TOXIC CHEMICALS IN COMPUTERS EXPOSED

Determining the presence of hazardous substances in five brands of laptop computers

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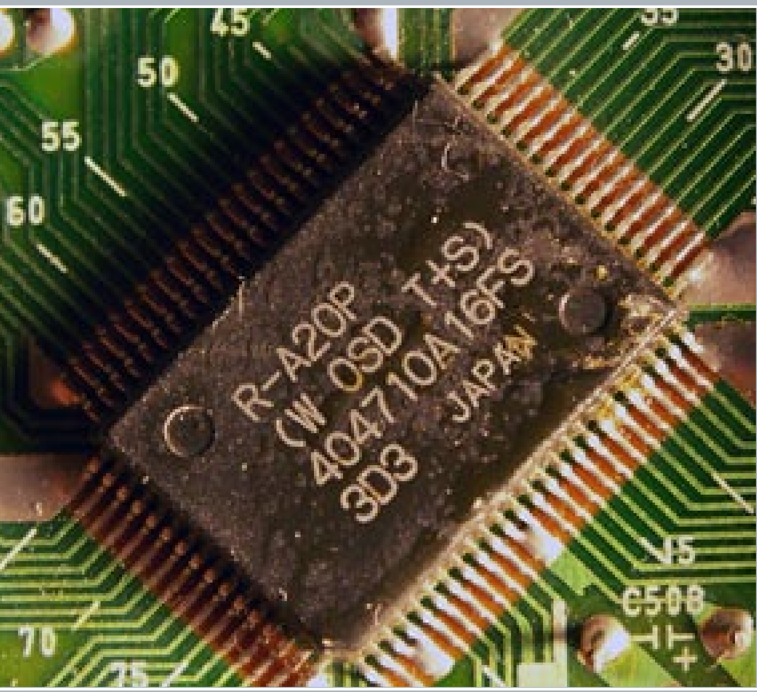

Dr Kevin Brigden and Dr David Santillo
Greenpeace Research Laboratories
Hatherly Building
School of Biosciences
Prince of Wales Road
University of Exeter
Exeter EX4 4PS, UK

SUMMARY

Concerns have recently grown over the use of hazardous chemicals in the manufacture of consumer goods, including the rapidly growing sector of electrical and electronic equipment. Some products, including computers, can contain heavy metals and other hazardous chemicals. The ongoing manufacture of electrical/electronic equipment incorporating 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.

This study was conducted by Greenpeace to gain information on the presence of certain hazardous substances in a range of laptop computers, and to investigate testing methodologies for verifying their presence or absence. Five popular brands of laptop computer were purchased in Europe by Greenpeace in March 2006, and the presence of certain hazardous substances was investigated in a wide variety of internal and external components. The laptops chosen for this investigation

- Acer Aspire 5670 Series (5672WLMi)
- Apple MacBook Pro
- Dell Latitude D810
- Hewlett Packard (HP) Pavilion dv4000 Series (dv4357EA)
- Sony VAIO VGN-FJ Series (FJ180)

A range of heavy metals and organic chemicals were investigated in this study, based partly on those substances controlled under the recently introduced European RoHS Directive1 which controls the presence of specific hazardous chemicals in electrical and electronic equipment sold within the EU, but also including additional substances; the plastic PVC, and the brominated flame retardants HBCD and TBBPA. Though including those chemicals controlled under the RoHS Directive, this study was not intended to test the products compliance with the Directive. The full range of substances included in this study were;

- The heavy metals; lead, mercury, hexavalent chrome (chromium (VI)) and cadmium
- Certain brominated flame retardants (BFRs); polybrominated biphenyls (PBBs), polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD) and tetrabromobisphenol A (TBBPA)
- PVC (polyvinyl chloride)

For each laptop, approximately 40 individual materials and components were analysed using X-ray microanalysis (EDAX) to determine the amounts of the metals, as well as the element bromine (as a first indication of the presence of brominated compounds) in the surface layers of the materials. Subsequently, one metallic material from each laptop was analysed for hexavalent chromium (VI), and one material showing consistently high bromine levels (the fan) was analysed for a range of solvent extractable brominated flame retardants. In addition five (four in the case of Dell) plastic coated internal wires in each laptop were analysed for the presence of PVC.

The Hewlett Packard (HP) laptop was the only model in which lead was identified. Of the 44 materials and components tested in the model, lead was found in three materials; two samples of solder (with surface concentrations of 4.5% and 13% lead) and one ‘internal connector’, which may also have been a soldered connection (9.8% lead). Of the other metals, chromium was identified in a number of components from all laptops; however, analysis of a single sample from each laptop did not identify the form of concern, hexavalent chromium (VI), in any model. For all laptops, no cadmium or mercury was identified in any of the materials and components tested.

For all laptops, bromine (an indicator of the possible presence of brominated compounds) was found in around a quarter of all the components and materials tested, at surface concentrations ranging from 0.19% to 9.4%. Materials testing positive for bromine included some, but not all, circuit boards, chips, cables and wires, plastic cable connectors, insulating materials, fans, fan casings and touch mouse pads. For all laptop models, the fan used to cool the internal circuitry while the laptop is in use, yielded consistently high values for surface bromine content (between 5.3 and 7% by weight).

Although a high bromine content is likely to result from the use of a brominated flame retardant (BFR) formulation, the bromine data from EDAX analysis does not give information on the chemical forms in which the bromine is present and further analysis was carried out to identify, where possible, specific brominated chemicals. It was only possible to carry out such analysis on one component per laptop, and this was performed on the fan from each laptop, as a result of the consistently high bromine levels in the fans from all models.

Of the BFRs quantified, only TBBPA and certain PBDEs were identified in any of the fans. No HBCD and no PBBs were identified in any of the samples. By far the highest levels of PBDEs were identified in the fan from the HP laptop. This fan contained 1650 mg/kg (or 0.165% by weight) of decaBDE and 2040 mg/kg (or 0.204% by weight) of nonaBDEs, as well as other PBDEs, though at much lower levels. The Apple fan contained low levels of decaBDE and nonaBDEs (8.5 mg/kg and 2.1 mg/kg respectively). For the Acer fan, only decaBDE was detected, at the even lower level of 1.0 mg/kg. No PBDEs were found in the fans from the Dell and Sony models. Traces of TBBPA were found in fans from four laptops, though not the Sony model. Concentrations ranged from 7.8 mg/kg to 262 mg/kg, the highest value in the Apple laptop fan.

The presence of PBDEs, including nona- and octabrominated forms, in fans from some of the laptops is significant. Though not in force when the laptops in this study were purchased, the EU RoHS Directive sets a limit of 0.1% for all PBDEs, other than decaBDE. The concentration of nonaBDE found in the fan from the HP laptop is above this value, at 0.204% by weight.

It is noteworthy that the concentration of BFRs quantified in the fans from all laptops do not account for the far higher levels of

total bromine identified in these components. Furthermore, the concentrations of PBDEs and TBBPA would seem unlikely to provide sufficient flame retardancy alone for the plastic material from which the fans are constructed. These results indicate that the bulk of the bromine in the fans must be due from the presence of brominated chemicals other than those BFRs specifically quantified in this study. The fans may contain other extractable brominated compounds not quantified in this study, though it seems more likely that the majority of the bromine is bound up in the polymeric material of the fan itself, or is present in high molecular weight oligomeric flame retardants, such as brominated epoxy oligomers (BEOs), which would not be detected by the methods employed. The presence of bromine in such forms is still significant. At the product's end of life, some disposal or recycling operations (e.g incineration, smelting and open burning) can potentially release the bromine in hazardous forms, including hydrogen bromide and brominated dioxins.

In addition to the heavy metals and brominated chemicals, the plastic PVC was also identified in the coating of internal wires within three laptops; two wires from the Hewlett Packard laptop, as well as a single wire from each of the Acer and Apple laptops. PVC was not identified in the remaining 20 plastic coated wires that were tested, and PVC is clearly not essential in the coatings of these wires.

