POPs in Construction and Demolition Waste

Phase 2

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Foreword

This report was produced by Vivien Lim, Joe Holland and Richard McKinlay on behalf of the Water Research Centre Limited (WRc).

WRc provides research and consultancy in water, waste and the environment in the United Kingdom, working with both public and private sector organisations. Amongst other activities, WRc supports the waste industry through the analysis of challenging waste streams, including waste electrical and electronic equipment, incinerator bottom ash and metal shredder residues.

WRc was commissioned to undertake this supplementary sampling and analysis programme by the Environment Agency (EA) to investigate the presence of substances classified as persistent organic pollutants (POPs). This study is a follow on to the initial national study on C&D waste which concluded in March 2025.

This report can be used by government, regulators, manufacturers, retailers, waste management companies and recyclers to understand which classified substances may be present in specific C&D products. It will help inform decision making on waste classification and management.

WRc would like to give special thanks to the companies who provided samples, and the expert laboratories who conducted a comprehensive suite of analyses.

Executive Summary

Background

In March 2025 WRc, working alongside European expert laboratories, completed a project on behalf of the Environment Agency to quantify persistent organic pollutants (POPs) and substances classified with hazard statement codes in construction and demolition (C&D) waste. The project included the design of a sampling strategy based on target categories, the collection of over 1,000 products, and the subsequent semi-quantitative and quantitative analysis for a range of POPs and classified substances.

Although the project provided significant insight into the types and quantities of target substances in C&D waste, further quantitative analysis was deemed beneficial to provide further certainty, and to provide information on a wider range of C&D products.

The results from Phase 1 showed that 27 out of 62 samples sent for quantitative analysis of chlorinated paraffins (CPs) contained short chained chlorinated paraffins (SCCPs) and/or medium chained chlorinated paraffins (MCCPs) above limits of quantification (LOQ). The concentrations of MCCPs (in the range of 1,000 – 10,000 mg/kg) were typically far greater than SCCPs (typically in the range of 1,000 – 2,000 mg/kg). SCCPs and MCCPs were primarily present in foam rubber insulation, traffic management products, adhesives and sealants and expanding fillers. Both SCCPs and MCCPs[1] are classified as POPs, with a POPs waste limit of 10,000 mg/kg for SCCPs and no limit yet defined for MCCPs.

Chemical screening used in Phase 1 to select samples for quantitative CP analysis showed limited success. In several instances, samples found to contain CPs from quantitative analysis were not identified by the screening test. Therefore, there is a knowledge gap with regards to the concentration of CPs in C&D waste.

Phase 1 also highlighted the potential for traffic management products (e.g. traffic cones) to contain SCCPs and MCCPs. This was based on the analysis of two samples, both with MCCP concentrations reported to be over 30,000 mg/kg. MCCPs are now listed as a POP, although no waste threshold has been established.

Data on brominated flame retardants (BFRs) in expanded and extruded polystyrene (EPS and XPS) insulation was also limited in Phase 1 due to the small number of samples that were identified at target sites. Testing identified one sample with a concentration of hexabromocyclododecane (HBCD) over 600 mg/kg. The POPs threshold for HBCD is

[1] MCCPs were listed under the Stockholm Convention in 2025, after Phase 1 of this study into C&D waste

1,000 mg/kg but due to analytical challenges, the actual concentration may be greater and could be above the threshold.

Objectives

The work carried out in Phase 2 had the following objectives:

- Further quantitative analysis of samples collected in Phase 1 that may contain CPs.
- The collection of traffic management products and quantitative analysis of CPs.
- The collection of EPS and XPS insulation foam and quantitative analysis of BFRs.

Results

This Phase 2 of the project utilised samples already collected in Phase 1 and included the collection of additional samples. Samples (from Phase 1) analysed included:

- un-plasticised polyvinyl chloride (uPVC) doors and window frames
- vinyl flooring
- pipes and ducting
- PIR (polyisocyanurate) and PUR (polyurethane) insulation.

Additional samples of traffic management products and EPS and XPS insulation foam were collected during Phase 2. Table 1 shows the number of samples collected and analysed in Phase 2.

Table 1 Samples collected and analysed in Phase 1 and Phase 2

Category	Samples collected in Phase 2	Samples analysed in Phase 2
uPVC doors and window frames	-	15
Vinyl flooring	-	15
Pipes and ducting	-	15
PIR insulation	-	3
PUR insulation	-	3
EPS / XPS insulation	10	5
Traffic management products	27	10

Samples collected in Phase 2 were screened using semi-quantitative x-ray fluorescence (XRF) to identify the levels of key elements of bromine, chlorine and antimony which may indicate the presence of BFRs or CPs. The Phase 1 and 2 samples were selected using the XRF data for new quantitative analysis at expert subcontracted laboratories.

The quantitative analysis showed that flooring, pipes and ducting and PIR/PUR insulation generally exhibited low CP concentrations, with six samples found to contain concentrations over the LOQ of 150 mg/kg. The results for these samples are given in Table 2. One of these samples (4153) exceeded the ecotoxic hazardous property (HP14) threshold (2500 mg/kg).

Table 2 New quantitative results for Phase 1 samples (flooring and pipes)

Sample	Category	Antimony (mg/kg)	Chlorine (mg/kg)	SCCP (mg/kg)	MCCP (mg/kg)
1196	PUR insulation	6,782	12,340	<150	576
2060	PIR insulation	18	8,589	<150	191
3033	Flooring	7,245	3,402	204	1,488
3068	Flooring	6,272	3,118	245	1,479
3098	Flooring	7,405	264,665	239	1,580
4153	Pipes	21,657	34,410	3,115	1,943

All of the door and window frame samples analysed were reported as <LOQ indicating an absence of SCCPs or MCCPs. This provides confirmation that unplasticised (rigid) PVC is unlikely to contain CPs.

The Phase 2 quantitative data matched well with the Phase 1 chemical screening data for samples where both tests were conducted. This provide some further confidence in the Phase 1 chemical screening results.

Certain traffic management products particularly cone bases, contained MCCPs at concentrations up to ~9,300 mg/kg, exceeding the HP14 threshold of 2,500 mg/kg. Of the 10 samples analysed, seven contained MCCPs at between 5,000 and 10,000 mg/kg. Levels of SCCPs were lower at 1,000 – 2,000 mg/kg in the same seven samples.

These products are typically made using post-consumer PVC cable granulate. MCCPs are currently used in these products, whereas SCCPs have been phased out but will still be present in legacy products which may be being recycled still. SCCPs were also used at lower concentrations than MCCPs due to their higher volatility.

The quantitative results for BFRs in EPS and XPS indicated that all of the samples were below detection limits for most BFRs quantified including polybrominated diphenyl ethers (PBDEs), tetrabromobisphenol A (TBBPA), and decabromodiphenyl ethane (DBDPE). However, hexabromocyclododecane (HBCD) was detected in four out of five insulation samples tested, with one sample exceeding the POPs waste limit of 1,000 mg/kg. It is possible the HBCD concentration is an underestimate due to analytical challenges, and based on the known use of HBCD in ESP and XPS insulation and the XRF bromine concentrations, it’s reasonable to assume the actual levels may be higher.

Obtaining additional EPS and XPS C&D samples proved challenging, resulting in a limited new dataset. Furthermore, the quantitative BFR analysis did not align with the bromine XRF results with higher bromine identified than in the quantitative analysis. This could potentially be due to the presence of insoluble BFRs that are difficult to extract and quantify (for example, deca-BDE). Additionally, there have previously been difficulties in accurately measuring HBCD due to matrix interferences. The challenges of CPs analysis were also noted, the multiple overlapping peaks in the chromatograms may lead to differences in results between laboratories, such as those seen in quality control samples.

This second phase of the national C&D arisings research project provides more evidence on the concentrations of CPs in various products, with a particular prevalence in traffic management products (i.e. traffic cones) made using post-consumer PVC cable granulate. Although additional EPS and XPS samples were difficult to source, of the 10 collected, four contained HBCD, with one having concentrations over the POPs limit. Due to uncertainties as to the accuracy of the HBCD quantitative data, all four samples found to contain HBCD may exceed the POPs waste threshold.

1. Introduction

1.1. Background

In March 2025 WRc, working alongside European expert laboratories, completed a project on behalf of the Environment Agency to quantify persistent organic pollutants (POPs) and substances classified with hazard statement codes in construction and demolition (C&D) waste. The project included the design of a sampling strategy based on target categories, the collection of over 1,000 products, and the subsequent semi-quantitative and quantitative analysis for a range of POPs and classified substances.

Although the project provided significant insight into the types and quantities of target substances in C&D waste, further quantitative analysis was deemed beneficial to provide further certainty, and to provide information on a wider range of C&D products.

A second phase of work has therefore been carried out, focusing on the analysis of short and medium-chained chlorinated paraffins (SCCPs and MCCPs) and brominated flame retardants (BFRs) in a number of target product categories. Since the completion of Phase 1, MCCPs have been listed under the Stockholm Convention as a POP, although no POPs waste threshold has been established.

Chemical screening used in the Phase 1 study (completed in March 2025) to select samples for quantitative CP analysis showed limited success. In several instances, samples found to contain CPs from quantitative analysis were not identified by the screening test. Therefore, there is a knowledge gap with regards to their abundance in C&D waste

Furthermore, additional clarity on the quantity of BFRs in insulation was sought.

This second phase of the project (Phase 2) utilised samples already collected in Phase 1 and included the collection of additional samples. This report should be read in conjunction with the Phase 1 report, in which the wider context and results are presented.

1.2. Aims

The objectives of the project were to:

- identify and prepare samples from materials collected in Phase 1, to be sent to for quantitative analysis at subcontracted laboratories.15 samples were selected from the following categories:
    - un-plasticised (rigid) PVC (uPVC) frames
    - pipes and ducting
    - vinyl flooring.

  Three samples were also selected from the following two categories:
    - polyisocyanurate (PIR) insulation
    - polyurethane (PUR) insulation
- obtain samples of traffic management products which may contain SCCPs and MCCPs. Traffic cones, signs and barriers are typically made using post-consumer materials such as cable sheathing which is known to contain these substances.
- carry out quantitative analysis for SCCPs and MCCPs for all 45 samples selected from Phase 1 and 10 traffic management products. Dechlorane plus was included in the analytical suite although was not a primary focus of the study.
- obtain samples of expanded polystyrene (EPS) and extruded polystyrene (XPS) insulation and carry out quantitative analysis for BFRs on up to 10 samples. The use of BFRs, specifically hexabromocyclododecane (HBCD), was known to be widespread in this product and so further evidence of the quantity in legacy products is needed.
- assess the consistency of laboratory reporting through the analysis of QC samples where quantitative POPs data was obtained in Phase 1.

2. Sampling Methodology

2.1. Sample Selection and Preparation

2.1.1. Phase 1

Chemical screening in Phase 1 for SCCPs and MCCPs showed limited correlation with the quantitative analysis. Both SCCPs and MCCPs have a classification of H410 which has a HP14, ecotoxic contribution threshold of 1,000 mg/kg and an additive hazardous threshold of 2,500 mg/kg. The POPs threshold for SCCPs is currently 10,000 mg/kg, with no limit set for MCCPs. Some samples in which quantitative analysis identified SCCPs and MCCPs concentrations above 1,000 mg/kg were not identified during screening. This created a knowledge gap in terms of their abundance in C&D waste.

As a result, additional chlorinated paraffins (CPs) quantification was carried out on 15 samples from each of the following product categories:

- uPVC windows and doors
- flooring (specifically vinyl flooring)
- pipes and ducting

Additionally, three samples of PIR (polyisocyanurate) and PUR (polyurethane) insulation, which had undergone XRF testing in Phase 1, were selected for further quantitative analysis of SCCPs, MCCPs and dechlorane plus in Phase 2.

The sections below set out the justifications for sample selection for quantitative analysis in Phase 2.

Doors and window frames

Quantitative analysis carried out in Phase 1 identified three samples with elevated (>1,000 mg/kg) concentrations of SCCPs or MCCPs. The sample with the highest concentration of SCCPs and MCCPs in the doors and window frames category was a “plastic door trim”. A brown/black window frame also contained SCCPs. All samples with SCCPs or MCCPs at >1,000 mg/kg also contained antimony at ~1,000 mg/kg or greater. Antimony is a known synergist for flame retardants, including CPs.

Arsenic did not appear to be correlated with elevated CPs concentration, however it is likely an indication of the age of the product (with older products more likely to contain arsenic) and so information on corresponding arsenic and CPs concentration may be helpful.

