industrial uses exist. Many phthalates are toxic to wildlife and humans, often through their metabolites (chemicals to which they breakdown in the body). **DEHP**, a widely used phthalate, is known to be toxic to reproduction, capable of causing changes to both male and female reproductive systems in mammals (e.g. development of the testes in early life[12]). Other phthalates (e.g. **DBP** and **BBP**) also exert reproductive toxicity[12]. Both **DEHP** and **DBP** are classified as "toxic to reproduction" within the EU[13]. There is also evidence of the reproductive toxicity of **DINP**[12], and this phthalate can also have effects on the liver and kidneys.

3.6.1 Phthalate composition and the presence of PVC

In all Apple laptops, the outer plastic coating of the cable from the power transformer (#35) tested negative for PVC. In contrast, in all other laptops but one, this material did contain PVC. The PVC-free material in the Apple laptops also contained by far the lowest total concentrations of phthalates found for this material in all other laptops.

In one of the four Acer laptops (LTOP12) this material was also PVC-free, and it had a very different phthalate composition. In this case, the cable coating contained a similar total level of phthalates to those in the other PVC-coated cables provided with Acer laptops, but the mixture consisted almost exclusively of DEHP, the most toxic of the three main phthalates identified in these materials. For the other Acer laptops in which the material did contain PVC, DEHP was a minor constituent of the phthalate mixture.

For the coating of the power transformer cables, the use of PVC-free material in the Apple laptops coincided with greatly reduced amounts of phthalates. The use of other alternative PVC-free materials that do not require plasticisers could have eliminated the need for phthalates altogether. Disappointingly, for the one Acer model in which a PVC based material was not used, the alternative material contained a very high concentration of the more toxic phthalate (DEHP). This example illustrates that, although PVC may be eliminated in these flexible applications, it does not necessarily mean that the plasticizers commonly used for flexible PVC applications will automatically also be eliminated.

13 EC (2001) Directive 2001/59/EC of the European Parliament and of the Council of 6 August 2001 adapting to technical progress for the 28th time Council Directive 67/548/EEC on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labeling of dangerous substances. Official Journal of the European Communities L225, 21.8.2001: 1-333 http://ecb.jrc.it/documents/Classification-Labelling/ATPS_OF_DIRECTIVE_67-548-EEC/28th_ATP.pdf

14 EC (2005) Directive 2005/84/EC of the European Parliament and of the Council of 14 December 2005 amending for the 22nd time Council 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 (phthalates in toys and childcare articles). Official Journal of the European Communities L344, 27.12.2005: 40-43 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:344:0040:0043:EN:PDF

15 EC (2004) Directive 2004/93/EC of the European Parliament and of the Council of 21 September 2004 amending Council Directive 76/768/EEC on the approximation of the laws of the Member States relating to cosmetic products. Official Journal of the European Communities L300, 25.9.2004: 13-41 http://eur-lex.europa.eu/LexUriServ/LexUri Serv.do?uri=CONSLEG:1976L0768:20060809:EN:PDF

Conclusions

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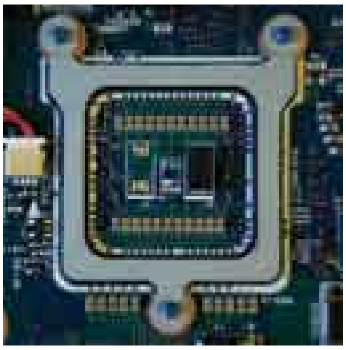

Toshiba CPU and Fan.
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This study covered a diverse range of components within the various laptops, though it was not feasible to test every individual component or homogeneous material of each laptop. As a result of the very high degree of complexity of products such as laptop computers, which include numerous small and complex components, compositional analysis of all individual homogeneous materials in such a product is an extremely large task. It is possible that some components or materials which were not tested may contain one or more of the chemicals investigated in this study. Therefore, for each laptop, the absence of a chemical in all samples analysed does not indicate that the laptop is entirely free of that chemical. Furthermore, each of the brands includes a range of different products available on the market. The results from this study are applicable to the specific models tested for each brand, and may not reflect the use of certain chemicals in the brand as a whole. These issues highlight the great difficulties in verifying that any individual product, or brand as a whole, is entirely free of a specific chemical, and hence whether or not a whole product is compliant with EU RoHS, or equivalent, regulations.

Nevertheless, this study into the presence of hazardous chemicals in laptop computers has revealed valuable information.

