

Brominated Flame Retardant Research
A Pilot Study of E-waste Plastic Sorting in New Zealand

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Acronyms and Abbreviations

ABS	acrylonitrile butadiene styrene
Basel Convention	The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal came into force in 1992. The Convention puts an onus on exporting countries to ensure that hazardous wastes are managed in an environmentally sound manner in the country of import
BDE	brominated diphenyl ether
BFR	Brominated flame retardants (BFRs), are commonly used to reduce the flammability of office and household items including computers, carpet, furniture fabrics and mattresses. They are also used in insulation products and in the upholstery and internal fittings of motor vehicles. Approximately 80 different types of brominated flame retardant are used commercially. The more widely used are the Polybrominated diphenyl ethers (see PBDEs).
BFR free	Pertaining (in this report) to WEEE plastics, BFR free means containing less than 0.1% (1000ppm) Br by weight
Br	bromine
BTBPE	1,2-bis(2,4,6-tribromophenoxy)ethane
c-octaBDE	commercial octaBDE
c-pentaBDE	commercial pentaBDE
c-decaBDE	commercial decaBDE
CBA	Cost benefit analysis
Class A Landfill	One of two types of landfill in New Zealand, Class A has a higher standard of environmental protection than Class B, and so can accept hazardous wastes within stated acceptance criteria
Computers & peripherals	Category of WEEE discussed in this report which includes desktop PCs, servers, laptops, monitors, keyboards, mice and modems
CRT	cathode ray tube
DBDPE	decabromodiphenyl ethane
e-waste	Electrical and electronic waste (interchangeable with WEEE)
EEE	Electrical and electronic equipment
GCMS	gas chromatography-mass spectrometry

HBCD	Hexabromocyclododecane
kg	kilogram
LCD	Liquid Crystal Display
LPCL	low POP control limit
MEA	Multilateral Environment Agreement
mg	milligram
(the) Ministry	The (New Zealand) Ministry for the Environment
MPCL	maximum POP control limit
OctaBDE	OctaBDE contains a range of BDE congeners (explained further in Section 2.2). However for the purposes of this report the term 'octaBDE' refers to commercial octaBDE (c-octaBDE).
PBDEs	Polybrominated diphenyl ethers (PBDEs) are a very common class of BFRs, and have attracted the most attention to date because of their potential to persist in the environment.
PentaBDE	PentaBDE contains a range of BDE congeners (explained further in Section 2.2). However for the purposes of this report the term 'pentaBDE' refers to commercial pentaBDE (c-pentaBDE).
POPs	Persistent organic pollutants (POPs) are hazardous and environmentally persistent substances which can be transported between countries by the earth's oceans and atmosphere. POPs accumulate in living organisms and have been traced in the fatty tissues of humans and other animals. There is general international agreement that they require global action to reduce their impact on humans and the environment.
POP-BDEs	Persistent organic pollutants brominated diphenyl ethers (POP-BDEs) is a term used to refer to the two commercial PBDE mixtures that are on the new list of Stockholm Convention substances. These are Penta-BDE and Octa-BDE.
POP-BDE free	Pertaining (in this report) to WEEE plastics, POP-BDE free means containing less than 0.1% (1000ppm) of pentaBDE and octaBDE combined by weight
POPRC	Persistent Organic Pollutants Review Committee, *a* subsidiary body to the Stockholm Convention
ppm	Parts per million. 1ppm = 0.0001%
RoHS Directive	Restriction of Hazardous Substances Directive

Stockholm Convention	The Stockholm Convention on Persistent Organic Pollutants came into force on 17 May 2004. The Convention is an MEA that aims to protect human health and the environment from the effects of POPs
TBBPA	tetrabromobisphenol A
TBPE	1,2-bistribromophenoyethane
WEEE	Waste Electrical and Electronic Equipment
XRF	X-Ray Fluorescence

Executive Summary

The New Zealand Ministry for the Environment (the Ministry) commissioned a Pilot Project led by ENVIRON Australia Pty Ltd and supported by Geo & Hydro – K8 Ltd, to investigate the practicalities of identifying, sorting and segregating plastics in the e-waste recycling industry, according to those components that contain brominated flame retardant (BFR) chemicals banned under the Stockholm Convention on Persistent Organic Pollutants (POPs).

In May 2009, nine new POPs were added to the Convention's annexes, including certain congeners contained in commercial pentabromodiphenyl ether (c-pentaBDE) and commercial octabromodiphenyl ether (c-octaBDE) and together referred to as POP-BDEs.

Based on recent studies, the Ministry believes that the most likely source of POP-BDEs in New Zealand is in electronic products manufactured up until the mid-2000's. But without affordable identification and sorting capabilities, New Zealand recyclers have been forced to send plastic components of suspect e-waste to Class A landfill, on the assumption that they contain POP-BDEs, thereby eliminating their downstream recycling value.

This report represents the results of the first of a two-part project:

- *Part 1*: A pilot study of e-waste plastic scanning and sorting for BFRs using a hand-held XRF scanner; and
- *Part 2*: A cost-benefit analysis that compares the different sorting options for waste that potentially contains BFRs (particularly POP-BDEs) against disposal of these wastes to Class A landfills in New Zealand.

Three major e-waste recycling companies with facilities throughout New Zealand were consulted as part of the Pilot:

- SIMS Recycling Solutions
- RCN Group
- RemarkIT Solutions.

Site visits were conducted at these facilities from the 28th to the 31st of May, involving observations and WEEE article measurement on the factory floor, using a handheld X-Ray Fluorescence (XRF) analyser optimised for bromine detection.

A further round of testing was carried out through destructive laboratory analysis for the specific PBDEs and TBBPA, plus qualitative scans for two other BFRs commonly used as replacements for the PBDEs, DBDPE and BTBPE. This was conducted on 15 plastic samples representative of the range of WEEE items that tested as high in Br by XRF.

More than 120 individual bromine measurements were taken across both SIMS and RCN sites in Auckland, encompassing 63 e-waste item samples such as TVs, computers & peripherals, printers, photocopiers, white goods and toner cartridges.

The results are provided in Appendix A.

For the purposes of data analysis, 'BFR-free' is defined by a Br result of <0.1% (RoHS Directive limit for PBDEs in new products imported into Europe). Similarly, 'PBDE-free' or 'POP-BDE-free' are defined by levels of these respective species below 0.1%.

Using the combined results of XRF scanning for Br (and therefore BFRs) with the destructive laboratory analysis data for the PBDEs and other speciated BFRs, risk-based decision tables have been developed for use by recyclers as a 'ready reckoner' approach to rapid, visual-based decisions on how to sort and segregate particular items of WEEE.

Conclusions from the Pilot were:

1. Annual data provided from the three recyclers involved in this Pilot indicates that the priority items by weight processed by New Zealand e-waste recycling facilities in 2012-13 were:

- TVs (36%)
- Business machines (photocopiers/ printers/ scanners/ faxes) (22%)
- Computers & Peripherals (20%) and
- White-ware (15%).

These four categories make up 93% of all e-waste processed by the three recyclers. The remaining category (7%) was recorded against the item type "not specified".

2. Based on the results of this Pilot study and recent literature data on measured quantities of BFRs and POP-BDEs in WEEE and product articles, Risk Based Decision Tables were derived, to provide guidance for New Zealand recyclers in making decisions about items that are likely to:

- be suitable for recycling;
- require Basel export permits; and
- require disposal to Class A landfill.

In terms of POP-BDEs, these tables indicate the following:

- CRT and LCD TVs are likely to be suitable for recycling, with the exception of CRT TVs manufactured in Europe prior to 1990
  - In making this decision, the authors recognise that the vast majority of CRT TVs processed by the recycling industry in New Zealand have been manufactured in Asia and have been manufactured after 1990.
- Business machines (photocopiers/ printers/ scanners/ faxes) are likely to be suitable for recycling, although the evidence is only available for post 2005 models;
- Computers & Peripherals EXCEPT CRT monitors are likely to be suitable for recycling. This Pilot was unable to obtain sufficient CRT monitors to test, so a risk based approach suggests that CRT monitors should be assumed to contain POP-BDEs, based on a limited number of high octaBDE results reported in recent literature.

  - Internal plastics such as fans and built in drives from pre-2005 should also be assumed to contain POP-BDEs and consequently landfilled.
- White-ware (such as fridges) is likely to be suitable for recycling.

Table E1: TV Decision Table

WEEE Category	**TVs***						
Equipment Type	**CRT****					**LCD**	
Date of manufacture	**European manufactured pre-1990*****	**Pre-2000**		**Post-2000**		**-**	**-**
Plastic component	**All**	**rim**	**back cover**	**rim**	**back cover**	**rim**	**back cover**
BFR free[1]?	N	Y	N	N	N	N	N
PBDE free[2]?	N	Y	N	Y	Y	N	N
POP-BDE free[3]?	N	Y	Y	Y	Y	Y	Y
Class A landfill?	Y	N	N	N	N	N	N
Currently OK to recycle (Stockholm compliant)?	N	Y	Y	Y	Y	Y	Y
Likely to be OK to recycle in future[4]?	N	Y	N	Y	Y	N	N
Requires a Basel permit?	Y	N	Y	Y	Y	Y	Y

Notes:
* Plasmas not included due to low plastic content - bodies almost always metal
** includes rear projection TVs
*** Applies to CRT TVs manufactured both before 1990 AND in Europe only
[1] - likely to be <0.1% BFRs
[2] - likely to be <0.1% PBDEs (includes c-penta, c-octa and c-deca mixtures)
[3] - likely to be <0.1% POP-BDEs (includes c-penta and c-octa)
[4] - In the event that decaBDE is added to the Stockholm Convention in the future
Legend: Y = Yes, N = No
ORANGE: likely but further sampling is recommended.

3. Extrapolation of the recommendations from these Risk Based Decision Tables on annual volume data supplied by the recyclers would give:

- 60% (by number) of all WEEE items handled by the three New Zealand recyclers is likely to be BFR-free

- 50% (by weight) of all WEEE items handled by the three New Zealand recyclers is likely to be BFR-free

- 99% (either by number or by weight) of all WEEE items handled by the three New Zealand recyclers is likely to be POP-BDE-free

4. A separate Cost Benefit Analysis (CBA) is being conducted by ACIL Allen Consulting as the second stage of this project. The scanning, sorting and segregation options derived through this Pilot for consideration in the CBA are:

- Status Quo – No Scanning, Sorting or Segregating of BFR/ non-BFR Plastics. Dispose all Candidate Plastics to Landfill
- Visual BFR - Visual inspection based on risk matrix, sort and segregate for high-risk BFR-containing components
- Visual POP-BDE – Visual inspection based on risk matrix, sort and segregate for high-risk POP-BDE-containing components
- Handheld Scanning BFR – handheld XRF scan, sort and segregate for high-risk BFR-containing components

5. Evidence from this Pilot indicates that routine use of a handheld XRF scanner (the final option above) is not feasible, based on a combination of operational and practical complexity, relatively high capital cost and a lack of sufficiently compelling benefits. In the context of a recycling facility, this option is an impractical and potentially unreliable way to balance proper management of environmental hazard with a facility's goal of maximising legal recycling of plastics.

This instrumentation is highly reliable for bromine detection. However, the combination of operator skills and its inability to distinguish between POP-BDEs and other more acceptable BFR alternatives means that the use of XRF screening as a surrogate for POP-BDE plastic separation would result in large numbers of false positives.

Recommendations from the Pilot were:

1. The four Risk Based Decision Tables outlined in Sections 5.1.1 – 5.1.4 should be used for visual inspection of WEEE items, as a means of sorting and segregating plastic components for suitability of recycling.

The recommendation is to follow the "POP-BDE free?" entry in each table to make the decision to recycle items; however the option exists to use the more stringent heading of "BFR-free?"

Should "POP-BDE free?" be the chosen approach, quality assurance testing, in the form of a combination of XRF Br screening and laboratory PBDE analysis, should be conducted at intervals such as 6-monthly, to give recyclers, recycled plastic customers and regulators confidence that recycled plastics are meeting legal requirements. This would also provide an ongoing check and challenge mechanism (of the Decision Tables) and an increasing data set over time.

The sampling program would primarily be designed to regularly check and validate the sorting Decision Table approach, so would focus on plastic samples from representative WEEE items. However, should there be value for downstream customers, this could also be an opportunity to test batches of combined scrap plastics to demonstrate compliance with BFR-related legal requirements.

2. The Risk Based Decision Tables were arrived at based on the results of this Pilot and limited but recent literature measurement data. This information points to instances, such as for CRT TVs, where the outcomes of this Pilot go against what was previously accepted as fact. Given the limited evidence base of this work, it is recommended that a further measurement study be carried out with a specific focus on the following, in order of priority:

- CRT TV back covers – test for presence of POP-BDEs
- CRT TV rims – test for presence of BFRs and to a lesser extent decaBDE
- CRT computer monitors – test for presence of POP-BDEs

Such a focussed follow up project could achieve significant sample size with a budget in the order of $20,000 NZ. This would provide further confidence in the rigour of the decision table approach, particularly in light of the current volume of CRT TVs being received under TV TakeBack.

3. A more detailed breakdown of the “not specified” category of WEEE volume data should be obtained from the recyclers involved in this Pilot, given that the category as a whole makes up 7% of all WEEE received. Further detailing of this data will help determine whether other WEEE categories need to be scrutinised.

4. Recycling decisions regarding plastics from items not covered by Decision Tables, such as hair dryers, VCRs, DVD players, microwave ovens, sound systems and heaters/ air conditioners should be treated conservatively, following the Ministry’s guidelines (http://www.mfe.govt.nz/publications/waste/bromide-flame-retardant-waste/html/index.html) in the event that no other information is available. Pilot results indicate if a manufacture date more recent than 2005 can be established for an item of WEEE, regardless of what it is, the item is likely to be POP-BDE free.

5. A watching brief should be kept on the progress of discussions regarding the potential candidacy of decaBDE on the Stockholm Convention, at POPs Review Committee (POPRC). A paper has been prepared on this issue for discussion at the next meeting (October 2013).

1 Introduction

The Ministry for the Environment (the Ministry) commissioned a consortium project team, led by ENVIRON Australia Pty Ltd and supported by Geo & Hydro – K8 Ltd and ACIL Allen Consulting, to supply research and analytical consultancy services relating to the end-of-life management of wastes that may contain brominated flame retardants (BFR).

Polybrominated diphenyl ethers (PBDEs), a subset group of BFRs, have been used globally since the late 1970s for their flame-retarding properties and have been applied as an additive to a range of products (articles) including electrical and electronic equipment (EEE), furniture upholstery, automobile interiors, mattresses, carpet underlay and other items that are required to be flame retardant.

In May 2009 the Stockholm Convention's Conference of Parties agreed to add nine new Persistent Organic Pollutants (POPs) to the Convention's annexes, including certain congeners contained in commercial pentabromodiphenyl ether (c-pentaBDE) and commercial octabromodiphenyl ether (c-octaBDE) and together referred to as POP-BDEs. (For the purposes of this report, c-pentaBDE and c-octaBDE are referred to pentaBDE and octaBDE, even though these are commercial mixtures that contain a number of PBDE congeners. These definitions are used under the Stockholm Convention.)

Based on recent studies, the Ministry believes that the most likely source of POP-BDEs in New Zealand is in electronic products manufactured up until the mid-2000s, particularly heat producing equipment such as televisions, hair-dryers and fan heaters.

The historical form of treatment of hard plastic e-waste in New Zealand is either direct article disposal to landfill or recycling and recovery via a small number of recycling facilities, with no form of scanning or segregation of BFR or, more specifically, POP-BDE-containing materials. These facilities remove components of value then export plastics for downstream recycling.

The Waste Minimisation Fund TV TakeBack Programme, recently launched by the Ministry, collects unwanted televisions for recycling on a phased basis that coincides with the regional schedule for digital switchover. POP-BDEs (and certainly BFRs) are likely to be present in the plastic components of some TVs collected by this programme. If destined for overseas recycling, the Basel Convention's export obligations apply to those plastic components, should they be deemed as hazardous waste).

If exporting from New Zealand for recycling, exporters must sort the plastic components before export and remove those components containing POP-BDEs. These components must be disposed of domestically through a class A landfill, or exported for destruction through high temperature incineration (with a Basel permit).