Although this study covered a diverse range of materials, it was not feasible to test every individual material or component within each model. It is possible that untested components contain some of chemicals investigated in this study, and therefore the absence of a chemical in all samples from a laptop does not indicate that the laptop is entirely free of that chemical. Furthermore, the results from this study are applicable only to the specific model tested for each brand, and do 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.

Dismantling of laptops to enable testing of individual components and materials for a range of hazardous substances.

Introduction

In recent years, concern has grown over the use of hazardous chemicals in the manufacture of consumer goods, and the resulting potential for chemical exposures and impacts on the environment and during the manufacture, use and disposal of such products. One sector where attention has been focused is electrical and electronic equipment. The production of such goods is increasing worldwide, while in many cases the lifespan of the products is decreasing. This is reflected in the already large, and rapidly increasing, wastestreams from this sector.

Some electrical products, including computers, contain heavy metals and other hazardous chemicals. Impacts resulting from the recycling and disposal of old electrical/electronic equipment containing hazardous chemicals was recently demonstrated by Greenpeace[1]

The continuing manufacture and sale of electrical/electronic equipment incorporating hazardous chemicals will prolong impacts on the environment and human health during their manufacture, use and disposal.

In light of these concerns, this study was conducted by Greenpeace to gain information on the presence of certain hazardous substances in a range of laptop computers, and to investigate testing methodologies for verifying their presence or absence. The specific substances investigated in this study included;

- The heavy metals; lead, mercury, hexavalent chrome (chromium (VI)) and cadmium
- Certain brominated flame retardants (BFRs); polybrominated biphenyls (PBBs), polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD) and tetrabromobisphenol A (TBBPA)
- PVC (polyvinyl chloride)

The presence or absence of these substances was investigated in five popular brands of laptop computer (see Table 1 below), in a wide variety of internal and external components (casing, touch mouse pads, cables, circuit boards, chips, connectors, insulators, etc.). The substances included in study were based in part on the substances controlled under the recently introduced EU RoHS Directive[2] (see below), which addresses specific hazardous chemicals in electrical and electronic equipment[3]. In addition to those substances controlled under RoHS, this study included two additional brominated flame retardants; HBCD (hexabromocyclododecane) and TBBPA (tetrabromobisphenol A), and also included a survey of the plastic coatings of internal cables and wiring for the presence or absence of PVC (polyvinyl chloride). Although not currently regulated under RoHS, PVC 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.

The investigation was not intended as a test for compliance with the European RoHS Directive, not least because the laptops under study were purchased in Europe during March 2006, before the RoHS Directive came into force, 1st July 2006. Rather those substances controlled under the RoHS directive was used as a basis for investigating hazardous substances in these products. The study also provides a snapshot of the readiness for RoHS for one small part of the electronics market in the lead up to RoHS as well as providing a first test of the suitability of routinely available analytical methods for future application to compliance monitoring, and an opportunity to develop those methods.

Although the requirements of the RoHS legislation are clear, and should now be in force in all EU Member States, the manner in which compliance with the Directive of electrical and electronic equipment put on the market since 1st July this year will be tested and monitored remains to be developed. Also unclear is the extent to which electrical and electronic goods on the market immediately before the entry into force of the Directive were already in compliance.

The EU's RoHS Directive

The European Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment, or the RoHS Directive, entered into force on July 1st 2006. The Directive prohibits the placing on the market of such equipment if it contains more than regulated amounts of lead, mercury, hexavalent chrome (chromium (VI)) cadmium, polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs). 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"[4].

A total of 21 'exempt applications' have been agreed in the Annex to the Directive[5], most of which permit continued use of lead or mercury for certain specific applications on the basis that alternatives are not currently available. There are also exemptions for certain uses of cadmium, hexavalent chromium and for the PBDE 'deca' (decabromodiphenyl ether, or BDE-209) in polymeric applications. The exemption for decaBDE is the subject of current legal challenges against the European Commission. Moreover, the European Commission has recently issued a legal opinion[6] clarifying that the exemption covers pure decaBDE only, and would therefore not exempt the use of commercial formulations of 'deca', which commonly contain percent levels of nonaBDE as an impurity, where their use would result in levels of nonaBDE in homogenous materials exceeding the 0.1% limit.

1. Brigden, K., Labunska, I., Santillo, D. & Allsopp, M. (2005) Recycling of electronic wastes in China and India: workplace and environmental contamination. Greenpeace Research Laboratories Technical Note 09/2005. http://www.greenpeace.to/publications.htm
2. Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. Official Journal L 037, 13/02/2003: 19-23
3. Cadmium, mercury and organic mercury compounds, and lead and organic lead compounds are also included on the list of substances for priority action under the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, 1998
4. Article 1 of the RoHS Directive 2002/95/EC
5. UK Statutory Instrument 2006 No. 1463. Environmental protection; The restriction of the use of certain hazardous substances in electrical and electronic equipment regulations 2006, Schedule 2
6. Scope of the exemption provided by "DecaBDE in polymeric applications" in the Annex to Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment. DG Environment, European Commission, Brussels, 21st June 2006

MATERIALS AND METHODS

Five individual laptop computers, the makes and models of which are given in Table 1, were purchased by Greenpeace during March 2006. The Acer, Apple and Hewlett Packard laptops were purchased from shops in Denmark while the Dell and Sony models were purchased from the UK via the internet.

Make	Model
Acer	Aspire 5672WLMi
Apple	MacBook Pro
Dell	Latitude D810
Hewlett Packard (HP)	Pavilion dv4357EA
Sony	VAIO VGN-FJ 180

Table 1: Details of the five laptops included in the analysis

All five laptops were forwarded intact to the laboratories of Eurofins Environmental A/S in Galten, Denmark. Eurofins dismantled each laptop in turn, taking care to avoid contamination of internal components, photographed successive layers of casing, circuitry and other components and identified on the photographs a range of materials and components as possible subjects for chemical analysis. In collaboration with the Greenpeace Research Laboratories, a total of approximately 40 individual materials and components from each laptop, a total of 195 samples, were selected to go forward for analysis. In making these selections, every effort was made to included examples of as many as possible of the diverse materials and components present, while at the same time ensuring as much consistency as possible between components selected in the different laptops for purposes of comparability. A complete list of those selected is provided at Annex 1 to this report.

Each identified component was subsequently removed from the laptops and subjected to X-ray microanalysis (EDAX), an analytical technique which allows the detection and quantification (as percent by mass) of major elements in the surface layers of the material analysed. This technique was used to identify the presence or absence of the metals lead (Pb), mercury (Hg), cadmium (Cd) and chromium (Cr; total amount, all ionic states), as well as the element bromine (Br) as first indication of the possible presence of organobromine compounds or brominated polymeric materials used as flame retardants. This technique does not provide data on the presence or absence of chlorine (Cl) in a material.

Based on these results, obtained for all selected component samples, individual components were selected for more detailed, confirmatory analysis as follows:-

a) for each laptop, one metallic component for which chromium had been detected using X ray microanalysis was subsequently analysed for the presence of chromium (VI), the most toxic and carcinogenic ionic form of chromium and the form controlled under RoHS
b) one component common to all laptops and showing consistently high bromine content under X-ray microanalysis, namely the fan, was analysed from each laptop for a range of extractable brominated flame retardants (BFRs), including PBDEs (tri- to deca-brominated congeners), PBBs (tetra- to deca-brominated congeners), HBCD (hexabromocyclododecane) and TBBPA (tetrabromobisphenol A)

In addition, a total of five internal wires per laptop (only four in the case of the Dell laptop) were analysed to confirm the presence or absence of PVC in the plastic insulating coating

Further details of all the analytical methods employed are given below.

X-ray microanalysis (EDAX)
The sample for analysis was placed in the Energy Dispersive X-Ray Fluorescence (EDAX) instrument at room temperature, and analysed for the surface concentrations of bromine (Br), cadmium (Cd), chromium (Cr), lead (Pb) and mercury (Hg).