The information shown in Table 2.1 was used to select 15 further samples for quantitative analysis.

Flooring

During Phase 1, four flooring samples were quantitatively analysed for CPs, with three found to contain SCCPs (>200 mg/kg) and MCCPs (>1,000 mg/kg). Two of these were vinyl flooring and the third was an underfloor backing layer.

As with the window and doors, there appears to be some correlation between antimony and CPs. Other than this, the chlorine level was the only other indicator of CPs that could be discerned from the limited data set. Samples were therefore selected based on antimony concentration, and whether the samples had already been analysed using chemical screening in Phase 1. Table 2.2 details the samples selected for quantitative analysis in Phase 2. A variety of colours/designs, as well as rigid vinyl were selected.

Pipes and ducting

During Phase 1 only two pipes and ducting samples were quantitatively analysed for CPs concentrations, with one sample found to contain high (>10,000 mg/kg) levels of MCCPs.

Aside from the chlorine concentration, there was no other information on which to base sample selection. Therefore, samples were selected based on whether chemical screening was carried out and the concentration of antimony, arsenic and lead. Table 2.3 details the samples selected for quantitative analysis in Phase 2.

Table 2.1 Window and door samples selected for Phase 2 quantitative analysis

Sample code	Description	Colour	Cl (mg/kg)	As (mg/kg)	Sb (mg/kg)	Pb (mg/kg)	Justification
2005	Window frame	Brown	149,565	216	957	10,560	Colour, elevated antimony concentration
2006	Window frame	White	273,332	1,249	18	32,143	Elevated arsenic concentration
2018	Window trim	White	218,971	884	18	23,761	Trim component, elevated arsenic concentration
2021	Window frame	Brown	101,296	390	920	18,007	Colour, elevated antimony concentration
2024	Window frame	Brown	56,382	510	553	22,900	Colour, presence of antimony and arsenic
2030	Window frame	White	341,942	302	909	10,534	Elevated antimony concentration
2035	Window frame	White	332,382	484	534	15,204	Presence of antimony and arsenic
2096	Window trim	White	295,183	359	18	14,450	Trim component, presence of arsenic
2121	Windowsill	White/ Brown	134,857	6	1,294	4	Elevated antimony concentration
2128	Window frame	Brown	45,760	6	18	14,121	Colour
6017	Window frame	Brown/Black	46,802	6	873	7,794	Colour
7022	Widow frame & expanding seal	White/Grey	115,458	75	18	3,798	Contains an expanding seal
R004	Window frame	White	217,602	459	18	15,875	Presence of arsenic
R022	Window trim	White	321,584	1,719	18	28,806	Trim component, elevated arsenic concentration
R024	Door frame	White	256,909	519	18	16,482	Presence of arsenic

Table 2.2 Flooring samples selected for Phase 2 quantitative analysis

Sample code	Description	Colour	Cl (mg/kg)	As (mg/kg)	Sb (mg/kg)	Pb (mg/kg)	Justification
1044	Vinyl flooring - wood pattern	Brown	200,542	3	18	4	Chemical screening results
2144	Vinyl flooring	Brown	86,485	6	18	7	Random selection
2155	Vinyl flooring reinforced with mesh	Grey	97,105	6	18	4	Chemical screening results
2158	Vinyl flooring	Grey	120,520	6	18	4	Random selection
3033	Vinyl flooring - wood pattern, on top of carpet	Brown	3,402	6	7,245	4	High antimony concentration
3068	Vinyl flooring	Brown	3,118	6	6,272	4	High antimony concentration
3098	Vinyl flooring	Brown	264,665	6	7,405	10	High antimony concentration
4134	Vinyl flooring	Grey	165,911	6	18	26	Random selection
6007	Rigid vinyl - wood pattern	Grey	16,188	9	18	15	Rigid vinyl material
6010	Vinyl flooring - wood pattern	Brown	44,677	6	18	4	Random selection
6016	Rigid vinyl - wood pattern	Grey	75,431	10	18	87	Rigid vinyl material
7016	Vinyl flooring - tile pattern	White/Black	27,977	6	18	4	Random selection
7028	Vinyl flooring	Grey	136,821	6	18	7	Random selection
R047	Vinyl flooring with insulation	Black	180,737	14	18	177	Chemical screening results
R051	Vinyl flooring	Brown	245,278	6	18	55	Chemical screening results

Table 2.3 Pipes and ducting samples selected for Phase 2 quantitative analysis

Sample	Description	Colour	Cl (mg/kg)	As (mg/kg)	Sb (mg/kg)	Pb (mg/kg)	Justification
1004	Plumbing pipe	Grey	307,701	1,611	276	31,936	Elevated arsenic concentration
1028	Drain pipe	Brown	523,279	3	573	4	Presence of antimony
1030	Gutter	Black	392,068	687	18	21,914	Presence of antimony
1035	Cable carrier	White	196,216	11	18	26	Used alongside cables and made in China
1098	Gutter	Black	186,722	390	18	15,743	Presence of antimony
1159	Pipe joint	Black	496,868	3	18	4	Chemical screening results
1164	External pipe	Orange	280,999	3	1,169	4	Elevated antimony concentration
1238	Gutter	Grey	75,323	71	18	17,212	Chemical screening results
3110	Hose with valve	Red	18,012	207	1,315	6,003	Elevated antimony concentration
4005	MUPVC Pipe	Grey	450,272	6	1,912	4	Elevated antimony concentration
4119	Pipe	White	391,238	6	18	4	Chemical screening results
4153	Bendy PVC hose	Black	34,410	610	21,657	11,603	Elevated antimony concentration
7043	Gutter	Black	150,512	2,870	18	57,623	High arsenic concentration
R002	Gutter	White	269,976	77	18	7,648	Chemical screening results
R015	Waste water pipe	Blue	376,893	6	18	8	Chemical screening results

PIR and PUR Insulation

During Phase 1, several PIR and PUR samples were tested for SCCPs and MCCPs. These are shown in Table 2.4.

Table 2.4 Quantitative and XRF results for PIR/PUR insulation from Phase 1

Sample	Category	Units	Sb	Cl	SCCP	MCCP
1194	PIR Insulation	mg/kg	<54	13,236	<700	2,800
N2	PIR Insulation	mg/kg	<54	32,875	<600	<600
2084	PUR Insulation	mg/kg	4,301	9,943	<600	<600
2085	PUR Insulation	mg/kg	<54	3,675	<600	<600
2161	PUR Insulation	mg/kg	<54	25,008	<600	<600
7007	PUR Insulation	mg/kg	<54	20,001	<600	<600
7040	PUR Insulation	mg/kg	5,499	8,463	<600	7,600

Of the six samples, two contained MCCPs above LOQ. Neither of these samples were identified from the chemical screening and it was therefore recommended that six further samples undergo testing for MCCPs, SCCPs and dechlorane plus. Three PIR samples were selected on the basis that they had low antimony concentrations, and three PUR samples were selected on the basis that they had high antinomy concentrations. This was to test the hypothesis that antimony is an indicator of MCCPs concentration. Table 2.5 shows the PIR and PUR samples selected for further testing.

Table 2.5 PIR and PUR insulation samples selected for Phase 2 quantitative analysis

Sample	Category	Units	Sb	Cl
1100	PIR Insulation	mg/kg	<54	31,276
2060	PIR Insulation	mg/kg	<54	8,589
2190	PIR Insulation	mg/kg	<54	11,764
1196	PUR Insulation	mg/kg	5,789	12,669
4030	PUR Insulation	mg/kg	6,782	12,340
7005	PUR Insulation	mg/kg	3,761	5,771

2.1.2. Phase 2

Analysis carried out in Phase 1 included the CP quantification in two traffic management products. Both samples were found to contain high concentrations of MCCPs (81,400 mg/kg and 37,000 mg/kg for samples 1069 and 1210, respectively). The limit of detection (LOD) for SCCPs was relatively high (< 5,200 mg/kg). Therefore, reducing the LOD was necessary to enable quantification of SCCPs. These products are typically made using post-consumer cable granule. PVC cable sheathing is known to contain CPs, as these were added to improve the flame retardancy of flexible PVC which is otherwise compromised by the inclusion of plasticisers.

End-of-life traffic management samples were provided by a traffic management company, who source equipment from multiple manufacturers. The company reported the cones rather than the bases are typically recycled at the end of their life, but the bases were typically disposed. The manufacturers are now offering a take back system for all parts of the cone, including the bases. WRc visited the traffic management company to collect a range of end of life (broken or damaged) products which were to be disposed of. In total 27 samples were obtained.

To collect insulation samples, WRc primarily contacted demolition contractors and tradespeople and requested any identifiable EPS and XPS insulation materials encountered during demolition. Recycling facility managers were also contacted to provide any insulation materials identified during their operations. Trade associations, local authorities and housing associations were also contacted to enquire if any active renovation projects were being carried out in which EPS or XPS may be being removed. Despite contacting substantial number of companies and individuals, the identification and collection of EPS and XPS was difficult, resulting in only 10 samples being obtained, which is considered to be a true reflection of the limited occurrence of this material from these sources.

Samples were collected by WRc or via a courier to the WRc laboratory in Swindon. At WRc, samples were labelled and photographed. Logging of samples was carried out and included the following details:

- a unique sample identification (ID) number and sample code
- the origin site code and site type
- date of sample collection
- C&D waste material category
- a description of the sample

2.2. Sample Preparation for Quantitative Analysis

Selected samples from Phase 1, as discussed in Section 2.1.1, were retrieved and cryogenically milled to <1 mm.

All insulation and traffic management samples were scanned using XRF to provide a semi-quantitative elemental composition. Initial XRF scanning was carried out to identify key elements indicative of POPs and samples were selected for quantitative analysis. This selection was based primarily on chlorine, bromine, antimony and arsenic concentrations. Selected samples were prepared by cryogenically milling to <1 mm before being submitted for quantitative analysis.

2.3. Analytical Methodology

2.3.1. Semi-quantitative analysis (XRF)

In-house XRF scanning was carried out, on every sample collected, using a handheld analyser (Brüker S1 Titan) with a mode specifically calibrated for polymers (restricted materials). Restricted materials mode utilises a number of calibrations, the most appropriate of which is automatically selected within the first few seconds of scanning based on the material under analysis. This includes low, mid and high-density polymer material calibrations. Five to six scans were undertaken on each sample to produce an average concentration of a range of elements including bromine, chlorine, antimony, lead and zinc.

Highly porous samples, such as foam insulation, were prepared using a 10-tonne hydraulic press to produce a compressed sample ahead of XRF analysis. The preparation was completed to try and minimise the under reporting of concentrations as a result of the materials low density.

A suite of target elements was identified and extracted from the XRF results to generate a dataset for initial characterisation of the samples. The target elements were identified as indicators for the presence of POPs or substances with hazard statement codes. For example, bromine would indicate the presence of brominated flame retardants (BFRs), several of which are POPs. From this suite, key elements of the most importance have been presented in this report, with the full XRF dataset available in the accompanying WRc spreadsheet report (UC19582.1).

Table 2.6 shows the key elements discussed in this report and the justification for their selection.

Table 2.6 Key target elements in XRF analysis

Element	Justification
Antimony	Antimony trioxide is a synergist for BFRs and was used to improve the flame retardancy of PVC. If antimony and bromine are present at significant levels (>1,000 mg/kg) it suggests the bromine can be linked to the presence of BFRs.
Arsenic	Arsenic has been used in polyvinyl chloride (PVC) as an additive. The exact arsenic compound present cannot be determined so a worst-case compound of arsenic trioxide has been assumed.
Bromine	Bromine present in brominated flame retardants was a common additive in plastic products. Several BFRs carry hazard statement codes of relevance to hazard classification and/or are classified as POPs.
Chlorine	Chlorine is a fundamental building block of PVC. Chlorine can be used as an indicator for the presence of chlorinated paraffins. Short chain chlorinated paraffins (SCCPs) are classified as a POP, and medium chain chlorinated paraffins (MCCPs) have been proposed for listing under the Stockholm convention as a POP.

2.3.2. Quantitative chlorinated paraffins analysis – Centexbel

Quantitative testing of CPs was carried out by Centexbel on 48 samples from Phase 1, and 10 traffic management samples.

Analytical method

Centexbel tested samples for SCCPs, MCCPs and dechlorane plus using gas chromatography negative ion chemical ionization mass spectrometry (GC-NCI-MS) according to the reference method ISO 22818:2021. The specific method used by Centexbel is described below:

1. 0.5 g of the target substance is weighed with an analytical balance in a reaction tube.

