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Dioxins and PCBs in soot and ash from biomass burning in Sweden

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Studien utfördes av forskare och teknisk personal verksamma vid kemiska institutionen vid Umeå universitet. Kontakterna med Sveriges Skorstensfejaremästares Riksförbund och medverkan från tre sotningsföreatg i olika delarna av landet som ingått i studien har varit helt ovärderliga och helt avgörande för studiens genomförandes under denna relativt korta tidsperiod. Rapportförfattarna vill här framföra ett stort tack för denna medverkan.

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Dioxins and PCBs in soot and ash from biomass burning in Sweden

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Summary: Regulation (EU) 2019/1021 on persistent organic pollutants (POP:s-regulation) amended through regulation (EU) 2022/2400, stipulates that the member states are requested to collect data on the levels of dioxins (PCDD/Fs) and PCBs from biomass combustion units. In the present report, results from a screening study on PCDD/Fs and PCBs in ash and soot from Swedish household small-scale biomass combustion units, are presented. An assessment of toxic equivalents (TEQs) in bottom ash and fly ash from biomass heat and power plants was performed based on existing data. The result shows low levels TEQs, below 0.5 µg TEQ WHO2005/kg in bottom ash and fly ash from larger biomass combustion units, as well as low levels of in wood ash from small-scale units. Soot samples from household small-scale biomass combustion show more variable concentrations with the highest TEQ-levels detected in the range 1-2 µg TEQ/kg soot. The data is in line with results reported from other EU states. The investigated small-scale units were typical and representative for Swedish conditions. Thus, the monitored TEQs from the present study is deemed to be representative for ash and soot from small-scale wood heating units in Sweden. The results indicate that ash and soot should not be classified as POPs-waste since TEQ-levels are significantly lower than the limit value of 5 µg TEQ WHO2005/kg set out in annex IV to the POP:s regulation.

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Förordning (EU) 2019/1021 om långlivade organiska föroreningar (POP:s-förordningen) ändrad genom förordning (EU) 2022/2400, föreskriver att medlemsländerna ska samla in data om halterna av dioxiner (PCDD/F) och PCB från förbränning av biomassa. I denna rapport presenteras resultat från en screeningstudie av PCDD/F och PCB i aska och sot från de svenska hushållens småskaliga biomassaförbränningsenheter. En bedömning av halter i bottenaska och flygaska från biomassapannor för värme- och kraftproduktion gjordes utifrån befintliga data. Resultateten visar låga halter av toxiska ekvivalenter (TEQ) under 0,5 µg TEQ WHO2005/kg i såväl bottenaska och flygaska från större biomassaförbränningsenheter som halter i vedaska från småskalig förbränning. Sotprover från hushållens småskaliga biomassaförbränning visar mer varierande koncentrationer med högsta halter detekterade i intervallet 1–2 µg TEQ/kg sot. Data stämmer överens med resultat som rapporterats från andra EU-länder. Resultaten från denna studie baseras på typiska och representativa prover på aska och sot från vedeldningsanläggningar i Sverige, och indikerar att halterna i aska och sot inte ska klassas som POP:s-avfall, dvs avfall som innehåller POP:s-ämnen i halter som överstiger gränsvärdena i bilaga IV till POP:s-förordningen, eftersom de är betydligt lägre än gränsvärdet på 5 µg TEQ WHO2005/kg.

Summary in English

Regulation (EU) 2019/1021 on persistent organic pollutants (POP:s-regulation) amended through regulation (EU) 2022/2400, stipulates that the member states are requested to collect data on the levels of dioxins (PCDD/Fs) and PCBs from biomass combustion units. In the present report, results from a screening study on PCDD/Fs and PCBs in ash and soot from Swedish household small-scale biomass combustion units, are presented. An assessment of toxic equivalents (TEQs) in bottom ash and fly ash from biomass heat and power plants was performed based on existing data. The result shows low levels TEQs, below 0.5 µg TEQ WHO2005/kg in bottom ash and fly ash from larger biomass combustion units, as well as low levels of in wood ash from small-scale units. Soot samples from household small-scale biomass combustion show more variable concentrations with the highest TEQ-levels detected in the range 1-2 µg TEQ/kg soot. The data is in line with results reported from other EU states. The investigated small-scale units were typical and representative for Swedish conditions. Thus, the monitored TEQs from the present study is deemed to be representative for ash and soot from small-scale wood heating units in Sweden. The results indicate that ash and soot should not be classified as POPs-waste since TEQ-levels are significantly lower than the limit value of 5 µg TEQ WHO2005/kg set out in annex IV to the POP:s regulation.

1 Background and aim of study

Regulation (EU) 2022/2400 of the European Parliament and of the Council of November 23, 2022 is amending Annexes IV and V to Regulation (EU) 2019/1021 on persistent organic pollutants (POP:s-regulation). One part of this amendment relates to ash and soot from private households as well as fly ash from biomass boilers for heat and power production and their amounts of polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs, and dioxin-like polychlorinated biphenyls (DL-PCBs). In the regulation, member states are requested to collect data on the levels of PCDD/Fs and DL-PCBs from biomass units and make the information available no later than July 1, 2026.

For fly ashes from biomass heat and power plants, a transitional value of 10 µg TEQs (PCDD/Fs + DL-PCBs)/kg should be applied until 30 December 2023. From 31 December 2023, the level is lowered to 5 µg TEQs/kg fly ash. Different values and schedule are set for ash and soot from private households and here a value of 15 µg TEQs/kg will be applied until 31 December 2024. A value of 5 µg TEQs will be applied from 1 January 2025. According to the POP:s regulation, the TEQs (toxic equivalents) based on the toxic equivalency factors (TEFs) defined by the WHO assessment panel 2005 (Martin van den Berg et al, 2006) should be used.

The amended regulation thus demands that member states should provide information on levels of PCDD/PCDFs and DL-PCBs in fly ash, bottom ash and soot from different kinds of biomass fueled units. Over the years, there have been much focus and mitigation efforts on reducing dioxin emissions via flue gases and to air. Much of the work has been focused on industrial waste incineration and energy recycling facilities and less on small scale biomass burning, and especially from small scale private household biomass units.

The aim of the present study was to generate new data on small scale household biomass combustion units and summarize existing information from Sweden. Representative soot and ash samples should be collected and analyzed for PCDD/PCDFs and DL-PCBs with approved and validated analytical techniques. In addition, the obtained data should be set into perspective of selected scientific and open data of relevance for the included biomass matrices.

2 Screening study dioxins and PCBs in soot and ash from private household biomass combustion units

A variety of different biomass heating installations exist in Sweden and the screening study focused on the most common types as reported by Swedish Energy Agency (Energimyndigheten, 2015). Most used are woodstoves and fireplaces for room heating showing increasing numbers of installations (estimated to 648.000 in 2013). Wood boilers and pellets boilers are also commonly used for heating of private households and the number of installations in Sweden were 2013 estimated to 219.000 and 132.000, respectively.

2.1 Sampling plan and sample collection

Contact was established with the Swedish Chimney Sweepers Association, confirming the three categories, i.e. wood stove/fireplace, wood boilers, and pellets boilers, are the most common types of biomass heating installations in private households in Sweden also in 2023.

Three chimney sweeper companies in three different geographical areas of Sweden (See Figure 1.) were contacted. Each company received a sampling equipment kit and sampling instructions (Appendix 1) and asked to collect soot and ash samples from twelve units per region, if possible, equally distributed between 1) Wood boilers, 2) Pellets boilers and 3) Fireplace/Wood stoves. The samples should be "typical" for biomass burning and thus representative for expected levels in Sweden. Each sample and combustion unit (approx. range 5-100 kW) were documented in a protocol describing location, type of unit, biomass used, estimated frequence of use, chimney sweeping frequence, and chimney sweeping technique used. The possibility to give open comments was also given. (Appendix 2)

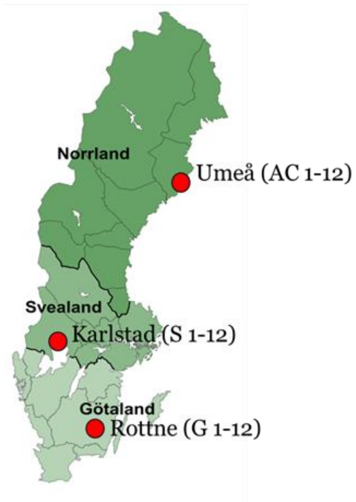

Figure 1. Sampling locations in Sweden

The sampling was conducted during the cold period late November 2023 until end of February 2024. All units were from one household's use. The chimney sweeping was performed according to professional standards by traditional roof sweeping or via rod sweeping". Different installations have different regulated chimney sweeping frequencies, ranging from three times per year to once every third year. The use intensity varied from every day to once a month, or even less frequent. The biomass used was mainly a mix of soft and hard wood logs, and in some cases birch wood only. For some units, also other types of wood were identified such as pallets. A full description of all samples is available in Appendix 3.