- The data provide a unique comparison of the composition of a wide range of components and materials from 18 laptop computers representing 6 separate brands, and available for purchase in many countries around the world.
- **Lead, cadmium** and **mercury** were not detected in any of the samples from all laptops tested by XRF (with detection limits of 0.01% for cadmium and 0.05% for lead and mercury)
- **Lead** was not detected in any of the samples of electrical solder analysed from all laptops using other methods (with a detection limit of 0.1%). These solders were composed of various different mixtures of other metals, with their composition depending on where they were used within the computer.
- **Hexavalent chromium** was not detected in any of the metallic samples tested for all laptops (with a detection limit of 0.1%).
- **Bromine**, indicative of brominated flame retardants (BFRs), was present in a wide range of different materials and components. Over 40% of the 523 samples tested in total contained bromine (above a detection limit of 0.1%), at surface concentrations ranging from 0.3% to 10% by weight.
- Of all the brands analysed, the Sony laptops gave by far the lowest number of samples testing positive for bromine (4 per laptop). There was little relative difference between the other brands for the overall frequency with which bromine was detected in components tested; the Dell laptops yielded the greatest number of positives (14-16 per laptop), the HP models had the least (11-12 samples per laptop).
- However, for those components and materials that contained bromine, the actual levels of bromine in many types of samples (i.e. discrete materials or components) did vary between laptops of the same brand, as well as between laptops of different brands.
- There were no universal differences between the brands for the presence and levels of bromine across all components and materials tested. Although differences between brands were apparent for some individual components, these patterns were not consistent across all component types. However, the Sony laptops did stand out from the other brands; bromine was not detected in many types of component that were found to contain bromine in some or all other brands, particularly for circuit boards.
- For each brand there were some differences between the country/region of purchase and the presence and/or levels of bromine in individual components. However the patterns were not consistent for different types of component. In most cases, the distinctions were not between countries/ regions with applicable laws that regulate the use of hazardous chemicals (e.g. EU and China) and those without such regulations.

- Components commonly found to have the highest levels of bromine included the internal cooling fans, ribbon cables, circuit boards, and plastic electrical connectors as well as some insulation sheets and mouse touchpads in certain models. External plastic housing samples from all laptops did not contain bromine, with the exception of 1 sample from an Apple laptop. However, for discrete types of samples (i.e. specific materials or components), there was variation in the levels of bromine between laptops of the same brand, as well as between laptops of different brands.

- In the case of circuit boards, in which the elimination of brominated flame retardants is widely seen as a difficult challenge, bromine was very frequently found in the boards tested, with the exception of the Sony laptops, and to a lesser extent a Toshiba laptop.

- For all Dell, Apple, Acer and HP laptops, all but a very small number of the boards that were tested contained bromine, including all the motherboards. Levels were generally high, and for equivalent components similar ranges of concentrations were seen across these four brands. Some differences did occur between laptops of the same brand, generally where different laptop models of a brand had been investigated.

- For the Sony models, only 1 of 6 type of circuit boards tested contained bromine; for the Toshiba model bromine was present in 2 of 5 samples tested. For both these brands the large motherboards did not contain detectable levels of bromine. The data from these models indicate that the use of 'bromine-free' circuit boards is possible across a wide range of applications.

- The levels of bromine in the cooling fans were very similar to the levels found in a related study carried out in 2006 on laptops purchased prior to the introduction of the EU RoHS Directive3. However, in this case it was not possible to subject the fans also to quantitative analysis for a range of extractable BFRs.

- **XRF analysis** is a widely used technique to determine material composition. This study has demonstrated that use of this technique may not be straight forward, and does require quality control checks to ensure the accuracy and reliability of any data obtained. For some complex non-homogeneous materials, such as circuit boards, XRF analysis inappropriately or incorrectly applied can produce false negative results, indicating the absence of an element such as bromine in a material that does actually contain a high concentration of that element.

- **Brominated flame retardants** were quantified in a relatively small number of samples (15). Two classes of extractable BFRs (TBBPA and PBDEs) were identified in 4 of these 15 samples; TBBPA was found in 4 samples, 3 from the Apple laptops (two ribbon cables and a mouse touchpad) and in a single sample from the Dell laptop (in a ribbon cable), though at relatively low levels of between 0.0013-0.0125%. PBDEs were also identified in the mouse touchpad from the Apple laptop, though at even lower levels. PBBs and HBCD were not identified in any of the 15 samples.

- Other brominated compounds were also identified in some other of the 15 samples. Though levels were not quantified, data indicate these were also present at relatively low levels. Some may be present due to trace contamination in brominated polymeric materials incorporated into the materials.

- For those samples quantified for specific BFRs, the vast majority of the bromine content could not be accounted for by the compounds identified. It seems likely that the majority of the bromine in the samples is bound up in the polymeric material of the samples, or is present as high molecular weight oligomeric flame retardants, such as brominated epoxy oligomers (BEOs), and therefore not amenable to identification using the methods available. To obtain information on these chemicals by analysis is likely to remain very difficult, and the only option may ultimately be for such information to be supplied by the component manufacturers themselves.

Macbook flexible circuit board.
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- **PVC** usage was investigated in two types of components from each laptop; ribbon cables and the plastic coating of wires/cables. PVC was not found in any of the 62 ribbon cables tested from all laptops, but was identified in 44% of all plastic coatings of internal wires and external cables (48 of 108 samples from all laptops), most commonly in the outer coating of the external power cable. For each brand, the number of samples that contained PVC varied significantly between individual laptops. However, none of the brands stood out as clearly containing fewer or greater number of PVC containing materials for the components tested.

- **Phthalates** were found in the outer plastic coating of the external power cable supplied with all laptops, at moderate to very high concentrations (up to over a quarter of the total weight of the plastic coating). For every sample a mixture of two or more phthalates were identified. By far the lowest total concentrations were found in the cable supplied with the Apple laptops (0.2-0.3%), and the highest levels in the cables supplied with the Acer and HP laptops (18-28%). There was no clear pattern between the country in which laptop was purchased, and the total level of phthalates, or the phthalate composition, in the cable coating.