If recovery facilities do not sort and remove POP-BDE components, all plastic components should be assumed to contain POP-BDEs and treated accordingly, thereby eliminating their downstream recycling value.

1.1 Scope of the Project

To satisfy its obligations under Stockholm, and ensure that export requirements under Basel are being followed, the Ministry needs more information about:

- Quantities of POP-BDEs in current articles presenting as waste EEE (WEEE)
- Practical ways of identification, sorting and segregation of POP-BDE containing components within the recycling process; and
- Practical options for, and costs and benefits accruing from, managing these wastes in accordance with international treaty obligations.

The task of obtaining this information has been tackled via a 2 stage research project:

- Part 1: A pilot study of e-waste plastic scanning and sorting for BFRs using a hand-held XRF scanner; and
- Part 2: A cost-benefit analysis that compares the different sorting options for waste that potentially contains BFRs (particularly POP-BDEs) against disposal of these wastes to Class A landfills in New Zealand.

1.2 Purpose of the Report

This report delivers on Part 1 above by describing the pilot study carried out by ENVIRON and Geo & Hydro of WEEE plastic sorting and segregation options for recyclers in New Zealand. The study collects new information about indicative BFR and POP-BDE concentrations in WEEE, and uses this to recommend practical options for recyclers to use in making sorting and segregation decisions about plastics both likely and unlikely to contain these chemicals at levels of concern.

A follow up report by ACIL Allen Consulting, as part of this project, will examine these options to conduct a Cost Benefit Analysis (CBA).

2 Background

2.1 Multilateral Environment Agreement (MEA) Obligations

The Stockholm Convention on Persistent Organic Pollutants became international law on 17 May 2004. New Zealand ratified in September 2004, and it entered into force for New Zealand on 23 December 2004. The Convention is an MEA that aims to protect human health and the environment from the effects of POPs. The Convention has a range of control measures to reduce and, where feasible, eliminate the release of POPs, including emissions of unintentionally produced POPs such as dioxins. The Convention also aims to ensure the sound management of stockpiles and wastes that contain POPs.

The POP-BDEs are listed on Annex A of the Convention which requires their use and production to be eliminated by Parties, subject to the exemptions allowed by the Convention. Since POP-BDE containing materials are still in use in some recycling flows and also in waste streams, the key requirements that Parties will need to satisfy are:

- Article 3 - to prohibit and eliminate the production, import, export and use of POP-BDEs except for laboratory scale research and reference samples, unintentional trace contaminants in products and articles or in pre-existing articles containing POP-BDEs; and
- Article 6 - Dispose of POP-BDE containing articles once they become waste in a way that leaves the POPs destroyed or irreversibly transformed or otherwise disposed of in an environmentally sound manner when destruction does not represent the environmentally preferable option.

The decision to list these POP-BDEs included specific exemptions which will expire at the latest in 2030, that together allow Parties to apply to recycle material containing POP-BDEs and use recycled materials containing these substances.

This exemption is qualified as follows:

> *The Party does not allow this exemption to lead to the export of articles containing levels/concentrations of tetrabromodiphenyl ether and pentabromodiphenyl ether (/ hexabromodiphenyl ether and heptabromodiphenyl) that exceed those permitted to be sold within the territory of the Party.*

Also, a decision of the 5th meeting of the Conference of the Parties to the Stockholm Convention, May 2011, recommended that:

> *Countries "in a position to do so" are called on to provide support for implementing the recommendations of the POPs Review Committee, including to establish and apply screening techniques, and to separate material containing BDEs to stop them being recycled* (United Nations Environment Programme 2011).

This intention to curb the re-emergence of POP-BDEs in future products made of recycled plastic, along with the fact that recycled plastic markets operate outside of New Zealand (and therefore require export) appear to be key factors in the Ministry's approach to managing its international obligations concerning these chemicals.

The listing also includes a general exemption that excludes articles having "low POP" contents from the scope of the convention, but a quantitative low POP content is yet to be defined (under Stockholm) for the newly listed POP-BDEs. However, a level of 1000ppm (0.1%) applies to e-waste in the EU, under the Restriction of Hazardous Substances Directive (RoHS Directive), with the same concentration used for e-waste in the USA and Korea. This figure has been used throughout this report as a reasonable practical limit for policy development purposes.

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, another MEA, first came into force in 1992. The Convention puts an onus on exporting countries to ensure that hazardous wastes are managed in an environmentally sound manner in the country of import. The Basel Convention places obligations on some 151 countries that are a party to it. These obligations are to:

- Minimise generation of hazardous waste;
- Ensure adequate disposal facilities are available;
- Control and reduce international movements of hazardous waste;
- Ensure environmentally sound management of wastes; and
- Prevent and punish illegal traffic.

The Basel Convention governs decisions about where and how wastes can be managed, if exported from (or imported into) New Zealand, which is of particular relevance to POP-BDEs, as they are commonly found in waste materials such as plastics that have a market value for recycled purposes.

In particular, the Basel Convention applies to wastes deemed to be hazardous due to the presence of "organohalogen compounds" at levels that "may present immediate or delayed adverse impacts to the environment by means of bioaccumulation and/or toxic effects upon biotic systems" (United Nations Environment Programme 1989). BFRs, PBDEs and POP-BDEs are all examples of organohalogen compounds.

2.2 Defining PBDEs on the Stockholm Convention

C-pentaBDE and c-octaBDE are not solely comprised of pentabrominated and octabrominated congeners, respectively, as suggested by their names. These names refer to an average number of bromine atoms.

Table 1 shows the typical PBDE homologue distribution in commercial POP-BDE products (La Guardia MJ 2006).

Table 1: Commercial mixtures listed on Annex A of the Stockholm Convention

Commercial Product	Congener % by weight						
	tetraBDEs	pentaBDEs	hexaBDEs	heptaBDEs	octaBDEs	nonaBDEs	decaBDEs
C-PentaBDE	24-38	50-60	4-8				
C-OctaBDE			10-12	44	31-35	10-11	<1

The overlap between the Stockholm listing as POPs and the commercial mixtures is not straightforward as the composition of the mixtures varied over time and with different manufacturers.

Under the Stockholm Convention the homologues “tetrabromodiphenyl ether and pentabromodiphenyl ether” were listed from c-pentaBDE[1]; and, “hexabromodiphenyl ether and heptabromodiphenyl ether” were listed from the c-octaBDE[2].

Therefore tetraBDE, pentaBDE, hexaBDE and heptaBDE are listed in Annex A of the Convention, and production and use has to be eliminated by Parties (subject to the exemptions allowed by the Convention). Accordingly, the term POP-BDE used in this report refers only to these ethers listed on the Stockholm Convention which are:

a) all tetra- and penta-bromodiphenyl ethers present in c-pentaBDE; and

b) all hexa- and hepta-bromodiphenyl ethers present in c-octaBDE.

Although octaBDE, nonaBDE and decaBDE ethers may be present in c-octaBDE they are not listed on the Convention; nor is a third commercial mixture, c-decaBDE, characterised by ethers with a high average number of bromines, listed on the Convention.

2.2.1 DecaBDE and the Stockholm Convention

While the production of commercial pentaBDE and octaBDE has stopped, the production of decaBDE continues. The potential impact of decaBDE is currently under review as there is some evidence that commercial decaBDE can degrade in thermal processes, environmental processes and in biota to lower brominated PBDEs, including POP-BDEs (United Nations Environment Programme 2010).

Norway has drafted a proposal to list commercial decaBDE on the Stockholm Convention, which is currently listed on the provisional agenda for the ninth meeting of the POPs Review Committee, to be held in Rome on14-18 October 2013. Should decaBDE be added to the Convention at some future time there will be major consequences for the e-waste recycling industry, as decaBDE use for flame retardancy in ABS plastics has historically been much more prevalent than octaBDE.

It is noted that decaBDE is now considered along with pentaBDE and octaBDE to be included in the definition of PBDE, and therefore regulated, under Europe’s RoHS Directive.

Although not a PBDE, another BFR known as HBCD (discussed in section 2.3 below), which has been historically used for flame retardancy in extruded and expanded polystyrene foams, has been listed on the Convention as recently as May 2013. At its 6th meeting, the Conference of the Parties to the Stockholm Convention adopted the decision to list hexabromocyclododecane (HBCD) to Annex A to the Convention with specific exemptions.

[1] With the main congeners 2,2', 4,4'- tetrabromodiphenyl ether (BDE-47 CAS No. 40088-47-9) and 2,2',4,4',5-pentabromodiphenyl ether (BDE-99 CAS No. 32534-81-9) and other tetra- and pentabromodiphenyl ethers present in commercial pentabromodiphenyl ether.

[2] With the main congeners 2,2',4,4',5,5'-hexabromodiphenyl ether (BDE-153, CAS No: 68631-49-2), 2,2',4,4',5,6'-hexabromodiphenyl ether (BDE-154, CAS No: 207122-15-4), 2,2',3,3',4,5',6-heptabromodiphenyl ether (BDE-175, CAS No: 446255-22-7), 2,2',3,4,4',5',6-heptabromodiphenyl ether (BDE-183, CAS No: 207122-16-5) and other hexa- and heptabromodiphenyl ethers

HBCD has not been used in ABS hard plastic housings of products like TVs and computers so, since it is not an issue of concern relevant to e-waste recycling, it has not been considered in this study.

2.3 The relationship between BFRs, PBDEs and POP-BDEs

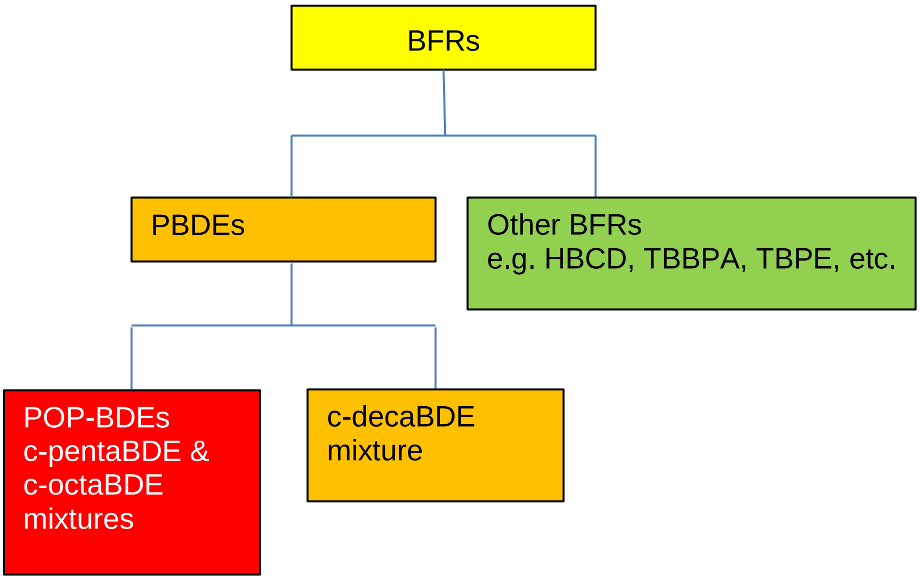

Figure 1: Hierarchy of brominated flame retardants of interest

The relationship between BFRs, PBDEs and POP-BDEs is described in hierarchical terms in Figure 1 above.

BFR is a generic term that describes chemicals used for their flame retarding properties which contain bromine atoms, which are responsible for these properties. PBDEs are one group of BFR chemicals, but there are as many as 70 (Mani 2011) types of BFRs that may have been used for flame retardancy, the most commonly encountered being hexabromocyclododecane (HBCD), tetrabromobisphenol A (TBBPA), 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE), decabromodiphenyl ethane (DBDPE) and 1,2-bistribromophenoyethane (TBPE).

PBDE describes a group of brominated chemicals with a common structural theme, as described in Section 2.2 above, of which two of the three historically used commercial mixtures are listed on the Stockholm Convention (c-pentaBDE and c-octaBDE) . The other PBDE mixture, c-decabromodiphenyl ether (decaBDE), is not listed on the Stockholm Convention because it is neither as toxic nor persistent as penta and octa, but it has the potential to be included on the Convention at some future point, as discussed in Section 2.2.1.

2.4 Relevant New Zealand Legislation

New Zealand is a signatory to a number of multilateral environmental agreements (MEAs). Of these, three MEAs place obligations on New Zealand's management of waste: The Stockholm Convention, the Basel Convention and the Convention to Ban the Importation into Forum Island Countries of Hazardous and Radioactive Wastes and to Control the Transboundary Movement and Management of Hazardous Wastes within the South Pacific region (the Waigani Convention).

The international requirements for these three MEAs are implemented domestically through the *Imports and Exports (Restrictions) Prohibition Order (No 2) 2004* (the Order). The Order was amended in August 2011 to reflect changes under the Stockholm Convention, including the addition of pentaBDE and octaBDE homologues onto Schedule 1. Further amendments have very recently been made, clarifying some of the definitions of waste and the movement of wastes between OECD countries. The *Imports and Exports (Restrictions) Prohibition Order (No 2) 2004 Amendment Order 2013* can be found at: http://www.legislation.govt.nz/regulation/public/2013/0315/latest/DLM5477601.html?search=ta_regulation_I_rc@rinf@rnif@raif_an@bn@rc_25_a&p=2.

To export wastes that contain BFRs, the exporter must obtain a permit from the EPA which can only be issued if the waste material will be processed in an environmentally sound manner at the destination facility. Under the Order, BFR-containing waste material that is likely to contain Stockholm-listed BDEs cannot be exported for reuse or recycling.

2.5 Other Hazardous Substances in e-waste

There are a number of other hazardous substances that may be present in e-waste such as mercury, lead, cadmium, beryllium, hexavalent chromium, antimony, polyvinyl chloride (PVC) and polychlorinated biphenyls. These are discussed in a report on the Ministry's website, titled *A Literature Review on the Environmental and Health Impacts of Waste Electrical and Electronic Equipment* (http://www.mfe.govt.nz/publications/waste/weee-literature-review-jun06/html/index.html).

In addition to issues associated BFRs in recycled plastics, these hazardous substances may have different environmentally sound management advice, may result restrictions on recycling and may also trigger the need for an export permit.

Specific handling and safety requirements for dealing with hazardous substances in e-waste are described in the recently released industry standard, *AS/NZS 5377:2013 Collection, storage, transport and treatment of end of life electrical and electronic equipment*.

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3 Methodology

The Pilot Study was conducted according to the following methodology.

3.1 Review BDE in articles data

Existing studies both published and unpublished were reviewed to obtain the most up to date understanding of measured BFR, PBDE and POP-BDE concentrations in WEEE articles. The studies reviewed included:

- Bentley, C. *Testing of Articles for Persistent Organic Pollutants (Draft).* Report for the Department of Sustainability, Environment, Water, Population and Communities, Brisbane: Entox Innovations (not yet published), 2013 (Bentley 2013);
- Latimer, G. *Reducing Releases of POP-BDEs to the Environment – Option Impact Analysis.* Report for the Department of Sustainability, Environment, Water, Population and Communities, Melbourne: KMH Environmental, 2013 (Latimer 2013);
- Furl, Chad, Callie Mathieu, and Tanya Roberts. *Evaluation of XRF as a Screening Tool for Metals and PBDEs in Children's Products and Consumer Goods.* Washington: Washington State Department of Ecology, 2012 (Furl, Mathieu and Roberts 2012);
- Sindiku, O, J O Babayemi, O Osibanjo, M Schlummer, M Schluep, and R Weber. *Assessing BFRs and POP-PBDEs in e-waste polymers in Nigeria.* University of Ibadan, Nigeria, 2012 (Sindiku, et al. 2012);
- Keet, Ben. *Pilot Study of Brominated Flame Retardants in Waste Electrical and Electronic Equipment (WEEE).* Report for the Ministry for the Environment, Havelock North, New Zealand: Geo & Hydru - K8 Ltd, 2011 (Keet 2011); and
- Keet, Ben, Nick Giera, R Gillett, and Karel Verschueren. *Investigation of Brominated Flame Retardants Present in Articles Being Used, Recycled and Disposed of in New Zealand.* Report for the Ministry for the Environment, Havelock North, New Zealand: Geo & Hydro - K8 Ltd, 2010 (Keet, Giera, et al. 2010).