After completing the sampling, the samples were shipped to Umeå University. Within the frame of the present study, 13 soot samples and 3 ash samples were selected (see Table 1) for the chemical analyses of 2,3,7,8-substituted PCDD/Fs, DL-PCBs as well as I-PCBs. The soot samples were selected to represent the three different types of household units. The sample clean-up and chemical analyses were performed at Umeå University according to approved and validated procedures. A brief description of the sample treatment, sample clean-up, and chemical analyses are described in Appendix 4.

Table 1. Selected samples for dioxin and PCB analyses.

Soot	Installation	Sample ID	Type	Comment fuel
1	Wood Boilers	AC5	Diom El &Ved 25	Wood logs
2		G11	CTC265	Logs, mixed wood
3		S1	Bari Bonus 30	Hardwood, mainly birch
4		G3	CTC260	Wood logs, other residual wood
5		G10	CTC260	Logs, mixed wood
6	Fireplace/Wood Stoves	AC11	Contura 460	Wood logs
7		S6	Kaminexperten Andorra	Mixed wood
8		S9	Contura i5	Mixed wood
9		AC7	Handöl 10	Wood logs
10	Pellets Boilers	AC3	Effecta Solid	Pellets
11		AC9	PE-20 Focus	Pellets
12		G1	CTC450	Pellets
13		S8	*Info missing*	8 mm pellets
Ash				
14	Wood Boiler	AC5	Diom El &Ved 25	Wood logs
15	Fireplace/Wood Stove	S9	Contura i5	Mixed wood
16	Pellets Boiler	AC9	PE-20 Focus	Pellets

3 Results screening study soot and ash

3.1 PCDD/Fs and DL-PCBs

All soot and ash samples contained detectable levels of PCDD/Fs, DL-PCBs and I-PCBs. The three ash samples showed levels close to background levels and ranged between 0.7 – 4.69 ng TEQ WHO2005/kg ash. The concentrations of PCDD/F TEQs in soot samples ranged between 0.6 – 2,242ng TEQ/kg soot (See Table 2 and Appendix 5). Ten out of the 13 soot samples showed TEQ-concentrations < 300 ng/kg, and in three samples S6, AC9, and S8, concentrations were somewhat higher: 1,127, 1,429, and 2,242 ng TEQ/kg, respectively. Although two of these samples were from pellets boilers, the elevated TEQ-level cannot be explained by the type of boiler or general fuel type, but rather to the individual unit specific performance and fuel type. The TEQ-concentrations of DL-PCBs were significantly lower as compared to TEQs for PCDD/Fs and ranged between 0.14 – 42.05 ng TEQ/kg soot, and 0.06 – 0.09 ng TEQ/kg ash. The somewhat elevated concentrations of PCB TEQs in soot were seen for samples S6, AC9 and S8.

Table 2. Concentrations (ng/kg) of WHO2005 TEQs of PCDD/Fs, DL-PCBs and Total TEQs (upper bound) in soot and ash samples from small scale household biomass burning.

Soot	Installation	S-ID	PCDD/F TEQs	DL-PCB TEQs	Tot-TEQs (upper bound)
1	Wood Boiler	AC5	34.00	0.38	34.38
2		G11	280.0	4.11	284.1
3		S1	94.00	3.31	97.31
4		G3	210.0	7.82	217.8
5		G10	4.20	0.42	4.62
6	Fireplace/Wood Stoves	AC11	3.60	0.22	3.82
7		S6	1,100	27.04	1,127
8		S9	270.0	2.11	272.1
9		AC7	9.40	0.35	9.75
10	Pellets Boilers	AC3	8.90	2.28	11.18
11		AC9	1,400	29.25	1,429
12		G1	0.46	0.14	0.60
13		S8	2,200	42.05	2,242
Ash					
14	Wood Boiler	AC5	4.60	0.09	4.69
15	Fireplace/Wood Stove	S9	0.00	0.07	0.07
16	Pellets Boiler	AC9	0.01	0.06	0.07

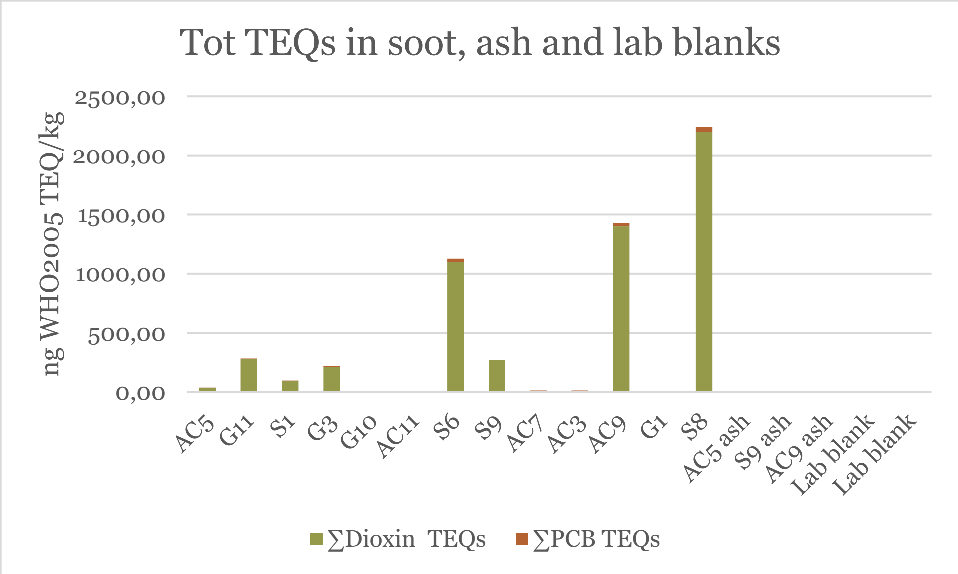

Figure 2. Dioxin and DL-PCB WHO 2005 TEQs in all soot and ash samples and lab blanks

Table 2 and Figure 2 shows the total WHO TEQ/kg of all soot and ash samples and the contribution of PCDD/Fs and DL-PCB TEQs. The contribution of DL-PCB TEQ to the total TEQ is minor, and for the samples showing increased tot TEQ-concentrations, such as S6, AC9, and S8, the contributions from DL-PCB TEQs were 2.4%, 2.0%, and 1.9%, respectively. As shown in Figure 3, the soot samples AC3 and G1 from pellets boilers are deviating from the rest of the samples and showed a 20% and 23% contribution of PCB TEQs to the total TEQ, respectively. However, the total TEQs for these two samples were 11.2 and 0.6 ng TEQ/kg soot, respectively, which is low in comparison to other samples.

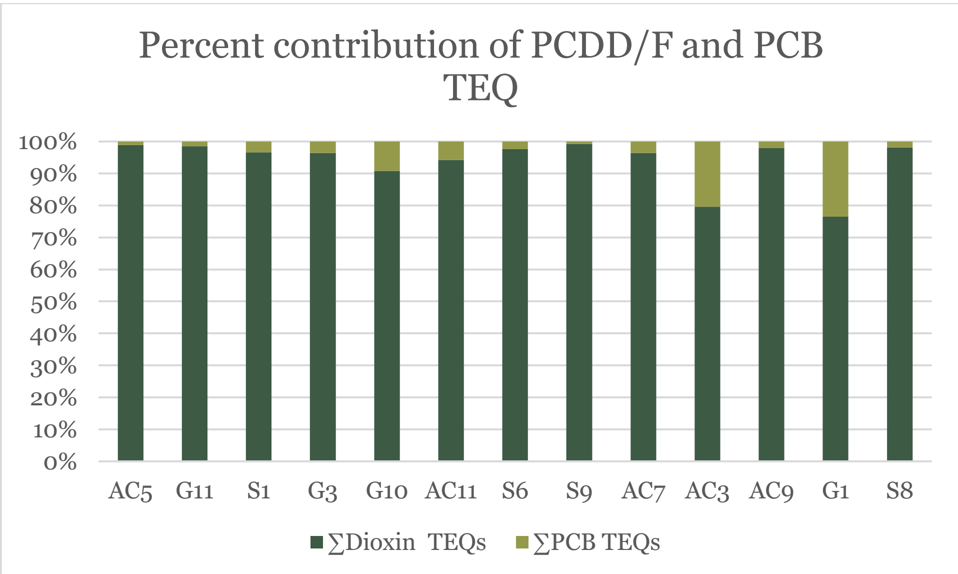

Figure 3. Contribution of PCDD/Fs and DL-PCBs to total TEQ in soot samples.