2. 5ml of toluene is added, before the reaction tube is closed and extracted in an ultrasonic bath at 60°C for 60 minutes. This is then allowed to cool to room temperature.

3. 2ml of the toluene extract is placed in a vapour sleeve and evaporated. 2ml of n-hexane is added and dissolved by shaking on a vortex for 30s.

4. 250 µl internal standard (C = 5 µg/ml Lindane) is added and the container is filled up to the mark with n-hexane.

5. 2 ml of the n-hexane extract is filtered through a membrane filter (0,45 µm) and transferred into a glass tube with screw cap.

6. 1 ml sulphuric acid > 96% is added and this is shaken for 30 minutes. To prevent phase separation the sample may be centrifuged.

7. 1 ml of the n-hexane phase is placed in a tube with 3 ml of demineralised water and centrifuged for 30s. The water phase is removed and this is vortexed again for 30s with 3 ml of demi-water.

8. The n-hexane phase is then filtered through a Na_2SO_4 filter into a GC vial.

9. After the purification the sample is measured by GC-NCI-MS

Table 2.7 provides the instrumental set-up criteria used by Centexbel. Quality control (QC) steps are in place to ensure measurements are reliable. Centexbel provided information on the instrumentation, methodology and QC process for SCCPs and MCCPs, shown in Table 2.8.

Table 2.7 GC/MS Parameters

Category	GC/MS Parameter
Carrier Gas	Helium Column flow: 1,0 mL/min, constant flow
Oven temperature Injector type	120 °C (2,0 min), 20 °C/min to 325 °C (7,75 min) PTV-injector
Mode	PTV Splitless (1,5 min), 10 ml/min split flow rate, constant septum purge
Injection program	50 °C, 8,5 °C/s, 280 °C (1,5 min)
Injection volume	1 µl
Column	Restek Rxi® 5 SIL MS 30 m x 0,25 mm x 0,25 µm
Transfer line temperature	300 °C
Source temperature	200 °C
Ionisation	Negative CI
CI gas	Methane, gas flow 1,5 ml/min
Emission current	50 µA
Scan parameters	SIM
Software	Chromeleon

Table 2.8 QC criteria for SCCP and MCCP

Parameters	QC Criteria
C1	Identification of all components with retention time in the chromatogram **Linear:** residual deviation < 25 % **Quadratic:** residual deviation < 25 %
Calibration solutions C1-C4	Correlation coefficient > 0,995 recovery IS: 70-130 % **Linear:** residual deviation STD-maximum 15 % (excl. C1 25 %) **Quadratic:** residual deviation STD-maximum 10 % (excl. C1 25 %)
Drift Control C4	Recovery IS: 70-130 %; Maximum deviation 25 %
Samples	Positive samples within measurement range calibration Dilution required (maximum 1:100) Recovery IS: 50 – 130 % If the recovery is lower than 20%, the results may not be reported. If the recovery is between 20 – 50 %, the results may be reported if lower than the reporting limit.
Sensitivity check C1	**Linear:** Maximum deviation 25 % **Quadratic:** Maximum deviation 25 % In case of deviation, positive samples between C1 and C2 cannot be reported, and the analysis is repeated.
Procedure blank (PB)	Interfering peaks must not exceed 1/2 peak height of standard C1 Recovery IS calculated from the area IS PB

2.3.3. Quantitative BFR analysis – Fraunhofer Institute

Quantitative testing of selected BFRs was also carried out by the Fraunhofer Institute for Process Engineering and Packaging IVV (Fraunhofer) on six insulation samples (including one QC insulation sample) and 10 traffic management samples. Fraunhofer have specific experience of testing these complex matrices, and they have previously carried out real time method adjustments to ensure the highest possible data quality.

The list of all samples selected for each analysis suite is provided in the accompanying WRc spreadsheet report (UC19582.1).

Analytical method

Each sample was first screened using XRF spectrometry to determine an initial bromine concentration in the finely ground test material. To extract the target substances, 0.1 g of sample material was dissolved in toluene and then filtered. Some samples, where the matrix was partially or completely dissolved, required an additional cleanup step using ethanol. The internal standards were added to the filtered solution. A procedural blank containing the internal standard was prepared in parallel. The list of the substances analysed by Fraunhofer is provided in Table 2.9. A full list of the substances quantified, alongside a more detailed methodology is provided in Appendix B.

Table 2.9 Substances included in quantitative analysis by Fraunhofer

Substance	Acronym
Polybrominated diphenyl ethers (mono to deca-BDE)	PBDEs
Tetrabromobisphenol A	TBBPA
Decabromodiphenyl ethane*	DBDPE
Hexabromocyclododecane	HBCD

*semi-quantitative

The analysis was carried out using gas chromatography mass spectrometry (GC-MS) and quantification was then achieved using the external calibration and the internal standards for PBDEs, HBCD and TBBPA. DBDPE is very insoluble in most solvents and this impacts on the efficacy of the extraction process for both the sample and internal standard. To produce semi-quantitative results for DBDPE, it was necessary to use deca-BDE as an alternative calibration standard. The residue precipitated and removed during the extraction process was also analysed by XRF to provide a measure of the bromine extraction efficiency of the procedure and provide further context to the test findings.

3. Results and Discussion

In addition to the 45 samples from Phase 1, a further 10 insulation samples and 27 traffic management samples were collected for analysis as part of Phase 2. This section provides a summary of the semi-quantitative XRF scanning, and the quantitative test results. The sample details and full analytical data is included in the excel spreadsheet that accompanies this report (WRc spreadsheet report UC19582.7).

3.1. Insulation – EPS/XPS

In total, 10 insulation samples were collected from residential and commercial demolition sites. Table 3.1 shows the number of insulation samples collected for each category. The insulation materials were primarily obtained during the demolition and renovation of residential and commercial buildings, particularly when parts of the building, such as outer walls and roofs, were being dismantled or removed.

Each sample was labelled with relevant data including the building age and context (demolition or construction). This information can be found in WRc spreadsheet UC19582.1.

Table 3.1 Insulation categories

Category	Count	Description
Expanded polystyrene (EPS) insulation	7	A lightweight packaging and insulating material manufactured using beads of polystyrene within a mould which when subjected to heat or steam expand and fuse together. Commonly white in colour.
Extruded polystyrene (XPS) insulation	2	Rigid polystyrene insulation board with smooth non-porous surface. Formed with controlled heat and pressure, the plastic mixture is forced through a die (extruded), then allowed to cool and expand into the desired shape. The resulting rigid foam board is then trimmed to the final product dimensions.
Unknown	1	Unknown insulation type – this was excluded from analysis

The collection of EPS and XPS was very challenging. Despite contacting a wide range of small contractors, large demolition contractors, local authorities, housing associations, waste management and skip hire companies, and engaging with trade associations, only a limited number of samples were collected.

EPS and XPS is typically used in wall, flooring and ceiling insulation, and will only be removed during major refurbishments or demolition. Although these were targeted these

products were not widely identified. It is considered likely that that with very limited arisings it may be mixed with the general waste at the refurbishment/demolition site.

However, it has been used in large quantities in big build projects and it is believed that the frequency of removal is likely to increase in future years. An expert in the field commented that contractors may encounter this material twice a year, whereas previously it would have been once a year or not at all. At present there are either very limited quantities arising, or it is not being identified during refurbishment or demolition.

3.1.1. XRF scanning

Each insulation sample was scanned five to six times, and an average taken to give a concentration for the sample as a whole. The range of target element concentrations are presented in Figure 3.1 and Table 3.2.

Figure 3.1 Insulation screening XRF results

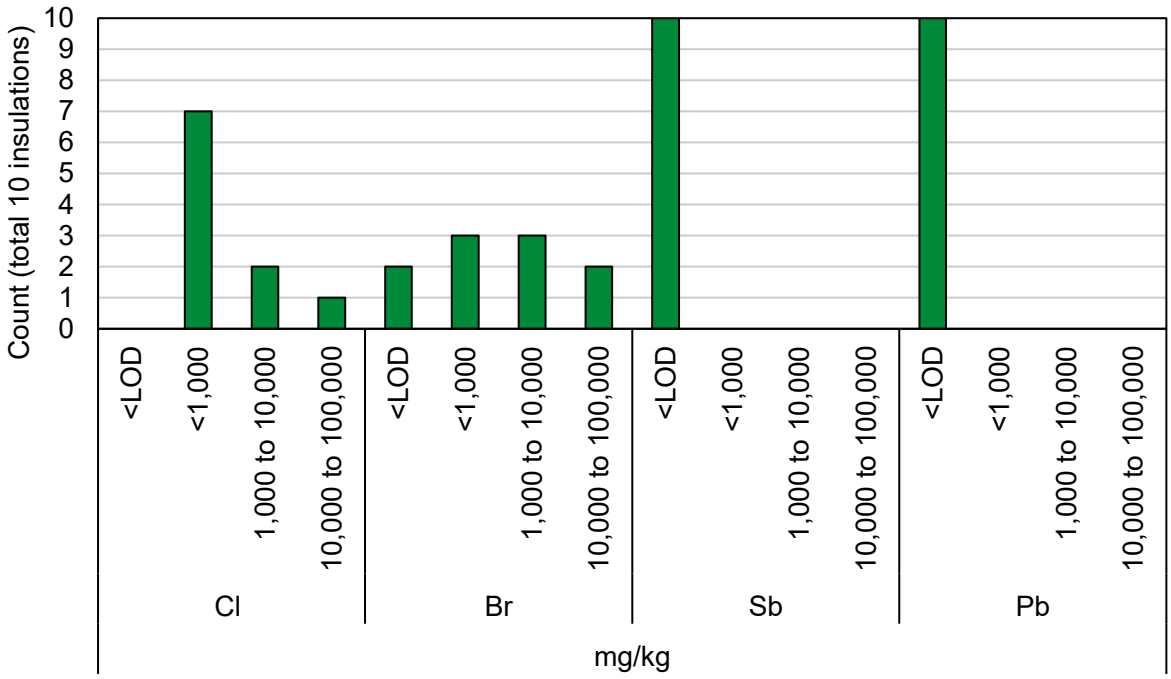


Table 3.2 XRF concentration ranges for each insulation category

Insulation	Chlorine (Cl)			Bromine (Br)		
	<1,000 mg/kg	1,000-10,000 mg/kg	10,000-100,000 mg/kg	<1,000 mg/kg	1,000-10,000 mg/kg	10,000-100,000 mg/kg
EPS	7	-	-	4	3	-
XPS	-	2	-	-	-	2
Unknown	-	-	1	1	-	-

Of the 10 insulation samples scanned, five contained bromine concentrations above 1,000 mg/kg. Two of these samples, both XPS, showed bromine levels above

10,000 mg/kg. The two XPS samples that contained bromine above 10,000 mg/kg also contained chlorine in the range of 1,000 to 10,000 mg/kg. These five insulation samples with bromine levels above 1,000 mg/kg were sent to Fraunhofer for quantitative BFRs analysis.

One additional sample, an unknown insulation type, had chlorine concentrations above 10,000 mg/kg. All other analysed elements, including zinc and lead were detected at concentrations below 1,000 mg/kg across all samples.

3.1.2. Quantitative results

Table 3.3 presents the quantitative concentrations of BFRs measured in the five insulation samples with bromine levels (XRF) above 1,000 mg/kg. A QC sample was also re-tested to assess analytical accuracy and method consistency, further discussed in Section 4.

Table 3.3 Insulation BFRs quantitative results - Fraunhofer

BFRs	Units	LOQ	EPS			XPS	
			8001	8002	8003	8004	8005
Bromine (XRF)	mg/kg	-	1,300	2,600	5,700	13,100	11,700
Hexa-BDE	mg/kg	7.7	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Hepta-BDE	mg/kg	2.6	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Octa-BDE	mg/kg	1.9	<LOQ	<LOQ	11.56	7.18	<LOQ
Nona-BDE	mg/kg	2.8	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Deca-BDE	mg/kg	2.4	21	<LOQ	<LOQ	<LOQ	<LOQ
TBBPA	mg/kg	10	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
DBDPE	mg/kg	4.8 *	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
HBCD	mg/kg	5.3	<LOQ	428	815	882	1,066

*estimated limit of quantification (LOQ) relying on the semi-quantitative approach based on similar responses of PBDE 209

The majority of BFRs in the insulation samples were below the limit of quantification (LOQ). Octa-BDE was detected at low concentrations (7.2 to 11.6 mg/kg) in two of the five samples. HBCD was detected in four insulation samples (two EPS and two XPS samples), with concentrations ranging from 428 mg/kg to 1,066 mg/kg.