This information was critical to giving useful direction to the Pilot's design, in particular to help determine:

- What articles (products, components and approx. age of manufacture) present the largest risk of POP-BDE concentration above 1,000ppm?
- What is the likely timeframe of retention of these articles in e-waste undergoing recycling in New Zealand? How long do we estimate POP-BDE articles to continue to present as e-waste at levels above 1,000ppm?
- What articles (products, components and approx. age of manufacture) present the smallest risk of POP-BDE concentration above 1,000ppm?
- What other scanning methods, such as visual identification of the low risk articles, could be employed by recyclers either in addition to or in place of XRF scanning?

This resulted in a targeted approach to XRF testing, used on specific items to fill key remaining knowledge gaps.

3.2 Consultation

The project team consulted with three major e-waste recycling companies with facilities throughout New Zealand:

- SIMS Recycling Solutions
- RCN Group
- RemarkIT Solutions.

These consultations involved site visits to each and extensive observations and article measurement on the factory floor, using a handheld X-Ray Fluorescence (XRF) analyser optimised for bromine detection.

Prior to the site visits, information about e-waste article types, volumes and processing approaches was sought.

Plastics New Zealand and Chinz Enterprises (a plastics broker and exporter) were also consulted to better understand the downstream markets for plastics recycled outside of New Zealand.

3.3 Target articles for testing

Based on information gained from 3.1 and 3.2 we gained a clearer idea of which items were most critical (in terms of the scanning/ sorting process) to reducing the greatest quantity of POP-BDEs from the plastics recycling stream. Knowing the highest priority items also helped inform the choice of scanning and sorting options.

3.4 Conduct site work

Preliminary site visits were conducted respectively at RemarkIT Solutions (Wellington) on 28/5/13, SIMS Recycling Solutions (Auckland) on 29/5/13 and RCN Group (Auckland) on 29/5/13. These visits focused on safety induction requirements, observing and understanding the dismantling/ recycling processes on the factory floor, as well as listening to the recyclers' views on current issues, expectations of the project, possible solutions and key drivers for the future direction of e-waste recycling in New Zealand.

Based on waste article volume information previously submitted by the recyclers, SIMS and RCN were chosen as appropriate sites to conduct the detailed XRF measurement studies to ensure good coverage of the priority article types. Subsequently over 120 individual bromine measurements were taken across 30/5/13 and 31/5/13, at both SIMS and RCN, covering e-waste such as TVs, computers & peripherals, printers, photocopiers, white goods and toner cartridges. These articles had previously been identified as reflective of the vast majority of waste processed by the three recyclers.

Meta data for each tested article was collected wherever possible, including brand, model number, product manufacturing date, country of manufacture, component part, plastic colour. Data not available from inspection of the item was determined where possible from follow up desktop research. An identification number was assigned to each article tested and each item was photographed with this number clearly shown.

3.5 Compile and analyse data

XRF test and meta data was compiled and analysed for indications of commonality and trends in respect to BFR and non-BFR articles, using the RoHS Directive's 1000ppm (0.1%) cut-off.

A number of conclusions were drawn from the data obtained, with further hypotheses identified that could be verified with the results of a further round of destructive testing, focusing on laboratory analysis for the specific PBDEs and other target BFRs.

3.6 Destructive testing for individual BFRs

Fifteen samples of plastic components (approximately 200g each) of WEEE articles were removed from both SIMS and RCN and stored for later testing for the following:

- PBDEs (particularly commercial octaBDE and decaBDE congeners)
- TBBPA and
- Qualitative scans to identify the presence of BTBPE and DBDPE.

All samples were screened as being high in bromine (all >3% Br and typically >10%). The purpose of this testing was to confirm the contributing brominated species giving rise to the high XRF screening results.

3.7 Options Identification, Reporting & Recommendations

A series of risk-based decision tables were produced for each article type to assist in identifying simple techniques that could potentially be used by recyclers to sort, segregate and further manage e-waste plastic components appropriately, to ensure New Zealand's international treaty obligations are met.

This report was compiled with key outputs of a confirmed set of feasible options for consideration in the cost benefit analysis, as well as recommendations for the future of e-waste plastic management in New Zealand.

4 Pilot Results

The outcomes of the pilot are discussed in the sub-sections below relating to:

- Observations about dismantling practices and supplied data from visits to the recycling facilities;
- Feedback from discussions with recyclers;
- The results of onsite testing of WEEE articles for bromine (Br), using a handheld XRF scanner and some analysis of these results by WEEE type; and
- The results of follow up laboratory testing on 15 WEEE samples identified by XRF as high in Br.

4.1 WEEE Recycling Facility Visits

Throughout the week of 27-31 June 2013, Geoff Latimer and Ben Keet visited the following recycling company operations in New Zealand:

- SIMS Recycling Solutions, Airport Oaks, Auckland
- RCN Group, Silverdale, Auckland
- RemarkIT Solutions, Grenada North, Wellington.

Both RemarkIT and RCN sites across New Zealand collect TVs under the Ministry for the Environment's TV TakeBack Programme, an initiative that involves the Government partnering with recyclers, waste producers and councils to help recycle more household TVs. This program is rolled out on a regional basis and the two regions concluded to date (Hawke's Bay/ West Coast and rest of South Island) have netted over 100,000 TVs.

SIMS will also join the scheme as a recycling partner when it rolls out in the remainder of the north island in the second half of 2013.

Item reuse where appropriate, plus article dismantling, sorting, separating and on-selling components of value were common practices across all three operators. However, the business priorities and processing techniques were observed to vary to some extent at each facility visited, as did the relative volumes of individual WEEE article types received.

Annual data provided from the three recyclers is summarised in Table 2 below, indicating the typical relative contributions of WEEE article types by weight presenting at recycling operations across New Zealand. This data indicates that the priority items by weight processed by the major New Zealand e-waste recycling facilities in 2012-13 were:

1. TVs (36%)
2. Business machines (photocopiers/ printers/ scanners/ faxes) (22%)
3. Computers & Peripherals (20%) and
4. White-ware (15%).

Table 2: Annual Weight of WEEE Articles collected from three major recyclers in New Zealand 2012/13[1].

WEEE Item	kg per year	% of Total
Desktop	205,677	9
Server	35,970	2
Laptop	49,470	2
Monitor	158,384	7
TV	833,296	36
Printer/copier/etc.	501,415	22
White-ware	360,000	15
Computer peripherals	8,000	0.3
Not specified	178,588	8

Notes:
[1] 12 months to April 2013

The ‘not specified’ category is likely to be dominated by white ware from one recycler, whose data was supplied without a breakdown of this category. Where the data was supplied in sufficient detail, there were no significant quantities (above 1,000 kg per annum) of the following items reported as received:

- VCRs, CD/DVD players
- Heaters (oil or fan)
- Hair dryers

Further discussion with each recycler revealed the following common themes:

- CRT monitors are a very small contributor to overall WEEE received – one recycler’s detailed data breakdown showed that more than 90% of all computer monitors received over the past 12 months were LCDs. Anecdotally, CRT monitors were described as “rarely received”.
- All recyclers indicated that since the majority of computer-related waste was from corporate change-out contracts, these items were typically <5 years old when received as WEEE.
- Similarly, business machines and fridges were received under contract from major suppliers, so item models tended to be homogeneous and relatively new, typically <5 years old.
- Under the TV TakeBack programme, recyclers are segregating and storing the ABS plastic components from CRT TVs or if storage capacity reaches its limit sending them to Class A landfill, as required by the Ministry, since they have no other information to indicate that POP-BDEs are not present in these items
- The issue of BFRs, PBDEs and POP-BDEs potentially in WEEE is a confusing issue for recyclers to understand how they should be compliant with Government requirements.

As part of a recycling program, the issue of sending some plastics to landfill left some staff perplexed as to the value of what they were doing and was universally recognised by management of these companies as difficult to explain to staff and stakeholders alike.

- Outside of the TV TakeBack programme, only low volumes of TVs have been received by recyclers.
- The three recyclers dealt directly with broker organisations in trading component parts of value from WEEE, who then sold bulked up commodity materials to recyclers overseas, typically in Asia.
- Recyclers confirmed that Items such as CD/VCR/DVD players, heaters, hair dryers and microwave ovens were rarely encountered. The authors observed none of these items during their inspections at each of the three recycler sites.

4.1.1 Onsite Sorting & Dismantling Processes

Each of the three facilities visited had slightly different approaches to how they processed and dismantled incoming WEEE. This was often a result of slightly different businesses built around a different mix of contributing WEEE items, as well as different requirements for how separated commodity components are provided to end customers.

However, the following process was common to all:

- The contents of shipments of incoming WEEE are recorded in detail, secured and stored in an organised fashion on pallets.
- Any items with potential for reuse or refurbishment and reuse are identified and separated.
- Items are manually dismantled on stations of work benches, following detailed procedures specific to each type of WEEE, to ensure the level of sub-components are separated to provide the maximum value to the broker/ customer. For example, a dismantled TV is typically separated into over a dozen component parts of different value for different downstream processors.
- Separated sub-components are placed in separate bins or bulker bags
- Under the TV TakeBack programme, TV sub-components are separately weighed and recorded.

4.2 XRF Testing for Bromine

More than 120 individual bromine measurements were taken across both SIMS and RCN sites in Auckland, encompassing 63 e-waste item samples such as TVs, computers & peripherals, printers, photocopiers, white goods and toner cartridges.

Meta data for each tested article was also collected wherever possible, including brand, model number, product manufacturing date, country of manufacture, component part and plastic colour. Data not available from inspection of the item was determined where possible from follow up desktop research. An identification number was assigned to each article tested and each item was photographed with this number clearly shown.

The results are provided in Appendix A.

For the purposes of data analysis, 'BFR-free' is defined by a Br result of <0.1% (RoHS Directive limit for PBDEs in new products imported into Europe). Similarly, PBDE-free or POP-BDE-free are defined by levels of these respective species below 0.1%.

XRF measurements were used as a first stage scanning technique to identify levels of Br that could be associated with BFRs, but not necessarily PBDEs or POP-BDEs. If results were <0.1%, it could be concluded that POP-BDEs, if present at all, would also be 0.1%, since the sum of all BFRs was <0.1% (BFR-free). Such samples require no further testing for a definitive classification of the presence of POP-BDEs.

If, on the other hand, results of >0.1% Br were observed by XRF, this indicates the sample is not BFR-free, but the result is inconclusive with respect to whether the sample is POP-BDE-free, and must be subject to laboratory analysis for the individual chemical species (section 4.4) to make this determination.

4.2.1 General Observations

Of the 125 measurements taken, 71 results were <0.1% Br and 54 results were >0.1% Br. However on closer inspection, we find that:

- 64 of the 71 <0.1% Br measurements were also <0.02% Br and
- 43 of the 54 >0.1% Br measurements were also >10% Br

In other words, 90% of the low BFR samples were well below the RoHS limit, and 80% of the high BFR samples were very high; in the range that you would expect if BFRs had been added for their flame retardancy (typically 5-15%).

107 of the 125 measurements (86%) are either very high in BFR or very low in BFR. The 18 samples in between (>0.02% but <10%) were weighted to the lower end of the range, with the average not far above the RoHS limit at 0.15%.

These high level observations suggest there are three types of plastics found in WEEE in New Zealand:

1. *High BFR*, deliberately added for flame retardancy at levels greater than 10% Br;
2. *BFR-free*, with no significant levels of any BFRs present; and
3. *Mid-level BFR* – the average sample result of 0.15% Br is insufficient to effect any flame retardancy so this group of plastics contained unintentional BFRs, contaminated from previously high BFR plastics used as recyclate in the formulation of new products.

There was no overall correlation between the presence of BFRs and meta-data identifiers such as brand, country of manufacture or plastic colour. Year of manufacture alone did not guarantee an outcome of either high or low BFR. However, as noted in the discussion under individual WEEE types, year of manufacture is the single most helpful piece of information when determining the likely POP-BDE levels in particular equipment types.

Interestingly, there was a significant number of pre-2005 items that were low- BFR (and therefore low-POP-BDE) – for example 15 out of 25 pre-2005 TV plastic samples were <0.1% Br. This indicates that while a blanket assumption that pre-2005 items (such as TVs) are likely to contain octaBDE might be a reasonable course of action from a risk management perspective, it is likely to be very conservative.

On the other hand, 12 out of 18 samples from post-2005 TVs were >>0.1% Br, which suggests some type of BFRs are still being used in relatively new products for flame retardancy purposes. These types of samples were isolated for laboratory testing (see section 4.3).

4.2.1.1 Locating Year of Manufacture

Year of manufacture was sometimes obtained directly from manufacturer data found on the item itself, typically a name plate at the rear of the item alongside other information such as serial number, model name/ number and country of manufacture. This information was more reliably found for computer equipment than TVs, copiers and white goods. However, a model number was almost always identified on the item, which was then used for desktop searching for documents such as equipment manuals, which were usually helpful in either accurately determining or estimating year of manufacture.

Figure 2: Back plate showing Year of Manufacture
(Source: Sample "7" Dell Desktop PC)

4.2.2 Equipment-specific Observations

The following sub-sections discuss the XRF scanner results for Br (and therefore BFRs) only. A subsequent discussion of more detailed BFRs, such as the POP-BDEs, is given in section 4.4.

4.2.2.1 TVs

(a) CRT TVs

XRF measurements were taken on 10 individual CRT TVs manufactured in the late 1980s and 1990s, 2 CRT TVs manufactured in 2004 and 2005 respectively, and one rear projection set manufactured in 2003. Measurements were taken on both the plastic rim piece wrapping around the CRT screen and the separate back casing plastic.

Eight out of 10 1980-2000 CRT TVs contained <0.01% Br in the rim plastic, whereas 6 out of 10 1980-2000 CRT TVs contained >0.1% Br in the back cover plastic piece.

The 2004 and 2005 CRT TVs tested contained >10% Br in both rim and back cover components and one of these was retained for laboratory testing (see section 4.4).

The rear projection TV contained <0.02% Br in both the rim and back components.

Regardless of laboratory testing, the XRF data from this study suggests that sending the rim component of older CRT TVs to landfill is probably unnecessary, as the risk of POP-BDEs being present at levels >0.1% on balance of a shipment batch is low.

The types of BFRs in the back cover pieces are investigated further in the laboratory testing section (4.3.2) and the data analysis section on TVs (5.1.1).

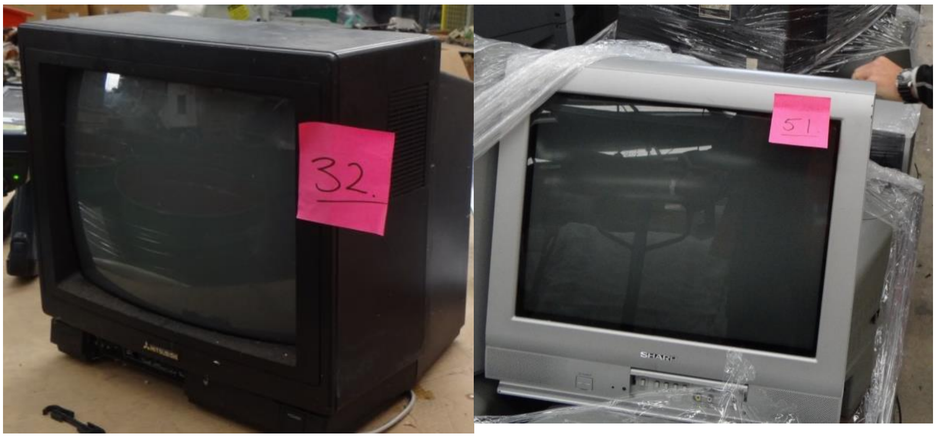

Figure 3: Example CRT TVs Tested: 1990 model (left) and 2004 model (right)

(b) LCD TVs

Eight LCD TVs were tested for Br by XRF, with dates of manufacture ranging from 2005-2012. Like CRTs, the rim and back pieces were tested.

In all but one sample, rims were lower Br than back covers. Four out of 8 rim pieces were tested to be <0.01%, but the other 4 were >10% Br, making broader conclusions impossible. However 6 of the 8 back pieces were >1% Br, with the other two at 0.09%, only marginally below RoHS limit value.