3.2 Comparison WHO-TEQ and International-TEQ

Over the years, a series of TEQ concepts has been proposed and used as results of different risk assessment activities based on the at the time existing toxicological data. The WHO-TEQs 2005 (Van den Berg et al, 2006) are today used as the standard, but in the

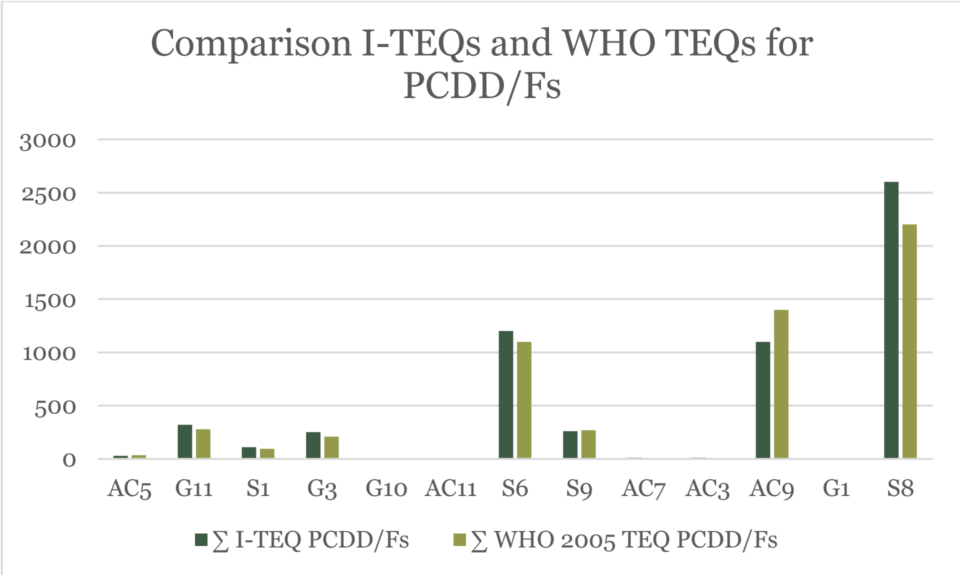

Figure 4. Comparison of WHO2005 TEQs and I-TEQs for PCDD/Fs in the present study.

combustion field, also the so-called International TEQs (I-TEQs) are still frequently used (Van den Berg M et al, 1998). The toxic equivalency factors (TEFs) for specific PCDD/F and PCB congeners vary between different TEQ concepts. In some cases, the reported data using different TEQ-concepts could not be compared (See Appendix 5 for different TEQ-concepts). Figure 4 above compares the results in the present study expressed both as WHO2005 TEQs and I-TEQs. As can be seen there are some variations between the results when comparing the two TEQ-concepts, but the TEQ-levels and conclusions are generally the same. Thus, if one is aware of the different TEFs, comparison among studies employing different TEQs may in most cases be made. A recent re-evaluation of TEFs for PCDD/Fs and DL-PCBs has been performed by a WHO expert group, which means that future data might adapt to these TEFs also in a regulatory context (DeVito M. et al, 2024) (See also Appendix 5)

3.3 Indicator-PCBs

In addition to the PCDD/Fs and DL-PCBs the so-called indicator PCBs were determined in the collected soot and ash samples. Figure 5 shows the total sum (ng/kg) of the tri-hepta chlorinated PCB congeners #28, #52, #101, #118, #138, #153, and #180. Three samples showed elevated concentrations, pellet boiler sample AC3 showing the highest concentration, almost 90.000 ng/kg soot. The two other samples were a wood boiler sample (sample G3) and another pellets boiler (sample AC9). Only sample AC9 showed a corresponding elevated concentration in tot TEQ (Figure 2), all remaining samples show lower PCDD/F TEQs. The reason for these elevated indicator PCB concentrations is unclear.

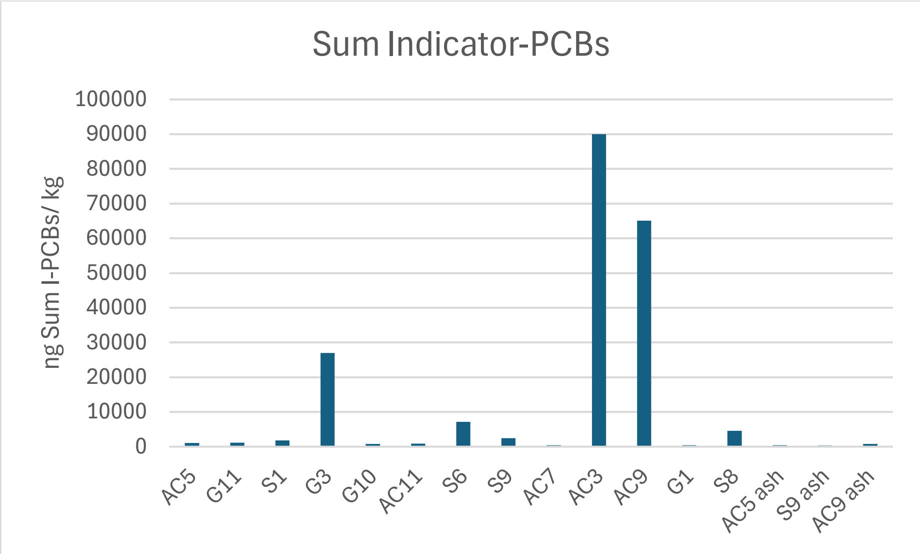

Figure 5. Sum Indicator-PCBs in soot and ash samples from small-scale household biomass combustion.

3.4 Congener composition

3.4.1 Dioxins and DL-PCBs

In order to understand the potential contribution of different formation mechanisms, sources and associated risk in a larger context it is important to know the congener composition of primary and secondary dioxin and PCB sources. Figure 6 shows the composition of all the 2,3,7,8-substituted PCDD/F congeners. As can be seen, the samples S9 and AC9 have a clear increase in HpCDD and OCDD, not necessarily resulting in a high TEQ as the TEFs for these congeners are low, 0.01 and 0.0003, respectively.

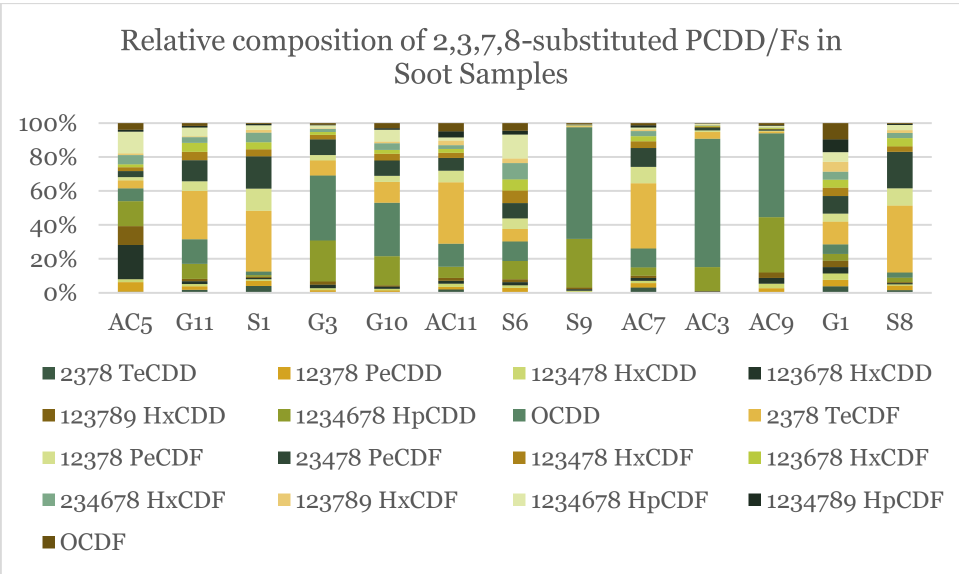

Figure 6. Relative composition of the 2,3,7,8-substituted PCDD/F congeners in soot samples.

Considering the composition of DL-PCBs the picture is different and here samples, S6, AC9 and S8 are the three samples showing a clear increase as well as from each other deviation composition (See Figure 7). If also comparing with the composition of indicator PCBs (Figure 8), sample AC3 have a very specific PCB signature, and the two samples (AC9 and G3) exhibit some similarities.

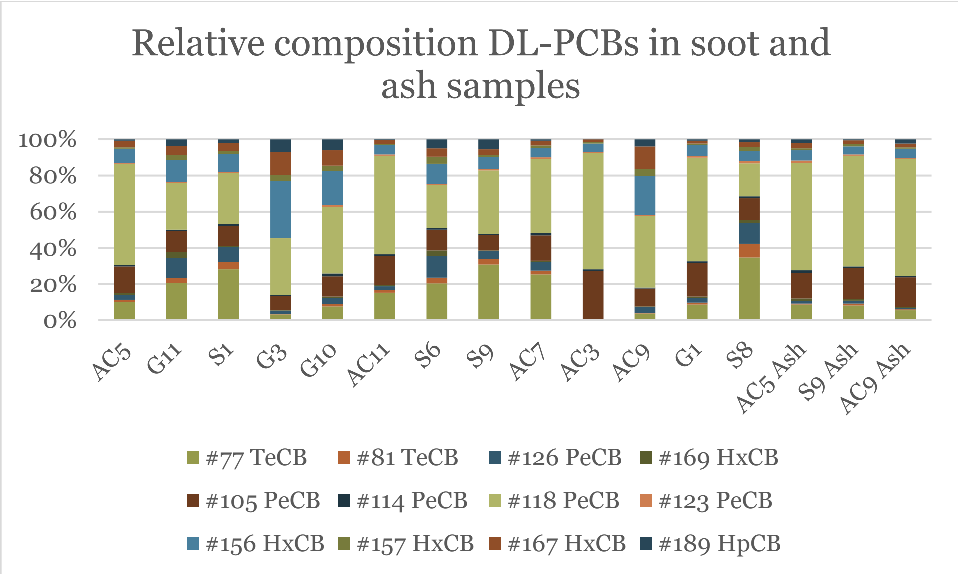

Figure 7. Relative composition of DL-PCBs in all soot and ash samples

3.4.2 Indicator PCBs

In case of composition of indicator PCBs shown in Figure 8 (also shown in Figure 5), three soot samples clearly deviate from the remaining samples, viz. samples from the two pellets boilers AC3 and AC9 as well as to some extent sample G3, from a wood boiler fired with mixed wood and possibly wood from pallets (comment from chimney sweeper).