- The phthalate mixtures were generally dominated by di isononylphthalate (DiNP) and di isodecylphthalate (DiDP), with lesser amounts of diethylhexylphthalate (DEHP). These chemicals are able to migrate out of the plastic materials over time. There is evidence for the toxicity of all of these phthalates; DEHP is classified in the EU as 'toxic to reproduction'.

Overall, these results provide further evidence for the feasibility of the substitution of hazardous chemicals and materials within the electronics sector. For almost every distinct type of material that was found to contain either bromine, a specific BFR, or the plastic PVC in one or more laptop, examples of equivalent materials that were free of these chemicals were found in other laptops.

For example, for all but one of the different types of materials and component tested, there were examples where bromine was not detectable. For one brand, Sony, only a small fraction of the materials tested contained bromine, while over a third of equivalent materials in other brands contained bromine. Similarly, across all laptops, various wires and cables had plastic coatings that contained PVC, although for each distinct type of component there were equivalent samples in other laptops with non-PVC plastic coatings, illustrating that it is not essential for PVC to be used for these applications. The use of PVC-free coating materials for a cable in the Apple laptops was associated with greatly reduced levels of phthalates in these materials.

The results from this study, however, do also document the continued presence of certain hazardous chemicals in many materials used in these popular brands of laptop computers. For some materials, the elimination of a particular hazardous chemical appears to be universal (for all samples tested), such as lead in electrical solders. This, however, was not the case for all chemicals under investigation, and the results document the continued presence of halogenated (i.e. brominated or chlorinated) materials and of certain hazardous chemicals in these popular brands of laptop computers. These include bromine, indicative of brominated flame retardants (BFRs), the use of PVC in plastic coatings for wires and cables, and the use of phthalates as plasticisers in external power cables. Moreover, some alternative materials to those found to be widely used in these products may be of similar concern; for example, in the case of one cable supplied with an Acer laptop, the apparent use of a material other than PVC was associated with a more hazardous mix of phthalate plasticisers, including a high level of DEHP.

Certain BFRs (including most PBDEs) that have been used in electrical products, some of which are now regulated in particular countries and regions, were present at only low levels or not at all in the subset of samples investigated. However, all these materials did contain high levels of bromine, indicative of the use of other brominated compounds or other bromine-containing materials in these samples. Despite the likelihood that the majority of the bromine in these and many of the other materials is present in oligomeric or polymer bound forms, the high levels of bromine is still significant. At the product's end of life, some disposal and/or recycling operations (especially incineration, smelting and open burning) can contribute to the formation of various hazardous products of combustion, including hydrogen bromide and brominated dioxins and furans11.

There were no clear and consistent differences in the prevalence of bromine, the presence of specific BFRs or the level and composition of phthalates in the tested components between laptops purchased in countries with or without applicable national regulations controlling the use of hazardous chemicals in electronics. In general, however, the data do suggest that actions to phase-out uses of lead, cadmium, mercury and hexavalent chromium, at least, have been implemented on a wide-spread basis. The substitution of these latter hazardous chemicals in the samples from the laptops investigated is almost certainly largely due to legislation in some countries, particularly the EU RoHS Directive, impacting more broadly on a globalised industry. All of the samples tested from all laptops of all brands were compliant with the EU RoHS directive, whether purchased with the EU or in non-EU countries. Furthermore, even though legislation in China came into force after the purchase date of these laptops, all samples from the laptops purchased in China would comply with the legislation if this type of product were to be listed as requiring the elimination of the regulated chemicals.

Current laws relevant to this sector, however, are only applicable in a fraction of countries where these products are sold. They do not prevent the sale in other countries of products that contain even the limited number of hazardous chemicals that they regulate. As an example, a recent investigation[16] found high levels of lead in electrical solder within an HCL-brand laptop purchased in India, one of many countries currently without specific regulations on the use of hazardous chemicals in electrical and electronic products. There is clearly a need for suitable regulations of the use of hazardous chemicals in such products in all countries where they are placed on the market. Given the global nature of the electronics industry, the same legislative requirements worldwide would ensure that all electronics manufacturing companies are operating to the same standards.

As they stand, even the laws in force in the EU and China do not regulate the use of all hazardous substances that can be present in electrical/electronic equipment. As this study has demonstrated, such products can contain additional hazardous substances to those currently covered under these laws (e.g. other BFRs, PVC and phthalates). Any legislation seeking to protect human health and the environment by restricting the use of hazardous chemicals in products must ultimately address the uses of all hazardous substances.

Elimination of all hazardous chemicals in laptops computers and other electrical and electronic equipment can be achieved through national legislation and/or self imposed commitments by manufacturers. Experience in the UK and EU relating to other hazardous chemicals has recognised that the implementation of voluntary or negotiated measures is most effective when driven by the promise of future regulation.