The discrepancy with the XRF results may be attributed to the presence of insoluble BFRs in the insulation materials, which are difficult to extract and therefore challenging to quantify.

The current POPs waste threshold for HBCD is 1,000 mg/kg, meaning only one sample exceeded this (sample 8005). Samples 8003 and 8004 are marginally below. However, it

is worth noting that Fraunhofer has previously encountered challenges in quantifying HBCD in insulation, Phase 1 samples were unable to be accurately quantified and there is a disparity between the semi-quantitative XRF bromine concentration and the quantified BFRs.

Data submitted to the Stockholm Convention[2] states that 13,426 tonnes of HBCD was produced in 2009, and 95% of this was used in polystyrene insulation foams. As a BFR it is effective at relatively low concentrations of ~7,000 mg/kg for EPS and ~25,000 mg/kg in XPS[3]. The levels quantified in this study are well below this, although the XRF concentration is closer to these levels, and is higher in XPS than EPS as the literature suggest.

Since this study is sampling products, it would be reasonable to assume that the HBCD has been added at a functional level, and it is unlikely it was added at lower levels. This product is also unlikely to contain significant recycled content that may contain POPs, as this kind of EPS is not readily available for recycling. If recycled content is present, it would likely be from EPS packaging (e.g. packaging around electronics) which is recycled at scale in the UK.

The XRF bromine concentration has been used to calculate a theoretical HBCD concentration, shown in Table 3.4. This assumes that any un-accounted for bromine is present as HBCD. This is indicative only as XRF is not a quantitative analysis method, but it provides an indication of the possible HBCD concentration. This is more in line with the literature on HBCD use in EPS and XPS.

[2] Submission of information specified in Annex F of the Stockholm Convention pursuant to Article 8 of the Convention, Bromine Science and Environmental Forum (BSEF), 2010

[3] EPS Moulders Association, USA, https://epsbuildings.com/wp-content/uploads/2024/06/HBCD_Fact_Sheet.pdf

Table 3.4 Theoretical HBCD concentration based on XRF data

		EPS		XPS	
	Sample	**8002**	**8003**	**8004**	**8005**
XRF bromine concentration	mg/kg	2,550	5,686	13,057	11,738
Quantified bromine	mg/kg	321	620	667	800
Unaccounted for bromine	mg/kg	2,229	5,065	12,390	10,938
Concentration of HBCD if all unaccounted for bromine is also present as HBCD*	mg/kg	3,400	7,568	17,402	15,650

*Includes the quantified HBCD. HBCD bromine content 75%, Octa BDE bromine content 79%

Based on the known difficulties of quantifying HBCD in foams, the known use, the functional levels in EPS and XPS and the semi-quantitative bromine results, it is reasonable to conclude that the quantitative analysis is an underestimate of the HBCD concentrations in insulation foam.

HBCD is also classified under hazard statement codes H361, H362, H400, and H410[4]. Using the quantitative data, although the concentration of HBCD in sample 8005 exceeds the 0.1% cut-off value of hazardous property HP14, the calculated value remains below the 25% limit after applying a multiplication factor of 100 (according to equation 3 of WM3[5]). However, if using the theoretical HBCD concentration based on XRF data, all four samples would exceed the HP14 limit.

Two additional common BFR compounds were also analysed, TBBPA (classified under H350, H400, H410) and DBDPE (classified under H413). Both TBBPA and DBDPE were not identified above the LOQ in any of the samples analysed. PBDEs were not quantified at any significant concentration.

[4] H400 and H410 are industry classifications under REACH and the CLP

[5] *Guidance on the classification and assessment of waste (1st edition V1.2.GB)*. Available at: https://assets.publishing.service.gov.uk/media/68ecdc33f159f887526bbd43/CD6.5.pdf

3.2. Traffic Management Products

A total of 27 traffic management samples (including one sample of cone + base) were collected. Table 3.5 shows the number of traffic management items collected for each category.

Table 3.5 Traffic management categories

Category	Picture	Count	Description
Cones (from traffic cones)		2	Conical shaped highly visible barriers used to guide or divert traffic. Typically made from polyvinyl chloride (PVC), high-density polyethylene (HDPE) or low-density polyethylene (LDPE).
One-piece traffic cone		1	One-piece traffic cones consist of a cone and base formed as a single unit. The entire cone is made from a single material, typically dense rubber. These one-piece traffic cones are commonly produced through compression moulding using low-grade recycled materials.
Traffic cone base		11	The bases of traffic cones are designed to provide stability and weight to ensure the cones stay upright. These bases are typically made using compression moulding, from low-grade recycled materials like rubber or plastic granulates (sometimes derived from cable waste).
Barrier foot		2	Heavy bases used to support temporary barriers. Barrier feet are typically made from heavy-duty recycled plastic such as recycled PVC blends.

Category	Picture	Count	Description
Q-sign frame		2	A Q-sign frame is a portable sign support designed to hold temporary signage, commonly used in traffic management, construction areas, and event settings. These frames are typically manufactured using injection moulding and are made from HDPE, chosen for its durability, impact resistance, and suitability for outdoor use.
Signs		2	Temporary traffic management signs widely used in the UK for roadworks and other short-term traffic control situations. They are typically made from recycled polypropylene with high-visibility reflective faces.
Blow moulded and injection moulded polyolefin parts	 	7	Various polyolefin parts from traffic management items. These include barriers and parts used as fixtures.
Unknown		1	Unknown origin made of dense rubber similar to traffic cone bases.

3.2.1. XRF scanning

Each traffic management sample was scanned five to six times. The range of target element concentrations recorded for all the traffic management samples are presented in categories in Table 3.6.

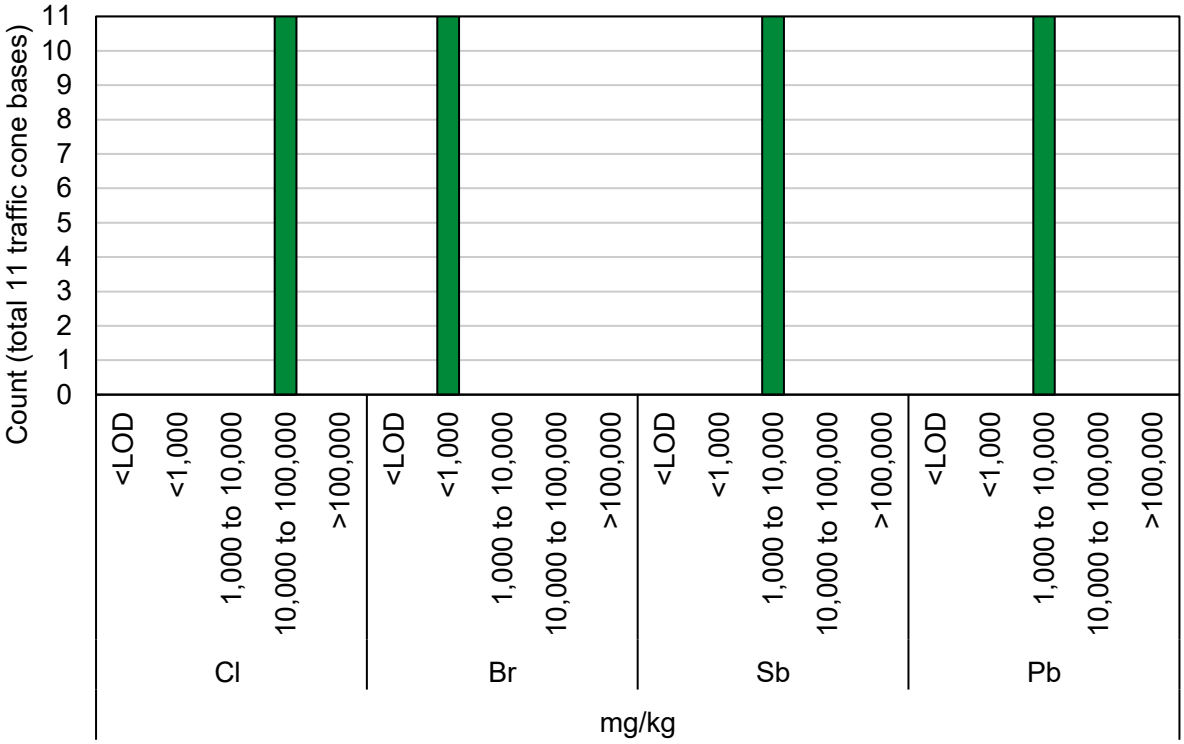
Table 3.6 XRF concentration ranges for each traffic management category

Traffic management products	Chlorine (Cl)		Antimony (Sb)	Lead (Pb)		Bromine (Br)
	10,000-100,000 mg/kg	>100,000 mg/kg	1,000-10,000 mg/kg	1,000-10,000 mg/kg	10,000-100,000 mg/kg	1,000-10,000 mg/kg
Cones	-	-	-	-	-	-
One-piece traffic cone	-	1	1	1	-	-
Traffic cone base	-	11	11	11	-	-
Barrier foot	-	2	2	2	-	-
Q-sign frame	2	-	-	-	-	-
Signs	-	-	1	-	-	1
Polyolefin parts	-	-	-	-	-	-
Unknown	-	1	1	1	-	1

All cones (i.e. the top part only) scanned contained less than 1,000 mg/kg of the target elements. The one-piece cone (a cone made from a single mounding with no discrete top or base) had elevated levels of chlorine (~45,000 mg/kg), antimony (~1,900 mg/kg), and lead (~3,500 mg/kg) as detected by XRF.

A total of 11 traffic cone bases were collected and scanned using XRF. The results indicated that all cone bases contained antimony and lead within the range of 1,000 mg/kg to 10,000 mg/kg. Additionally, chlorine was present in all traffic cone bases at concentrations exceeding 10,000 mg/kg. These bases are manufactured using compression moulding, a process that has a higher tolerance for various contaminants. As a result, lower grade recycled materials, such as cable granulate, can be used without compromising the structural integrity or performance of the bases. The range of the key four element concentrations recorded for the traffic cone bases are presented in Figure 3.2.

Figure 3.2 Traffic cone bases screening XRF results



XRF analysis of two barrier feet showed that both samples contained antimony and lead concentrations above 1,000 mg/kg. Chlorine concentrations in these samples ranged from 10,000 to 100,000 mg/kg.

Two Q-sign frames were scanned, which showed chlorine concentrations between 1,000 and 10,000 mg/kg. Lead, antimony, and bromine concentrations in these frames were below 1,000 mg/kg.

Additionally, two traffic signs were scanned, with only one showing elevated levels of antimony, bromine, and chlorine.

Of the seven blown/injection moulded polyolefin parts collected, none contained elevated concentrations of the elements of interest. This may be attributed to the nature of injection and blow moulding processes, which are more sensitive to contaminants. These processes typically require higher purity raw materials, resulting in lower concentrations of bromine, antimony, and lead in the finished products.

One unknown sample, composed of dense rubber similar to that of the traffic cone bases, exhibited elevated concentrations of bromine, antimony, and lead above 1,000 mg/kg.

3.2.1. Quantitative results

Ten traffic management samples were selected to undergo quantitative testing for SCCPs, MCCPs and dechlorane plus by Centexbel. The results of the quantitative CP analysis are presented in Table 3.7.

Table 3.7 Chlorinated paraffins quantitative results - traffic management samples

Category	Sample ID	Units	Sb (mg/kg)	SCCPs (mg/kg)	MCCPs (mg/kg)	Dechlorane + (mg/kg)
Traffic cone (with base)	9001*	mg/kg	2,413	784	4,564	10.5
One-piece cone	9002	mg/kg	2,081	1,036	8,083	9.9
Traffic cone base	9007	mg/kg	3,909	1,273	7,960	82.0
	9008	mg/kg	4,922	1,650	7,327	109
	9009	mg/kg	5,064	1,022	5,113	37.3
	9012	mg/kg	1,923	1,079	8,906	7.9
	9015	mg/kg	2,315	1,830	9,276	25.6
Barrier foot	9013	mg/kg	4,645	1,068	7,903	13.3
Q-sign frame	9017	mg/kg	18	63.6	809	4.1
Sign	9019	mg/kg	2,173	<150**	<150**	<3**

*The cone and base were milled separately and recombined to one sample according to their original weight ratio.
**Centexbel reported values at limit of detection (LOD); for consistency, these values were multiplied by three to obtain LOQ values.