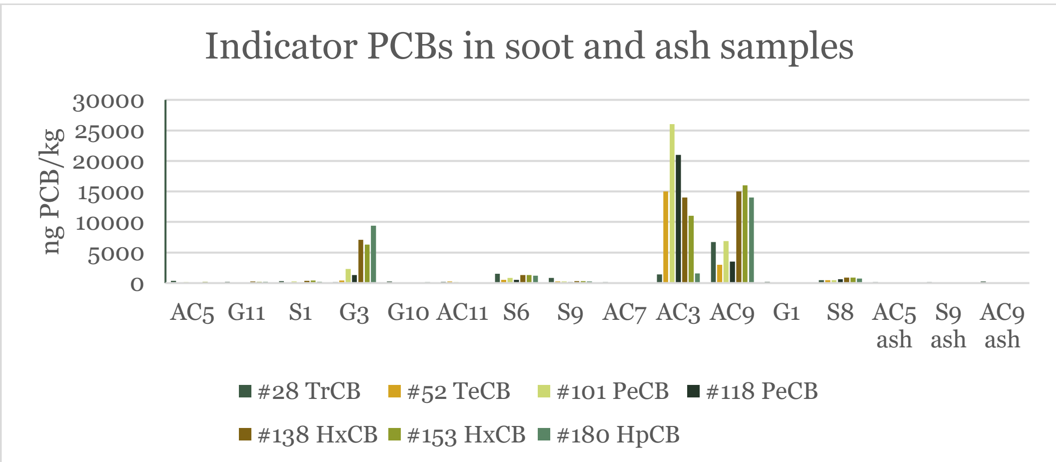

Figure 8. Composition of indicator PCBs.

The composition of the indicator-PCBs suggests a "technical mixture" of PCBs, AC3 showing similarities with Aroclor 1254 (Clophen50) and samples AC9 and G3 similarities with Aroclor 1260 (Clophen A60). The composition of indicator PCBs in these samples cannot likely be explained by formation in the combustion process, but by pellets and residual wood might be contaminated with PCBs and thus not appropriate for use in biomass burning units. However, the reason for these findings is unclear.

4 Comparison with selected open data and scientific research literature on dioxins and PCBs from biomass burning

4.1 Small scale private household wood combustion

In the late 1980's and early 1990's dioxin formation in different types of combustion processes were investigated (see e.g. Rappe et al, 1986), including emissions via flue gas and levels in bottom ash from small-scale biomass combustion. German researchers published a series of studies presenting PCDD/F formation during biomass combustion. Bacher R et al (1992) reported on profiles and patterns of mono- to octa PCDD/Fs in chimney corresponding to 720 ng I-TEQ/kg soot. In Sweden, the same year, Karlsson and Gustavsson (1992) reported "non detectable concentrations of PCDD/Fs" in flue gases from two wood fired units. Dumler-Gradl R et al (1993) reported PCDD/F concentrations in soot and ash from wood combustion in house-heating systems. Like the present study, soot and ash samples were collected in connection to normal chimney sweeping. Both tile stoves and wood heating/ovens were studied (4-30 kW). Ash samples were found to have low PCDD/F levels as compared with the soot samples. The soot dioxin levels were in many cases > 1,000 ng I-TEQ/kg soot and is expected to be a result of using additional waste as fuel.

The same research group reported results from controlled combustion experiments in different house heating systems (8.5 – 30 kW) and different fuels (Launhardt T et al, 1998). The combustion of paper, cartons, painted wood and wood with 2-5% PVC resulted in 380 – 2,240 ng I-TEQ/kg chimney soot. The PCDD/F concentrations in chimney soot using pure natural wood were at 32 ng I-TEQ/kg soot. A follow-up study on domestic heating systems investigated PCDD/F in soot and ash using various solid biofuels (Launhardt T and Thoma H, 2000). Here, triticale crop, hay, wheat straw and spruce wood showed levels in soot of 247, 1,711, 1,691, and 61 ng I-TEQ/kg soot, respectively. The combustion chamber ash showed much lower levels, viz. corresponding values of 8, 12, 24, and 5 ng I-TEQs/kg ash. The extensive literature on different biofuels and combustion conditions was summarized by Lavric E L et al (2004). In this review "Dioxin levels in wood combustion – a review" several additional studies can be found in the section covering dioxins in soot and ash, confirming that waste or contaminated biomass do generate higher dioxin levels in ash and soot. Soot from pure wood combustion have higher levels compared to low levels in ash, and combustion performance and unit specific factors generate a variability in the results.

In the coming section, focus will be given existing data that also include DL-PCBs and more recent data. Hedman et al (2006) reported on emissions of PCDD/Fs, PCBs and hexachlorobenzene (HCB) from combustion of firewood and pellets in residential stoves and boilers. This study was part of a larger survey on the formation on unintentionally formed POPs in Sweden (Bergqvist et al, 2005, Naturvårdsverket, 2005). The study also investigated different combustion conditions and fuel composition (both coniferous wood and hardwood wood). Data on PCDD/F TEQs and PCB-TEQs (WHO 1998) in 12 ash samples were presented. The concentrations in the ash varied typically between <0.9 – 83 ng PCDD/F TEQ/kg ash (See Table 3). Three samples showed >50 ng TEQ/kg ash, of which one sample showed deviating increased levels of 680 ng TEQ/kg ash, which was a case of a mixed fuel of birchwood, paper and plastics and during performance conditions with reduced air. The PCB TEQs varied between <0.1 ng – 49 PCB TEQ/kg ash, the highest level corresponding to the highest levels obtained for PCDD/Fs. The total TEQs (PCDD/Fs + PCBs) varied between <1.0 – 729 ng TEQ WHO1998/kg ash. The mean contribution of PCB-TEQs to the total TEQ-value was 6.3% and the highest contribution (ca 10%) was found for samples with low total TEQ which in many cases showed values close to blank values.

Table 3. Summary of reported TEQ concentration ranges (ng TEQ/kg) in ash and soot from small scale household combustion units.

Matrix type	PCDD/F TEQs	PCB TEQs	Total TEQ	Reference
Ash				
Present study[1]	0.01 – 4.6	0.06 – 0.09	0.07 – 4.69	Present report
Ash[3]	5	NA		Launhardt T and Thoma H, 2000
Ash[2]	<0.9 - 83 (680*)	<0.1 – 4.9 (49*)	<1.0 – 88 (729*)	Hedman B et al, 2006
Ash[1]	2,0	NA		Avfall Sverige, 2021
Ash[1]	1.6 - 182	NA		Miljøstyrelsen, 2023
Soot				
Present study[1]	0.46 – 2,200	0.14 - 42	0.6 – 2,242	Present report
Soot[3]	720	NA		Bacher R et al, 1992
Soot[3]	32			Launhardt T et al, 1998
Soot[3]	61			Launhardt T and Thoma H, 2000
Soot[1]	124 - 1290	NA		Miljøstyrelsen, 2023

[1]: WHO2005 TEQs, [2]: WHO1998 TEQs, [3]: I-TEQs *High value, fuel wood+paper+plastics, NA= Not Analyzed,

Avfall Sverige (2021) reported a small study on combustion of waste in mountain cabins including pure wood combustion. The reported 2 ng TEQ/kg ash is in line with the present study. Another more extensive study representing Nordic conditions, was recently published by the Danish Environmental Protection Agency, investigating PCDD/Fs in ash and soot from private small scale biomass boilers (Miljøstyrelsen, 2023). Several small biomass units (4.5 – 7 kW) from households in five geographical areas in Denmark were included. The biomass used was e.g. mixed wood, mainly hard wood, and some cases of construction wood residues. The results showed lower levels in ash ranging from 1.6 – 182 ng TEQ/kg ash (See Table 3). The soot samples showed, in agreement with other studies, higher levels in soot, in the range 124–1,290 ng TEQ/kg soot. The study couldn't identify any geographical differences between regions and the variation could be related to combustion unit specific factors and combustion performance.