The types of BFRs in LCD TVs are investigated further in the laboratory testing section (4.3.2) and the data analysis section on TVs (5.1.1).

Note that Plasma TVs were observed to be encased in metal covers with limited plastic components so did not pose a significant risk BFR or POP-BDE risk. Consequently none were tested for Br by XRF.

4.2.2.2 Printers/ Copiers/ Scanners/ Faxes

(a) Business Machines

Three late model business machines were tested by XRF, with dates of manufacture 2008, 2009 and 2010 respectively. These were indicative of the batches of machines on the factory floor. A range of plastics from exterior pieces and internal components were tested and the results ranged from <0.001% Br to >10% Br, with no observable pattern as to which components were low and which were high.

From a BFR point of view, these results indicate the risk of business machine components being >0.1% is high.

Figure 4: Example business machine tested

(b) Home/ Small Office Machines

Fourteen samples various types of small business/ home machines such as inkjet printers, laser printers, small copiers and faxes were tested by XRF. Ten of the 14 were <0.01% Br, two were between 0.01% and 0.5% and two were >10% Br.

In terms of age of the items, the two samples above 10% were both manufactured before 1995, the two 0.01 – 0.5% samples were late 1990s models and the remaining 10 BFR-free samples were manufactured between 1998 and 2006.

4.2.2.3 Computer Equipment

(a) CRT Monitors

Only two CRT monitors were found to test across the two sites. Both were early 2000s manufactured and both gave Br results >0.1%.

(b) LCD Monitors

Six LCD monitors were located to test. One sample tested >1% and the remaining five samples were <0.1% Br. The high result was from a 2000 manufactured product.

These results indicate that the risk of LCD monitor casings and rims testing >0.1% Br is low, so they are similarly likely to be POP-BDE free.

(c) Desktop PCs

Only two desktop PCs were tested, one manufactured in 2001 and the other 2005. Both were <0.001% Br, although the older item's CD, DVD and floppy drives were all >10% Br.

While only a single sample was found to test, a number of internal component plastics of an Apple PowerMac G5 computer were >10% Br, although the casing plastic was <0.01% Br.

(d) Laptops

Three laptops of ages 1998, 2007 and 2012 were all <0.1% Br and therefore BFR and POP-BDE free.

(e) Other Peripherals

Five other peripheral devices (three modems, a keyboard and a projector), ranging in age from 2005 – 2011, were all <0.1% Br and therefore BFR and POP-BDE free.

4.2.2.4 White-Ware

Three recently manufactured fridges (2009 and newer) showed all component plastics to be <0.1% Br, except for a small plastic piece on the back of the units, used to cover the electrical wiring, which was >10% Br. This electrical cover is shown in Figure 5.

Fridges are usually received by recyclers as part of commercial contracts with suppliers (demonstration stock, returns, faulty items, etc.) and as a consequence are typically late model items.

These results indicate that fridges are BFR and POP-BDE free, although their electrical cover pieces are high in BFRs.

Figure 5: Electrical cover on rear of fridge

4.2.2.5 Other WEEE

Approximately 20 toner cartridges from business machines were tested and all but one returned an XRF result of <0.001% Br. A single sample (Figure 6) was >1% Br.

These results indicate that toner cartridges are likely to be BFR and POP-BDE free.

No items of potential interest such as microwave ovens, fan heaters, hair dryers, VCRs and DVD/CD players were found during site testing.

Figure 6: The single high BFR toner cartridge

Figure 7: Variety of toner cartridges tested

4.3 Destructive Laboratory Testing

4.3.1 Analytical Method

As part of the Pilot program undertaken at the three chosen NZ Recycler facilities, fifteen plastic samples were taken from WEEE components measured by XRF to be above 10% Br. These samples were shipped to Institute for Environmental Studies, VU University Amsterdam, The Netherlands, for analysis.

Each of the 15 plastic samples was homogenized and ground to fine particles and extracted in organic solvent, using ultrasound to aid dissolution where necessary. Clean-up was performed using silica columns. The purified extracts were analysed by gas chromatography (GC) with electron capture negative ionization technique and mass spectrometry detection (GC/ENCI-MS) for PBDEs and TBBP-A using a 50 and 15 meter GC column and measuring the specific bromine m/z 79, 81, 484, 486, 544 and 542, as described by De Boer et al (Brandsma, et al. 2012), (Lopez, et al. 2011). Internal standards (BDE58, 13C BDE209, and 13C TBBP-A) were added to all samples. Blank and reference sample (poly (ethyleneterephthalate) (PET), containing BDE47, BDE99, BDE183 and BDE209, were measured as quality control.

4.3.2 Results

Results for PBDE congeners relevant to pentaBDE, octaBDE and decaBDE, plus TBBPA are shown expressed as µg/g (ppm) in Table 3 below. Two other BFRs commonly used as alternatives to PBDEs, 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE) and decabromodiphenyl ethane (DBDPE), were also detected (though not quantified) in 7 samples, as designated by “XX” in Table 3.

Although XRF Scanning determined all samples to be very high in Br, no pentaBDE (main congeners BDE47, BDE99) or octaBDE (main congeners BDE 153, BDE 183, BDE196, BDE197[3]) were detected.

DecaBDE (main congener BDE209) was detected in two samples, a 2000 CRT computer monitor (2.05%) and a 1990 CRT TV (6.02%).

TBBPA was detected in two samples, a 1990 CRT TV (8.30%) and a 2007 LCD TV (15.9%).

BTBPE was found to be present in one sample, a 1989 home office photocopier, while DBDPE was qualitatively detected in 6 samples as follows:

- The small electrical cover from a recent model fridge;
- A 2010 LCD TV (both back and rim samples);
- A 2006 LCD TV;
- The lone Br positive toner cartridge sample; and
- A 2004 CRT TV.

Five samples (3 printer/ copiers and 2 CRT TVs) showed no detectable results for the BFRs tested, which indicates that BFRs different to the suite tested for were probably added for flame retardancy in these instances. This illustrates the variety of BFRs that have historically have been applied, as mentioned in Section 2.3.

Table 3: Laboratory analysis of individual BFRs in plastic WEEE samples

Sample number	12	14	16	17	24	28	32B	37	41	47B	47Fr	48B	50	51Fr	51B
Equipment type (µg/g)	copier	laser printer	printer/ copier	printer/ copier	CRT monitor	Fridge – elec cover	CRT TV - portable	CRT TV	LCD TV	LCD TV	LCD TV	LCD TV	Toner cartridge	CRT TV	CRT TV
BDE28	<10	<10	<10	<10	<10	<10	<9	<10	<10	<9	<10	<10	<10	<9	<10
BDE49	<10	<10	<9	<10	<10	<10	<9	<10	<10	<9	<10	<9	<10	<8	<10
BDE71	<10	<10	<10	<10	<10	<10	<9	<10	<10	<9	<10	<10	<10	<9	<10
BDE47	<10	<10	<9	<10	<10	<9	<8	<10	<10	<8	<9	<9	<9	<8	<10
BDE66	<10	<10	<10	<10	<10	<10	<9	<10	<10	<9	<10	<10	<10	9	<10
BDE77	<9	<8	<7	<8	<9	<8	<7	<9	<8	<7	<8	<7	<8	<7	<8
BDE100	<8	<7	<6	<7	<8	<7	<6	<8	<7	<6	<7	<6	<7	<6	<7
BDE119	<9	<8	<7	<8	<9	<8	<7	<8	<8	<7	<8	<7	<8	<6	<8
BDE99	<8	<8	<7	<8	<9	<7	<6	<8	<8	<6	<7	<7	<7	<6	<8
BDE85	<7	<7	<6	<7	<7	<6	<5	<7	<7	<5	<6	<6	<6	<5	<6
BDE126	<8	<7	<6	<7	<8	<6	<6	<7	<7	<6	<7	<6	<7	<6	<7
BDE154	<10	<10	<10	<10	<10	<10	<9	<10	<10	<9	<10	<10	<10	<9	<10
BDE153	<9	<8	<7	<8	<9	<7	<7	<8	<8	<7	<8	<7	<8	<6	<8
BDE138	<7	<6	<6	<6	<7	<6	<5	<6	<6	<5	<6	<5	<6	<5	<6
BDE156	<20	<10	<10	<10	<20	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
BDE184	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
BDE183	<20	<20	<10	<20	<20	<20	<10	<20	<20	<10	<20	<10	<20	<10	<20
BDE191	<30	<30	<20	<30	<30	<30	<20	<30	<30	<20	<30	<20	<30	<20	<30
BDE197	<50	<50	<40	<50	<60	<50	<40	<50	<50	<40	<50	<40	<50	<40	<50
BDE196	<50	<50	<40	<50	<60	<50	<50	<50	<50	<50	<50	<50	<50	<40	<50
BDE209	<60	<60	<50	<60	**20500**	<50	<50	**60200**	<60	<50	<50	<50	<50	<50	<50
TBBPA	<40	<30	<30	<30	<40	<30	<30	**83000**	**159000**	<30	<30	<30	<30	<30	<30
BTBPE	**XX**														
DBDPE						**XX**				**XX**	**XX**	**XX**	**XX**		**XX**

5 Data Analysis

This section takes the results and observations of Section 4 and provides analysis and a concise interpretation in terms of:

- Risk-based Decision Tables for each WEEE type;
- Supporting evidence for the positions taken in these tables;
- Recommended Scanning and Sorting Actions arising; and
- An extrapolation of these findings across current and anticipated future volumes of WEEE entering the New Zealand recycling market.

5.1 Findings by WEEE Item

Using the combined results of XRF scanning for Br (and therefore BFRs) with the destructive laboratory analysis data for the PBDEs and other speciated BFRs, risk-based decision tables have been developed for use by recyclers as a 'ready reckoner' approach to rapid, visual-based decisions on how to sort and segregate particular items of WEEE.

A decision table has been produced for each WEEE category (and sub-category) below, with a summary of supporting evidence behind the sorting decisions.

Accompanying actions required to implement these Decision Tables are then discussed, along with a brief commentary on practical scanning and sorting implications.

While the Decision Table headings are self-explanatory in the main, "Likely to be OK to recycle in future?" requires some explanation. As discussed in Section 2.2, decaBDE is currently under review for potential future inclusion on the Stockholm Convention. While this chemical may not ultimately make it onto the Convention, due to question marks over the rate of possible debromination and persistence (Rae 2011), the fact that it is already regulated by the RoHS Directive and has been actively phased out by some EEE manufacturers suggests it is a strong candidate for inclusion.

Consequently, the "Likely to be OK to recycle in future?" heading in each Decision Table is shorthand for is *likely to be decaBDE free?*

5.1.1 TVs

5.1.1.1 Supporting Evidence

(a) Literature reported PBDE levels in TVs

OctaBDE has been routinely reported in the literature as having been historically added to acrylonitrile butadiene styrene (ABS) polymers for the casing of EEE at concentrations between 10-18 % by weight (Consortium ESWI (Expert Team to Support Waste Implementation) 2011).

However, one recent and extensive study involving laboratory analysis of CRT TV plastics has shown the presence of octaBDE to be rare in comparison with decaBDE and TBBPA:

- Sindiku, et al. (2012) found only 5 out of 159 samples of CRT TVs manufactured from 1981-2004 contained levels of octaBDE above 0.1%.
    - Three of these 5 were found at levels used for flame retardancy (>5%) and the other two at 0.10% and 0.66%, which indicates unintentional contamination of recyclate.
    - This equates to 97% of all samples below the RoHS limit of 0.1%.
    - However, as an indication of the impact of a small number of high percentage level BFR plastics can have, the average concentration calculated across the entire 159 TVs tested was 0.69%, which is above the 0.1% RoHS limit.
    - Importantly, all 5 high octaBDE CRT TV samples identified were manufactured prior to 1990 (Only one of the 13 CRT TVs measured in the current Pilot study was manufactured prior to 1990.)
    - In addition, 4 out of these 5 high results came from European manufactured items, with the fifth (Chinese manufactured) item only measuring 0.1% octaBDE, right on the RoHS limit.
    - (None of the 13 CRT TVs measured in the current Pilot study were identified as having been manufactured in Europe.)
    - 61 out of these 159 samples contained some form of BFR, such as decaBDE, TBPE and TBBPA.

Keet, Giera, et al. (2010) analysed 16 plastic samples from a variety of article types, including one TV back cover. Only two of the 16 samples contained >0.01% octaBDE, including the TV back cover (0.13%) and an electrical power board (0.02%), but in both cases there was also decaBDE present at concentrations which dwarfed the respective octaBDE result by 100-200 times. This suggests that the octaBDE present was due to unintended recyclate contamination.

Wäger, Schluep and Muller (2010) analysed 7 CRT TVs for PBDEs and related BFRs, and found that, while two of the CRT TVs contained octaBDE above 0.1% (0.10% and 0.35%), these levels were indicative of contaminated recyclate and the average of the batch of seven samples was below the RoHS limit. All 7 samples were >0.1% in decaBDE. This study also undertook a detailed review of PBDE measurement surveys carried out in Europe from 1999-2009 and came to the conclusion that the number of residual articles still containing POP-BDEs has now dropped to low levels in Europe.

Furl, Mathieu and Roberts (2012) used XRF screening of WEEE for Br, followed by laboratory testing of the high Br samples. While this study found only one out of 12 samples of 1989 – 2006 CRT TVs contained PBDEs above 0.1%, the PBDEs analysed were pentaBDE and decaBDE congeners and did <u>not</u> include the primary congeners of octaBDE (BDE 183, BDE196 and BDE197).

Bentley's (2013) study of a large variety of new products found 11 out of 12 brand new LCD TVs had octaBDE levels below 0.1%, with the 12th sample measuring right on the RoHS limit at 0.10%. However, 6 of these 12 LCD TVs contained decaBDE above 0.10% and all 12 contained high levels of some type of BFR.

(b) Laboratory PDBE test data (from Section 4.3)

Laboratory results obtained as part of this Pilot study, as listed in Table 3, showed that none of the 15 high Br samples, including four CRT TV samples, contained any POP-BDEs. Of these four CRT samples:

- two contained no detectable BDEs/ BFRs (penta, octa, decaBDE, TBBPA, BTBPE and DBDPE all below detection limits);
- one contained decaBDE and TBBPA at >5% (1994 model); and
- one contained DBDPE (2004 model).

Four LCD plastic samples gave the following results:

- All had no detectable PBDEs (penta, octa and decaBDE all below detection limits)
- One sample (2007 model) contained 16% TBBPA); and
- Three samples contained DBDPE.

(c) End of Life WEEE soon to be POP-BDE free

Within a short space of time – possibly as little as 2 years - not just TVs but all WEEE presenting at recycling facilities in New Zealand is likely to be effectively POP-BDE free.

Latimer (2013) conducted a Material Flow Study which quantified historical article and PBDE flows in Australia throughout their lifecycle and identified potential environmental impact points. This study determined that all articles likely to contain either pentaBDE or octaBDE will have become waste in Australia by 2015, at the end of their useful lives, as shown for octaBDE in Figure 8.

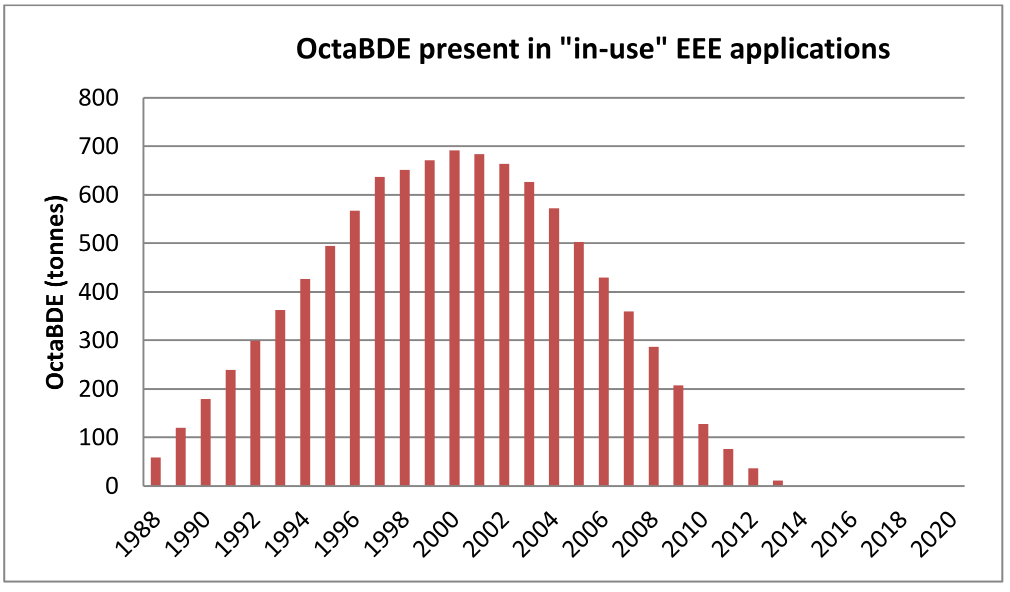

Figure 8: Graph showing octaBDE in use for EEE applications
(Source: **(Latimer 2013)**)

This study relied upon rigorous import data for articles expected to contain pentaBDE and octaBDE, obtained from the Australian Bureau of Statistics (ABS) for the period 1988 to

2011. The data included import codes for each article category, number of items, weight of items, year of import and country of origin. It also drew on an average useful life of an article before disposal - deemed to be 12 years for vehicles and upholstered furniture and 10 years for electrical and electronic items.