Chromium (VI)
The analysis was carried out in accordance with method IEC 62321/1CD, 111/24/CD-method 9[7]. To the surface of each sample, a solution of 0.4 g of 1,5-diphenylcarbazide, 20 ml acetone, 20 ml ethanol (96%), 20 ml orthophosphoric acid solution and 20 ml of demineralised water. The presence of hexavalent chromium being 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.

PBDEs, PBBs and HBCD
Each sample was separately extracted with toluene using a soxhlet extraction method, incorporating an internal ^{13}C 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 ^{13}C labelled standards.

TBBPA
Each sample was separately homogenised and acidified and then extracted with toluene, incorporating an internal ^{13}C 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 ^{13}C labelled standard.

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.

7 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

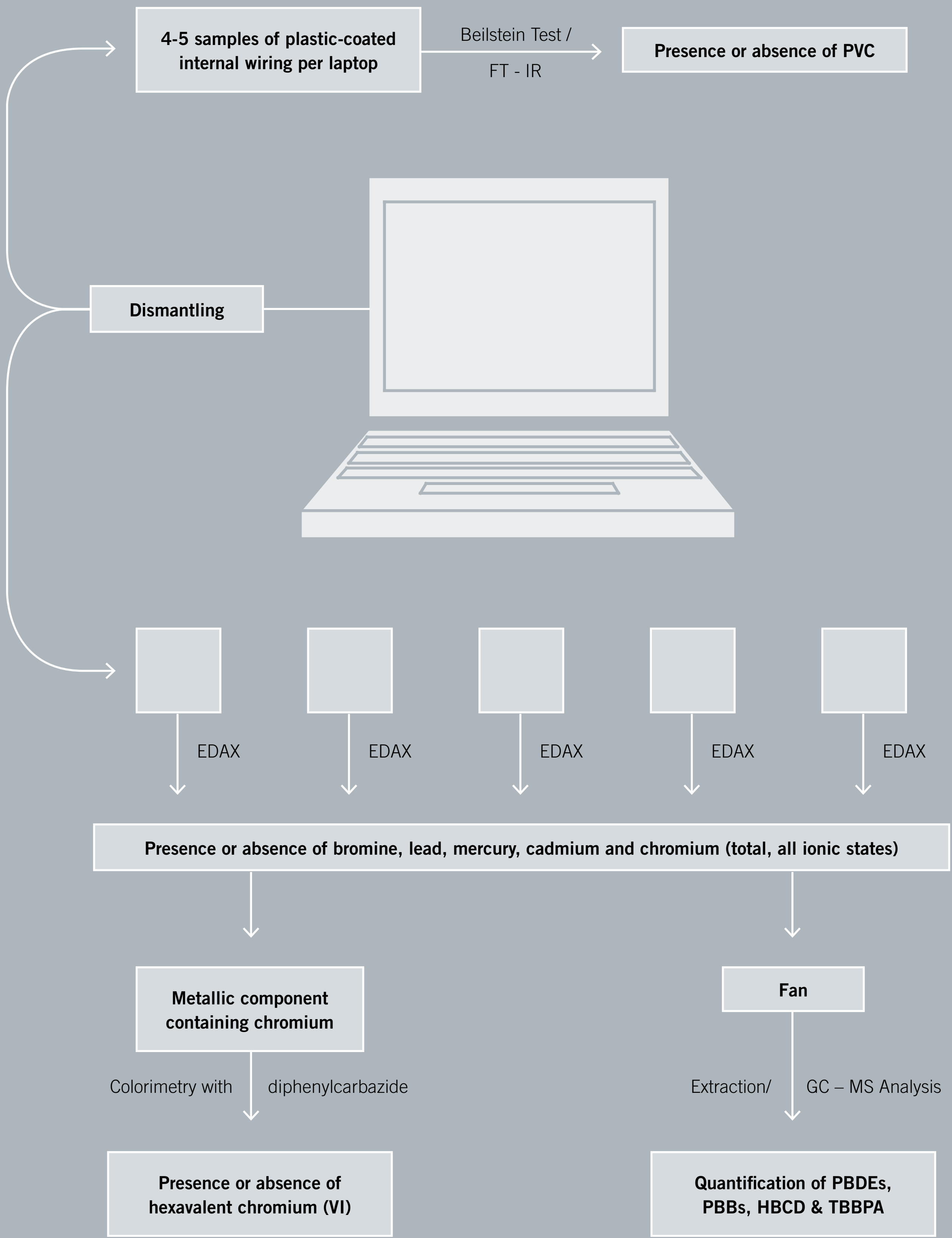

Figure 1. Dismantling of the laptop's components and their analysis

RESULTS AND DISCUSSION

The results of the X-ray microanalyses for the five different elements are presented and discussed below, followed by those for the additional confirmatory tests applied. A summary of the number of samples found to contain the metals cadmium, chromium, lead and mercury by X-ray microanalyses, and the range of concentrations found, is presented in Table 2. A complete list of data from all analyses is provided for each model at Annex 1 to this report. These data relate to those materials and components tested within each laptop, a fraction of the total number of materials and components within each laptop. The absence of a certain chemical in all samples from an individual laptop does not indicate that the laptop is entirely free of that chemical.

Model	Number of samples containing each metal (range of concentrations)			
	lead (Pb)	chromium (Cr)*	cadmium (Cd)	mercury (Hg)
Acer	0	4 (0.37-18%)	0	0
Apple	0	5 (0.23-18%)	0	0
Dell	0	3 (0.27-0.32%)	0	0
Hewlett Packard	3 (4.5-13%)	4 (0.13-9.0%)	0	0
Sony	0	3 (0.29-17%)	0	0

Table 2. Number of samples found to contain different metals by EDAX analysis, and the range of surface concentrations, in all laptop models. Method detection limits; Cd (0.01%), Cr (0.1%), Hg (0.05%), Pb (0.05%), Br (0.1%). * Total chromium concentration; in all cases, one sample from each laptop subsequently tested negative for hexavalent chromium (Cr VI)

Lead

Of the 195 different components subjected to X-ray microanalysis, only 3 revealed the presence of lead at detectable levels, all in materials from the Hewlett Packard (HP) laptop. Two of the positive results were for samples of solder (4.5% and 13% lead by weight at the material surface) and one was identified as an ‘internal connector’, but may also have been a soldered connection (9.8% lead). For electrical solders that contain lead, the amount of lead and overall composition of the solder varies depending on the application for which the solder is used. though an alloy of tin and lead (63% tin to 37% lead) has been widely used in electrical solder[8]. The lower levels of lead found in the 3 samples may be a result of the surface analysis method employed. The X-ray microanalysis technique quantifies percent elemental composition at the very surface of the material being tested, and as such may not be fully representative of the concentration in the homogenous material overall. Separate quantitative analysis of the samples to obtain concentration data for the materials as a whole, and to determine whether the percent composition of the surface layer was indeed representative of the whole, was not possible in this study.

The levels of lead found in all 3 samples indicate the intentional use of lead in these materials, far exceeding trace levels that could potentially be present as a result of the unintentional trace contamination of solder with lead. Furthermore, although not applicable to these laptops, regulations controlling the presence of lead in such materials set a limit far below the levels found in these samples (e.g. EU RoHS Directive; 0.1% with certain exceptions).

Chromium

All laptops sampled contained a number of components containing chromium (a total of 19 out of 195 components sampled), at surface concentrations ranging from 0.13% to as high as 19% chromium. The highest recorded values (17-19% chromium) were associated with the metal casings of internal drives or external card slots. However, subsequent analysis of one chromium containing metallic component from each laptop showed that none contained detectable levels of hexavalent chromium (VI), determined using the qualitative diphenylcarbazide colorimetric method.

Cadmium

None of the 195 components contained cadmium at levels detectable using X-ray microanalysis.

Mercury

None of the 195 components contained mercury at levels detectable using X-ray microanalysis.