16 Brigden, K. & Santillo, D. (2007) Analysis of hazardous substances in a HCL laptop computer Greenpeace Research Laboratories Technical Note 02/2007 www.greenpeace.to/publications.asp

Appendix

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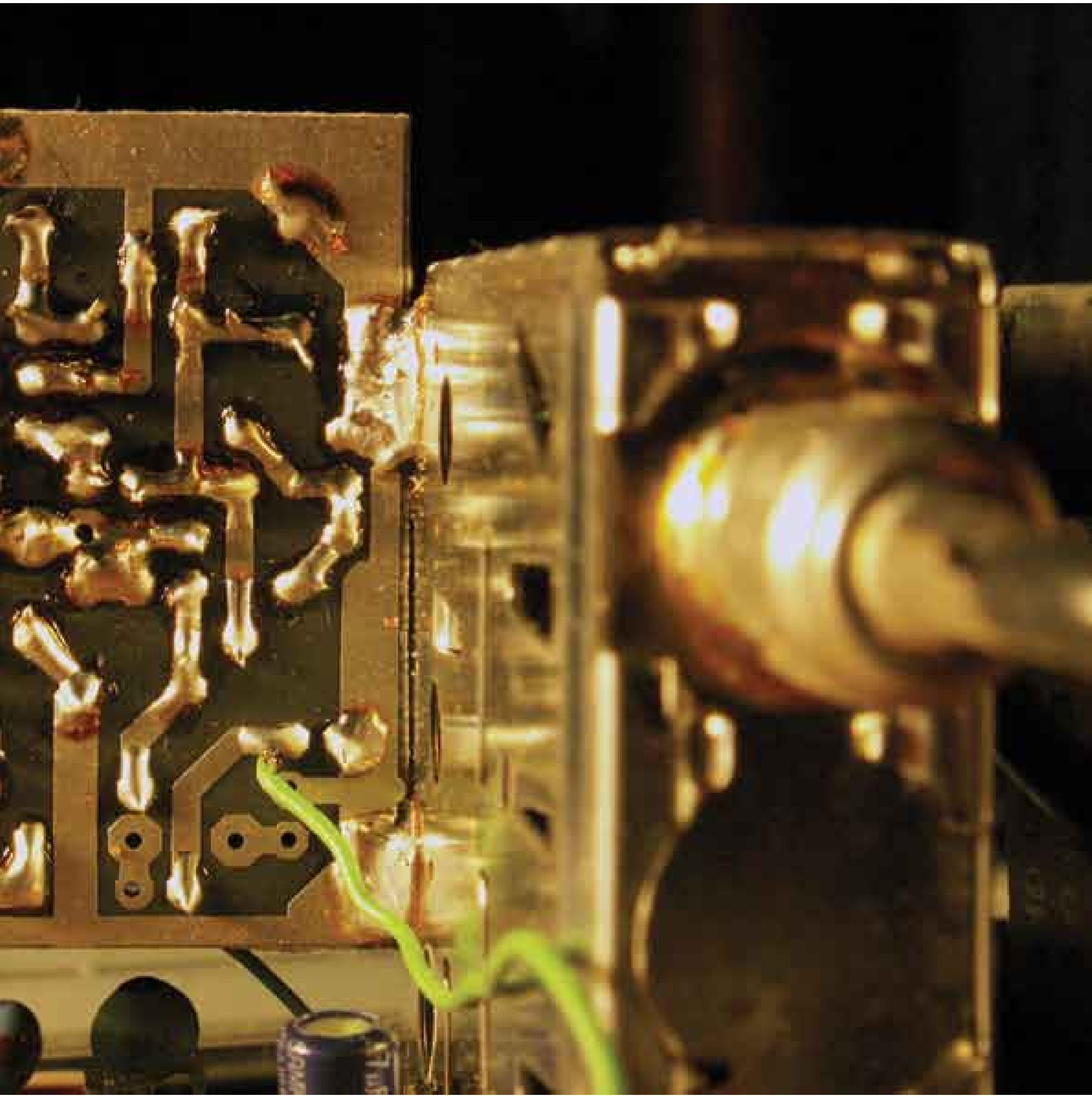


Appendix 1; Analytical methods

Lead and other metals in electrical solder

Each sample of solder was separated from the component using a cleaned scalpel blade and accurately weighed. Concentrated hydrochloric acid (1ml) was added to each sample. After standing for 12 hours, concentrated hydrochloric acid (0.5 ml) and concentrated nitric acid (0.5 ml) were added, and the solution left until all sample material had dissolved. Deionised water was added to make a final volume of 10ml, and the solution analysed by ICP atomic emission spectrometry (AES).

Hexavalent chromium (Cr VI)

Analysis of materials was carried out in accordance with method IEC 62321/1CD, 111/24/CD-method 9[18]. To the surface of each sample, was added 0.2 ml of the testing solution (0.4 g of 1,5-diphenylcarbazide, 20 ml acetone, 20 ml ethanol, 20 ml orthophosphoric acid solution and 20 ml of demineralised water). The presence of hexavalent chromium was indicated by the formation of a red-violet colour. In each case, the method was applied in turn to 1) untreated surface, 2) surface finely abraded to remove any reduced chromate surface, but not remove the whole chromate layer, 3) surface vigorously abraded to exposure deeper layers.

Extractable BFR quantification

Analysis of components and materials for a range of extractable BFRs was carried out using two separate methods, each for a distinct group of BFRs;

a) PBDEs, PBBs and HBCD

Each sample was separately extracted with toluene using a soxhlet extraction method, incorporating an internal 13C labelled standard. The extract solution was subsequently cleaned by column chromatography and analysed using capillary gas chromatography – mass spectrometry (GC-MS) with identification of analytes using the molecular and fragmentation ions. Quantification of PBDEs, PBBs and HBCD was performed using 13C labelled standards.

b) TBBPA

Each sample was separately homogenised and acidified and then extracted with toluene, incorporating an internal 13C labelled TBBPA standard. Extracted TBBPA was derivatives in solution using acetic anhydride, prior to column chromatography clean-up and analysis using capillary gas chromatography – mass spectrometry (GC-MS). Identification was made from molecular and fragmentation ions, and quantification of TBBPA was performed using a 13C labelled standard.