The POPs waste limit for SCCPs is 10,000 mg/kg, therefore, all samples were below this threshold. However, the EU has a lower limit (1,500 mg/kg), and if this is implemented in the UK, sample 9008 and 9015 would exceed this limit. To date, no waste threshold has been established for MCCPs and dechlorane plus.

Both SCCPs and MCCPs are classified as H410, which corresponds to an additive HP14 hazardous property threshold of 2,500 mg/kg. Therefore, all traffic cone bases, the one-piece once and the barrier foot exceed this HP14, ecotoxic, limit due to exceedances of MCCPs concentrations. The high levels of chlorinated paraffins found in traffic cone bases are not unexpected as these bases are made using lower grade recycled materials, including cable granulate (commonly made from PVC).

SCCPs are also classified under H351, however all traffic management samples contained SCCPs at levels below the 10,000 mg/kg threshold for HP7, carcinogenic.

The quantity of MCCPs in the traffic management samples analysed in Phase 2 is an order of magnitude lower than the data provided by VU Amsterdam in Phase 1. However,

VU Amsterdam had significant difficulties in testing this matrix and were forced to undertake significant dilution. It is possible this may have skewed the reported data. The concentrations reported by Centexbel are more in line with SCCP and MCCP analysis of PVC cable granulate and are considered to provide a reliable determination of these parameters in this matrix.

Dechlorane plus, for which there is not yet a POPs waste threshold, was detected above the LOQ in all but one sample. The levels were typically low (<100 mg/kg).

Antimony concentration remains an indicator of the presence of SCCPs or MCCPs.

3.3. Doors and Window Frames

Table 3.8 shows the number of samples selected from each category. One additional sample of plastic door trim tested in Phase 1 was also included as a QC sample.

Table 3.8 Doors and window frames categories

Category	Count	Description
PVC frame	10	A rigid polyvinyl chloride frame commonly used for windows and doors. Provides structural support and durability, typically in white or brown finishes.
PVC frame with expanding seal	1	A PVC frame that includes an expanding seal to improve insulation and reduce air or water ingress.
PVC trim	3	Narrow PVC strips used as decorative or finishing elements around windows and doors. Often lighter and thinner than main frames.
PVC windowsill	1	A horizontal PVC component installed at the base of a window opening, designed to provide a neat finish and protect against moisture.

3.3.1. XRF scanning

The range of target element concentrations recorded for all the doors and window frames samples are presented in categories in Figure 3.3, and the breakdown by category is shown in Table 3.9.

Figure 3.3 Doors and window frames screening XRF results

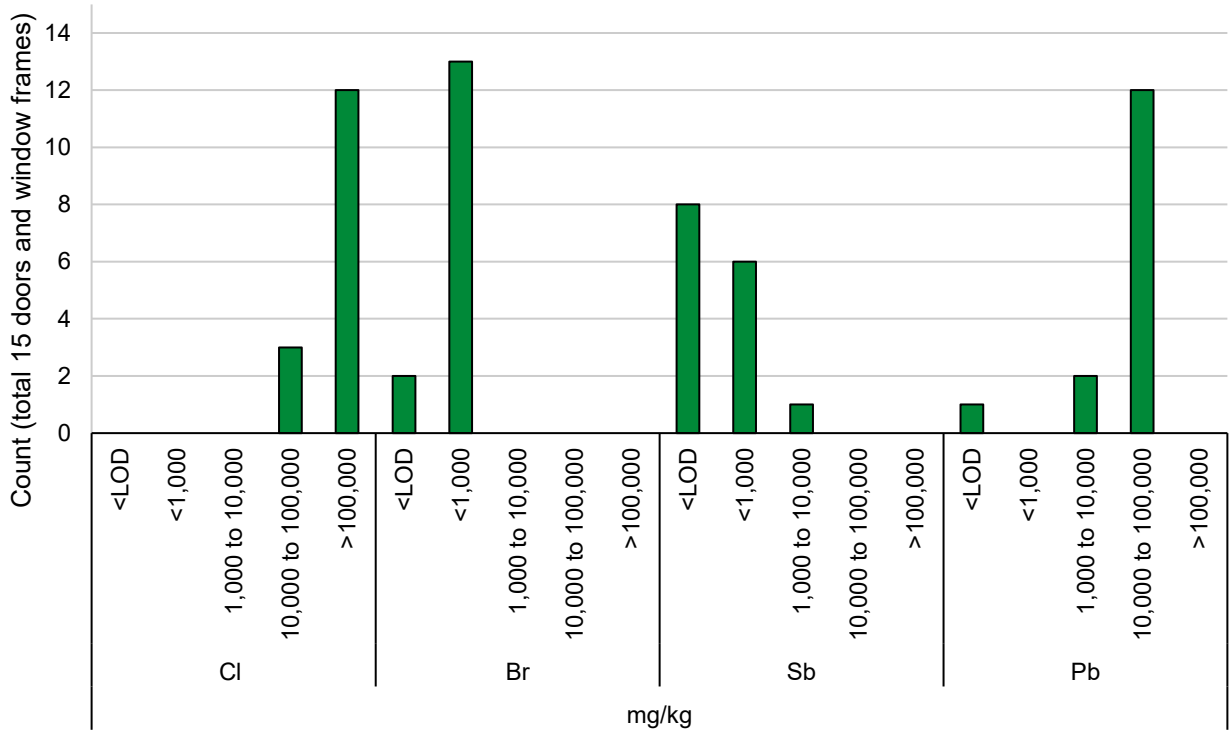


Table 3.9 XRF concentration ranges for door and window frames

Category	Chlorine (Cl)		Antimony (Sb)	Lead (Pb)		Bromine (Br)
	10,000-100,000 mg/kg	>100,000 mg/kg	1,000-10,000 mg/kg	1,000-10,000 mg/kg	10,000-100,000 mg/kg	1,000-10,000 mg/kg
PVC frame	3	7	-	1	9	-
PVC frame with expanding seal	-	1	-	1	-	-
PVC trim	-	3	-	-	3	-
PVC windowsill	-	1	1	-	-	-

Of the 15 door and window frame samples analysed (excluding QC), 12 exhibited chlorine concentrations above 100,000 mg/kg, while the remaining three contained approximately 40,000 mg/kg to 50,000 mg/kg. Antimony was detected above 1,000 mg/kg in only one sample (PVC windowsill), with two others slightly below this threshold. In contrast, nine PVC frames and all three PVC trims contained lead concentrations exceeding

10,000 mg/kg. Bromine levels were consistently low across all samples, remaining below 100 mg/kg.

3.3.2. Quantitative results

In total, 15 samples were sent for quantitative testing of chlorinated paraffins, and the results are presented in Table 3.10.

Table 3.10 Chlorinated paraffins quantitative results - doors and window frame samples

Category	Sample ID	Units	SCCPs	MCCPs	Dechlorane +
PVC frame	2005	mg/kg	<150	<150	<3
	2006	mg/kg	<150	<150	<3
	2021	mg/kg	<150	<150	<3
	2024	mg/kg	<150	<150	<3
	2030	mg/kg	<150	<150	<3
	2035	mg/kg	<150	<150	<3
	2128	mg/kg	<150	<150	<3
	6017	mg/kg	<150	<150	<3
	R004	mg/kg	<150	<150	<3
	R024	mg/kg	<150	<150	<3
PVC frame with expanding seal	7022	mg/kg	<150	<150	<3
PVC trim	2018	mg/kg	<150	<150	<3
	2096	mg/kg	<150	<150	<3
	R022	mg/kg	<150	<150	<3
PVC sill	2121	mg/kg	<150	<150	<3

*Centexbel reported values at limit of detection (LOD); for consistency, these values were multiplied by three to obtain LOQ values.

None of the 15 door and window frame samples showed concentrations of SCCPs, MCCPs, and dechlorane plus above their limits of quantification. All samples therefore remain well below the applicable POPs waste limits.

Chemical screening was carried out on 11 of the samples in Phase 1, in which none were identified as containing SCCP or MCCP. This correlates with the Phase 2 quantitative data.

Using Phase 1 and 2 data, of the 21 samples where quantitative analysis was carried out, three were found to contain SCCPs or MCCPs. Table 3.11 shows the CPs concentration for the three windows and door samples where levels were detected above the LOQ.

Table 3.11 Windows and door samples containing SCCP and MCCP above LOQ in Phase 1 and 2

			XRF (mg/kg)	Chemical Screening (mg/kg)		Quantitative Analysis (mg/kg)	
Sample	Category	Test Phase	Sb	SCCPs	MCCPs	SCCPs	MCCPs
1201	PVC frames	1	906	ND	ND	<600	1,600
2107	PVC frames	1	982	ND	ND	1,600	<600
5012	Other doors and window frames	1	10,648	>1,000	>10,000	5,200	27,550

ND = Chemical screening was carried out but no substance detected

3.4. Flooring

Table 3.12 shows the number of samples selected from each category.

Table 3.12 Flooring categories

Category	Count	Description
Vinyl flooring	9	Made from PVC with added plasticisers for flexibility. It usually includes a wear layer, printed design layer, and a backing layer for support and comfort.
Laminate flooring	4	Multi-layered floor that mimics real wood or stone. Made from four main layers (bottom layer, core board made of high-density fibreboard, decorative layer and a transparent surface protection for wear and tear) pressed in one single operation at a very high temperature and pressure.
Rigid vinyl	2	Rigid vinyl flooring features a stone or plastic composite core that makes it fully waterproof and more stable than laminate flooring.

3.4.1. XRF scanning

The range of target element concentrations measured using XRF for flooring samples are presented in categories in Figure 3.4 and Table 3.13.

Figure 3.4 Flooring screening XRF results

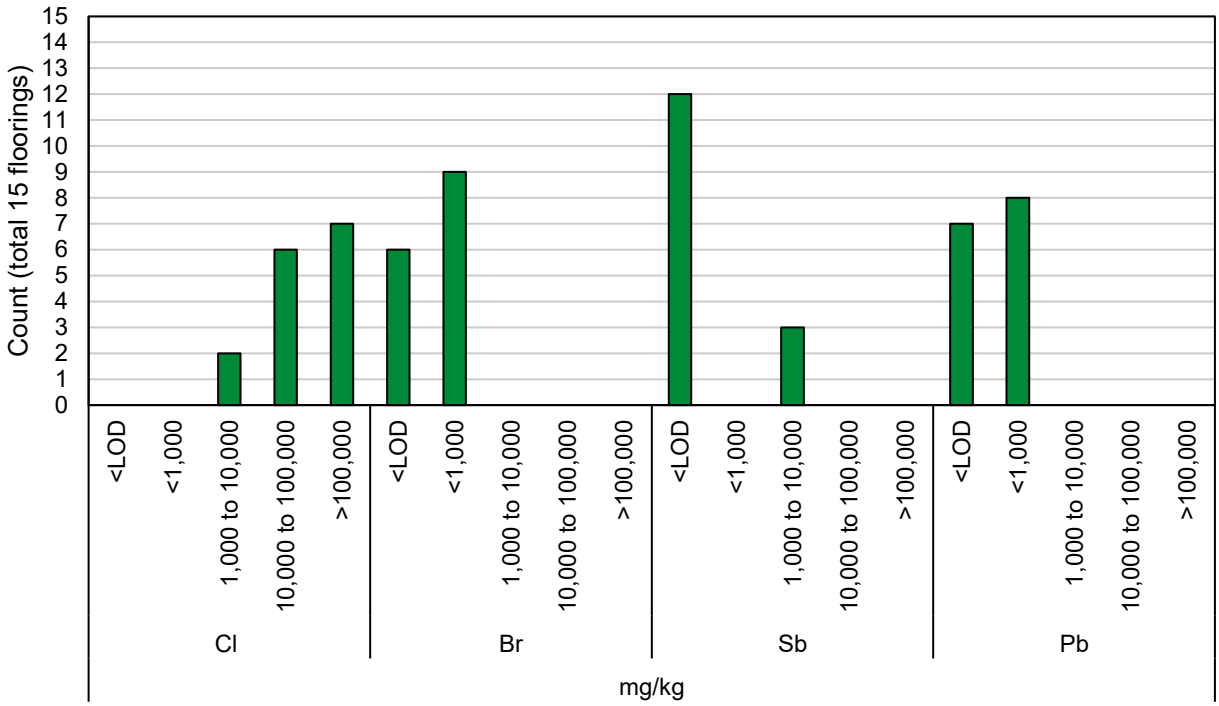


Table 3.13 XRF concentration ranges for flooring

Category	Chlorine (Cl)		Antimony (Sb)		Lead (Pb)		Bromine (Br)	
	10,000-100,000 mg/kg	>100,000 mg/kg	1,000-10,000 mg/kg	10,000-100,000 mg/kg	1,000-10,000 mg/kg	10,000-100,000 mg/kg	1,000-10,000 mg/kg	10,000-100,000 mg/kg
Vinyl flooring	2	6	1	-	-	-	-	-
Laminate flooring	2	1	2	-	-	-	-	-
Rigid vinyl	2	-	-	-	-	-	-	-

All flooring samples contained chlorine concentrations above 1,000 mg/kg, with seven of the 15 samples exceeding 100,000 mg/kg, suggesting they are PVC, a common polymer used for resilient flooring. Two samples (one vinyl and one laminate) had chlorine levels of approximately 3,000 mg/kg. Additionally, three samples (two laminate and one vinyl) contained antimony concentrations around 6,000 mg/kg. Lead and bromine levels across all flooring samples were consistently low or below the limit of detection.