Bromine

Around a quarter of all the components and materials tested in every laptop contained detectable levels of bromine, at surface concentrations ranging from 0.19% to 9.4%. These bromine-positive samples included some, but not all, circuit boards, chips, cables and wires, plastic cable connectors, insulating materials, fans and fan casings, touch mouse pads and various other internal components which could not be fully identified. Results are summarised by component type in Table 3 below.

8 Geibig, J.R., Socolof, M.L. (2005) Solders in Electronics: A Life-Cycle Assessment. US EPA 744-R-05-001

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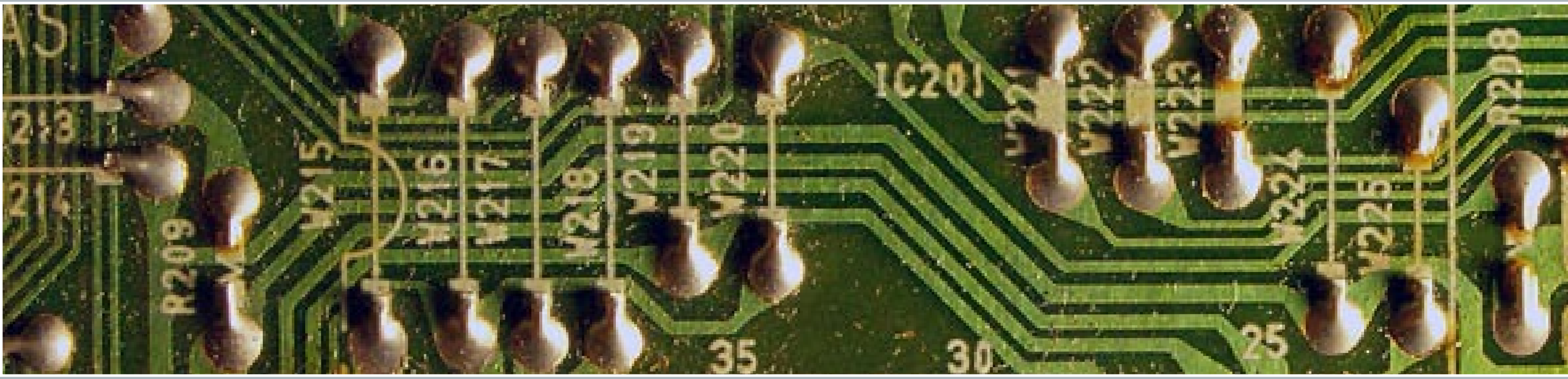


All four touch mouse pads analysed (that for the Sony laptop was not included in the analysis) contained bromine at between 0.24% and 8.1% by weight, with the HP touch mouse pad yielding the highest levels. In the case of the Sony laptop, a touch mouse button was analysed, itself revealing a surface bromine content of 2.6%. In contrast, none of the keyboard keys analysed contained any detectable bromine.

For all models, the fan used to cool the internal circuitry while the laptop is in use, yielded consistently high values for surface bromine content, between 5.3 and 7% by weight. It was on this basis that the fans were selected as the component from each laptop to go forward for specific quantitative analysis for a range of extractable brominated flame retardants; the results of these analyses are presented and discussed below.

In total, around one third of all circuit boards (7 of 19) and chips (3 of 9) analysed, and around half of all ribbon cables (9 of 15), wires (5 of 9) and internal plastic connectors (7 of 14) analysed were found to contain bromine, at concentrations generally ranging from less that 1% to a few percent by weight. There was no clear and consistent relationship between component or material type and level of bromine detected, other than the observations that the three bromine-positive chips yielded relatively low levels (0.24-0.59%), while the seven internal plastic wire connectors and five plastic coated wires which contained bromine gave rather higher results (1.5-8.7%), with all but one in each case yielding values over 3%. The highest bromine content detected of all the components analysed was 9.4% surface bromine by weight, in an internal insulation sheet found in the HP laptop.

It is important to note that, although the X-ray microanalysis provides a reliable and quantitative detection method for total bromine content of the surface layers of a material, it does not yield information on the chemical form in which the bromine is present, i.e. the nature of the organic molecular backbone to which it is bound. Although a high bromine content is likely to result from the use of a brominated flame retardant formulation, the method is unable to distinguish between bromine present in loosely bound additive flame retardants and bromine far more tightly bound in reactive, polymeric formulations. In order to obtain further information regarding the nature of the brominated material, it is necessary to conduct further confirmatory analysis for a range of solvent-extractable brominated compounds, commonly used as flame retardants.

Component or material type	**Number analysed / number containing bromine / concentration range of all values above detection limits**			**Laptop brand yielding highest bromine concentration for each component or material type**
Circuit boards	19	7	0.26-7.1%	Dell (7.1%)
Chips	9	3	0.24-0.59%	Apple (0.58%)
Ribbon cables	15	9	0.83-6.7%	Acer (6.7%)
Other internal coated wiring	9	5	1.5-6.4%	Acer (6.4%)
Insulation sheets	6	2	2.6-9.4%	HP (9.4%)
Internal plastic connectors	14	7	1.5-8.7%	Sony (8.7%)
Fans	5	5	5.3-7.0%	Apple & Dell (7%)
Keyboard surrounds	4	1	7.2%	Dell (7.2%)
Touch mouse pads	4	4	0.24-8.1%	HP (8.1%)

Table 3: Summary of total bromine content among key component groups analysed

Brominated flame retardants (BFRs)

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.

PBDEs are a group of related chemicals, differing in the amount and arrangement of bromine within the molecule. PBBs are a similar group based on a different molecular backbone. For both PBDEs and PBBs, the individual chemicals, known as congeners, are grouped by the degree of bromination on the molecule (e.g. octaBDE incorporating 8 bromine atoms per molecule). HBCD is also a group of related chemicals, each containing the same degree of bromination but with different arrangements within the molecule TBBPA is a single individual chemical.

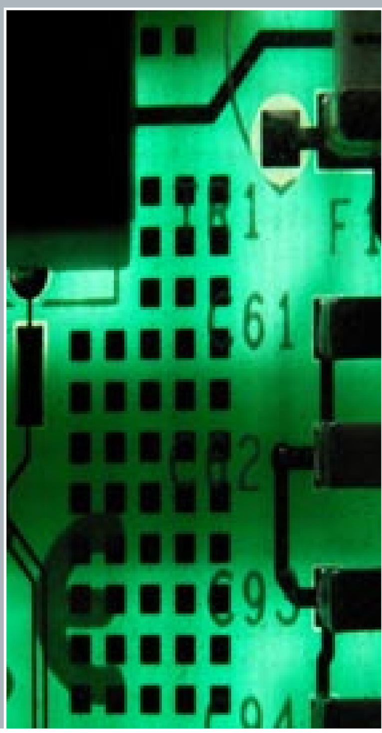
Of the BFRs quantified, the most commonly used in modern electronics are undoubtedly 'deca', i.e. commercial formulations of decaBDE, in additive mode, and TBBPA, in either additive or, far more commonly, in reactive (polymer-bound) mode. Indeed, the use of TBBPA in reactive mode in brominated epoxy resin circuit boards represents one of the major uses of this compound worldwide. In reactive mode, 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 used remains as unreacted TBBPA monomer that can be isolated by solvent extraction. Some older electrical and electronic equipment may be expected to contain a far wider range of PBDEs, or even PBBs, despite the fact that PBBs have been phased out of new production for some time. HBCD is another commonly used additive brominated flame retardant which can be readily extracted if present.

Due to resource limitations, it was possible to subject only one component per laptop to quantitative determination of these brominated flame retardants for the purposes of this preliminary study. For consistency, and in recognition of their consistently high bromine content, the fans were selected from each laptop to undergo such analysis.