PVC

The analysis was carried out on the insulating plastic coatings of each component (ribbon cable, internal wire or external cable) to determine the presence or absence of the plastic PVC. Each sample was tested for the presence of the element chlorine (an indicator of PVC) using the Beilstein test. For those samples testing positive for chlorine, the presence of PVC was confirmed using Fourier Transform Infrared (FT-IR) analysis.

Phthalates

For each sample, a portion was accurately weighed and then extracted into dichloromethane, with the addition of internal standards for quality control purposes. The extract was analysed using capillary gas chromatography coupled with a mass spectrometer (GC-MS) for the identification and quantification of nine phthalates; di-n-butylphthalate (DBP), butylbenzylphthalate (BBP), diethylhexylphthalate (DEHP), di-n-octylphthalate (DOP), dimethylphthalate (DMP), diethylphthalate (DEP), di-iso-butylphthalate (DiBP), di-isononylphthalate isomers (DiNP), di-isodecylphthalate isomers (DiDP).

18 International Electrotechnical Commission (IEC) Test for the presence of hexavalent chromium (Cr VI) in colorless and colored chromate coating on metallic samples. Procedures for the determination of levels of six regulated substances (lead, mercury, hexavalent chromium, polybrominated biphenyls, polybrominated biphenyl ether) in electrotechnical products IEC 62321

Appendix 2: Composition of electrical solder samples; concentrations of all metals quantified (mg/kg)

BRAND	Dell			Sony		Apple				Acer				HP				Toshiba
LAPTOP	L01	L02	L03	L04	L05	L06	L07	L08	L09	L10	L11	L12	L13	L14	L15	L16	L17	L18
Sample S01																		
Antimony	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<0.5	<0.5	<0.5	0.6	0.6	0.7	0.7	0.6	0.6	0.6	0.6	0.7	0.6	<0.5	<0.5	<0.5	0.7	0.6
Copper	1.0	1.3	1.7	1.5	1.4	0.9	0.9	0.8	0.8	1.6	0.8	0.8	0.8	0.8	1.3	0.9	0.8	0.8
Indium	<0.5	<0.5	<0.5	8.8	9.7	9.7	9.8	8.8	9.0	9.9	9.2	9.5	8.6	<0.5	<0.5	<0.5	10	9.9
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Silver	3.6	3.8	3.6	3.5	3.3	4.0	4.0	3.7	3.9	4.1	3.7	3.9	3.7	3.5	3.7	3.5	3.7	3.8
Tin	92	91	94	84	81	83	82	82	83	83	80	80	83	90	91	90	84	83
Zinc	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sample S02																		
Antimony	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<0.5	<0.5	<0.5	0.5	<0.5	0.6	0.7	0.5	0.6	0.5	0.5	0.5	0.5	<0.5	<0.5	<0.5	0.5	0.5
Copper	4.2	2.9	3.5	3.5	1.5	1.4	1.4	15.5	5.2	2.6	14	13	2.9	8.2	3.7	4.4	14	8.8
Indium	<0.5	<0.5	<0.5	8.1	8.5	8.8	9.5	6.9	10	8.3	7.2	7.4	7.9	<0.5	<0.5	<0.5	8.5	8.0
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	<0.1	<0.1	5.6	0.5	0.5	0.4	<0.1	0.1	<0.1	0.0	0.6	0.4	0.1	<0.1	<0.1	<0.1	<0.1	2.0
Silver	3.7	3.8	3.6	3.4	3.7	4.5	4.7	3.8	4.8	3.6	3.3	3.3	3.6	2.9	3.5	3.0	3.7	3.4
Tin	90	94	87	80	81	82	81	69	75	81	71	71	80	85	90	90	73	74
Zinc	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.08	<0.05	<0.05	<0.05	<0.05	0.03
Sample S03																		
Antimony	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<0.5	<0.5	<0.5	0.5	0.6	0.5	<0.5	0.5	0.5	0.6	0.5	0.6	0.5	<0.5	<0.5	<0.5	0.7	0.5
Copper	1.6	4.3	2.9	19	2.3	5.5	39	12	15	1.3	5.2	4.0	29	13	3.5	6.8	9.9	23
Indium	<0.5	<0.5	<0.5	7.0	9.3	7.5	3.4	7.3	7.3	9.5	8.6	8.5	5.5	<0.5	<0.5	<0.5	12	7.5
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	0.1	<0.1	0.4	<0.1	<0.1	0.6	4.5	1.4	1.7	<0.1	0.0	0.1	0.6	0.6	0.6	0.1	0.4	0.2
Silver	0.6	2.8	1.5	3.0	3.8	3.5	1.6	3.4	3.4	3.9	3.4	3.6	2.5	3.0	3.7	2.8	5.1	3.4
Tin	92	90	94	70	81	79	31	68	63	82	76	79	58	80	90	89	67	62
Zinc	<0.05	<0.05	<0.05	<0.05	<0.05	1.2	19	3.6	4.0	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	<0.05	0.03