Findings from a 2012 global survey (NPD Display Search 2012) of TV replacement practices across more than 14,000 respondents in 14 countries indicate that, over the past year, the TV replacement cycle decreased on a global scale, from 8.4 to 6.9 years. The study found a variety of reasons for this trend, including declining prices, a wider variety of sizes, and desire for the latest technologies.

The TV TakeBack Programme combined with the imminent digital switchover (all of New Zealand by end 2013) would be expected to create a spike in household disposal of TVs greater than 10 years old, due to the inclination for people to retain old items in garages, attics and other storage.

While older items will continue to present at recycling facilities beyond TV TakeBack, it is reasonable to assume that beyond the programme's life (2014), the majority of end of life televisions in New Zealand are likely to be 10 years old or newer, and are therefore likely to be POP-BDE free.

(d) Summary of Evidence

Literature

Historical literature describes high levels of octaBDE use in TV ABS plastics, prior to its phase out in the mid-2000s, depending on the product's requirement for flame retardancy. While a sizeable number of PBDE measurement studies conducted on environmental and biological samples is present in the literature, up until very recently there has been limited information regarding actual measurements of PBDEs in WEEE plastics.

The recent studies that do exist, i.e., Sindiku, et al. (2012) (158 CRT TVs), Wäger, Schluep and Muller (2010) (7 CRT TVs) and this Pilot study (13 CRT TVs), have found limited evidence of POP-BDE above 0.1%, despite expectations to the contrary. However, the fact that all 4 of Sindiku et al's (2012) study samples above 0.1% octaBDE were pre-1990 European manufactured items, and two out of 7 (European models) tested by Wäger, Schluep and Muller (2010) were a little over 0.1% octaBDE, these factors of regional origin and age of item are worth factoring into a risk based decision matrix.

New product testing by Bentley (2013) indicates that LCD TVs are very unlikely to be contain POP-BDEs, but highly likely to contain decaBDE (PBDEs) and non-POP-BDE BFRs such as TBBPA, BTBPE and DBDPE.

Pilot

Out of 13 CRT TVs tested for Br in this Pilot (rim and back cover pieces separately), 11 rim pieces were also tested for POP-BDEs. Eleven out of these 11 CRT rim samples showed POP-BDEs below 0.10%. In terms of the remaining 2 high Br rim samples, evidence from laboratory testing of samples of similar age to these suggest they are likely to contain non-POP-BDE retardants such as decaBDE, TBBPA or DBDPE.

In terms of CRT TV rim samples taken from CRT TVs aged 1980 – 1999, 8 out of 10 were BFR free, and 8 out of 9 were measured to be decaBDE free, with one sample returning a positive result of 6.02%.

Data gained for the CRT rim pieces from 3 post-2000 items tested indicate that BFRs are likely to be present, but not POP-BDEs and probably not decaBDE.

For CRT back pieces, 8 out of 8 samples tested for POP-BDEs returned results <0.1%. The other 5 high BFR samples are likely not to be due to POP-BDEs, since the three laboratory back samples (all PBDE negative) were chosen from models/ dates that represent them. This evidence suggests that back cover plastics on CRT TVs have a low risk of containing POP-BDEs. Post-2000 models offer even more confidence in this regard than pre-2000 models, due to the latter's proximity to the widespread POP-BDE manufacturing phase out period.

LCD TVs tested in this Pilot showed no evidence of POP-BDEs, some evidence of decaBDE (PBDEs) and routine evidence of non-POP-BDE BFRs such as TBBPA, BTBPE and DBDPE.

Summary

CRT TVs received by recyclers in New Zealand are unlikely to contain POP-BDEs, with the exception of CRT TVs manufactured in Europe prior to 1990, which on the basis of literature data is assumed to potentially contain POP-BDEs. In making this decision, the authors recognise that the vast majority of CRT TVs processed by the recycling industry in New Zealand have been manufactured in Asia and have been manufactured after 1990.

Although further measurement study is recommended, on the basis of the information gained in this study, CRT rim pieces manufactured prior to 2000 (not fitting the pre-1990 European made criteria) are also likely to be BFR and decaBDE (PBDE) free. CRT backs typically contain BFRs and pre-2000 models may contain decaBDE.

LCD TVs are very unlikely to be contain POP-BDEs, but highly likely to contain decaBDE (PBDEs) and non-POP-BDE BFRs such as TBBPA, BTBPE and DBDPE.

5.1.1.2 Recommended Scanning and Sorting Action

TVs encountered in the New Zealand WEEE recycling market are recommended to be managed according to Table 4, a risk-based decision table developed from the evidence above.

Orange boxes indicate a recommendation that is likely but could be strengthened with additional test data.

Should different management actions accrue from different ranges of date of manufacture, and the age of a particular model cannot be established, the more conservative management action should be followed.

Table 4: TV Decision Table

WEEE Category	TVs*						
Equipment Type	CRT**					LCD	
Date of manufacture	European manufactured pre-1990***	Pre-2000		Post-2000		-	-
Plastic component	All	rim	back cover	rim	back cover	rim	back cover
BFR free[1]?	N	Y	N	N	N	N	N
PBDE free[2]?	N	Y	N	Y	Y	N	N
POP-BDE free[3]?	N	Y	Y	Y	Y	Y	Y
Class A landfill?	Y	N	N	N	N	N	N
Currently OK to recycle (Stockholm compliant)?	N	Y	Y	Y	Y	Y	Y
Likely to be OK to recycle in future[4]?	N	Y	N	Y	Y	N	N
Requires a Basel permit?	Y	N	Y	Y	Y	Y	Y

Notes:

* Plasmas not included due to low plastic content - bodies almost always metal

** includes rear projection TVs

*** Applies to CRT TVs manufactured both before 1990 AND in Europe only

[1] - likely to be <0.1% BFRs

[2] - likely to be <0.1% PBDEs (includes c-penta, c-octa and c-deca mixtures)

[3] - likely to be <0.1% POP-BDEs (includes c-penta and c-octa)

[4] - In the event that decaBDE is added to the Stockholm Convention in the future

Legend: Y = Yes, N = No

ORANGE: likely but further sampling is recommended.

5.1.2 Copiers/ Printers

5.1.2.1 Supporting Evidence

Business machines are typically recycled in New Zealand under contract from major brands, and are usually relatively recently manufactured (post-2005). Ages newer than 2005 were confirmed for most of the items available on the factory floor, via records such as service history logbooks that were observed to be attached to most of the items.

Three units underwent XRF scanning, including several plastic component parts present within and inside the body of each machine. These three units were either identical to, or indicative of, the remaining 20 or so items on the factory floor.

As was previously found by Keet (2010 and 2011), Br levels varied from >10% to <0.01% for different component parts tested within the same machine, even though the appearance of the component plastics was similar. However, testing of those components high in Br showed that no POP-BDEs, decaBDE, TBBPA, BTBPE or DBDPE were present above detectable levels.

The combination of test results (showing no detectable POP-BDEs) with the recent dates of manufacture (further reducing the likelihood of POP-BDEs), suggests that business machines are highly likely to be POP-BDE free.

Fourteen smaller, home use machines such as laser and ink-jet printer/ copiers and faxes were tested by XRF, resulting in 10 out of 14 samples below 0.01% Br. Of the remaining 4 high Br samples, two were >10% Br and two were between 0.2% and 0.5%, indicating contamination of the recyclate. The two highest samples were laboratory tested and both returned results less than the limit of detection for POP-BDEs, decaBDE and TBBPA. One of these two showed a positive test for BTBPE.

In summary, 12 out of 14 small office machines were <0.1% in POP-BDEs, with the remaining two at recyclate contamination levels of unidentified BFRs. Small office machines are likely to be POP-BDE free.

5.1.2.2 Recommended Scanning and Sorting Action

Copiers/ printers/ faxes encountered in the New Zealand WEEE recycling market are recommended to be managed according to Table 5, a risk-based decision table developed from the evidence above.

Should different management actions accrue from different ranges of date of manufacture, and the age of a particular model cannot be established, the more conservative management action should be followed.

Table 5: Copiers/ Printers Decision Table

WEEE Category	Copiers/ Printers/faxes		
Equipment Type	**Business Machine (large)**	**Home use machines (small)**	**Toner cartridges**
Date of manufacture	**Post-2005***	**-**	**-**
BFR free[1]?	N	N	Y**
PBDE free[2]?	Y	Y	Y
POP-BDE free[3]?	Y	Y	Y
Class A landfill?	N	N	N
Currently OK to recycle (Stockholm compliant)?	Y	Y	Y
Likely to be OK to recycle in future[4]?	Y	Y	Y
Requires a Basel permit?	Y	Y	N

Notes:

* - no items pre-2005 tested. Assume pre-2005 equipment >0.1% POP-BDE in the absence of other data

** - One out of approx. 20 toner cartridges was found to be >0.1% Br, which was confirmed by laboratory analysis to be DBDPE.

1 - likely to be <0.1% BFRs

2 - likely to be <0.1% PBDEs (includes c-penta, c-octa and c-deca mixtures)

3 - likely to be <0.1% POP-BDEs (includes c-penta and c-octa)

4 - In the event that decaBDE is added to the Stockholm Convention in the future

Legend: Y = Yes, N = No

5.1.3 Computers & Peripherals

5.1.3.1 Supporting Evidence

(a) Literature reported PBDE levels in CRT monitors

OctaBDE has been routinely reported in the literature as having been historically added to acrylonitrile butadiene styrene (ABS) polymers for the casing of EEE at concentrations between 10-18 % by weight (Consortium ESWI (Expert Team to Support Waste Implementation) 2011).

However, one recent and extensive study involving laboratory analysis of CRT computer monitor plastics has shown the presence of octaBDE to be rare in comparison with TBBPA, TBPE and decaBDE, in that order:

- Sindiku, et al. (2012) found only 3 out of 224 samples of CRT computer monitors manufactured from 1987-2006 contained levels of octaBDE above 0.1%.
  - This equates to 99% of all samples below the RoHS limit of 0.1%.
  - One of the 3 high samples was USA-made with octaBDE added at a flame retarding level (5.09%) while the other two (USA and China manufactured) at 0.9% were more reflective of contaminated recyclate.
  - 152 out of these 224 samples contained some form of BFR, such as TBBPA, TBPE and decaBDE.
  - The average concentration calculated across the entire 224 CRT monitors tested was 0.05%, below RoHS limit.
- Wäger, Schluep and Muller (2010) analysed 5 CRT monitors for PBDEs and related BFRs, and found that all contained octaBDE above detection limits and one sample showed an octaBDE result of 1.1%.
  - The average of the batch of 5 samples was 0.25%, which is above the RoHS limit.
  - All 5 samples were ≥0.1% in decaBDE.

(b) Monitors - CRT or LCD as a Visual Sort Cue

Latimer (2013) postulated that identification of computer monitors containing octaBDE may be able to be achieved by visual inspection, on the basis of whether the monitor was CRT or LCD. Australian import data obtained for the study shows that the phase-out of CRT computer monitors in favour of non-CRT models coincided approximately with the worldwide ban on the production of octaBDE in 2004/ 2005. Assuming that this is the case, it would be possible to identify BDE-containing monitors on the basis of them either being CRT or LCD, a process that could be quite feasibly achieved at WEEE collection and recovery centres. Figure 9 below demonstrates how the annual number of CRT computer monitors imported to Australia began to decrease in 2000 and rapidly decreased in 2004.

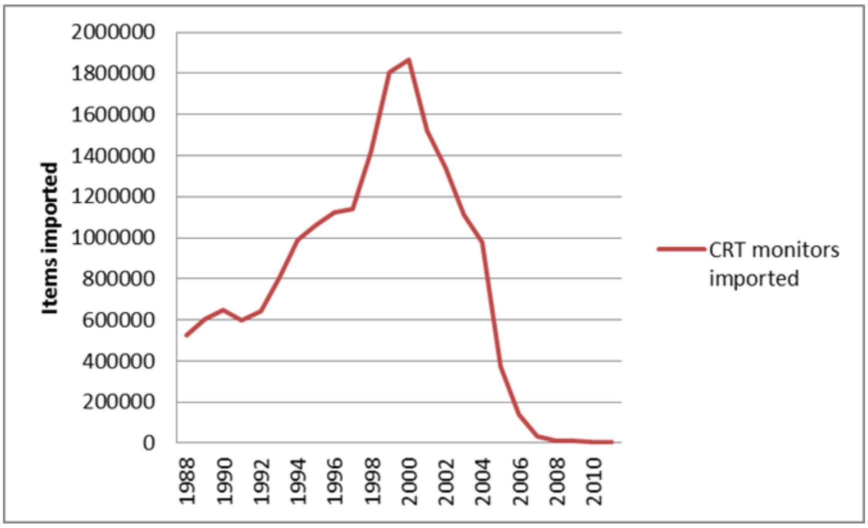

Figure 9 – Import of CRT monitors into Australia
(Source: Latimer (2013))

(c) Laboratory PDBE test data (from Section 4.3)

Eight computer monitors were tested in all, 6 LCDs and 2 CRTs. The two CRTs were >0.1% Br, with the highest one laboratory tested and found to be high in decaBDE. Five of the 6 LCD monitors were <0.1% Br, with the high result coming from a very early model LCD (manufactured in 2000).

Limited measurements were taken of other computer equipment, including 2 desktop PCs, 3 laptops, one Apple Power Mac G5 computer, 4 modems and one keyboard. Apart from the Apple product, which recorded a Br result of >10%, all other results returned results of <0.1% Br (BFR) and by extension, <0.1% POP-BDEs and decaBDE respectively.

(d) Summary of Evidence

Despite the literature describing high levels of octaBDE use in CRT monitor ABS plastics, in a similar vein to CRT TVs there is limited actual measured data for WEEE items that backs this up. While this study could only find two CRT monitors to test, Sindiku, et al. (2012) provides solid evidence that 99% of a large number of CRT monitors were below 0.1% in octaBDE.

However, the 5 sample European study by Wäger, Schluep and Muller (2010) did show octaBDE above 0.01% in all samples and, while the average of the 5 results was below the RoHS level of 0.1%, there was one sample that recorded octaBDE at 1.1%.

Given that this Pilot contributes only one PBDE measurement, a risk based approach, albeit on the conservative side, suggests that CRT monitors should be assumed to contain POP-BDEs. However, the Nigerian study results suggest that it may be worthwhile to conduct further PBDE analysis of CRT monitors to challenge this recommendation.

As postulated in b) above, results from this Pilot indicate that LCD computer monitors are unlikely to contain POP-BDEs. The results also suggest that decaBDE and BFRs more generally are unlikely to be present.

Other Computer related items

Plastic casings of other computer related items such as desktop PCs, laptops, modems and keyboards are unlikely to contain POP-BDEs.

The qualifier with this advice is that DVD, CD or old floppy drives, along with internal fan plastic components, can contain high levels of BFRs. While more testing is recommended to determine the likelihood that internal component plastics from parts like drives and fans might contain POP-BDEs, a responsible approach based on limited data is to assume that:

- the measured BFR levels in pre-2005 manufactured DVD, CD or floppy drive and internal fan plastic components are likely to be due to POP-BDEs, and therefore these component plastics should be landfilled
- Post-2005 manufactured internal drives and fan plastic components are likely to be high in BFRs but not POP-BDEs, and can be recycled.