Despite many of the floorings being PVC-based, lead was not found in high concentrations. Europe has a strong vinyl flooring manufacturing industry, and it is likely that these products were produced in the UK or EU, where lead stabilisers have been phased out. This suggests that lead is not prevalent in this waste stream because older

lead stabilised materials have largely been replaced, due to the shorter lifespan of flooring compared to rigid PVC products.

3.4.2. Quantitative results

In total, 15 flooring samples were sent for quantitative CPs analysis at Centexbel. The results are presented in Table 3.14.

Table 3.14 Chlorinated paraffins quantitative results – flooring samples

Category	Sample ID	Units	SCCPs	MCCPs	Dechlorane plus
Vinyl flooring	3033	mg/kg	204	1,488	<3
	1044	mg/kg	<150	<150	<3
	6010	mg/kg	<150	<150	<3
	2158	mg/kg	<150	<150	<3
	2163	mg/kg	<150	<150	<3
	4134	mg/kg	<150	<150	<3
	7028	mg/kg	<150	<150	<3
	7016	mg/kg	<150	<150	<3
	R051	mg/kg	<150	<150	<3
Laminate flooring	2155	mg/kg	<150	<150	<3
	2144	mg/kg	<150	<150	<3
	3068	mg/kg	245	1,479	<3
	3098	mg/kg	239	1,580	<3
Rigid vinyl	6007	mg/kg	<150	<150	<3
	6016	mg/kg	<150	<150	<3

*Centexbel reported values at limit of detection (LOD); for consistency, these values were multiplied by three to obtain LOQ values.

Most flooring samples were below the LOQ for SCCPs and MCCPs. Three samples (one vinyl and two laminates) contained SCCPs at approximately 200 mg/kg, well below the current 10,000 mg/kg POPs waste limit, and below a possible future (current EU limit) 1,500 mg/kg limit. MCCPs were also detected for these three samples at around 1,500 mg/kg, but no threshold has currently been established for MCCPs.

This quantity of MCCPs is not likely to be functional or intentionally added and is possibly due to unintentional levels in the virgin PVC used to manufacture the product. Recycled content that could contain POPS is not used in the manufacture of flooring. The manufacturing process severely limits what recyclate could be used, and due to concerns

over legacy plasticisers, manufacturers very tightly control any recyclate. The MCCPs are therefore unlikely to be a result of using POPs containing recyclate.

SCCPs and MCCPs are classified as H410, with an additive threshold of 2,500 mg/kg for HP14, meaning all flooring samples remain below this limit. SCCPs are also classified as H351, but all samples are well below the 10,000 mg/kg threshold for HP7. The POPs waste limit for SCCPs is likewise set at 10,000 mg/kg.

Chemical screening in Phase 1 was only carried out on samples 1044 and 2155, and in both cases no CPs were detected. This correlates with the quantitative analysis of Phase 2.

Using Phase 1 and 2 data, of the 19 samples where quantitative analysis was carried out, six were found to contain SCCPs or MCCPs. Table 3.15 shows the CPs concentration for the six flooring samples where levels were detected above the LOQ.

Table 3.15 Flooring samples containing SCCP and MCCP above LOQ in Phase 1 and 2

			XRF (mg/kg)	Chemical Screening (mg/kg)		Quantitative Analysis (mg/kg)	
Sample	Category	Test Phase	Sb	SCCPs	MCCPs	SCCPs	MCCPs
3105	Vinyl/Laminated	1	18	ND	ND	<600	1,500
2179	Underfloor sheeting	1	18	ND	>10,000	<600	46,000
5015	Vinyl/Laminated	1	2,672	ND	ND	2,900	<600
3033	Vinyl flooring	2	7,245	N/A	N/A	204	1,488
3068	Laminate flooring	2	6,272	N/A	N/A	245	1,479
3098	Laminate flooring	2	7,405	N/A	N/A	239	1,580

ND = Chemical screening was carried out but no substance detected
N/A = Chemical screening was not carried out in Phase 1

3.5. Pipes and Ducting

Table 3.16 shows the number of pipes and ducts collected for each category.

Table 3.16 Pipes categories

Category	Count	Description
Indoor pipes	7	Indoor pipes typically include components used within buildings for plumbing and utility connections. Examples are bendy PVC hoses, pipe joints, and plumbing pipes, which are designed for flexibility and durability to be used in confined spaces.
Outdoor pipes	8	Outdoor pipes and ducting are typically used for external drainage and water management systems. Common examples include gutters and drainpipes, which are exposed to weather conditions and often made from rigid PVC or similar materials for strength and longevity.

3.5.1. XRF scanning

Each sample was scanned five to six times. The range of target element concentrations recorded for pipes and ducting samples is presented in categories in Figure 3.5 and the breakdown by category is presented in Table 3.17.

Figure 3.5 Pipes and ducting screening XRF results

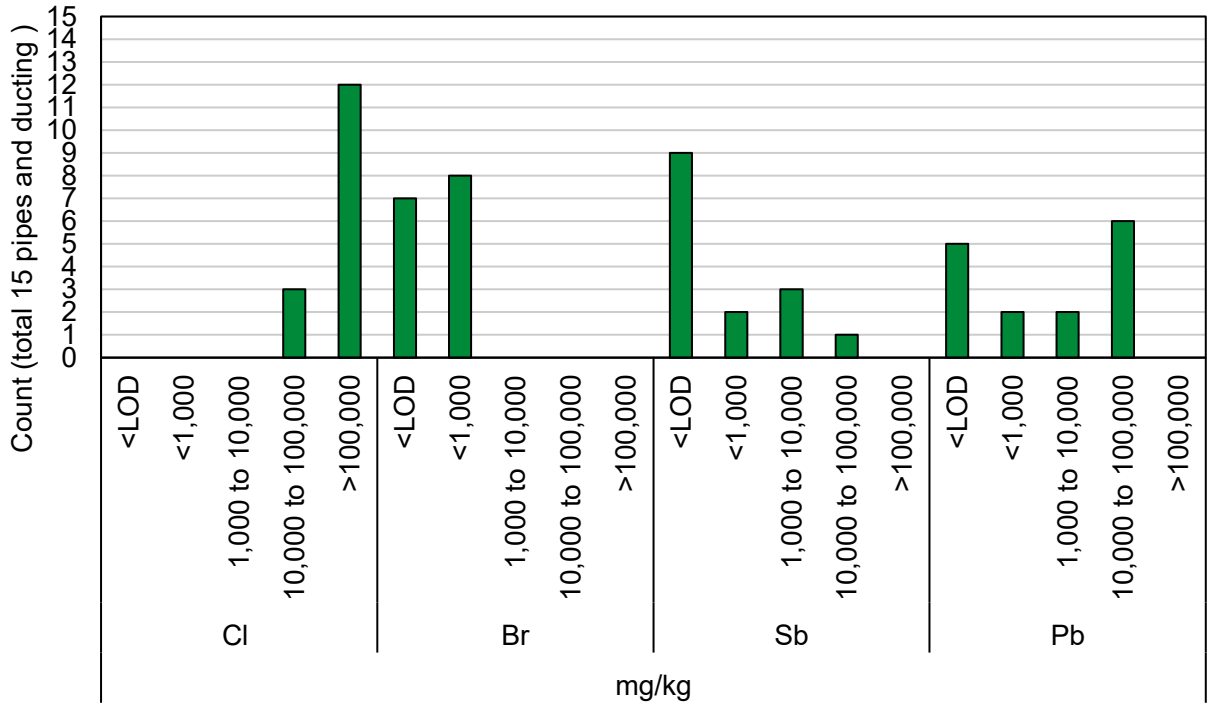


Table 3.17 XRF concentration ranges for pipes

Category	Chlorine (Cl)		Antimony (Sb)		Lead (Pb)		Bromine (Br)	
	10,000-100,000 mg/kg	>100,000 mg/kg	1,000-10,000 mg/kg	10,000-100,000 mg/kg	1,000-10,000 mg/kg	10,000-100,000 mg/kg	1,000-10,000 mg/kg	10,000-100,000 mg/kg
Indoor pipes	2	5	2	1	1	2	-	-
Outdoor pipes	1	7	1	-	1	4	-	-

All selected pipes had chlorine concentrations above 10,000 mg/kg, with 12 out of 15 exceeding 100,000 mg/kg. Most samples had low antimony levels (<1,000 mg/kg), though four contained more than 1,000 mg/kg, including one indoor pipe with a notably high concentration (~20,000 mg/kg). Lead was present above 1,000 mg/kg in eight samples (three indoor and five outdoor), and six of these exceeded 10,000 mg/kg. XRF analysis showed that none of the 15 samples contained bromine at levels above 1,000 mg/kg.

3.5.2. Quantitative results

All 15 samples were prepared and sent to Centexbel for quantitative CPs and dechlorane plus analysis. Results are presented in Table 3.18.

Quantitative analysis of the SCCPs and MCCPs concentration showed that all pipes, with the exception of one indoor pipe sample, were below the LOQ (<150 mg/kg). Sample 4153 contained 3,115 mg/kg SCCPs and 1,943 mg/kg MCCPs. Although the SCCPs concentration is below the 10,000 mg/kg POPs waste limits, this sample would exceed the 1,500 mg/kg EU POPs threshold for waste if adopted in the UK. To date, no waste threshold has been established for MCCPs and dechlorane plus. Figure 3.6 shows a photograph of sample 4153.

Figure 3.6 Sample 4153 – bendy PVC hose

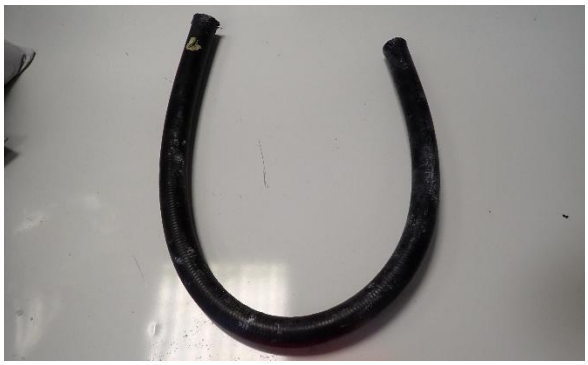


Table 3.18 Chlorinated paraffins quantitative results – pipes samples

Category	Sample ID	Units	SCCPs (mg/kg)	MCCPs (mg/kg)	Dechlorane plus (mg/kg)
Indoor pipes	1004	mg/kg	<150	<150	<3
	1159	mg/kg	<150	<150	<3
	3110	mg/kg	<150	<150	<3
	4005	mg/kg	<150	<150	<3
	4119	mg/kg	<150	<150	<3
	4153	mg/kg	3,115	1,943	<3
	R015	mg/kg	<150	<150	<3
Outdoor pipes	1028	mg/kg	<150	<150	<3
	1030	mg/kg	<150	<150	<3
	1035	mg/kg	<150	<150	<3
	1098	mg/kg	<150	<150	<3
	1164	mg/kg	<150	<150	<3
	1238	mg/kg	<150	<150	<3
	7043	mg/kg	<150	<150	<3
	R002	mg/kg	<150	<150	<3

*Centexbel reported values at limit of detection (LOD); for consistency, these values were multiplied by three to obtain LOQ values.

SCCPs and MCCPs are classified as H410, with a HP 14 threshold of 2,500 mg/kg. Therefore, sample 4153 (flexible PVC hose) exceeded this limit due to its high SCCP concentration. SCCPs are also classified under H351, but all samples remained well below the 10,000 mg/kg threshold for HP7.