BRAND LAPTOP	Dell L01	 L02	 L03	Sony L04	 L05	Apple L06	 L07	 L08	 L09	Acer L10	 L11	 L12	 L13	HP L14	 L15	 L16	 L17	Toshiba L18
Sample S04																		
Antimony	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Copper	3.3	1.8	4.0	0.8	1.8	4.8	1.6	3.2	1.8	3.3	10	2.7	29	19	3.0	1.7	2.1	14
Indium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	0.3	0.4	0.1	<0.1	0.1	0.3	<0.1	0.3	<0.1	<0.1	0.6	0.1	1.6	0.1	0.2	0.2	<0.1	0.2
Silver	3.2	4.1	3.3	3.2	3.7	4.6	3.9	4.5	4.0	3.4	1.8	3.1	2.0	3.2	3.8	3.5	4.0	3.5
Tin	88	92	89	93	92	84	90	85	90	91	84	92	61	72	91	91	92	81
Zinc	1.1	<0.05	<0.05	<0.05	0.38	<0.05	<0.05	<0.05	<0.05	0.05	1.9	0.20	0.60	<0.05	<0.05	<0.05	<0.05	<0.05
Sample S05																		
Antimony	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Copper	1.4	1.3	0.8	1.4	2.0	1.1	1.0	0.9	0.9	1.1	1.3	1.0	0.9	1.0	0.9	1.0	7.5	1.1
Indium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Silver	3.4	4.1	3.4	3.4	3.7	4.0	3.6	3.5	3.7	4.2	4.0	3.8	3.5	4.2	3.4	4.0	4.1	3.8
Tin	91	91	93	91	94	95	93	95	92	90	88	93	92	91	91	92	87	93
Zinc	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sample S06																		
Antimony	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Copper	14	1.1	6.8	2.4	3.5	1.1	1.3	1.3	0.7	1.1	0.3	0.4	10	5.1	1.3	1.9	1.0	0.9
Indium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	<0.1	<0.1	<0.1	0.7	1.1	<0.1	<0.1	<0.1	<0.1	0.8	0.1	0.1	2.9	<0.1	0.1	0.4	0.1	<0.1
Silver	2.7	3.3	3.2	2.9	3.1	4.5	5.3	5.4	3.1	4.6	4.9	4.6	3.3	3.6	3.9	2.8	3.9	3.6
Tin	79	92	90	90	89	93	90	91	93	88	91	90	78	87	91	93	91	94
Zinc	0.21	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sample S07																		
Antimony	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Copper	20	30	5.8	7.5	10	1.3	6.1	1.8	5.4	2.7	4.5	4.7	6.0	0.9	20	1.1	5.0	1.3
Indium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	<0.1	<0.1	<0.1	2.6	3.3	<0.1	<0.1	<0.1	<0.1	1.2	1.4	1.2	2.1	<0.1	0.4	0.4	1.4	<0.1
Silver	2.5	2.4	3.0	2.7	2.8	4.3	5.0	4.3	4.2	4.3	4.5	4.3	4.0	3.4	2.7	2.9	3.0	3.5
Tin	72	67	87	86	82	91	88	89	89	88	89	85	84	92	72	94	82	92
Zinc	0.07	<0.05	<0.05	<0.05	0.03	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.27	<0.05	<0.05	<0.05	0.97	<0.05

BRAND		Dell		Sony			Apple				Acer				HP			Toshiba
LAPTOP	L01	L02	L03	L04	L05	L06	L07	L08	L09	L10	L11	L12	L13	L14	L15	L16	L17	L18
Sample S08																		
Antimony	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Copper	1.9	2.0	1.1	1.1	1.2	9.4	7.6	5.6	25	2.8	17	9.5	1.8	0.9	1.7	1.3	1.0	0.6
Indium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	0.2	<0.1	<0.1	<0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.3	3.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Silver	3.3	3.7	3.8	3.5	3.8	3.7	4.4	3.7	3.1	3.8	3.2	3.2	3.4	3.7	4.4	4.1	4.0	3.4
Tin	95	93	96	93	90	81	86	88	69	89	77	83	90	91	91	94	91	95
Zinc	<0.05	<0.05	<0.05	<0.05	<0.05	0.12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sample S09																		
Antimony	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Copper	2.1	3.9	0.8	10	6.6	1.6	6.8	1.5	1.3	14	0.9	0.9	0.8	1.3	1.4	0.9	0.8	2.1
Indium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.5	<0.1	<0.1	5.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Silver	3.2	3.3	3.5	3.0	3.3	4.5	4.1	3.7	3.9	2.8	3.4	3.5	3.3	4.5	3.6	3.7	3.6	3.5
Tin	91	93	95	86	89	91	85	93	93	72	93	93	92	92	94	92	90	90
Zinc	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sample S10																		
Antimony	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Copper	21	6.8	3.2	41	38	66	58	25	60	24	40	20	19	16	18	12	17	20
Indium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	0.2	<0.1	0.0	<0.1	<0.1	1.1	1.1	0.7	1.6	0.4	1.8	<0.1	<0.1	<0.1	1.7	2.0	2.2	0.7
Silver	2.3	2.9	3.3	1.7	1.9	1.5	2.2	3.3	1.6	2.4	1.5	2.3	2.1	3.1	3.2	3.0	2.8	2.5
Tin	69	89	93	53	59	29	39	71	35	68	51	76	72	80	77	79	75	74
Zinc	<0.05	<0.05	<0.05	<0.05	<0.05	0.15	0.13	0.05	0.13	0.05	0.08	0.03	<0.05	<0.05	0.08	0.11	0.07	<0.05