Of the brominated flame retardants quantified in this study (PBDEs, TBBPA, HBCD, PBBs), only TBBPA and PBDEs (hepta- to decaBDEs congeners) were found at levels above method detection limits. HBCD was not detected in any of the fans analysed, and, as expected for components in laptops which had been brought to the market relatively recently, no traces of PBBs were found. The concentrations of TBBPA and PBDE congener groups in the 5 fans are presented in Table 4.

BFR	Congener groups	Acer	Apple	Dell	HP	Sony
PBDEs	heptaBDEs	nd	nd	nd	0.6	nd
	octaBDEs	nd	nd	nd	56.7	nd
	nonaBDEs	nd	2.1	nd	2040	nd
	decaBDE	1.0	8.5	nd	1650	nd
TBBPA	---	55.4	262	7.8	86.7	nd

Table 4: Summary of the concentrations of extractable brominated flame retardants (BFRs) identified in the fans from the five laptops; nd-not detected above 0.5 mg/kg. All other quantified BFRs were not present above the method detection limits of 0.5 mg/kg



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Three of the fans analysed contained detectable levels of PBDEs. For the fans from the Apple and Acer laptops, levels of those PBDEs identified were only slightly above detection limits. The Apple fan contained decaBDE at 8.5 mg/kg and nonaBDEs at 2.1 mg/kg. For the Acer fan, only decaBDE was detected, at the even lower level of 1.0 mg/kg.

By far the highest levels of PBDEs were identified in the fan from the HP laptop. This fan contained 1650 mg/kg (or 0.165% by weight) of decaBDE and 2040 mg/kg (or 0.204% by weight) of nonaBDEs, as well as other PBDEs, though at much lower levels; heptaBDE (0.6 mg/kg) and octaBDE (56.7 mg/kg).

The level of nonaBDEs is higher than the level of decaBDE extracted from the same fan, and above the 0.1% by weight limit for nonaBDE in homogenous materials which would apply to electronic equipment put on the market after 1st July 2006 under the provisions of the EU RoHS Directive.

Traces of TBBPA were found in fans from four of the five laptops, with concentrations ranging from 7.8 mg/kg to 262 mg/kg, the highest value in the Apple laptop fan. No TBBPA was detected in the fan from the Sony laptop (again at a detection limit of 0.5 mg/kg). It cannot be deduced from these results alone whether the concentrations of extractable TBBPA in the four fans are due to low level addition in additive mode or the inevitable presence of a small proportion of unreacted TBBPA resulting from its use in reactive mode.

Two things, however, are apparent. Firstly, the concentrations of both PBDEs and TBBPA determined here, even at the highest levels found, would seem unlikely to provide sufficient flame retardancy alone for the plastic material from which the fans are constructed. Secondly, given that all five fans revealed bromine contents of between 5.3 and 7% by weight under X-ray microanalysis, it seems clear that the bulk of this 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.

The fans may contain other extractable brominated compounds not quantified in this study, though it seems more likely that the majority of the bromine is bound up in the polymeric material of the fan itself, or at least is present in 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 as to the chemical nature of the majority of the detectable bromine content in the fans 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.

PVC

Of a total of 24 sections of plastic-coated internal wiring subject to PVC analysis (four from the Dell and five from the other four brands), only four recorded positive for the presence of PVC. Three of these were the wires leading to the fans in the Acer, Apple and HP laptops. The fourth was a wire leading to a small internal battery casing, again in the HP laptop. Wires leading to the fans in the Dell and Sony laptops did not appear to be coated with PVC. PVC was not identified in the other 20 plastic-coated internal wires that were tested, including the wires leading to the fans in the Dell and Sony models.

CONCLUSIONS

Although limited in scope, this study has proven to be a valuable exercise in demonstrating the ability and limitations of a range of analytical methods used for the determination of hazardous substances in laptops. The X-ray microanalysis technique provided a relatively simple and cost-effective screening tool to help identify which materials and/or components should go forward for more in-depth, confirmatory and/or quantitative analysis for specific compounds of concern. This study demonstrates the need to develop further the range and application of such additional analyses for selected materials and components of interest to gain a fuller understanding of the presence of hazardous substances in these products

As noted above, while this study covered a diverse range of materials and components within each laptop, it was not feasible to test every individual material or component within each model. It is possible that untested components contain one or more of the chemicals investigated in this study, and therefore the absence of a chemical in all samples from a laptop does not indicate that the laptop is entirely free of that chemical. Furthermore, within each brand there exists a high degree of complexity in the different laptop models available on the market. The results from this study are applicable to the specific model tested for each brand, and do 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.

Nevertheless, as a initial study into the presence of hazardous and RoHS-relevant chemicals in a number of popular brands of laptop computers, on the market in Europe prior to the entry into force of the RoHS Directive, the study has revealed some valuable information as it stands.

- Of the four potentially hazardous metals included in this study, only lead was found to be present in the samples tested, and then only in three samples of solder or other connecting materials in the HP laptop.

- Bromine was detected in roughly a quarter of the 195 components tested, at levels up to 9.4% by weight (though generally in lower percentage levels), presumably as a result of the use of brominated organic materials to confer flame retardancy.

- Around one third of the circuit boards and chips analysed, roughly half of all internal ribbon cables, wiring and plastic cable connectors analysed, and all the touch mouse pads and fans analysed, contained bromine.

- Analysis of the fan from each laptop for a range of commonly or historically used brominated flame retardant additives (PBDEs, PBBs, HBCD, TBBPA) revealed only TBBPA (in four out of five), and PBDEs; decaBDE (in three out of five) and nona- and octaBDE (in only one out of five). All were present at relatively low levels compared to the amounts typically used to provide flame retardancy in such materials[9]. Nether HBCD or PBBs were detected in any of the fans.

- For all PBDEs, the highest concentrations were found in the fan from the HP laptop, which contained decaBDE at a concentration of 0.165% and nonaBDEs at a concentration of 0.204%, as well as being the only laptop fan containing octaBDE, though at a lower level (0.006%).

- The levels of the identified brominated flame retardants do not account for the far higher quantities of bromine, in all

9 Lassen, C., Lokke, S. & Hansen, L.I. (1999) Brominated Flame Retardants: substance flow analysis and substitution feasibility study. Danish Environmental Protection Agency Environmental Project No. 494, Copenhagen, ISBN 87-7909-415-5: 240 pp.
10 Stutz, M., Riess, M., Tungare, A.V., Hosseinpour, J., Waechter, G., Rottler, H. (2000) Combustion of Halogen-free Printed Wiring Boards and Analysis of Thermal Degradation Products. Proceedings Electronic Goes Green 2000, 127-132.

forms, present in the fans (5.3-7%). Although the range of solvent extractable brominated flame retardants quantified was not exhaustive, it seems likely that the bulk of the bromine identified in the fans under X-ray microanalysis is present in brominated polymeric or oligomeric forms and, therefore, not amenable to identification by solvent extraction and GC-MS analysis.

- Nevertheless, the fact that PBDEs, including nona- and octabrominated forms, have been found at all in fans from some of the laptops is significant. Though not in force when the laptops in this study were purchased, the EU RoHS Directive sets a limit of 0.1% for all PBDEs, other than decaBDE. The concentration of nonaBDE found in the fan from the HP laptop is above this value, at 0.204% by weight.

- Despite the likelihood that the majority of the bromine in the fans is present in oligomeric or polymer bound forms, the high levels of bromine in these and in other materials is still significant. At the product's end of life, some disposal or recycling operations (e.g incineration, smelting and open burning) can potentially release the bromine in hazardous forms, including hydrogen bromide and brominated dioxins.[10]

- The presence of PVC coatings was found in a small proportion of the internal cables and wires tested (4 out of 24). These included 2 wires from the HP laptop and 1 from each of the Acer and Apple models. PVC was not identified in the coatings of all other internal wires tested. For these wires the use of PVC is clearly not essential in the plastic coating.