Chemical screening was not carried out on sample 4153. For the 11 samples which were included in the chemical screening in Phase 1, none had CPs detected which correlates with the Phase 2 quantitative analysis.

Using Phase 1 and 2 data, of the 17 samples where quantitative analysis was carried out, two were found to contain SCCPs or MCCPs. Table 3.19 shows the CPs concentration for the six flooring samples where levels were detected above the LOQ.

Table 3.19 Pipes and ducting containing SCCP and MCCP above LOQ in Phase 1 and 2

			XRF (mg/kg)	Chemical Screening (mg/kg)		Quantitative Analysis (mg/kg)	
Sample	Category	Test Phase	Sb	SCCPs	MCCPs	SCCPs	MCCPs
7035	Outdoor pipe	1	9	ND	ND	<600	10,400
4153	Indoor pipes	2	1,141	N/A	N/A	3,115	1,943

ND = Chemical screening was carried out but no substance detected
N/A = Chemical screening was not carried out in Phase 1

3.6. Insulation – PIR/PUR

3.6.1. XRF Scanning

Each sample was scanned five to six times. The range of target element concentrations recorded for the PIR and PUR samples is presented in Figure 3.7 and a breakdown by insulation type is presented in Table 3.20.

Figure 3.7 Insulation screening XRF results for PIR and PUR insulation

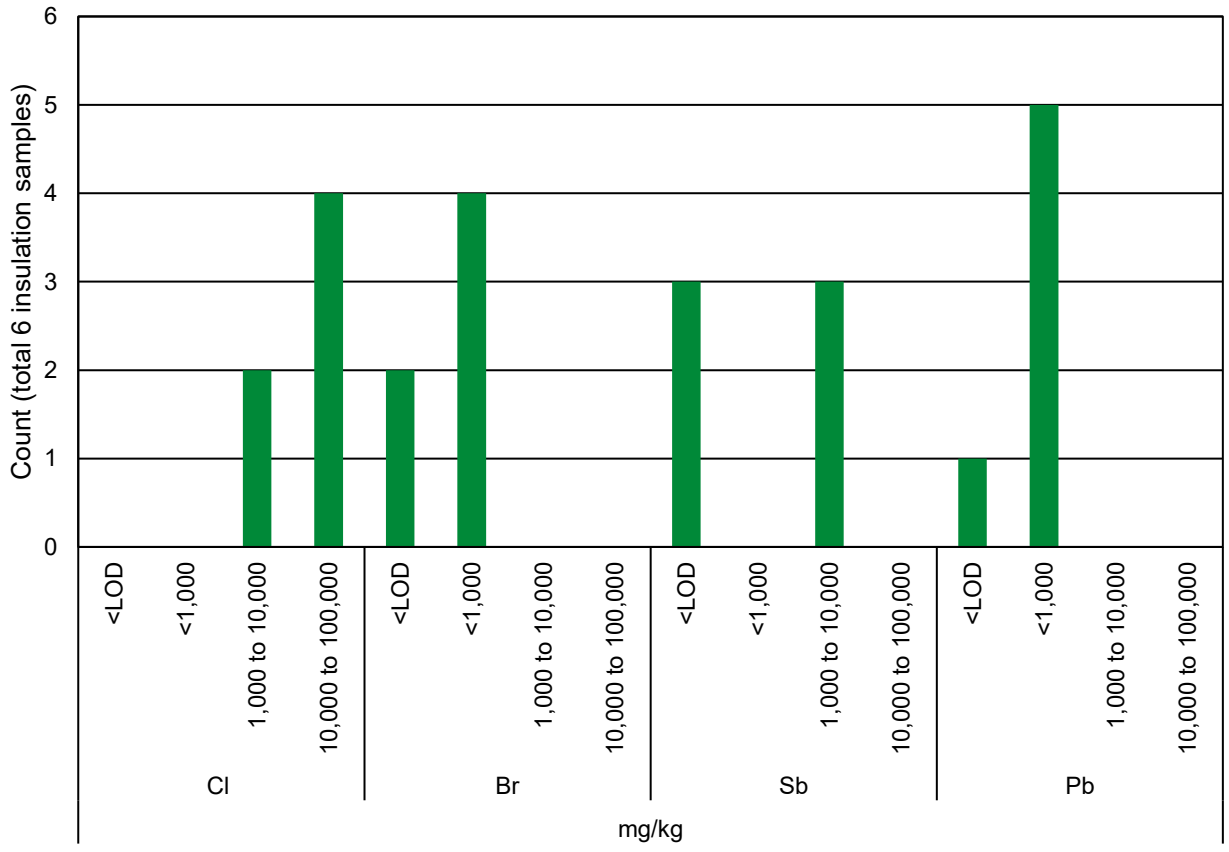


Table 3.20 XRF concentration ranges for PIR and PUR insulation

Category	Chlorine (Cl)		Antimony (Sb)	Lead (Pb)	Bromine (Br)
	1,000-10,000 mg/kg	10,000-100,000mg/kg	1,000-10,000 mg/kg	<1,000 mg/kg	<1,000 mg/kg
PIR insulation	1	2	-	3	2
PUR insulation	1	2	3	2	2

3.6.2. Quantitative results

All six samples were prepared and sent to Centexbel for quantitative CPs and dechlorane plus analysis. These results are presented in Table 3.21.

None of the samples showed SCCP or dechlorane plus concentrations above the limit of quantification.

One of the PIR samples had an MCCP concentration of 191 mg/kg and one of the PUR samples had an MCCP concentration 576 mg/kg. All other samples were reported as not detected above the limit of quantification.

Table 3.21 Insulation CPs and dechlorane plus quantitative data (Centexbel)

Sample ID	Category	Units	SCCP	MCCP	Dechlorane plus
1100	PIR insulation	mg/kg	<150	<150	<3
2060	PIR insulation	mg/kg	<150	191	<3
2190	PIR insulation	mg/kg	<150	<150	<3
1196	PUR insulation	mg/kg	<150	<150	<3
4030	PUR insulation	mg/kg	<150	576	<3
7005	PUR insulation	mg/kg	<150	<150	<3

*Centexbel reported values at limit of detection (LOD); for consistency, these values were multiplied by three to obtain LOQ values.

This concentration of MCCPs is not likely to be functional, but may be present in some residual adhesive or sealant on the boards.

All six samples were included in the chemical screening in Phase 1, with none having detectable concentrations of CPs. The screening test did have a limited sensitivity, so the Phase 2 quantitative data does correlate well despite some level of MCCPs being present.

Using Phase 1 and 2 data, of the 13 samples where quantitative analysis was carried out, four were found to contain MCCPs. Table 3.22 shows the CPs concentration for the four PIR/PUR samples where levels were detected above the LOQ.

Table 3.22 PIR/PUR insulation containing MCCP above LOQ in Phase 1 and 2

			XRF (mg/kg)	Chemical Screening (mg/kg)		Quantitative Analysis (mg/kg)	
Sample	Category	Test Phase	Sb	SCCPs	MCCPs	SCCPs	MCCPs
1194	PIR insulation	1	18	ND	ND	<700	2,800
7040	PUR insulation	1	5,499	ND	ND	<600	7,600
2060	PIR insulation	2	18	ND	ND	<150	191
4030	PUR insulation	2	6,782	ND	ND	<150	576

ND = Chemical screening was carried out but no substance detected

4. Analytical Evaluation

4.1. XRF Scanning

XRF scanning provided a measure of the elemental composition of each sample which was used as the basis of sample selection for quantification as well as the evaluation of the effectiveness of some analytical suites, such as BFRs.

Multiple scans were carried out to account for variability and provide a representative elemental profile for each sample. The variability of XRF scans results was most pronounced in multi-component items, since XRF is a surface-based technique.

All scan data was reviewed by an experienced analyst, and wherever issues were identified, samples were rescanned to ensure accuracy.

4.2. Brominated Flame Retardants

Table 4.1 presents the results of the QC insulation sample sent for quantitative BFR analysis. The same sample was tested once by VU Amsterdam and three times by Fraunhofer (once in Phase 1 and twice in Phase 2).

Table 4.1 BFRs results for QC sample

Sample	Laboratory	Phase	Deca-BDE (mg/kg)	TBBPA (mg/kg)	DBDPE (mg/kg)	HBCD (mg/kg)
4067	VU Amsterdam	1	53,600	<270	<620	<140
	Fraunhofer	1	160,273	85	3	95
		2	8,413	<10	<4.8	<5.3
		2	17,024	-	-	-

The quantitative BFR results varied significantly between test laboratories and between Phases 1 and 2. The differences in the results may be due to the heterogeneity of the samples, although since the testing was done on individual items rather than a mixed waste stream such a difference wouldn't be expected. It demonstrates the challenges of quantifying POPs, although in all cases the concentration far exceeds the POPs waste threshold.

The analysis of insulation foams presents significant challenges due to difficulty of recovering all the solvent post extraction. This can lead to under-reporting if residual solvent retains target substances, reducing recovery and accuracy. Using a more aggressive extraction process could improve recovery, but risks full dissolution of the polymer matrix, which may introduce interferences during quantification.

Fraunhofer also identified that quantifying HBCD in certain matrices is challenging, with consistently low recoveries observed. Initially, this was thought to be caused by thermal degradation during injection into the mass spectrometer. Over the past year, Fraunhofer has undertaken significant method development and believes the current approach minimises this risk. Despite these improvements, accurate quantification of HBCD remains difficult. Even when spiking with internal standards, recoveries are lower than expected for the matrices relevant to this study. It is also theorised that other BFRs present may interfere with quantification. While HBCD can be detected, precise quantification may not always be achievable, and understanding recovery limitations through internal standards is essential. This challenge could become more critical if POPs thresholds are reduced.

4.3. Chlorinated Paraffins

Table 4.2 provides the QC results for CPs and dechlorane plus from both Phase 1 and Phase 2 of the study.

Table 4.2 CPs and dechlorane plus results for the QC sample

Sample	Phase	Laboratory	SCCPs (mg/kg)	MCCPs (mg/kg)	Dechlorane plus (mg/kg)
4067	1	VU Amsterdam	2,200	164,000	<60
	2	Centexbel	1,300	110,000	<3
4152	1	VU Amsterdam	5,100	4,300	-
	2	Centexbel	69	<150	<3
5012	1	VU Amsterdam	5,200	27,550	-
	2	Centexbel	4,200	16,000	<3

Sample 4152 was a rigid fire extinguisher sign. The sign was made of two rigid plastic boards stuck together with an adhesive and foam. It is possible therefore that the sample tested in phase 1 included more of this foam and adhesive, and this was where the CPs were present. It highlights the challenges in creating a fully representative sample, and introduces the possibility of over or under-estimating the chemical composition.

The results from Centexbel for samples 4067 and 5012 are lower than the data reported by VU Amsterdam, especially for MCCPs. This may be due to variations in the prepared sample on a small particle basis or the challenges of quantifying CPs in the laboratory. The quantification of SCCPs and MCCPs is challenging due to their complex composition, which leads to multiple overlapping peaks in the chromatograms rather than clearly separated signals. This overlap makes peak integration difficult and increases measurement uncertainties. Additionally, differences in calibration standards used between laboratories could contribute to the inconsistencies of reported concentrations.

Differences in sample heterogeneity, peak integration, data processing, recovery of internal standards and instrument response can therefore contribute to variability and differences in results between laboratories. It means that in effect, “quantitative” analysis of CPs can only provide a qualitative conclusion. Where concentrations are far from thresholds this is not problematic but could be difficult when trying to demonstrate a non-POPs status if concentrations are close to a limit.

4.4. Chemical Screening

The Phase 1 report concluded that the chemical screening for SCCPs and MCCPs was ineffective, as there were instances of samples where CPs were detected in quantitative analysis which were not identified during screening.

In all cases, where chemical screening was carried out in Phase 1 the screening data matched with the Phase 2 quantitative data. This indicates that although there were instances of mismatch in Phase 1, based on additional quantitative analysis in the target categories it can be concluded that the presence of CPs is low in frequency.

5. Conclusions

This study was carried out by first selecting samples from Phase 1 that were chemically screened for CPs but not quantified. It was concluded in Phase 1 that chemical screening was ineffective and therefore additional CPs quantification was carried out in this phase of the project for the following samples:

- 15 x uPVC windows and doors
- 15 x flooring (specifically vinyl flooring)
- 15 x PVC pipes and ducting
- 3 x PIR insulation
- 3 x PUR insulation

EPS and XPS insulation samples were also collected and tested to quantify the BFRs concentration. A total of 10 additional insulation samples were collected, and five were sent to Fraunhofer for BFR analysis. A total of 27 traffic management samples were also collected, 10 of which were sent to Centexbel for analysis of CPs and dechlorane plus.