Very few studies have included DL-PCBs and thus limited data on a total TEQ-value is available. The existing PCB data suggests a low contribution from DL-PCBs to the total TEQ-concentrations, for small-scale units maximum of 10%.

4.2 Biomass boilers for heat and power production

The literature on PCDD/Fs from larger biomass heat and power units is even more extensive compared to the small-scale biomass combustion area. Different biofuels, with or without waste fractions and combustion conditions have been reviewed (e.g. Lavric E L et al (2004). Like the smaller units the bottom ash has low levels and the fly ash elevated levels with higher variability. Bjurström H (2006) reviewed the existing fly ash data on and concluded levels in the range 3 – 27 ng TEQ/kg fly ash. This was in the same range as reported mixed bottom ash and fly ash samples 15 –24 ng TEQ/kg reported by Johansson (2005).

The text below focus on two more recent Swedish and Danish studies. The Swedish study was a screening study of PCDD/Fs as well as brominated dioxins (PBDDs) and dibenzofurans (PBDFs) conducted by Sweco (2015). In the study, six samples of biofuel incineration bottom ash and six samples of biofuel incineration fly ash was collected from six different roster and CFB plants. As shown in Table 4, the bottom ash samples ranged between 0.88 – 8.4 ng PCDD/F WHO TEQ/ kg bottom ash. The corresponding fly ash samples showed levels of 2.2 – 120 ng TEQ/kg fly ash. No PCB TEQs were determined.

Table 4. Summary of reported TEQ concentration ranges (ng TEQ/kg) in bottom ash and fly ash from biomass boilers for heat and power production

Matrix type	PCDD/F TEQs	PCB TEQs	Total TEQ	Reference
Bottom Ash				
Bottom Ash[1]	0.88 – 8.4	NA		SWECO, 2015
Bottom Ash[2]				Bjurström H., 2006
Mix of Bottom Ash and Fly Ash[2]	15 - 24	0.3 – 0.6	15.3 – 24.6	Johansson L., 2005
Bottom Ash[1]	0.8 – 3.3	NA		Miljøstyrelsen, 2023
Fly ash				
Fly Ash[1]	2.2 - 120	NA		SWECO, 2015
Fly Ash[2]	3 - 27	NA		Bjurström H. 2006
Fly Ash[1]	2.4 - 422	NA		Miljøstyrelsen, 2023

[1]: WHO2005 TEQs, [2]: WHO1998 TEQs, [3]: I-TEQs

The most recent study, also representative for Nordic conditions is a study reported by Danish Miljöstyrelsen, 2023. Five plants using straw as biofuel and five plants using wood chips or wood pellets were selected in different regions of Denmark. The size of the plants was 1-40 MW. The results showed very low levels in bottom ash, 0.8 – 3.3 ng TEQ/kg bottom ash. The fly ash showed levels of 14 – 437 ng TEQ/kg fly ash for wood fired plants (79 – 142 ng TEQ/kg in wood pellets fired plants). The straw fired plants showed 2 – 417 ng TEQ/kg fly ash. The Swedish and Danish studies thus show similar results confirmed also by other existing data.

Information on DL-PCB TEQs is very limited but existing data suggests that the contribution to total expected TEQ is even lower than in the case with small-scale combustions units. Thus, estimates of total TEQ levels can be made and which not change the overall picture and conclusions.

Another factor of uncertainty is the different TEF-scales used in the calculations of TEQs. Figure 9 shows the TEQ from the Swedish study expressed with four different TEQ-concepts. As can be seen the differences between scales are minor and this data from different time periods and based on different TEF-scales can be compared and assessed.

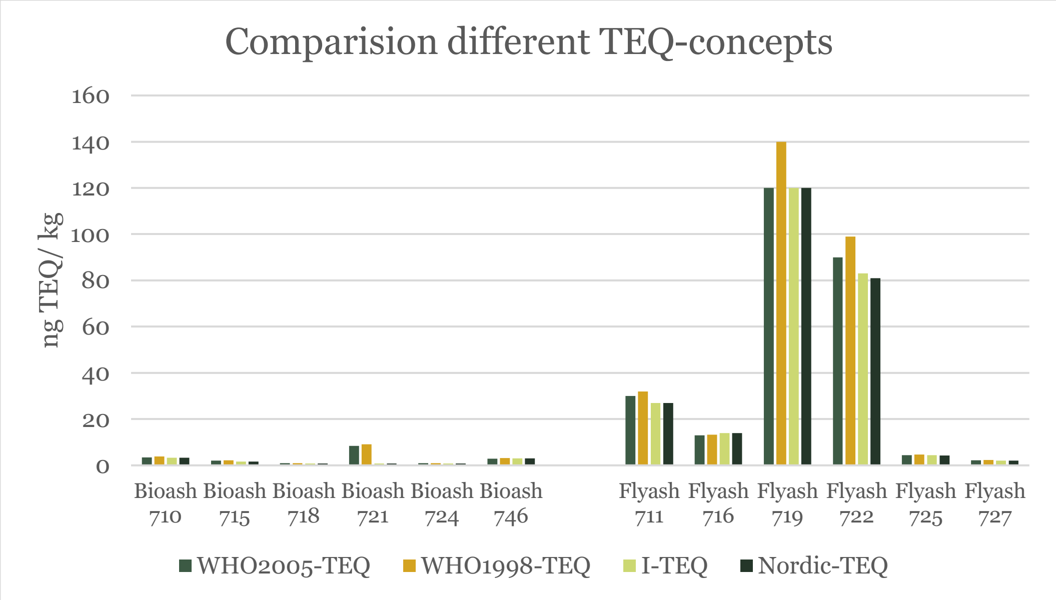

Figure 9. Comparison TEQ-concentrations in bottom ash and fly ash expressed with four different TEQ-concepts, WHO2005-TEQ, WHO1998-TEQ, I-TEQ and Nordic-TEQ (Based on results from SWECO, 2015)

5 Synthesis of data

In order to sum-up and compare data with the new limit values in the amended POP:s-regulation, the most recent Swedish and Danish data on small-scale household biomass units and biomass heat plants are compared using the unit µg TEQ/kg. Data from the present study and the Danish study (2023) are included regarding small-scale household biomass combustion units. The small-scale combustion units varies but have similar performance and are used to produce heat and hot water in private households. The data on larger biomass heat plants originates from Swedish and Danish facilities and is reported in the studies by Sweco (2015) and Miljøstyrelsen (2023) respectively. All three studies can be considered to be representative for biomass plants run on relevant biofuels in Nordic conditions, allowing combining data from Sweden and Danmark. Figure 10 shows the combined data for both larger biomass plants for heat and power as well as small-scale household type biomass burning.

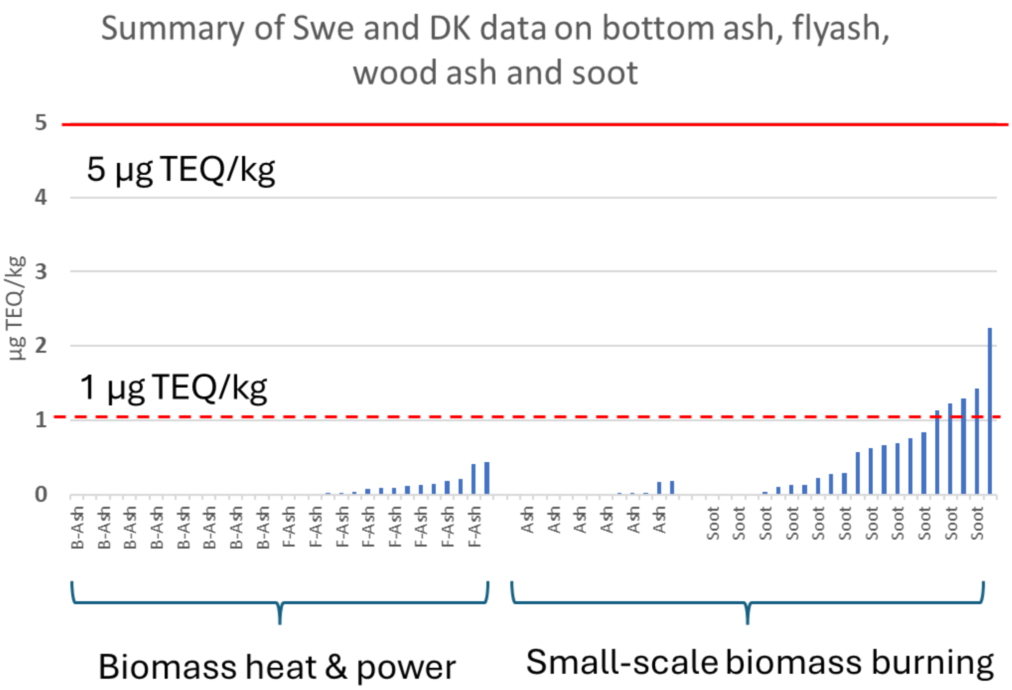

Figure 10. Summary of all data from the present study, data from recent the Danish study (Miljøstyrelsen, 2023) and Swedish study (SWECO, 2015).