ANNEX 1:

Description of all materials and components analysed and the results obtained for each laptop model

Dismantling of laptops to enable testing of individual components and materials for a range of hazardous substances.
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Data from X-ray microanalysis (EDAX)

sample	component	Cd (%)	Cr (%)	Hg (%)	Pb (%)	Br (%)
1	main plastic body adjacent to keyboard	nd	nd	nd	nd	nd
2	mouse central button	nd	nd	nd	nd	nd
2a	mouse pad	nd	nd	nd	nd	4.7
3	mouse right button	nd	nd	nd	nd	nd
4	internal metal casing	nd	nd	nd	nd	nd
5	space key	nd	nd	nd	nd	nd
6	keyboard surround	nd	nd	nd	nd	nd
*7	ribbon cable	nd	nd	nd	nd	1.0
8	internal metal plate	nd	18	nd	nd	nd
9	small circuit board	nd	nd	nd	nd	nd
*10	plastic coating on internal wire	nd	nd	nd	nd	6.4
11	circuit board	nd	nd	nd	nd	nd
12	electrical contact	nd	nd	nd	nd	nd
13	part of motherboard	nd	nd	nd	nd	nd
14	small chip	nd	nd	nd	nd	0.4
15	electrical insulation sheet	nd	nd	nd	nd	2.6
16	solder	nd	nd	nd	nd	nd
17	metal casing on external card slot	nd	18	nd	nd	nd
18	internal wire	nd	nd	nd	nd	6.0
19	small internal component	nd	nd	nd	nd	0.5
20	black plastic internal component	nd	2.5	nd	nd	nd
21	white plastic internal component	nd	nd	nd	nd	7.1
22	electrical insulation sheet	nd	nd	nd	nd	nd
23	black internal component	nd	nd	nd	nd	0.55
24	internal component	nd	nd	nd	nd	nd
25	small internal component	nd	nd	nd	nd	0.72
26	motherboard	nd	nd	nd	nd	nd
27	solder	nd	nd	nd	nd	nd
28	internal plastic casing	nd	nd	nd	nd	nd
29	ribbon cable	nd	nd	nd	nd	6.7
30	small component on circuit board #31	nd	nd	nd	nd	nd
31	small printed circuit board	nd	nd	nd	nd	3.6
32	fan	nd	nd	nd	nd	6.0
33	fan cover	nd	nd	nd	nd	nd
34	black adhesive tape on fan	nd	nd	nd	nd	nd
35	metal casing of CD drive	nd	0.37	nd	nd	nd
36	screen	nd	nd	nd	nd	nd
37	material surrounding large chip	nd	nd	nd	nd	nd
38	large chip	nd	nd	nd	nd	nd

nd; not detected above method detection limits; Cd (0.01%), Cr (0.1%), Hg (0.05%), Pb (0.05%), Br (0.1%) *- also analysed for presence of PVC

Quantification of selected brominated flame retardants in the fan (sample 32)

BFR	Congener group	Concentration (mg/kg)
PBDE	Tri-BDEs	nd
	Tetra-BDEs	nd
	Penta-BDEs	nd
	Hexa-BDEs	nd
	Hepta-BDEs	nd
	Octa-BDEs	nd
	Nona-BDEs	nd
	Deca-BDE	1.0
PBB	Tetra-BBs	nd
	Penta-BBs	nd
	Hexa-BBs	nd
	Hepta-BBs	nd
	Octa-BBs	nd
	Nona-BBs	nd
	Deca-BB	nd
HBCD	---	nd
TBBPA	---	55.4

nd; not detected above method detection limit of 0.5 mg/kg for all analytes

Analysis for the presence of PVC using Beilstein/FT-IR

sample	component	PVC
7	ribbon cable	nd
10	plastic coating on internal wire	nd
33a	red plastic coating on wire to fan	PVC
34a	white plastic coating on internal wire	nd
39	plastic coating on wire to fan	nd

nd - not detected; PVC - presence of PVC confirmed

Analysis for the presence of hexavalent chromium, Cr (VI)

sample	component	Cr (VI)
8	internal metal plate	nd

nd; not detected

Data from X-ray microanalysis (EDAX)

sample	component	Cd (%)	Cr (%)	Hg (%)	Pb (%)	Br (%)
1	main plastic body around keyboard	nd	0.51	nd	nd	nd
2	mouse pad	nd	nd	nd	nd	0.84
3	keyboard (space key)	nd	nd	nd	nd	nd
4	grey frame around keyboard	nd	nd	nd	nd	nd
5*	internal ribbon cable	nd	nd	nd	nd	1.2
6	small blue circuit board	nd	nd	nd	nd	0.52
7	small internal component	nd	nd	nd	nd	nd
8	internal black plastic sheet	nd	nd	nd	nd	nd
9	internal mesh	nd	nd	nd	nd	nd
10	electrical insulation sheet	nd	nd	nd	nd	nd
11	internal part of external port	nd	nd	nd	nd	nd
12	internal plastic wire connector	nd	nd	nd	nd	nd
13	fan	nd	nd	nd	nd	7.0
14	motherboard	nd	nd	nd	nd	1.6
15	small internal component	nd	nd	nd	nd	nd
16	plastic wire connector	nd	nd	nd	nd	1.5
17	internal speaker	nd	nd	nd	nd	nd
18	plug in card	nd	nd	nd	nd	nd
*19	plastic coating on internal wire	nd	nd	nd	nd	nd
20	internal component	nd	nd	nd	nd	2.6
21	solder	nd	nd	nd	nd	nd
22	internal speaker	nd	nd	nd	nd	nd
23	plastic casing	nd	nd	nd	nd	nd
24	housing for memory chip	nd	nd	nd	nd	nd
25	fan casing	nd	0.23	nd	nd	nd
26	internal cable	nd	nd	nd	nd	3.5
27	solder	nd	nd	nd	nd	0.25
28	internal chip	nd	nd	nd	nd	nd
29	screen	nd	nd	nd	nd	nd
30	metal casing of CD drive	nd	0.35	nd	nd	nd
31	internal chip	nd	nd	nd	nd	0.59
32	ribbon cable	nd	nd	nd	nd	2.2
33	hard drive casing	nd	nd	nd	nd	nd
34	memory chip circuit board	nd	nd	nd	nd	nd
35	internal casing	nd	18	nd	nd	nd
36	of CD drive	nd	18	nd	nd	nd
37	material surrounding large chip	nd	nd	nd	nd	0.70
38	large chip	nd	nd	nd	nd	nd

nd; not detected above method detection limits; Cd (0.01%), Cr (0.1%), Hg (0.05%), Pb (0.05%), Br (0.1%)   *- also analysed for presence of PVC

Quantification of selected brominated flame retardants in the fan (sample 13)

BFR	Congener group	Concentration (mg/kg)
PBDE	Tri-BDEs	nd
	Tetra-BDEs	nd
	Penta-BDEs	nd
	Hexa-BDEs	nd
	Hepta-BDEs	nd
	Octa-BDEs	nd
	Nona-BDEs	2.1
	Deca-BDE	8.5
PBB	Tetra-BBs	nd
	Penta-BBs	nd
	Hexa-BBs	nd
	Hepta-BBs	nd
	Octa-BBs	nd
	Nona-BBs	nd
	Deca-BB	nd
HBCD	---	nd
TBBPA	---	262

nd; not detected above method detection limit of 0.5 mg/kg for all analytes

Analysis for the presence of PVC using Beilstein/FT-IR

sample	component	PVC
5	internal ribbon cable	nd
16a	blue plastic coating on wire to fan	PVC
19	plastic coating on internal wire	nd
25a	plastic coating on internal wire	nd
39	plastic coating on wire to wire connector #12	nd

nd - not detected; PVC - presence of PVC confirmed

Analysis for the presence of hexavalent chromium, Cr (VI)

sample	component	Cr (VI)
36	metal casing of CD drive	nd

nd; not detected

Data from X-ray microanalysis (EDAX)