Table A2.1 Concentrations of metals in solder samples S01-S10 in all laptops, LTOP01-LTOP18 (mg/kg)

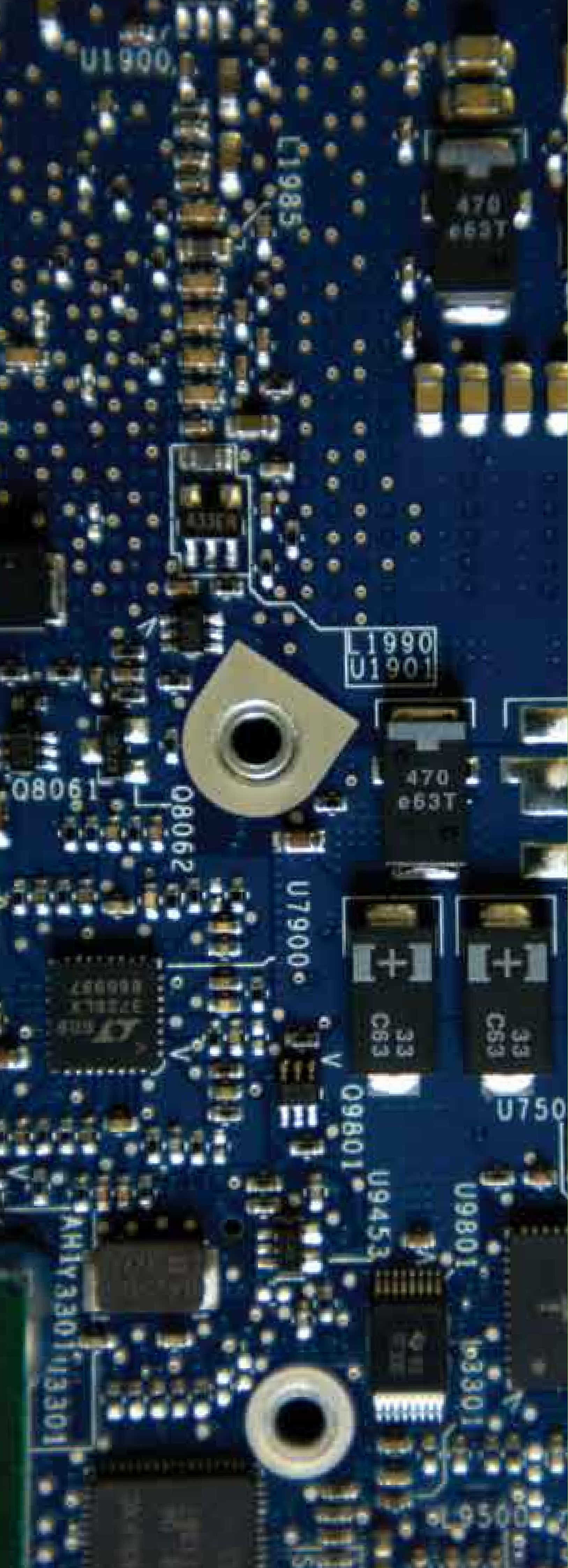
Appendix 3: Data from X-ray microanalysis (XRF) for all laptops