The results are in line with previously reported data from different types of biomass burning units of different sizes. The bottom ash from biomass plants and small-scale household biomass burning show low levels in the range of 0.0008 – 0.008 µg TEQ/kg bottom ash and 0.0008 – 0.18 µg TEQ/kg wood ash, respectively. Also fly ash from biomass plants shows low levels and range from 0.002 – 0.44 µg TEQ/kg fly ash. Two samples show levels >0.4 µg TEQ/kg, having wood chips and straw, respectively, as related biomass fuel.

The soot samples from small-scale household biomass combustion show the highest and most variable TEQ- concentrations in a range of 0.0006 – 2.242 µg TEQ/kg soot (mean = 0.55, median = 0.28 µg TEQ/kg soot. The Swedish soot samples showed higher variation as compared to the Danish results (mean value of 0.690 µg TEQ/kg soot). Among the three samples exceeding 1.0 µg TEQ/kg soot, the two highest, 1.429 and 2.242 µg TEQ/kg soot were found from pellets burning, and the third highest, 1.127 µg TEQ/kg soot was from wood burning in a wood stove. The variation in soot concentrations cannot be related to unit type of boiler or general fuel type and is most likely connected to the efficiency of the combustion performance and possible variations in fuel as reported by Hedman et al (2006) seeing a significant increase in PCCD/F in wood ash if paper and plastics were added to the fuel.

6 Summary and conclusions

Based on the present study and other existing data the following conclusions can be drawn:

Small-scale household biomass burning:

- The total PCDD/F and DL-PCBs WHO_{2005} TEQ concentrations in ash and soot samples from typical Swedish small-scale household biomass burning units are well below the amended POP:s regulation limit value of 5 µg TEQ/kg.
- The contribution of TEQs from DL-PCBs to the total TEQ in soot and ash samples from small-scaled biomass burning is low or very low, close to lab blanks.
- Neither installation type and geographical location nor reported fuel type used at sampling occasion correlate with the variation in TEQs found for soot and ash samples from small-scale biomass burning units.
- Combustion performance, and not least, the type of fuel used are the most likely explanation for the observed three orders of magnitude variability in TEQ concentrations in soot samples.
- Observed elevated levels of indicator PCB concentrations in some soot samples may indicate use of waste as fuel and/or waste contaminated biofuels (wood pallets and pellets), which might need further studies.
- Comparing data based on TEQ-concentrations calculated with different TEF factors (e.g. WHO_{2005}, WHO_{1998}, and I-TEQ) shows good agreement and does not change the overall picture and conclusions.

Biomass heat and power plants:

- The total PCDD/F and DL-PCBs WHO $_{2005}$TEQ concentrations in bottom ash and fly ash samples from typical Swedish biomass heat and power plants are well below the POP:s regulation limit value of 5 µg TEQ/kg.
- The contribution of TEQs from DL-PCBs to the total TEQ in bottom ash and fly ash samples from biomass power plants is low or very low close to lab blanks.
- Comparing data based on TEQ-concentrations calculated with different TEF factors (e.g. WHO_{2005}, WHO_{1998}, and I-TEQ) shows good agreement and does not change the overall picture and conclusions.

In summary, despite the limited number of samples in the present study, but supported by other existing data, the TEQ-concentrations of PCDD/F and DL-PCB in soot and ash samples are significantly below the threshold of 5 µg TEQ/kg set by the amended POP:s regulation. The TEQ-concentrations of PCDD/Fs and DL-PCBs in soot showed higher variability as compared to the ash concentration. The results from the present study can be considered to be representative for soot and ash from wood heating units in Sweden. The observed concentrations indicate that both soot and ash should not be classified as POPs-waste, as they are significantly lower than the limit value of 5 µg/kg set by the amended POP:s regulation.

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Appendices 1- 6

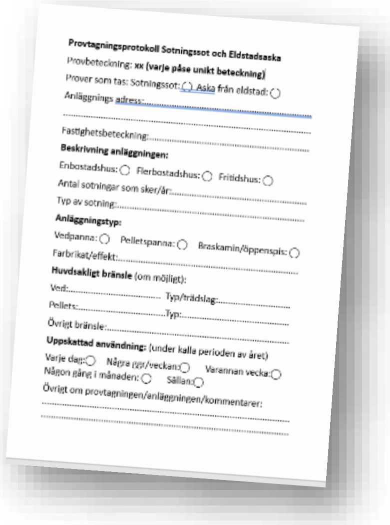
Appendix 1 – Sampling instruction

2023-11-17

Provtagningsinstruktion

Provtagning av sot och aska småskaliga bioförbränningsanläggningar

Varje provtagningspåse består av denna instruktion, två flaskor, två skedar, påse med provtagningsprotokoll + penna.



Provtagningsprotokoll Sotningssot och Eldstadsaska

Provbeteckning: **xx (varje påse unikt beteckning)**

Prover som tas: Sotningssot: ◯ Aska från eldstad: ◯

Anläggnings adress:...

....

Fastighetsbeteckning:...

Beskrivning anläggningen:

Enbostadshus: ◯ Flerbostadshus: ◯ Fritidshus: ◯

Antal sotningar som sker/år:...

Typ av sotning:...

Anläggningstyp:

Vedpanna: ◯ Pelletspanna: ◯ Braskamin/öppenspis: ◯

Farbrikat/effekt:...

Huvdsakligt bränsle (om möjligt):

Ved:.................................... Typ/trädslag:..............................

Pellets:....................................Typ:..............................

Övrigt bränsle:...

Uppskattad användning: (under kalla perioden av året)

Varje dag: ◯ Några ggr/veckan: ◯ Varannan vecka: ◯

Någon gång i månaden: ◯ Sällan: ◯

Övrigt om provtagningen/anläggningen/kommentarer:

....

....

1. Fyll i provtagningsprotokollet som finns i den mindre påsen.
2. Provta eldstadsaska före sotningen med en av skedarna. Undvik större kolbitar. Fyll flaskan minst till hälften – inte mer än 2/3. Förslut flaskan väl! Släng skeden!
3. Efter sotning tas prov på sotningssotet med den andra skeden. Ta prover på olika platser i hink eller annan behållare som sotet samlats upp i. Fyll flaskan till minst hälften – inte mer än 2/3. Förslut flaskan väl! Släng skeden!
4. Kontrollera provtagningsprotokollet och ge evt kommentarer. Lägg tillbaka protokollet i mindre plastpåse och förslut väl och lägg sedan tillsammans med de väl förslutna flaskorna i den större plastpåsen. Förslut plastpåsen!
5. Provtagningen klar!

Om oklarheter, ring Mats Tysklind, Umeå universitet på mobil [redacted]

Appendix 2 – Sampling protocol

Provtagningsprotokoll Sotningssot och Eldstadsaska

Provbeteckning: **xx (varje påse har unik beteckning)**

Prover som tas: Sotningssot: ◯ Aska från eldstad: ◯

Anläggnings adress:. ....

....

Fastighetsbeteckning/Enhets ID:..

Beskrivning anläggningen:

Enbostadshus: ◯ Flerbostadshus: ◯ Fritidshus: ◯

Antal sotningar som sker/år:...

Typ av sotning:...

Anläggningstyp:

Vedpanna: ◯ Pelletspanna: ◯ Braskamin/öppenspis: ◯

Farbrikat/effekt:..

Huvdsakligt bränsle (om möjligt):

Ved:................................... Typ/trädslag:............................

Pellets:.................................Typ:..

Övrigt bränsle:...

Uppskattad användning: (under kalla perioden av året)

Varje dag:◯ Några ggr/veckan:◯ Varannan vecka:◯ Någon gång i månaden: ◯ Sällan:◯

Övrigt om provtagningen/anläggningen/kommentarer:

....
....