sample	component	Cd (%)	Cr (%)	Hg (%)	Pb (%)	Br (%)
1	main plastic body around keyboard	nd	nd	nd	nd	nd
2	mouse pad	nd	nd	nd	nd	0.24
3	plastic frame around keyboard	nd	nd	nd	nd	nd
4	space key	nd	nd	nd	nd	nd
5	internal ribbon cable	nd	nd	nd	nd	nd
*6	plastic coating around internal wires	nd	nd	nd	nd	nd
*7	ribbon cable	nd	nd	nd	nd	2.0
8	internal plastic wire connector	nd	nd	nd	nd	3.5
9	metal casing on PCMCIA external card slot	nd	0.32	nd	nd	nd
10	ribbon cable	nd	nd	nd	nd	2.3
11	internal plastic housing	nd	nd	nd	nd	nd
12	fan cover	nd	nd	nd	nd	7.2
13	fan	nd	nd	nd	nd	7.0
14	PCMCIA external card	nd	nd	nd	nd	nd
15	material surrounding large chip	nd	nd	nd	nd	0.26
16	large chip	nd	nd	nd	nd	nd
17	ribbon cable	nd	nd	nd	nd	nd
18	plastic coating around internal wires	nd	0.30	nd	nd	nd
19	small circuit board	nd	nd	nd	nd	7.1
20	external interface circuit board	nd	nd	nd	nd	nd
21	internal structural plastic	nd	nd	nd	nd	nd
22	solder	nd	nd	nd	nd	nd
23	metal heat conductor	nd	nd	nd	nd	nd
24	internal part of external port	nd	nd	nd	nd	nd
25	casing of CD drive	nd	nd	nd	nd	nd
26	small component	nd	nd	nd	nd	1.2
27	small circuit board	nd	nd	nd	nd	nd
28	plastic wire connector	nd	nd	nd	nd	8.6
29	solder	nd	nd	nd	nd	nd
30	plastic wire connector	nd	nd	nd	nd	nd
31	ribbon cable	nd	nd	nd	nd	4.7
32	casing on external card slot	nd	nd	nd	nd	nd
33	internal metal heat sink	nd	0.27	nd	nd	nd
34	small structural component	nd	nd	nd	nd	nd
35	not analysed	--	--	--	--	--
36	small internal component	nd	nd	nd	nd	nd
37	small component	nd	nd	nd	nd	nd
38	screen	nd	nd	nd	nd	nd
39	motherboard	nd	nd	nd	nd	1.6
40	small circuit board	nd	nd	nd	nd	nd

nd; not detected above method detection limits; Cd (0.01%), Cr (0.1%), Hg (0.05%), Pb (0.05%), Br (0.1%) *- also analysed for presence of PVC

Quantification of selected brominated flame retardants in the fan (sample 13)

BFR	Congener group	Concentration (mg/kg)
PBDE	Tri-BDEs	nd
	Tetra-BDEs	nd
	Penta-BDEs	nd
	Hexa-BDEs	nd
	Hepta-BDEs	nd
	Octa-BDEs	nd
	Nona-BDEs	nd
	Deca-BDE	nd
PBB	Tetra-BBs	nd
	Penta-BBs	nd
	Hexa-BBs	nd
	Hepta-BBs	nd
	Octa-BBs	nd
	Nona-BBs	nd
	Deca-BB	nd
HBCD	---	nd
TBBPA	---	7.8

nd; not detected above method detection limit of 0.5 mg/kg for all analytes

Analysis for the presence of PVC using Beilstein/FT-IR

sample	component	PVC
6	plastic coating around internal wires	nd
7	ribbon cable	nd
41	plastic coating on wire to fan	nd
42	plastic coating on red internal wire	nd

nd - not detected; PVC - presence of PVC confirmed

Analysis for the presence of hexavalent chromium, Cr (VI)

sample	component	Cr (VI)
9	metal casing on PCMCIA external card slot	nd

nd; not detected

Data from X-ray microanalysis (EDAX)

sample	component	Cd (%)	Cr (%)	Hg (%)	Pb (%)	Br (%)
1	main plastic body around keyboard	nd	nd	nd	nd	0.22
2	mouse pad	nd	nd	nd	nd	8.1
3	plastic frame around keyboard	nd	nd	nd	nd	nd
4	space key	nd	nd	nd	nd	nd
5	external plastic housing	nd	nd	nd	nd	nd
6	DVD control button	nd	nd	nd	nd	nd
*7	ribbon cable	nd	nd	nd	nd	nd
8	plastic internal wire connector	nd	nd	nd	nd	6.8
9	internal metal plate	nd	0.20	nd	nd	nd
10	internal metal plate	nd	nd	nd	nd	nd
11	internal foil	nd	nd	nd	nd	nd
12	small circuit board	nd	nd	nd	nd	nd
13	internal chip	nd	nd	nd	nd	nd
14	small internal component	nd	nd	nd	nd	nd
15	small internal component	nd	nd	nd	nd	nd
16	large chip	nd	nd	nd	nd	nd
17	material surrounding large chip	nd	nd	nd	nd	0.56
18	fan	nd	nd	nd	nd	5.3
*19	plastic coating around internal wires	nd	nd	nd	nd	1.5
20	not analysed	--	--	--	--	--
21	foil	nd	nd	nd	nd	0.86
22	internal housing	nd	nd	nd	nd	nd
23	plastic casing of main body	nd	nd	nd	nd	nd
24	internal housing	nd	nd	nd	nd	nd
25	electrical insulation sheet	nd	nd	nd	nd	9.4
26	mother board	nd	nd	nd	nd	nd
27	internal metal plate	nd	0.20	nd	nd	nd
28	solder??	nd	nd	nd	4.5	0.86
29	metal casing of CD drive	nd	0.13	nd	nd	nd
30	ribbon cable	nd	nd	nd	nd	1.9
31	external casing	nd	nd	nd	nd	nd
32	solder	nd	nd	nd	nd	nd
33	plastic internal wire connector	nd	nd	nd	nd	3.2
34	plastic coating on internal wire	nd	9.0	nd	nd	nd
35	small internal battery cover	nd	nd	nd	nd	nd
36	internal electrical connector	nd	nd	nd	9.8	nd
37	metallic connector	nd	nd	nd	nd	0.19
38	connector - edge of small circuit board	nd	nd	nd	nd	nd
39	metal clip on edge of hard drive	nd	nd	nd	nd	nd
40	ribbon cable	nd	nd	nd	nd	nd
41	casing	nd	nd	nd	nd	nd
42	plastic wire connector	nd	nd	nd	nd	nd
43	screen	nd	nd	nd	nd	nd
44	solder	nd	nd	nd	13	nd

nd; not detected above method detection limits; Cd (0.01%), Cr (0.1%), Hg (0.05%), Pb (0.05%), Br (0.1%) *- also analysed for presence of PVC

Quantification of selected brominated flame retardants in the fan (sample 13)

BFR	Congener group	Concentration (mg/kg)
PBDE	Tri-BDEs	nd
	Tetra-BDEs	nd
	Penta-BDEs	nd
	Hexa-BDEs	nd
	Hepta-BDEs	0.6
	Octa-BDEs	56.7
	Nona-BDEs	2040
	Deca-BDE	1650
PBB	Tetra-BBs	nd
	Penta-BBs	nd
	Hexa-BBs	nd
	Hepta-BBs	nd
	Octa-BBs	nd
	Nona-BBs	nd
	Deca-BB	nd
HBCD	---	nd
TBBPA	---	86.7

nd; not detected above method detection limit of 0.5 mg/kg for all analytes

Analysis for the presence of PVC using Beilstein/FT-IR

sample	component	PVC
7	ribbon cable	nd
19	plastic coating around internal wires	nd
45	plastic coating on white wire to small board (#37/#38)	nd
46	red plastic coating on wire to internal battery cover	PVC
47	plastic coating on wire to fan	PVC

nd - not detected; PVC - presence of PVC confirmed

Analysis for the presence of hexavalent chromium, Cr (VI)

sample	component	Cr (VI)
27	internal metal plate	nd

nd; not detected

Data from X-ray microanalysis (EDAX)