5.1.3.2 Recommended Scanning and Sorting Action

Computers and their peripheral products encountered in the New Zealand WEEE recycling market are recommended to be managed according to Table 6, a risk-based decision table developed from the evidence above.

Table 6: Computers & Peripherals Decision Table

WEEE Category	Computers & peripherals							
Equipment Type	CRT Monitors	LCD Monitors	Desktop computers*	Computer internal drives**, fans etc.		Laptops	Keyboards / mice	Modems
Date of manufacture				Pre 2005	Post 2005			
BFR free[1]?	N	Y	Y**	N	N	Y	Y	Y
PBDE free[2]?	N	Y	Y**	N	N	Y	Y	Y
POP-BDE free[3]?	N	Y	Y**	N	Y	Y	Y	Y
Class A landfill?	Y	N	N	Y	N	N	N	N
Currently OK to recycle (Stockholm compliant)?	N	Y	Y**	N	Y	Y	Y	Y
Likely to be OK to recycle in future[4]?	N	Y	Y**	N	N	Y	Y	Y
Requires a Basel permit?	Y	N	N	Y	Y	N	N	N

Notes:

* - Only one Apple desktop computer found. This included plastic components high in BFRs

** - CD, DVD & floppy drives in one test item (2001) found to contain high BFR, while remaining plastic components in item BFR free. Drives should be separated.

[1] - likely to be <0.1% BFRs

[2] - likely to be <0.1% PBDEs (includes c-penta, c-octa and c-deca mixtures)

[3] - likely to be <0.1% POP-BDEs (includes c-penta and c-octa)

[4] - In the event that decaBDE is added to the Stockholm Convention in the future

Legend: Y = Yes, N = No

ORANGE: likely but further sampling is recommended.

5.1.4 Refrigerators

5.1.4.1 Supporting Evidence

Like business machines, the presence of refrigerators in WEEE recycling in New Zealand is due to contracts with major suppliers, which from time to time involved recycling of items that are faulty, off spec or otherwise damaged. These items are typically less than 5 years old.

Three fridges were tested by XRF. All returned Br results <0.1%, with the exception of a small piece of plastic used as a cover over electrical wiring, which was >10% Br. Laboratory analysis confirmed this to be DBDPE.

Consequently, due to these measurements and the recent manufacture date of fridges presenting for WEEE recycling, these items are unlikely to exceed 0.1% POP-BDEs.

5.1.4.2 Recommended Scanning and Sorting Action

Refrigerators encountered in the New Zealand WEEE recycling market are recommended to be managed according to Table 7, a risk-based decision table developed from the evidence above.

Table 7: Refrigerators Decision Table

WEEE Category	**Refrigerators**	
Equipment Type	**Plastic skin**	**Electrical cover (small)***
BFR free[1]?	Y	N
PBDE free[2]?	Y	Y
POP-BDE free[3]?	Y	Y
Class A landfill?	N	N
Currently OK to recycle (Stockholm compliant)?	Y	Y
Likely to be OK to recycle in future[4]?	Y	Y
Requires a Basel permit?	N	Y

Notes:
* - Small (~10x20cm) piece on back of item used to cover electrical wiring. Should be removed and separated from remaining fridge plastics
1 - likely to be <0.1% BFRs
2 - likely to be <0.1% PBDEs (includes c-penta, c-octa and c-deca mixtures)
3 - likely to be <0.1% POP-BDEs (includes c-penta and c-octa)
4 - In the event that decaBDE is added to the Stockholm Convention in the future
Legend: Y = Yes, N = No

5.1.5 Other WEEE Items

The risk based decision tables described in this report represent all of the WEEE item categories reported as received by the three New Zealand recyclers involved in this study.

Other items, such as hair dryers, VCRs, DVD players, microwave ovens and heaters were not observed at recycling facilities.

5.2 Pilot Data Extrapolation

Data from Appendix A shows that out of 125 individual XRF measurements taken, 61 relevant individual WEEE items were tested. Of these, 56% contained BFRs.

The selection of items XRF tested was broadly based on what items presented on the factory floor, but it was not meant to accurately represent the proportion of WEEE category volumes shown in Table 2. To answer the question of what proportion of New Zealand recyclers' WEEE is likely to be BFR free, the results of the Decision Tables of section 5.1 have been overlaid with the annual recycler-provided volume data of Table 2 to produce Table 8 below. An estimate of the likely POP-BDE free proportion of WEEE items has also been calculated using the same approach.

From Table 8's extrapolation, the key findings, based on WEEE volumes provided by the 3 Pilot participant recyclers are:

1. 60% (by number) of all WEEE items handled by the three New Zealand recyclers is likely to be BFR-free

2. 50% (by weight) of all WEEE items handled by the three New Zealand recyclers is likely to be BFR-free

3. 99% (either by number or by weight) of all WEEE items handled by the three New Zealand recyclers is likely to be POP-BDE-free

Table 8: Extrapolated estimates of BFR and POP-BDE free WEEE handled by three major recyclers in New Zealand 2012/13[1].

WEEE category	Total (kg)	Total (units)	% of items (by number) likely to be BFR free	Number of items likely to be BFR free	% Plastic content in WEEE items	Weight of plastic in WEEE items (kg)	Weight of WEEE plastics likely to be BFR free (kg)	% of total WEEE plastic (by weight) likely to be BFR free	% of items (by number) likely to be POP-BDE free	Number of items likely to be POP-BDE free	Weight of WEEE plastics likely to be POP-BDE free (kg)	% of total WEEE plastic (by weight) likely to be POP-BDE free
Desktop	205,677	13712	100%	13712	42%	86384	86384	12%	100%	13712	86384	100%
Server	35,970	1439	100%	1439	42%	15107	15107	2%	100%	1439	15107	100%
Laptop	49,470	5497	100%	5497	42%	20777	20777	3%	100%	5497	20777	100%
Monitor[2]	158,384	10285	90%	9256	30%	47515	42764	6%	90%	9256	42764	90%
TV[3,4,5]	833,296	41665	54%	22499	21%	174992	38248	5%	100%	41665	174992	100%
Printer/copier/etc.	501,415	25071	0%	0	42%	210594	0	0%	100%	25071	210594	100%
White ware[6]	360,000	3600	99%	3564	42%	151200	149688	21%	100%	3600	151200	100%
Computer peripherals[7]	8,000	11429	100%	11429	80%	6400	6400	1%	100%	11429	6400	100%
Total	**2152212**	**112696**	**60%**	**67395**	**-**	**712971**	**359369**	**50%**	**99%**	**111668**	**708219**	**99%**

Notes:
1 Data covers 2 months to April 2013
2 Assume only 10% of monitors received as WEEE are CRT (ref: report section 4.1)
3 Assume 90% of TVs currently received as WEEE are CRT (ref: discussions with recyclers)
4 Assume 60% of CRT TVs received are pre-2000 (author estimate)
5 Based on only rim pieces of CRTs being BFR free and rim being 40% by weight of an average TV's plastics (source RCN supplied weights)
6 Assume plastic proportion of white ware is the same as UNEP (United Nations Environment Programme 2011) estimates for computers, printers and copiers (42%)
7 Assume plastic proportion of computer peripherals is 80% (author estimate)
8 Assumptions cannot be made for the "not specified" category, so data has been removed for this analysis

6 Sorting Options

Based on the results of the Pilot, four scanning, sorting and segregation options have been identified and are summarised below, that could in theory be implemented in the New Zealand recycling industry. A fifth option, Handheld Scanning BFR and Laboratory Testing, has not been investigated any further, due to impracticalities of cost, scale and time delays (in addition to issues applicable to XRF screening) that accrue from laboratory testing.

6.1 Status Quo – No Scanning, Sorting or Segregating of BFR/ non-BFR Plastics. Dispose all Candidate Plastics to Landfill

The Ministry's website guidance (http://www.mfe.govt.nz/publications/waste/bromide-flame-retardant-waste/html/index.html) suggests that recyclers should landfill all candidate plastics (models manufactured before 2008) if unsorted by BFR/ non-BFR. This is a conservative approach. In practice, Ministry intervention to date has only resulted in CRT TV plastics going to landfill.

Consequently the base case reflects the status quo, i.e., only CRT TVs are sent to Class A Landfill, while all remaining plastics are recycled.

6.2 Visual BFR – Visual inspection based on risk matrix, sort and segregate for high-risk BFR-containing components

Using the ready reckoner approach given in the Risk Based Decision Tables for each major category of WEEE, decisions about whether to recycle plastics from a particular article or not are made simply by visual identification of the type of the article, in some cases augmented by its likely manufacturing date.

This option uses the Decision Table guidance for the presence of any BFRs – not just POP-BDEs – in the event that the Ministry's preference was to use a more stringent approach to ensure compliance with the *Imports and Exports (Restrictions) Prohibition Order (No 2) 2004* and the Stockholm Convention itself.

This option would result in the following WEEE categories being sent to Class A landfill:

- All CRT and LCD TV plastics, with the exception of pre-2000 (non-European manufactured) rim pieces only, which are available for recycling
- All copier/ printer/ fax plastics
- CRT computer monitor plastics, with all other peripheral plastics (excluding internal fans and drives) available for recycling
- Fridge electrical covers, with fridge casing plastics available for recycling.

6.3 Visual POP-BDE – Visual inspection based on risk matrix, sort and segregate for high-risk POP-BDE-containing components

Using the ready reckoner approach given in the Risk Based Decision Tables for each major category of WEEE, decisions about whether to recycle plastics from a particular article or not are made simply by visual identification of the type of the article, in some cases augmented by its likely manufacturing date.

This option uses the Decision Table guidance for the presence of POP-BDEs, to manage compliance with the *Imports and Exports (Restrictions) Prohibition Order (No 2) 2004* and the Stockholm Convention itself.

This option would result in the following WEEE categories being sent to Class A landfill:

- Only pre-1990 European manufactured CRT TV plastics – all other TV plastics available for recycling
- No copier/ printer/ fax plastics to landfill – all recycled
- CRT computer monitor plastics and internal fans and drives from pre-2005 items only – LCD monitors and all other computer peripheral plastics available for recycling
- Fridge electrical covers only.

6.4 Handheld Scanning BFR – handheld XRF scan, sort and segregate for high-risk BFR-containing components

This option requires the onsite use of one or more XRF Handheld Scanners to physically measure at-risk items to determine the presence of BFRs, as a means of scanning, sorting and segregating into BFR and non-BFR plastic categories, with only non-BFR components processed for further recycling.

This option would result in all items tested to be above 0.1% Br being sent to Class A landfill. Based on Pilot data, this is likely to involve the majority of the following WEEE categories:

- All CRT and LCD TV plastics, with the exception of pre-2000 (non-European manufactured) rim pieces only, which hare available for recycling
- All copier/ printer/ fax plastics
- CRT computer monitor plastics, with all other peripheral plastics (excluding internal fans and drives) available for recycling
- Fridge electrical covers, with fridge casing plastics available for recycling.

Note that this option has the potential to identify some items from the above list that do not exceed 0.1%Br upon testing and consequently would be expected to send less of the above WEEE items to landfill than option 6.2 Visual BFR.

6.4.1 Feasibility of Onsite Use of XRF Scanner

One of the objectives of the Pilot was to investigate the use of a portable XRF scanner by recycler staff as part of the dismantling and sorting process.

An indicative price to purchase such an instrument is approximately NZD$40,000 and, depending on the individual recycler's processing procedures and staffing levels, more than one scanner may be required per site.

It is theoretically possible that each item could be scanned in this way during the dismantling process to enable a decision about the fate of the scanned component. However there are a number of practical limitations to this being feasible on the factory floor, including:

1. Licencing requirements

Licences to use Ionising Radiation are issued under the Radiation Protection Act 1965, and must be renewed annually. Such a licence is required to operate an XRF device in New Zealand. Licence conditions vary but typically require a qualified, trained and experienced operator with proven technical understanding of the risks of working with X-ray radiation, to be the sole or directly supervising operator of the instrument. In addition use of radiation must be in accordance with a specified Radiation Safety Plan, and adherence to this is audited by the National Radiation Laboratory on a regular basis.

2. Lack of technical staff on the dismantling floor

Staff employed on the floor at recycling operations are not trained in the technical skills required to obtain and maintain a licence as described above. While training is possible to allow use such an instrument, the lack of technical qualification of staff in these roles would make proper use and ongoing retention of licences challenging.

3. Training

   Ongoing training in the proper and safe use of an XRF scanner would be required, particularly as new staff are hired.

4. Measurement Technique Complexity

The use of XRF scanners to obtain meaningful results on WEEE article plastics is more complex and nuanced than it may appear. For example, the X-rays penetrate to 5-10mm of depth of the sample, so erroneous readings often result when other Br sources are nearby, such as printed circuit boards or cooling fans underneath equipment casings. Pre-existing knowledge of these risks results in an experienced user measuring with the scanner angled to the plastic surface, or finely locating the device on the edge of an item – the difference between an accurate and spurious result can 1000-fold.

5. Regular Calibration

Regular calibration with certified (and expensive) bromine standards is required to ensure the values returned by the instrument are valid. In addition to tight calibration procedures, this requires that the operator have an understanding of calibration range, significant figures and quality control, skills common to scientifically and technically qualified people.

6. Time impact on dismantling process

Each measurement takes approximately 30 seconds. However, to record the identifier information about the item tested details need to be entered into the scanner itself via touchscreen/ stylus (or similar). Data is downloaded from the scanner at a later time. But of most time impact is the fact that it is common for different plastic components within the same WEEE item to have been made from different source materials (despite looking identical) producing wildly different Br readings. All of these aspects can make the testing of a single item of WEEE by XRF take an operator 5 minutes.

Feedback from one of the recyclers suggest than an average sized TV takes approximately 17 minutes to dismantle. Consequently XRF scanning could add an additional 29% to current item processing times.

7. Variability of Br content between WEEE items

Similar to the variability of Br levels within the plastic components of a single item, there can also be variability between one apparently identical item and the next, as highlighted throughout the results at Appendix A. While some WEEE categories have been shown by this study to be reasonably predictable in this regard, there are others such as later model TV and computer items where, in terms of BFRs, there is no apparent pattern. Consequently, if using BFR/ non-BFR as sort criteria, XRF as the screening method would regularly need to be on an individual item by item basis, which adds significant time to the dismantling process.

8. Inability of technology to distinguish POP-BDEs

This study and the others discussed in Section 5 regularity show high Br results in late model items, without a correspondingly high POP-BDE level. For those studies (such as this one) where detailed PBDE analysis has accompanied XRF Br scanning, results have consistently shown recent and current use of retardant chemicals like decaBDE and TBBPA, neither of which are listed under the Stockholm Convention. While XRF is a particularly powerful and dynamic way of accurately measuring Br, use of it alone would result in a significant number of “false positive” decisions through a highly conservative approach to Stockholm compliance. This would result in unnecessary landfilling of WEEE plastics with subsequent negative resource and financial outcomes for recyclers – perversely using a high capital cost method (scanning device) to reduce the benefit side of the recycling equation.

9. Lack of price driver for BFR-free plastics

While this consultancy has been unable to obtain detailed market prices for ABS plastic commodities, discussions with a plastics broker operating in the Asian market suggested that the differential between BFR-containing and BFR-free ABS plastics was not currently significant, since the presence of flame retardancy was seen as a product value for some applications which played against any environmental premium a BFR-free commodity could attract.

10. Lifecycle of remaining POP-BDE articles “in use”

As discussed in Section 5, evidence from a recent Australian study (KMH Environmental 2013[9]) suggests that, after the spike of the TV TakeBack Programme, the bulk of WEEE items entering end of life will have been manufactured after the mid-2000s ban on the use of POP-BDEs as flame retardants. If the primary driver of BFR identification in WEEE is the Stockholm Convention, then the significant investment required to incorporate XRF scanning into recyclers’ processes will have rapidly diminishing value. In this case the capital outlay and operational costs of XRF scanning is likely to outweigh the longevity of any ongoing benefit.