Appendix 3 – Collected samples

Umeå											
	Sot	Aska	Typ	Fabrikat	Fastighetstyp	Fastighets nr/ID	Sotningsfrekvens	Typ av sotning	Bränsle	Uppskatta	Kommentar:
AC1	X	X	Öppen Spis, insats	Keddy insats	Enbostad		1 ggr/år	Stavsotning, roterande	Ved, Björkved	Varje dag	
AC2	X	X	Braskamin	Contura 550	Enbostad		vart 3de år	Traditionell	Ved, mest björk	Någon gån	Pre-modul skorsten (standard), mkt lite sot
AC3	X	X	Pelletspanna	Effecta Solid	Enbostad		2 ggr/år	Traditionell	Pellets, Klint	Varje dag	
AC4	X	X	Vedpanna	Värmeb. Vedolux CU max 35kW	Enbostad		2 ggr/år	Traditionell	Ved	Varje dag	Välskött anläggning
AC5	X	X	Vedpanna	Diom El&Ved 25	Enbostad		3 ggr/år	Traditionell	Ved	Varje dag	
AC6	X	X	Vedpanna	Diom EB1	Enbostad		saknas	Stavsotning med skruvdra	Ved, blandat papper Kartong	Varje dag	
AC7	X	X	Öppen spis, insats	Handöl 10	Enbostad		1 ggr/år	Stavsotning, manuellt	Ved	Varje dag	
AC8	X	X	Öppen Spis, insats	Handöl 10	Enbostad		1 ggr/år	Traditionellt med rep	Ved	Varje dag	Överdimensionerad tegelmur
AC9	X	X	Pelletspanna	PE-20 Focus	Enbostad		2 ggr/år	Traditionellt	Pellets	Varje dag	Uppskattn. 3 ton pellets/år
AC10	X	X	Vedpanna-Pelletsb	ABSO PK-0 + Lcn Fire brännare	Enbostad		2 ggr/år	Traditionellt med rep	Pellets	Varje dag	
AC11	X	X	Braskamin	Contura 460	Enbostad		1 ggr/år	Stavsotning, manuellt	Ved	Någon gång I veckan	
AC12	X	X	Vedpanna	Norrahammar 2205	Enbostad		vart 3de år	Traditionellt med rep	Ved	Någon gång I mån - sällan	
Rottne											
	Sot	Aska	Typ	Fabrikat	Fastighetstyp	Fastighets nr	Sotningsfrekvens	Typ av sotning	Bränsle	Uppskatta	Kommentar:
G1	X	X	Vedpanna	CTC450	Enbostad		3ggr/år	traditionell	Pellets 8 mm	Varje dag	
G2	X	X	Vedpanna	CTC V35	Enbostad		3	traditionell	Ved blandved	Varje dag	
G3	X	X	Vedpanna	CTC260	Enbostad		3	traditionell	Ved, evt pallvirke	Varje dag	Fastighetsägaren elallergiker
G4	X	X	Braskamin	Contura 500	Enbostad		1ggr/3 år	traditionell	Björkved	Någon gån	extremt lite aska kvar, lite sot
G5	X	X	Vedpanna	Egor V25	Enbostad		saknas	traditionell	Blandved	Varje dag	
G6	X	X	Vedpanna	Atmos DC30 SF	Enbostad		3	traditionell	Blandved	Varje dag	
G7	X	X	Vedpanna	CTC V25	Enbostad		3	traditionell	Blandved	Varje dag	Liten sotmängd pga svår dragning
G8	X	X	Vedpanna	Baxi Solo Innova	Enbostad		3	traditionell	Blandved	Varje dag	
G9	X	X	Vedpanna	Viadrus U22	Enbostad		saknas	traditionell	Blandved	Varje dag	Förekommer bricketter, oklart om de används
G10	X	X	Vedpanna	CTC260	Enbostad		3	traditionell	Blandved	Varje dag	"Här eldas nog lite vad som helst"
G11	X	X	Vedpanna	CTC265	Enbostad		3	traditionell	Blandved	Varje dag	
G12	X	X	Vedpanna	Baxi Solo Plus Innova	Enbostad		3	traditionell	Björk/lövved	Varje dag	
Karlstad											
	Sot	Aska	Typ	Fabrikat	Fastighetstyp	Fastighets nr	Sotningsfrekvens	Typ av sotning	Bränsle	Uppskatta	Kommentar:
S1	X	X	Vedpanna	Bari Bonus 30	Enbostad		3	Från tak	80% björk 10% asp 10% gran	Varje dag	
S2	X	X	Vedpanna	Focus PE-20	Enbostad		3	Från tak	Blandved	Någon gång I veckan	
S3	X	X	Vedpanna	Maya MA80	Enbostad		saknas	Dirty Clean/Stavsotning	Barrträd	Varje dag	
S4	X	X	Vedpanna	Focus Eco Nature	Enbostad		3	Trad från tak	Blandved	Varje dag	
S5	X	X	Vedpanna	Calmos Johnson V23	Enbostad		2	Trad från tak	Björk	Varje dag	Väldigt tjärigt
S6	X	X	Braskamin	Kaminexperten Andorra	Enbostad		1	Trad från tak	Blandved	några ggr/vecka	
S7	X	X	Braskamin	Saraholms Stöberi nr10	Enbostad		1ggr/3 år	Trad från tak	Blandved, rönn, asp, gran	Varannan	Väldigt öppet system så aska förekommer även I skorsten
S8	X	X	Pelletspanna	saknas	Enbostad		3	Trad från tak	8 mm pellets	Några ggr/	Väldigt ny panna
S9	X	X	Braskamin	Contura i5	Enbostad		1	Trad från tak	Blandved	Varje dag	

Appendix 4 – Sample treatment, clean-up and chemical analysis

Method description
The methods used in the analysis are validated and proven in recurring international intercalibration studies. The analyses are performed according to Swedish and European Standards SS-EN 1948:2-4. The technique is gas chromatography coupled to mass spectrometry (GC-MS). A summary of the methods is following below.

Sample Preparation
^{13}C-labeled standards were added to the sample before extraction. These standards consist of isotopically labeled substances with the same characteristics as the subjects analyzed, but with different molecular weight. The sample was then Soxhlet extracted with toluene for 16 hours.

Sample Purification
The clean-up of polychlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzofurans (PCDF) and polychlorinated biphenyls (PCB) was performed, first by a multistep silica column, followed by a basic alumina column. The final step was made on a Carbon column. On the carbon column the PCDD/F and planar PCBs are separated from the rest of the PCBs. The PCB fraction was further purified on a mini multi-layer silica column. To the final extract, a keeper solvent (tetradecane) and ^{13}C labeled recovery standards was added, before the evaporation to the final volume.

Analysis
Isomer specific analysis was performed using gas chromatography (GC) coupled with mass spectrometry (MS). The separation of substances occurs on the GC and the detection on the mass spectrometer. In MS analysis, the substances with different atomic masses are detected selectively. This enables the use of synthetic 13C-isotopically enriched compounds (13C-congeners), which were used as internal standards. The so-called isotope dilution methodology. Accordingly, a comparison of the response ratio between natural congeners and 13C congeners in the sample with the corresponding ratio in a quantification standard, containing both known amounts of natural and added 13C-congeners, was performed. This procedure meant that the results were automatically compensated for potential losses during clean-up. For the PCDD/F and planar-PCBs, a Waters Autospec Ultima MS instrument (accredited) with high mass resolution has been used. For mono-ortho PCBs and indicator PCBs an Agilent QQQ MSD with low resolution was used (new instrument in process of inclusion in the accreditation but presently formally outside accreditation). Both instruments were run electron impact ionization (EI) mode, and then specific ions were selected and recorded (SIR).

Concentration determination has been carried out following the standard, EN 1948: 3 mentioned above, and recovery rates of the sampling (PS) and internal standards (IS) added samples were calculated and expressed as a percentage of the original amount. In some cases, interfering compounds and disturb chromatography for the TCDF and PeCDF influenced the recovery and increased the uncertainty in the results. For indicator-PCBs, in some cases, co-elution with other non-dioxin like PCBs was observed, which likely resulted in overestimated concentrations.

When a congener can't be detected, the limit of detection (LOD) is calculated. It corresponds to a signal from the analyzer which is three times higher than the noise level and is assigned a less than value. LOD depends on several factors and therefore varies somewhat from sample to sample, between different congeners and from one analysis to another. The measurement uncertainly given in the analysis report is valid at the limit of quantification (LOQ), defined as signals exceeding ten times the noise level, and above. In the interval between three and ten times the noise level measurement uncertainty is elevated but the values still provide valuable contributions to the results and the TEQ calculations.

Calculation of the TCDD equivalents (TEQ)

Based on the individual concentrations of the congeners, the TCDD equivalents (TEQ) were calculated. TCDD equivalents relate the dioxin like toxicity of the congeners to the most toxic one, 2,3,7,8-TeCDD, by giving them different weight using toxic equivalency factors (TEF's):

$$TEQ = concentration \times TEF$$

Several different TEF scales have been used over the years. Today, the WHO-TEF scale, last updated 2005, is the established one but the results can be converted according to the tables as desired in Appendix 6.

In many cases not all congeners can be detected and TCDD equivalents are normally calculated at three levels. A lower concentration limit (lower bound) where LOD is replaced with zero for all non-detected congeners. a mean concentration (medium bound) where LOD is replaced with ½ LOD and an upper concentration limit (upper bound) where LOD is directly used in the calculation of TEQ. In cases where all congeners are detected the TEQ values from the three calculations coincide. In the analysis report column called "WHO-TEQ", the percentage contribution to the total TEQ was calculated using the upper bound.