sample	component	Cd (%)	Cr (%)	Hg (%)	Pb (%)	Br (%)
1	plastic casing (black)	nd	nd	nd	nd	nd
2	main plastic body around keyboard	nd	nd	nd	nd	nd
3	return key	nd	nd	nd	nd	nd
4	right mouse button	nd	nd	nd	nd	2.6
5	ribbon cable	nd	nd	nd	nd	nd
6	internal casing	nd	nd	nd	nd	nd
7	internal structural component	nd	nd	nd	nd	nd
8	small circuit board	nd	nd	nd	nd	nd
9	ribbon cable	nd	nd	nd	nd	2.0
10	ribbon cable	nd	nd	nd	nd	nd
11	plastic internal wire connector	nd	nd	nd	nd	8.7
12	electrical insulation sheet	nd	nd	nd	nd	nd
13	small internal component	nd	nd	nd	nd	nd
*14	ribbon cable	nd	nd	nd	nd	0.83
15	small internal component	nd	nd	nd	nd	0.83
16	fan	nd	nd	nd	nd	6.3
17	processor housing	nd	nd	nd	nd	nd
18	material surrounding large chip	nd	nd	nd	nd	0.55
19	large chip with surrounding material	nd	nd	nd	nd	nd
20	large chip	nd	nd	nd	nd	0.24
21	electrical insulation sheet	nd	nd	nd	nd	nd
22	motherboard	nd	nd	nd	nd	2.8
23	solder	nd	nd	nd	nd	nd
24	small circuit board	nd	nd	nd	nd	0.26
25	internal structural component	nd	nd	nd	nd	nd
26	small internal component	nd	nd	nd	nd	nd
27	chip on small circuit board (#26)	nd	nd	nd	nd	nd
28	part of hard drive	nd	nd	nd	nd	nd
29	external casing underside	nd	nd	nd	nd	nd
30	hard drive circuit board	nd	nd	nd	nd	nd
31	memory housing	nd	nd	nd	nd	nd
32	solder	nd	nd	nd	nd	0.31
33	metal casing on external card slot	nd	17	nd	nd	nd
34	internal metal plate	nd	0.34	nd	nd	nd
35	fan casing	nd	nd	nd	nd	nd
36	metal casing of CD drive	nd	0.29	nd	nd	nd
37	screen	nd	nd	nd	nd	nd
38	solder	nd	nd	nd	nd	nd

nd; not detected above method detection limits; Cd (0.01%), Cr (0.1%), Hg (0.05%), Pb (0.05%), Br (0.1%) *- also analysed for presence of PVC

Quantification of selected brominated flame retardants in the fan (sample 16)

BFR	Congener group	Concentration (mg/kg)
PBDE	Tri-BDEs	nd
	Tetra-BDEs	nd
	Penta-BDEs	nd
	Hexa-BDEs	nd
	Hepta-BDEs	nd
	Octa-BDEs	nd
	Nona-BDEs	nd
	Deca-BDE	nd
PBB	Tetra-BBs	nd
	Penta-BBs	nd
	Hexa-BBs	nd
	Hepta-BBs	nd
	Octa-BBs	nd
	Nona-BBs	nd
	Deca-BB	nd
HBCD	---	nd
TBBPA	---	nd

nd; not detected above method detection limit of 0.5 mg/kg for all analytes

Analysis for the presence of PVC using Beilstein/FT-IR

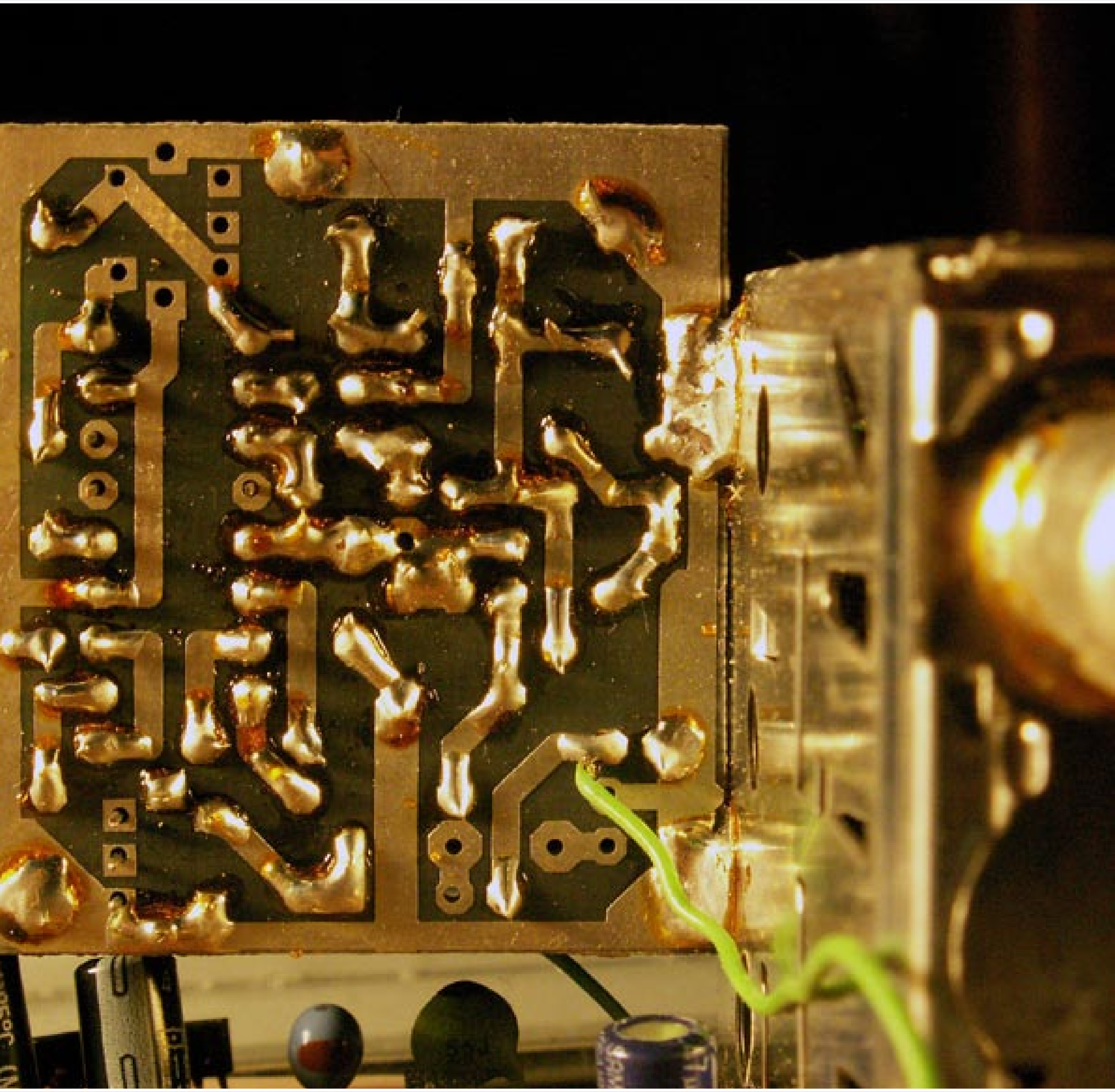
sample	component	PVC
14	ribbon cable	nd
39	plastic coating on wire to fan	nd
40	plastic coating on internal wire (adjacent to #24)	nd
41	plastic coating on grey internal wire (adjacent to #21)	nd
42	plastic coating around internal wires (adjacent to #21)	nd

nd - not detected; PVC - presence of PVC confirmed

Analysis for the presence of hexavalent chromium, Cr (VI)

sample	component	Cr (VI)
33	metal casing on external card slot	nd

nd; not detected



Published by Greenpeace International
Ottho Heldringstraat 5
1066 AZ Amsterdam
The Netherlands
t +31 20 718 2000
f +31 20 514 8151
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