The key conclusions of the quantitative analysis are:

- Traffic management bases showed elevated CPs concentrations, particularly MCCPs which exceeded the HP14 threshold and were present at concentrations of 5,000 – 10,000 mg/kg.
- Dechlorane plus was only detected in traffic management products at a concentration of up to 100 mg/kg.
- Flooring, pipes and ducting, and PIR/PUR insulation generally exhibited low CPs concentrations, with only isolated cases exceeding HP14 limits but no exceedances of POPs thresholds.
- CPs concentrations for doors and window frames were consistently below the limit of quantification.
- All samples were below the POPs waste limit for SCCPs (10,000 mg/kg), although traffic management products were found to contain 1,000 – 2000 mg/kg SCCPs.
- Phase 1 chemical screening data (for samples where this was carried out) correlated well with Phase 2 quantitative data, with a total match. This provides some more confidence in the Phase 1 screening data.
- HBCD was detected in four insulation samples of the 10 collected, with one exceeding the POPs waste limit of 1,000 mg/kg, and two other insulation samples just below this limit. Other BFRs (including PBDEs) were close to or below the limit of quantification.

Analytical challenges remain even when using very experienced test laboratories, including variability in SCCPs/MCCPs quantification, challenges in extracting substances from foams, and difficulties accurately measuring compounds due to matrix interferences.

This indicates that for challenging matrices and substances, quantitative analysis may be more indicative than conclusive resulting in underestimations of the POPs content.

While these findings do not represent the entire C&D waste stream, this additional analysis can be used to provide further guidance on which products may contain CPs or BFRs above current or future POPs thresholds.

Appendix A – XRF Analytical Method

X-ray fluorescence is based on the excitation of atoms in a test sample, for example antimony. A primary X-ray, typically generated in an X-ray tube, hits an inner shell electron of an elemental atom causing its ejection. The open position is filled by an electron from a further outer shell and fluorescence radiation is emitted. The fluorescence energy is equal to the energy difference between the two electron shells. The energy of this radiation is unique to the atom and can therefore be used at an atomic level to identify elements that are present. In an energy dispersive XRF instrument, fluorescence radiation is detected using a semi-conductor with the signals are collated in a multi-channel-analyser.

The detector of a modern XRF machine can handle 1 million counts (signals) per second. Even with a short measurement time, the spectrum can give sufficient information to calculate intensities, which can be used to estimate the composition of the sample. Using a longer measurement time allows for better statistics, resulting in better precision and better peak-to-background ratios, thus resulting in improved detection thresholds.

As a minimum a few million counts should be collected for the accurate determination of the presence of an element. Collection of fewer counts (linked to the time over which data is accrued) is possible where concentrations are high, but where concentrations are low and specifically close to the threshold of detection an increased ‘scan’ time should be used.

XRF analysis was undertaken at the WRc laboratory using a Bruker S1 Titan handheld X-Ray fluorescence (XRF) analyser. This instrument has specific calibration programmes including ‘restricted materials’ for the analysis of elements in plastic/polymers. Previous XRF scanning experience by WRc has shown a scan time of 30 seconds is sufficient to provide reliable XRF data with a good threshold of detection for different types including WEEE polymer of varying density and textiles used in soft furnishings.

The level of detection is different for each element within different materials. Therefore, a fixed value was applied as the level of detection concentration (in mg/kg) for each element based on the average level of detection for the instrument and based on the lowest concentrations detected during scanning of all samples. The threshold limit of detection (LOD) value is different for each element within different sub-modes. Therefore, for statistical analysis a fixed value was applied as the LOD for each element based on the lowest value recorded buy the instrument. The LOD values applied during the data analysis are outlined in Table A.1.

Table A.1 XRF threshold of detection

Element	LOD (mg/kg)
Aluminium (Al)	260
Chlorine (Cl)	41
Titanium (Ti)	6
Vanadium (V)	1
Nickel (Ni)	6
Zinc (Zn)	2
Arsenic (As)	3
Bromine (Br)	1
Cadmium (Cd)	12
Tin (Sn)	9
Antimony (Sb)	18
Barium (Ba)	24
Lead (Pb)	4

XRF analysis is a semi-surface technique, and the depth to which the X-ray beam penetrates is dependent on a number of factors, including the composition of the sample itself. Therefore, the X-ray beam can penetrate to varying degrees which can introduce a factor of variability. This is particularly significant for the analysis of chlorine which is likely to be present at high concentrations in a PVC material. Therefore, if the beam penetration depth is variable it is possible that a determined concentration may vary between scans as a direct result of the X-ray beam penetration depth. Additionally, porous material such as foams can present a challenge for analysis as the empty pores serve to articifially reduce determined concentrations. In order to minimise under reporting of concentrations in highly porous materials the samples were compressed using a 10-tonne hydraulic press ahead of XRF analysis.

Where a determined concentration of an element was below the level of detection, it was assumed to be at the level of detection, e.g. for bromine al '< LOD' values were noted to be 2 mg/kg for statistical analysis. This is a 'worst-case' approach. It should be noted that the LOD concentration values for each element are typically at least one factor below the most stringent concentration/threshold thresholds for a POPs waste asessment and therefore this approach would not affect the outcome of any assessment. For example, where antimony may be present as antimony trioxide, the HP assessment cut-off and concentration thresholds are 1,000 mg/kg and 10,000 mg/kg. Therefore an assumption that concentrations below LOD values are present at 18 mg/kg would have negligible impact on the assessment. There were no instances in the data analysis where a concentration was within 10 mg/kg of a cut-off, concentration threshold or threshold threshold.

Appendix B – BFRs Analytical Method (Fraunhofer Institute)

The method used by Fraunhofer (IVV Methode PA 1_633) is no longer accredited due to a number of changes in the analytical method, however the quality of the data is considered to be high and the changes carried out were made to improve upon the accuracy.

A 0.1 g sample of the material was weighed into 20 ml glass vials together with 10 ml toluene. The extraction was carried out for 24 h at 60°C. Most of the extracts were only filtrated whereas some of them, in which the sample matrix was partially or completely dissolved in the solvent, underwent further clean-up steps. To these extracts 40 ml of ethanol was added. The resulting precipitated sample matrices were also removed by filtration. The filtrate was then evaporated to 5 ml and then filled up with toluene to an end volume of again 10 ml. The internal standard (13C- labelled PBDEs) was added to an aliquot of the filtrated solution.

The analysis was carried out via GC-MS (QP2010-MS, Shimadzu) in SIM-Scan mode. The target substances were identified through known mass fragments in the SIM mode. The quantification was done by external calibration and secured by use of mass-labelled internal standards. In the case of Decabromodiphenylethane (DBDPE) no adequate external standard substance was available due to solubility issues. Therefore, the calibration standard of deca-BDE was used for a semi-quantitative approach. TBBPA and HBCD were quantified with internal standard substances through spiking experiments.

Table B.1 provides the GC parameters and B.2 the MS parameters used by Fraunhofer.

Table B.1 GC instrument parameters

Parameters	Details
Temperature program	120°C (2 min) – 30°C/min – 230°C (5.5 min) – 20°C/min – 340°C (3 min)
Carrier gas	Helium
Column Flow	1.35 ml/min (constant flow)
Injector temperature	300°C
Injection mode	Splitless
Injection volume	2 µl
Column	Rtx-5MS, 14.5m x 0.1 µm x 0.25 mm

Table B.2 MS instrument parameters

Substance	Retention time [min]	m/z target ion	m/z reference ion
BDE17	5.410	248.00	406.00
BDE28	5.510	248.00	406.00
BDE28L	5.510	260.00	418.00
BDE49	6.200	326.00	486.00
BDE71	6.250	326.00	486.00
BDE47	6.380	326.00	486.00
BDE47L	6.380	338.00	498.00
BDE79L	6.450	498.00	338.00
BDE66	6.530	326.00	486.00
BDE77	6.810	326.00	486.00
BDE100	7.430	404.00	563.00
BDE100L	7.430	416.00	575.00
BDE119	7.560	404.00	563.00
BDE99	7.840	404.00	563.00
BDE99L	7.840	416.00	575.00
BDE85	8.770	404.00	563.00
BDE126	8.950	563.00	404.00
BDE126L	8.950	575.00	416.00
BDE154	9.430	643.00	484.00
BDE154L	9.430	655.00	496.00
BDE153	10.510	643.00	484.00
BDE153L	10.510	655.00	496.00
BDE138	12.000	643.00	484.00
BDE138L	12.000	496.00	655.00
BDE156	12.400	643.00	484.00
BDE184	12.790	561.00	721.00
BDE183	13.080	721.00	561.00
BDE183L	13.080	733.00	573.00
BDE191	13.480	561.00	721.00
BDE204	14.580	641.00	801.00
BDE197	14.590	641.00	801.00
BDE197L	14.590	653.00	813.00
BDE196	14.830	641.00	801.00
BDE207	15.840	719.00	361.00
BDE207L	15.840	731.00	367.00
BDE206	16.030	719.00	361.00
BDE206L	16.030	731.00	367.00
BB209	16.270	783.00	623.00
BB209L	16.270	795.00	635.00
BDE209	16.920	799.00	801.00
BDE209L	16.920	811.00	813.00

Substance	Retention time [min]	m/z target ion	m/z reference ion
HBCD	11.440	239.10	236.80
TBBPA	10.590	529.00	544.00
DBDPE	17.670	811.00	495.70

The limits of detection were estimated through the smallest detectable calibration standards. Regarding the weighed portion of the sample and the dilution factor of extraction and precipitation the detection limits range from 250 ng/g (Tetra- and PentaBDE) and 500 ng/g (Hexa-, Hepta- and OctaBDE) to 2500 ng/g (Nona- and DecaBDE) in the sample material.

Table B.3 provides the full list of substances included in the Fraunhofer analytical suite.

Table B.3 Full list of substances quantified by Fraunhofer

Substance	Acronym	Congener
Monobromodiphenyl ether	Mono-BDE	BDE 3
Dibromodiphenyl ether	Di-BDE	BDE 7 and BDE 15
Tribromodiphenyl ether	Tri-BDE	BDE 17 and BDE 28
Tetrabromodiphenyl ether	Tetra-BDE	BDE 47, BDE 49, BDE 66, BDE 71 and BDE 77
Pentabromodiphenyl ether	Penta-BDE	BDE 85, BDE 99, BDE 100, BDE 119 and BDE 126
Hexabromodiphenyl ether	Hexa-BDE	BDE 138, BDE 153, BDE 154 and BDE 156
Heptabromodiphenyl ether	Hepta-BDE	BDE 183, BDE 184 and BDE 191
Octabromodiphenyl ether	Octa-BDE	BDE 196 and BDE 197
Nonabromodiphenyl ether	Nona-BDE	BDE 206 and BDE 207
Decabromodiphenyl ether	Deca-BDE	BDE 209
Tetrabromobisphenol A	TBBPA	-
Decabromodiphenyl ethane*	DBDPE	-
Hexabromocyclododecane	HBCD	-

*Semi-quantitative

List of abbreviations

Abbreviation	Definition
BDE	Brominated diphenyl ether
BFR	Brominated flame retardant
C&D	Construction and demolition
CPs	Chlorinated paraffins (includes SCCPs and MCCPs)
DBDPE	Decabromodiphenyl ethane
EA	Environment Agency
EPS	Expanded polystyrene
GC-MS / GC-NCI-MS	Gas chromatography–mass spectrometry / Gas chromatography–negative chemical ionisation mass spectrometry
HBCD	Hexabromocyclododecane
HP14	Hazardous property classification: Ecotoxic
LOD	Limit of detection
LOQ	Limit of quantification
MCCPs	Medium-chain chlorinated paraffins
PBDEs	Polybrominated diphenyl ethers
POPs	Persistent organic pollutants
PVC/uPVC	Polyvinyl chloride/Unplasticised polyvinyl chloride
QC	Quality control
SCCPs	Short-chain chlorinated paraffins
SIM	Selected ion monitoring (mass-spec mode)
TBBPA	Tetrabromobisphenol A
VU	Vrije Universiteit Amsterdam
XPS	Extruded polystyrene
XRF	X-ray fluorescence