6.5 Comparison of options

The costs of options 6.2 and 6.3 would be similar but option 6.3 would enable more items to be recovered and recycled. However, option 6.2 would give the Ministry greater certainty that current and future domestic and international obligations regarding BFRs will be met.

Option 6.4 is more expensive than options 6.2 and 6.3, but would give the Ministry the additional comfort that no BFR-containing items will slip through and that no non-BFR items will be inadvertently prevented from being recycled.

The evidence above indicates that routine use of a handheld XRF scanner (Option 6.4) is not feasible, based on a combination of operational and practical complexity, relatively high capital cost and a lack of sufficiently compelling benefits. In the context of a recycling facility, this option is an impractical and potentially unreliable way to balance proper management of environmental hazard with a facility's goal of maximising legal recycling of plastics.

This instrumentation is highly reliable for bromine detection. However, the combination of operator skills and its inability to distinguish between POP-BDEs and other more acceptable BFR alternatives means that the use of XRF screening as a surrogate for POP-BDE plastic separation would result in large numbers of false positives.

While a little under half of the items tested were BFR-free (and therefore POP-BDE free), no POP-BDEs at all were not found in any of the 15 high BFR samples selected to best represent those samples likely to contain POP-BDEs. Therefore the Pilot data indicates a low likelihood of the presence of POP-BDEs above the RoHS limit of 0.1% across all of the WEEE category plastics observed (TVs, copiers/ printers, computers and peripherals and fridges). On this basis, option 6.3 appears to be the most attractive, due to similar costs but greater benefits in terms increased plastics volumes that could be acceptably recycled.

A detailed assessment of the costs and benefits of these options is provided in the second stage of this study, conducted by ACIL Allen Consulting.

7 Conclusions and Recommendations

7.1 Conclusions

1. Annual data provided from the three recyclers involved in this Pilot indicates that the priority items by weight processed by New Zealand e-waste recycling facilities in 2012-13 were:

- TVs (36%)
- Business machines (photocopiers/ printers/ scanners/ faxes) (22%)
- Computers & Peripherals (20%) and
- White-ware (15%).

These four categories make up 93% of all e-waste processed by the three recyclers. The remaining category (7%) was recorded against the item type “not specified”.

2. Based on the results of this Pilot study and recent literature data on measured quantities of BFRs and POP-BDEs in WEEE and product articles, Risk Based Decision Tables were derived, to provide guidance for New Zealand recyclers in making decisions about items that are likely to:

- be suitable for recycling;
- require Basel export permits; and
- require disposal to Class A landfill.

In terms of POP-BDEs, these tables indicate the following:

- CRT and LCD TVs are likely to be suitable for recycling, with the exception of CRT TVs manufactured in Europe prior to 1990
  - In making this decision, the authors recognise that the vast majority of CRT TVs processed by the recycling industry in New Zealand have been manufactured in Asia and have been manufactured after 1990.
- Business machines (photocopiers/ printers/ scanners/ faxes) are likely to be suitable for recycling, although the evidence is only available for post 2005 models;
- Computers & Peripherals EXCEPT CRT monitors are likely to be suitable for recycling. This Pilot was unable to obtain sufficient CRT monitors to test, so a risk based approach suggests that CRT monitors should be assumed to contain POP-BDEs, based on a limited number of high octaBDE results reported in recent literature.
  - Internal plastics such as fans and built in drives from pre-2005 should also be assumed to contain POP-BDEs and consequently landfilled.
- White-ware (such as fridges) is likely to be suitable for recycling.

3. Extrapolation of the recommendations from these Risk Based Decision Tables on annual volume data supplied by the recyclers would give:

- 60% (by number) of all WEEE items handled by the three New Zealand recyclers is likely to be BFR-free
- 50% (by weight) of all WEEE items handled by the three New Zealand recyclers is likely to be BFR-free
- 99% (either by number or by weight) of all WEEE items handled by the three New Zealand recyclers is likely to be POP-BDE-free

4. A separate Cost Benefit Analysis (CBA) is being conducted by ACIL Allen Consulting as the second stage of this project. The scanning, sorting and segregation options derived through this Pilot for consideration in the CBA are:

- Status Quo – No Scanning, Sorting or Segregating of BFR/ non-BFR Plastics. Dispose all Candidate Plastics to Landfill
- Visual BFR - Visual inspection based on risk matrix, sort and segregate for high-risk BFR-containing components
- Visual POP-BDE – Visual inspection based on risk matrix, sort and segregate for high-risk POP-BDE-containing components
- Handheld Scanning BFR – handheld XRF scan, sort and segregate for high-risk BFR-containing components

5. Evidence from this Pilot indicates that routine use of a handheld XRF scanner (the final option above) is not feasible, based on a combination of operational and practical complexity, relatively high capital cost and a lack of sufficiently compelling benefits. In the context of a recycling facility, this option is an impractical and potentially unreliable way to balance proper management of environmental hazard with a facility's goal of maximising legal recycling of plastics.

This instrumentation is highly reliable for bromine detection. However, the combination of operator skills and its inability to distinguish between POP-BDEs and other more acceptable BFR alternatives means that the use of XRF screening as a surrogate for POP-BDE plastic separation would result in large numbers of false positives.

7.2 Recommendations

1. The four Risk Based Decision Tables outlined in Sections 5.1.1 – 5.1.4 should be used for visual inspection of WEEE items, as a means of sorting and segregating plastic components for suitability of recycling.

The recommendation is to follow the "POP-BDE free?" entry in each table to make the decision to recycle items; however the option exists to use the more stringent heading of "BFR-free?"

Should "POP-BDE free?" be the chosen approach, quality assurance testing, in the form of a combination of XRF Br screening and laboratory PBDE analysis, should be conducted at intervals such as 6-monthly, to give recyclers, recycled plastic customers and regulators confidence that recycled plastics are meeting legal requirements. This would also provide an ongoing check and challenge mechanism (of the Decision Tables) and an increasing data set over time.

The sampling program would primarily be designed to regularly check and validate the sorting Decision Table approach, so would focus on plastic samples from representative WEEE items. However, should there be value for downstream customers, this could also be an opportunity to test batches of combined scrap plastics to demonstrate compliance with BFR-related legal requirements.

2. The Risk Based Decision Tables were arrived at based on the results of this Pilot and limited but recent literature measurement data. This information points to instances, such as for CRT TVs, where the outcomes of this Pilot go against what was previously accepted as fact. Given the limited evidence base of this work, it is recommended that a further measurement study be carried out with a specific focus on the following, in order of priority:

- CRT TV back covers – test for presence of POP-BDEs
- CRT TV rims – test for presence of BFRs and to a lesser extent decaBDE
- CRT computer monitors – test for presence of POP-BDEs

Such a focussed follow up project could achieve significant sample size with a budget in the order of $20,000 NZ. This would provide further confidence in the rigour of the decision table approach, particularly in light of the current volume of CRT TVs being received under TV TakeBack.

3. A more detailed breakdown of the "not specified" category of WEEE volume data should be obtained from the recyclers involved in this Pilot, given that the category as a whole makes up 7% of all WEEE received. Further detailing of this data will help determine whether other WEEE categories need to be scrutinised.

4. Recycling decisions regarding plastics from items not covered by Decision Tables, such as hair dryers, VCRs, DVD players, microwave ovens, sound systems and heaters/ air conditioners should be treated conservatively, following the Ministry's guidelines (http://www.mfe.govt.nz/publications/waste/bromide-flame-retardant-waste/html/index.html) in the event that no other information is available. Pilot results indicate if a manufacture date more recent than 2005 can be established for an item of WEEE, regardless of what it is, the item is likely to be POP-BDE free.

5. A watching brief should be kept on the progress of discussions regarding the potential candidacy of decaBDE on the Stockholm Convention, at POPs Review Committee (POPRC). A paper has been prepared on this issue for discussion at the next meeting (October 2013).

8 Limitations

ENVIRON Australia prepared this report in accordance with the scope of work as outlined in our proposal to The Ministry for the Environment dated 2nd May 2013 and in accordance with our understanding and interpretation of current regulatory standards.

A representative program of site sampling, analysis by XRF scanner and laboratory analyses was undertaken as part of this investigation, based on knowledge from previous studies. While every care has been taken, concentrations of contaminants measured may not be representative of concentrations across all WEEE received to date or in future by WEEE recycling companies in New Zealand.

The conclusions presented in this report represent ENVIRON's professional judgment based on information made available during the course of this assignment and are true and correct to the best of ENVIRON's knowledge as at the date of the assessment.

ENVIRON did not independently verify all of the written or oral information provided to ENVIRON during the course of this investigation. While ENVIRON has no reason to doubt the accuracy of the information provided to it, the report is complete and accurate only to the extent that the information provided to ENVIRON was itself complete and accurate.

This report does not purport to give legal advice. This advice can only be given by qualified legal advisors.

Appendix A

XRF Measurement Data for Bromine (Br)

Appendix A: XRF Measurement Data for Bromine (Br).

Sample No.	Date	Recycler	Equipment type	Br (ppm) by XRF	Year of manufacture	Model	Component Part	Brand	Country of manufacture	Plastic colour	Sample collected?	Size
1	5/30/2013	SIMS	LCD monitor	14	2004		Back cover	IBM	Korea	black	no	N/A
2	5/30/2013	SIMS	modem	6	2011	TG582n	case	Technicolor	Belgium	white	no	N/A
3	5/30/2013	SIMS	modem	186	2011	Speed touch ST536 V6	case	Thomson	Belgium	black	no	N/A
4	5/30/2013	SIMS	modem	5	2011	TG585v7	case	Thomson	Belgium	white	no	N/A
5	5/30/2013	SIMS	modem	152	2008	2701HGV-W	case edge	2 Wire Gateway	China	white	no	N/A
5	5/30/2013	SIMS	modem	58	2008	2701HGV-W	case top/ bottom	2 Wire Gateway	China	grey	no	N/A
6	5/30/2013	SIMS	projector	82	2011	EB-S9 H376B	case	Epson	China	white	no	N/A
6	5/30/2013	SIMS	projector	71176	2011	EB-S9 H376B	lens	Epson	China	white	no	N/A
6	5/30/2013	SIMS	projector	81273	2011	EB-S9 H376B	filter	Epson	China	white	no	N/A
7	5/30/2013	SIMS	desktop PC	8	2005	DCNE	case	Dell	Malaysia	black	no	N/A
8	5/30/2013	SIMS	keyboard	110	2005	SK8115	body	Dell	China	black	no	N/A
9	5/30/2013	SIMS	laptop	9	2012	Satellite L850	screen edge	Toshiba	China	white	no	N/A
9	5/30/2013	SIMS	laptop	7	2012	Satellite L850	keyboard	Toshiba	China	white	no	N/A
10	5/30/2013	SIMS	laptop charger	2449	2012	PA5035E-1AC3	charger/ ACDC adaptor	Toshiba	China	black	no	N/A
11	5/30/2013	SIMS	laptop	170	2007	X18-1280ED	screen edge	HP	China	black	no	N/A
11	5/30/2013	SIMS	laptop	187	2007	X18-1280ED	keyboard	HP	China	black	no	N/A
11	5/30/2013	SIMS	laptop	110	2007	X18-1280ED	battery	HP	China	black	no	N/A
12	5/30/2013	SIMS	copier	8	1989	SF-7850	lid	Sharp	France	cream	no	N/A

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Sample No.	Date	Recycler	Equipment type	Br (ppm) by XRF	Year of manufacture	Model	Component Part	Brand	Country of manufacture	Plastic colour	Sample collected?	Size
12	5/30/2013	SIMS	copier	215441	1989	SF-7850	body	Sharp	France	cream	yes	N/A
12	5/30/2013	SIMS	copier	228187	1989	SF-7850	front cover	Sharp	France	cream	no	N/A
13	5/30/2013	SIMS	bubble jet printer	58	1998	BJC 4300	lid, front cover, case	Canon	Japan	cream	no	N/A
14	5/30/2013	SIMS	laser printer	161450	1994	Laser-jet 4MV	paper feeder	HP	Japan	cream	yes	N/A
14	5/30/2013	SIMS	laser printer	1108	1994	Laser-jet 4MV	other component	HP	Japan	cream	no	N/A
14	5/30/2013	SIMS	laser printer	118184	1994	Laser-jet 4MV	other component	HP	Japan	cream	no	N/A
14	5/30/2013	SIMS	laser printer	84733	1994	Laser-jet 4MV	other component	HP	Japan	cream	no	N/A
15	5/30/2013	SIMS	printer/ copier	10	2009	Aticio MP 5500	body	RICOH	Japan	white	no	N/A
15	5/30/2013	SIMS	printer/ copier	168516	2009	Aticio MP 5501	internal plastic	RICOH	Japan	white	no	N/A
16	5/30/2013	SIMS	printer/ copier	1801	2010	MPC 2500	side body	RICOH	Japan	white	no	N/A
16	5/30/2013	SIMS	printer/ copier	161698	2010	MPC 2500	top cover	RICOH	Japan	white	yes	N/A
16	5/30/2013	SIMS	printer/ copier	12	2010	MPC 2500	internal plastic	RICOH	Japan	white	no	N/A
16	5/30/2013	SIMS	printer/ copier	139375	2010	MPC 2500	internal plastic	RICOH	Japan	white	no	N/A
16	5/30/2013	SIMS	printer/ copier	97279	2010	MPC 2500	external document holder	RICOH	Japan	white	no	N/A
17	5/30/2013	SIMS	printer/ copier	153090	2008	MP 2000 LE	top cover	RICOH	Japan	cream	yes	N/A
17	5/30/2013	SIMS	printer/ copier	6	2008	MP 2000 LE	keypad	RICOH	Japan	white	no	N/A
17	5/30/2013	SIMS	printer/ copier	11	2008	MP 2000 LE	internal plastic	RICOH	Japan	white	no	N/A
17	5/30/2013	SIMS	printer/ copier	9	2008	MP 2000 LE	scan glass edge	RICOH	Japan	white	no	N/A
18	5/30/2013	SIMS	LCD Monitor	62	2000	9493AG-1	body	IBM	Korea	black	no	N/A

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Sample No.	Date	Recycler	Equipment type	Br (ppm) by XRF	Year of manufacture	Model	Component Part	Brand	Country of manufacture	Plastic colour	Sample collected?	Size
19	5/30/2013	SIMS	LCD Monitor	267	2000		body	Dell	China	black	no	N/A
19	5/30/2013	SIMS	LCD monitor	1012	2000		screen rim	Dell	China	black	no	N/A
19	5/30/2013	SIMS	LCD monitor	586	2000		base	Dell	China	black	no	N/A
20	5/30/2013	SIMS	LCD monitor	26338	2000	TFT 1780+	cover	AOC	China	black	no	N/A
20	5/30/2013	SIMS	LCD monitor	2242	2000	TFT 1780+	base	AOC	China	black	no	N/A
20	5/30/2013	SIMS	LCD monitor	196	2000	TFT 1780+	screen rim	AOC	China	silver	no	N/A
21	5/30/2013	SIMS	LCD monitor	13	2008		back cover	Philips	China	black	no	N/A
21	5/30/2013	SIMS	LCD monitor	65	2008		screen rim	Philips	China	black	no	N/A
22	5/30/2013	SIMS	LCD monitor	10	2006		body	Dell	China	blck	no	N/A
23	5/30/2013	SIMS	laptop	374	1998		screen edge	Compaq	Taiwan	black	no	N/A
23	5/30/2013	SIMS	laptop	6	1998		keyboard	Compaq	Taiwan	black	no	N/A
23	5/30/2013	SIMS	laptop	165	1998		lid	Compaq	Taiwan	black	no	N/A
24	5/30/2013	SIMS	CRT monitor	1519	2000		Back cover	Toshiba	China	white	no	N/A
24	5/30/2013	SIMS	CRT monitor	39919	2000		screen rim	Toshiba	China	white	yes	N/A
25	5/30/2013	SIMS	desktop PC	5	2001		front cover	Compaq	Czech Republic	white	no	N/A
25	5/30/2013	SIMS	desktop PC	102646	2001		CD drive	Compaq		white	no	N/A
25	5/30/2013	SIMS	desktop PC	148019	2002		DVD drive	Philips		white	no	N/A
25	5/30/2013	SIMS	desktop PC	117208	2001		floppy drive	Compaq		white	no	N/A
26	5/30/2013	SIMS	CRT monitor	1886	2001		Back cover	Compaq	Czech Republic	white	no	N/A

Appendix A: XRF Measurement Data for Bromine (Br).