Sample #	Component	Notes
1	Mouse touchpad	
2	Mouse button (left)	For two Brands (Acer, HP), some laptops were slightly different models and therefore some individual components differ between
3	Keyboard space bar	laptop models of the same make.
4	Screen surface	
5	External casing: plastic casing surrounding mouse touchpad & buttons	
6	Ribbon cable (internal); connected to keyboard	
7	External casing: plastic casing surrounding screen	
8	External casing: outside top casing (reverse of screen)	
9(a)	External casing: plastic casing inside battery compartment	(a) Apple models-large rear plastic casing (battery compartment is metal);
10	cooling fan (internal)	
11(b)	External casing: casing immediately around keyboard	(b) no such material for Sony and Apple models;
12(c)	Electrical insulating sheet by cooling fan	(c) Apple models-sheet attached to rear plastic casing (#9); Acer models-black sheet inside front casing;
13(d)	Electrical insulation sheet	(d) no universal material; tested similar materials within different laptop makes & models;
14	Circuit board, base board; motherboard	
15(e)	Circuit board, base board; memory chips	(e) no such material for 2 Dell (LTOP01, LTOP03) and 1 Sony (LTOP05) models;
16(f)	Ribbon cable between motherboard and component (flex. circuit board)	(f) Dell; flexible PWB motherboard to HDD; Sony flexible PWB motherboard to small PWB; Apple flexible PWB motherboard-DVD drive; Acer thin white ribbon on motherboard; HP thin white ribbon on motherboard; Toshiba white ribbon motherboard to small PWB;
17(g)	Circuit board, base board; hard drive	(g) Apple; different hard drives used (LTOP07-Seagate; LTOP08-09-Toshiba); Acer LTOP12 has different hard drive to other Acers tested;
18	Circuit board, base board; under mouse touchpad	(h) not analysed for LTOP01 and LTOP018; (i) Sony-PWB with USB sockets; Apple-small PWB linked to motherboard; HP- PWB linking DVD drive to motherboard;
19(i)	Circuit board, base board; DVD drive	
20(j)	Circuit board, base board; laptop dependant	(j) Dell-PWB for flash memory card; Sony-PWB for ethernet socket; Apple-small PWB linked to motherboard; Acer-small PWB with LEDs; HP-PWB with USB sockets; Toshiba-small PWB linked to motherboard (via #16);
21	Socket on motherboard for external battery	
22	External battery casing	
23(k)	Ribbon cable; connected to mouse touchpad PWB, or PWB sample #20	(k) to mouse touchpad PWB (Sony, Apple, HP, Toshiba); PWB sample #20 (Dell, Acer);
24(l)	Ribbon cable to component	(l) Dell-to PCMCIA card slot; Sony-to headphone socket PWB; Acer-to motherboard; HP-to PWB attached to keyboard plate; Toshiba - to small separate PWB;
25	Plastic socket for pin connector, on motherboard (see #28)	
26(m)	Plastic socket for memory chip ciruit board	(m) Dell-LTOP01 black plastic, LTOP02-03 white plastic; HP-LTOPO14 white plastic, LTOP15-17 black plastic;
27(n)	Plastic connector socket for DVD drive	(n) Dell and Sony models; plastic connector socket for WLAN CARD;
28(o)	Plastic pin connector, fitting into #25	(o) Sony-no pin connector to #25 (direct cable input), different pin connector tested.
29	External power transformer plastic casing	
30	Surface of main chip on motherboard	

Table A3.1. Samples analysed by X-ray microanalysis (XRF).

Sample #		Dell		Sony			Apple				Acer				HP			Toshiba
	LT01	LT02	LT03	LT04	LT05	LT06	LT07	LT08	LT09	LT10	LT11	LT12	LT13	LT14	LT15	LT16	LT17	LT18
1	2.2					4.6	4.6	5	4.8									0.54
2		1.5																
3																		
4																		
5																		
6																		
7																		
8						0.68												
9																		
10	6.4	6.4	5.9	6.1	4.6	6.1	6.5	6.6	5.3	4.5	6	4.6	6.4	5.0	4.4	5.3	4.7	5.9
11				x	x	x	x	x	x									
12	3.4	2.4	5.8			2.9	2.8	2.8	2.8									
13	2.8	1.8	1.4										1.9					
14	2.2	1.8	2.4		x	3.2	4.4	2.1	4.0	2.7*	2.9	4.3*	2.0	2.6	2.5	2.8	2.4	
15	x	6.0	x	6.0	x	6.1	4.0	6.1	7.4	8.1	4.2	6.2		6.6			6.4	6.6
16	2.2	2.1	1.8			2.2	2.3	6.6	6.8	0.2	2.1	2.1	2.4	2.3	2.2	3.5		2.2
17						2.5	2.7					4.7		4.5	1.9	2.4		
18	x	6.0	5.1			0.37	0.16	0.15	0.21	7.3	5.9	4.8	3.9	6.0	5.1	5.4	7.5	x
19	6.2	4.5	3.9			7.0	3.8	6.5	5.6	8.2	8.1	6.1	2.2	2.1	2.7	6.4	4.8	7.7
20	4.7	2.1	5.7			4.6	4.5	4.9	5.4	7.5	8.0	5.6	6.4	2.1	2.5	2.4	2.1	
21	8.3	7.9	8.5			6.9	7.6	9.9	8.0	8.6	8.4	8.8	8.8	8.1	9.5	8.3	8.5	9.2
22			0.64							1.4					1.4			
23	0.58	0.79	0.96			1.1	4.3	3.2	1.2	2.1	1.6	1.5	2.4					1.8
24	2.3	2.8	2.7			x	x	x	x	2.2	3.0	1.5	x	2.3	2.6	3.7	1.3	1.7
25	10	8.4			9.3	6.3	6.4	6.4	7.4	7.3	10	7.5	6.5	6.0	7.0	6.2	6.3	8.7
26																	0.26	
27								0.2										
28	5.6	4.7	3.7	9.4	9.3					6.1	4.5	6.3	7.4					4.8
29			0.57		2.8					0.18								0.32
30	0.3	0.35	0.33	0.38		0.38	0.34	0.33	0.30	0.30	0.36	0.28	0.33	0.35	0.39	0.42	0.29	0.36

*Table A3.2. Results of analyses of samples 1-30 from all laptops (LT01-LT18) by X-ray microanalysis (XRF) showing surface concentrations of bromine; empty cells indicate bromine was not detected above method detection limits (0.1%); 'x' sample not present or not analysed, * data from XRF analysis of ground sample*



GREENPEACE

Greenpeace is an independent global campaigning organisation that acts to change attitudes and behaviour, to protect and conserve the environment and to promote peace.

Greenpeace International
Ottho Heldringstraat 5,
1066 AZ Amsterdam,
The Netherlands
t +31 20 718 2000
f +31 20 514 8151
www.greenpeace.org

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