Sample No.	Date	Recycler	Equipment type	Br (ppm) by XRF	Year of manufacture	Model	Component Part	Brand	Country of manufacture	Plastic colour	Sample collected?	Size
26	5/30/2013	SIMS	CRT monitor	1525	2001		screen rim	Compaq	Czech Republic	white	no	N/A
27	5/30/2013	SIMS	fridge	12	2009+	RL14013J	internal skin	Samsung		white	no	N/A
28	5/30/2013	SIMS	fridge	10	2009+		back panel	Samsung		white	no	N/A
28	5/30/2013	SIMS	fridge	254	2009+		external body	Samsung		grey	no	N/A
28	5/30/2013	SIMS	Fridge	195514	2009+		PCB cover (small)	Samsung		darker grey	yes	N/A
29	5/30/2013	SIMS	fridge	23	2009+		internal skin	Samsung		white	no	N/A
29	5/30/2013	SIMS	fridge	682	2009+		internal cover on compressor	Samsung		white	no	N/A
30	5/30/2013	SIMS	Power Mac G5 computer	228406	2005	G5	fan	Apple	unknown	white	no	N/A
30	5/30/2013	SIMS	Power Mac G5 computer	12	2005	G5	case	Apple	unknown	white	no	N/A
30	5/30/2013	SIMS	Power Mac G5 computer	137441	2005	G5	other components	Apple	unknown	white	no	N/A
30	5/30/2013	SIMS	Power Mac G5 computer	175536	2005	G5	other components	Apple	unknown	white	no	N/A
31	5/31/2013	RCN	CRT TV - wooden panel	8	1980-e	Z20C505	CRT Rim	Philips	unknown	grey	no	50cm
31	5/31/2013	RCN	CRT TV - wooden panel	27	1980-e	Z20C505	back	Philips	unknown	black	no	50cm
32	5/31/2013	RCN	CRT TV -	16	1990-e	CT-1447NZM	CRT rim	Mitsubishi	Singapore	black	no	30cm

Appendix A: XRF Measurement Data for Bromine (Br).

Sample No.	Date	Recycler	Equipment type	Br (ppm) by XRF	Year of manufacture	Model	Component Part	Brand	Country of manufacture	Plastic colour	Sample collected?	Size
			portable									
32	5/31/2013	RCN	CRT TV - portable	21	1990-e	CT-1447NZM	side	Mitsubishi	Singapore	black	no	30cm
32B	5/31/2013	RCN	CRT TV - portable	97856	1990-e	CT-1447NZM	back	Mitsubishi	Singapore	black	yes	30cm
33	5/31/2013	RCN	CRT TV	29	1990-e	CT-2007A	rim/side	Akai	China	black	no	35cm
33	5/31/2013	RCN	CRT TV	3422	1990-e	CT-2007A	back	Akai	China	black	no	35cm
34	5/31/2013	RCN	CRT TV	8	1990-e	Trinitron KV-2184AS	rim/side	Sony	Malaysia	black	no	48cm
34	5/31/2013	RCN	CRT TV	19	1990-e	Trinitron KV-2184AS	back	Sony	Malaysia	black	no	48cm
35	5/31/2013	RCN	CRT TV	67	1990-e	TX-21GF10Z	rim/side	Panasonic	Malaysia	black	no	50cm
35	5/31/2013	RCN	CRT TV	187020	1990-e	TX-21GF10Z	back	Panasonic	Malaysia	black	no	50cm
36	5/31/2013	RCN	CRT TV	10	1990-e	TC-1400Z	rim/side	Panasonic	Malaysia	black	no	30cm
36	5/31/2013	RCN	CRT TV	14	1990-e	TC-1400Z	back	Panasonic	Malaysia	black	no	30cm
37	5/31/2013	RCN	CRT TV	209735	1990-e	Trinitron KV-2185AS	rim/side	Sony	Malaysia	black	no	50cm
37	5/31/2013	RCN	CRT TV	196894	1990-e	Trinitron KV-2185AS	back	Sony	Malaysia	black	yes	50cm
38	5/31/2013	RCN	CRT TV	49	1990-e	TC-20S10M2	rim/side	Panasonic	Malaysia	black	no	48cm
38	5/31/2013	RCN	CRT TV	173608	1990-e	TC-20S10M3	back	Panasonic	Malaysia	black	no	48cm
39	5/31/2013	RCN	CRT TV	34581	1990-e	TX-68P22Z	rim/side	Panasonic	Malaysia	grey	no	62cm
39	5/31/2013	RCN	CRT TV	193778	1990-e	TX-68P22Z	back	Panasonic	Malaysia	dark grey	no	62cm
40	5/31/2013	RCN	CRT TV	87	1990-e	25PT4273/75T	rim/side	Philips	China	black	no	58cm
40	5/31/2013	RCN	CRT TV	48	1990-e	25PT4273/75T	back	Philips	China	black	no	58cm

Appendix A: XRF Measurement Data for Bromine (Br).

Sample No.	Date	Recycler	Equipment type	Br (ppm) by XRF	Year of manufacture	Model	Component Part	Brand	Country of manufacture	Plastic colour	Sample collected?	Size
41	5/31/2013	RCN	LCD TV	159582	2007	KLV-32U300A	rim	Sony Bravia	Taiwan	black	yes	42in
41	5/31/2013	RCN	LCD TV	189883	2007	KLV-32U300A	back	Sony Bravia	Taiwan	black	no	42in
42	5/31/2013	RCN	LCD TV	19	2009	TH-L32U30Z	rim	Panasonic Viera	Malaysia	black	no	32 in
42	5/31/2013	RCN	LCD TV	197743	2009	TH-L32U30Z	back	Panasonic Viera	Malaysia	black	no	32 in
43	5/31/2013	RCN	LCD TV/ DVD combo	189877	2007	20SLD1	rim	Toshiba	China	black	no	32in
43	5/31/2013	RCN	LCD TV	142019	2007	20SLD1	back	Toshiba	China	black	no	32in
44	5/31/2013	RCN	LCD TV	98	2012	LEDTV32FHDF	rim	Vivo	China	black	no	31.5 in
44	5/31/2013	RCN	LCD TV	934	2012	LEDTV32FHDF	back	Vivo	China	black	no	31.5 in
45	5/31/2013	RCN	LCD TV	11	2010	LA26C450E1M	rim	Samsung	China	black	no	26in
45	5/31/2013	RCN	LCD TV	11190	2010	LA26C450E1M	back	Samsung	China	black	no	26in
46	5/31/2013	RCN	LCD TV	18	2005	LCD32XR1	rim	Sanyo	China	black	no	32in
46	5/31/2013	RCN	LCD TV	890	2005	LCD32XR1	back	Sanyo	China	black	no	32in
47B	5/31/2013	RCN	LCD TV	151354	2010	TH-L19X10ZP	rim	Panasonic Viera	Malaysia	silver	yes	19in
47Fr	5/31/2013	RCN	LCD TV	230711	2010	TH-L19X10ZP	back	Panasonic Viera	Malaysia	dark grey	yes	19in
48	5/31/2013	RCN	LCD TV	106930	2006	TL42WRA-W	rim	Uniden	China	white	no	42in
48B	5/31/2013	RCN	LCD TV	173140	2006	TL42WRA-W	back	Uniden	China	white	yes	42in
49	5/31/2013	RCN	TV rear projection	87	2003	unknown	back	unknown	unknown	grey	no	very large
49	5/31/2013	RCN	TV rear projection	161	2003	unknown	side	unknown	unknown	grey	no	very large

Appendix A: XRF Measurement Data for Bromine (Br).

Sample No.	Date	Recycler	Equipment type	Br (ppm) by XRF	Year of manufacture	Model	Component Part	Brand	Country of manufacture	Plastic colour	Sample collected?	Size
50	5/31/2013	RCN	Toner cartridge	74476		4047	unit	Konica Minolta	China	black	yes	N/A
51Fr	5/31/2013	RCN	CRT TV	182843	2004	CX51HF3	rim/side	Sharp	Malaysia	grey	yes	51cm
51B	5/31/2013	RCN	CRT TV	183115	2004	CX51HF3	back	Sharp	Malaysia	dark grey	yes	51cm
52	5/31/2013	RCN	CRT TV	187846	2005	KV-XR29M31	rim/side	Sony Trinitron	Malaysia	silver	no	68cm
52	5/31/2013	RCN	CRT TV	218133	2005	KV-XR29M31	back	Sony Trinitron	Malaysia	dark grey	no	68cm
53	5/31/2013	RCN	Printer inkjet	6		DCP-165C	lid	Brother	China	white	no	N/A
53	5/31/2013	RCN	Printer inkjet	11		DCP-165C	back	Brother	China	white	no	N/A
54	5/31/2013	RCN	Printer inkjet	164	2001	C8942A	lid	HP	Thailand	cream	no	N/A
54	5/31/2013	RCN	Printer inkjet	62	2001	C8942A	side	HP	Thailand	blue	no	N/A
55	5/31/2013	RCN	Printer inkjet	11	2006	C9079A	lid	HP	Thailand	cream	no	N/A
55	5/31/2013	RCN	Printer inkjet	17	2006	C9079A	side	HP	unknown	grey	no	N/A
56	5/31/2013	RCN	Printer inkjet	18		unknown		Canon	unknown		no	N/A
57	5/31/2013	RCN	laser printer	2208	1998	LaserWriter 12/640PS		Apple	unknown		no	N/A
58	5/31/2013	RCN	laser printer	54	1999	unknown		HP	unknown		no	N/A
59	5/31/2013	RCN	laser printer	22		8051		HP	unknown		no	N/A
60	5/31/2013	RCN	laser printer	4738	2000-e	8L1430		Brother	unknown		no	N/A
61	5/31/2013	RCN	laser printer	54		FIL-1430		Brother	unknown		no	N/A
62	5/31/2013	RCN	fax	11		Fax2850		Brother	unknown		no	N/A
63	5/31/2013	RCN	fax	4		Fax1840		Brother	unknown		no	N/A

Notes:
[1] Results obtained using handheld Innov-X Alpha-4000 X-Ray Fluorescence Analyser, optimised for a detection limit of approximately 10ppm.

Appendix A: XRF Measurement Data for Bromine (Br).

Sample No.	Date	Recycler	Equipment type	Br (ppm) by XRF	Year of manufacture	Model	Component Part	Brand	Country of manufacture	Plastic colour	Sample collected?	Size

[2] The use of “e” in *Year of Manufacture* column denotes the author’s best estimate.
[3] 10,000 ppm = 1%.

Appendix B

BFR (including PBDE) Laboratory Analysis Report

UNIVERSITY AMSTERDAM

Institute for Environmental Studies (IVM)

2980

Geoff Latimer | Senior Manager
ENVIRON Australia Pty Ltd
Level 3, 224 Queen Street
Melbourne, VIC 3000
Australia

DATE	OUR REFERENCE	YOUR LETTER DATED	YOUR REFERENCE	
12 August 2013	C13/0073/SB/bs			
E-MAIL	TELEPHONE	FAX	ENCLOSURE(S)	PAGE
sicco.brandsma@vu.nl	+31 (0)20-5989566	+31 (0)20-5989553	Appendix 1	1 of 2

Subject: **Final Results Tender P-13/42**

Dear Geoff,

Enclosed you receive the final results of the PBDEs and TBBPA analyzed in the 15 plastic samples. The results are listed in Appendix 1. Two samples contain high levels of BDE209 and two samples contain high levels of TBBPA. In Appendix 1 I have also included the detection of BTBPE in one sample and DBDPE in six samples.

The plastic samples are homogenized and grinded to fine particles to extraction. The plastics that dissolve in organic solvent will be extracted by liquid/liquid extraction. The plastics that do not dissolve in the organic solvent were grinded and ultrasonic extracted. Cleanup was performed following IVM protocol using silica columns. The purified extracts were analyzed by gas chromatography (GC) with electron capture negative ionization technique and mass spectrometry detection (GC/ENCI-MS) for PBDEs and TBBP-A using a 50 and 15 meter GC column and measuring the specific bromine m/z 79, 81, 484, 486, 544 and 542.

For the QA/QC we included two blank samples, and one of the plastic samples was extracted and analyzed in duplicate. In addition, we included a IRMM references sample of poly ethyleneterephtalate (PET) containing BDE47, BDE100, BDE183 and BDE209. In the table below you can see that the results of the references sample, analysed in the same run as the 15 plastic samples, is in good agreement for all four the PBDEs. The values are within the ranges given for the certified references sample (CRM).

µg/g	CRM assigned values	CRM measured values
BDE47	227 ± 25	205
BDE99	307 ± 31	307
BDE183	94 ± 18	98
BDE209	689 ± 126	805

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Two blanks were included and no PBDEs were detected in the blanks. Limit of detection (LOD) were calculated by 3 times the noise in the samples divided by the peak height of the standards multiplied by the concentration of the standard.

Kind regards,

Sicco Brandsma
Researcher

Appendix I: BFR concentration (µg/g) found in the plastic samples.

Sample number	12	14	16	17	24	28	32B	37	41	47B	47Fr	48B	50	51Fr	51B
Equipment type (µg/g)	copier	laser printer	printer/ copier	printer/ copier	CRT monitor	Fridge	CRT TV - portable	CRT TV	LCD TV	LCD TV	LCD TV	LCD TV	Toner cartridge	CRT TV	CRT TV
BDE28	<10	<10	<10	<10	<10	<10	<9	<10	<10	<9	<10	<10	<10	<9	<10
BDE49	<10	<10	<9	<10	<10	<10	<9	<10	<10	<9	<10	<9	<10	<8	<10
BDE71	<10	<10	<10	<10	<10	<10	<9	<10	<10	<9	<10	<10	<10	<9	<10
BDE47	<10	<10	<9	<10	<10	<9	<8	<10	<10	<8	<9	<9	<9	<8	<10
BDE66	<10	<10	<10	<10	<10	<10	<9	<10	<10	<9	<10	<10	<10	9	<10
BDE77	<9	<8	<7	<8	<9	<8	<7	<9	<8	<7	<8	<7	<8	<7	<8
BDE100	<8	<7	<6	<7	<8	<7	<6	<8	<7	<6	<7	<6	<7	<6	<7
BDE119	<9	<8	<7	<8	<9	<8	<7	<8	<8	<7	<8	<7	<8	<6	<8
BDE99	<8	<8	<7	<8	<9	<7	<6	<8	<8	<6	<7	<7	<7	<6	<8
BDE85	<7	<7	<6	<7	<7	<6	<5	<7	<7	<5	<6	<6	<6	<5	<6
BDE126	<8	<7	<6	<7	<8	<6	<6	<7	<7	<6	<7	<6	<7	<6	<7
BDE154	<10	<10	<10	<10	<10	<10	<9	<10	<10	<9	<10	<10	<10	<9	<10
BDE153	<9	<8	<7	<8	<9	<7	<7	<8	<8	<7	<8	<7	<8	<6	<8
BDE138	<7	<6	<6	<6	<7	<6	<5	<6	<6	<5	<6	<5	<6	<5	<6
BDE156	<20	<10	<10	<10	<20	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
BDE184	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
BDE183	<20	<20	<10	<20	<20	<20	<10	<20	<20	<10	<20	<10	<20	<10	<20
BDE191	<30	<30	<20	<30	<30	<30	<20	<30	<30	<20	<30	<20	<30	<20	<30
BDE197	<50	<50	<40	<50	<60	<50	<40	<50	<50	<40	<50	<40	<50	<40	<50
BDE196	<50	<50	<40	<50	<60	<50	<50	<50	<50	<50	<50	<50	<50	<40	<50
BDE209	<60	<60	<50	<60	**20500**	<50	<50	**60200**	<60	<50	<50	<50	<50	<50	<50
TBBPA	<40	<30	<30	<30	<40	<30	<30	**83000**	**159000**	<30	<30	<30	<30	<30	<30
BTBPE	**XX**														
DBDPE						**XX**				**XX**	**XX**	**XX**	**XX**		**XX**

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