Appendix 5 – Toxic Equivalency Factors (TEFs)

TEF for calculating toxic equvivalents (TEQs) for 2,3,7,8-substituted PCDD/Fs:

Congener:	PCDD/ PCDF	Weight factor (TEF):				
		WHO 2005[a]	WHO 1998[b]	Interna-tional	Nordic	WHO 2022[c]
2,3,7,8	-TeCDD	1	1	1	1	1
1,2,3,7,8	-PeCDD	1	1	0,5	0,5	0,4
1,2,3,4,7,8	-HxCDD	0,1	0,1	0,1	0,1	0,09
1,2,3,6,7,8	-HxCDD	0,1	0,1	0,1	0,1	0,07
1,2,3,7,8,9	-HxCDD	0,1	0,1	0,1	0,1	0,05
1,2,3,4,6,7,8	-HpCDD	0,01	0,01	0,01	0,01	0,05
	OCDD	0,0003	0,0001	0,001	0,001	0,001
2,3,7,8	-TeCDF	0,1	0,1	0,1	0,1	0,07
1,2,3,7,8	-PeCDF	0,03	0,05	0,05	0,01	0,01
2,3,4,7,8	-PeCDF	0,3	0,5	0,5	0,5	0,1
1,2,3,4,7,8	-HxCDF	0,1	0,1	0,1	0,1	0,3
1,2,3,6,7,8	-HxCDF	0,1	0,1	0,1	0,1	0,09
1,2,3,7,8,9	-HxCDF	0,1	0,1	0,1	0,1	0,2
2,3,4,6,7,8	-HxCDF	0,1	0,1	0,1	0,1	0,1
1,2,3,4,6,7,8	-HpCDF	0,01	0,01	0,01	0,01	0,02
1,2,3,4,7,8,9	-HpCDF	0,01	0,01	0,01	0,01	0,1
	OCDF	0,0003	0,0001	0,001	0,001	0,002

TEFs for calculating toxic equvivalents (TEQs) for DL-PCB's:

Congener:	PCB	Weight factor (TEF):		
		WHO 2005a	WHO 1998b	WHO 2022c
3,4,4′,5	-TeCB (81**)	0,0003	0,0001	0,006
3,3′,4,4′	-TeCB (77*)	0,0001	0,0001	0,0003
3,3′,4,4′,5	-PeCB (126*)	0,1	0,1	0,05
3,3′,4,4′,5,5′	-HxCB (169*)	0,03	0,01	0,005
2,3,3′,4,4′	-PeCB (105*)	0,00003	0,0001	0,00003
2,3,4,4′,5	-PeCB (114*)	0,00003	0,0005	0,00003
2,3′,4,4′,5	-PeCB (118*)	0,00003	0,0001	0,00003
2′,3,4,4′,5	-PeCB (123*)	0,00003	0,0001	0,00003
2,3,3′,4,4′,5	-HxCB (156*)	0,00003	0,0005	0,00003
2,3,3′,4,4′,5′	-HxCB (157*)	0,00003	0,0005	0,00003
2,3′,4,4′,5,5′	-HxCB (167*)	0,00003	0,00001	0,00003
2,3,3′,4,4′,5,5′	-HpCB (189*)	0,00003	0,0001	0,00003

* Numbering according to IUPAC; [a] Van den Berg M et al, 2006, [b] Van den Berg M et al, 1998, [c] DeVito M et al, 2024

Appendix 6 – Results TEQs, PCDD/Fs, DL-PCBs, and indicator-PCBs

Results WHO2005 TEQs for PCDD/Fs and DL-PCBs in soot and ash samples

Soot	Installation	S-ID	PCDD/F TEQs	DL-PCB TEQs	Tot-TEQs (upper bound)
1	Wood Boilers	AC5	34.00	0.38	34.38
2		G11	280.0	4.11	284.1
3		S1	94.00	3.31	97.31
4		G3	210.0	7.82	217.8
5		G10	4.20	0.42	4.62
6	Fireplace/Wood Stoves	AC11	3.60	0.22	3.82
7		S6	1,100	27.04	1,127
8		S9	270.0	2.11	272.1
9		AC7	9.40	0.35	9.75
10	Pellets Boilers	AC3	8.90	2.28	11.18
11		AC9	1,400	29.25	1,429
12		G1	0.46	0.14	0.60
13		S8	2,200	42.05	2,242
Ash					
14	Wood Boiler	AC5	4.60	0.09	4.69
15	Fireplace/Wood Stove	S9	0.00	0.07	0.07
16	Pellets Boiler	AC9	0.01	0.06	0.07

Results PCDD/Fs																		
Provmärkning	AC5	G11	S1	G3	G10	AC11	S6	S9	AC7	AC3	AC9	G1	S8	AC5*	S9	AC9	Blank	Blank
UmU provmärkning	3966:1	3966:2	3966:3	3966:4	3966:5	3966:6	3966:7	3966:8	3966:9	3966:10	3966:11	3966:12	3966:13	3966:14	3966:15	3966:16	3966:B1	3966:B2
Provtyp	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Aska	Aska	Aska	Blank	Blank
Mängd analyserat prov (g)	2,54	5,01	4,91	4,1	5,04	2,53	4,76	4,36	4,68	4,79	4,92	4,97	4,84	4,62	4,52	4,67	5	5
Enhet	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g
2378 TeCDD	1,6	42	20	6,3	ND(0,3)	0,63	62	11	2	0,76	87	ND(0,4)	220	ND(022)	ND(0,33)	ND(0,32)	ND(0,3)	ND(0,3)
12378 PeCDD	16	47	16	45	0,59	0,54	270	61	1,8	1,1	760	ND(0,4)	340	0,86	ND(0,33)	ND(0,32)	0,64	ND(0,4)
123478 HxCDD	4,7	30	4	34	0,67	ND(0,59)	170	230	ND(0,85)	0,79	810	ND(0,4)	76	ND(0.22)	ND(0,66)	ND(0,64)	0,53	1,2
123678 HxCDD	55	38	3,7	68	0,76	ND(0,59)	210	260	ND(1,1)	1,4	1000	ND(0,4)	100	2,4	ND(0,66)	ND(0,64)	0,52	ND(0,6)
123789 HxCDD	31	28	3,7	56	0,5	ND(0,59)	200	260	ND(0,85)	1,1	1000	ND(0,4)	72	1,9	ND(0,66)	ND(0,64)	0,52	ND(0,6)
1234678 HpCDD	40	200	5,5	760	11	2,2	1200	7400	3,2	75	9900	ND(0,4)	360	1,8	ND(0,66)	0,68	1,6	0,88
OCDD	21	330	10	1200	20	4,5	1300	17000	7,2	400	15000	ND(0,6)	380	2,4	ND(1,1)	1,4	2,5	1,6
2378 TeCDF	13	640	180	280	7,8	12	830	160	25	21	350	1,4	5100	2,1	ND(0,66)	ND(0,64)	ND(0,4)	ND(0,3)
12378 PeCDF	5,3	130	65	100	2,3	2,3	700	10	6,3	5,3	100	ND(0,5)	1300	1	ND(0,66)	ND(0,64)	0,72	ND(0,4)
23478 PeCDF	9,9	280	96	290	5,8	2,5	1000	51	7,2	8,7	260	1,1	2800	1,2	ND(0,66)	ND(0,64)	0,47	ND(0,4)
123478 HxCDF	5,9	110	21	82	2,5	1	830	28	2,6	2,8	130	ND(0,5)	410	1,7	ND(1,1)	ND(1,1)	0,49	ND(0,4)
123678 HxCDF	4,6	120	21	54	1,4	0,76	740	23	2	1,8	130	ND(0,5)	620	1	ND(1,1)	ND(1,1)	ND(0,4)	ND(0,4)
234678 HxCDF	15	77	28	59	2,6	0,74	1100	30	1,9	2,7	73	ND(0,5)	410	1,4	ND(1,1)	ND(1,1)	0,87	ND(0,4)
123789 HxCDF	3	8,1	8,6	14	ND(0,6)	0,89	280	12	ND(0,64)	1,3	77	ND(0,6)	210	20	ND(1,1)	ND(1,1)	ND(0,6)	ND(0,4)
1234678 HpCDF	35	120	13	52	4,4	0,61	1600	85	0,7	3,1	220	ND(0,6)	390	2,4	ND(1,1)	ND(1,1)	0,79	0,81
1234789 HpCDF	2,9	23	3,8	15	ND(0,6)	ND(1,2)	260	43	ND(0,85)	0,88	140	ND(0,8)	73	1,1	ND(1,1)	ND(1,1)	0,67	ND(0,6)
OCDF	11	36	2,9	26	1,9	ND(1,6)	500	180	ND(0,85)	ND(1,0)	360	ND(1,0)	66	3,5	ND(1,1)	ND(1,1)	3,3	1,9

Instrument: Waters Autospec Ultima MS instrument, * Agilent QQQ MSD

Results DL-PCBs																		
Provmärkning	AC5	G11	S1	G3	G10	AC11	S6	S9	AC7	AC3	AC9	G1	S8	AC5*	S9	AC9	Blank	Blank
UmU provmärkning	3966:1	3966:2	3966:3	3966:4	3966:5	3966:6	3966:7	3966:8	3966:9	3966:10	3966:11	3966:12	3966:13	3966:14	3966:15	3966:16	3966:B1	3966:B2
Provtyp	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Aska	Aska	Aska	Blank	Blank
Mängd analyserat prov (g)	2,54	5,01	4,91	4,1	5,04	2,53	4,76	4,36	4,68	4,79	4,92	4,97	4,84	4,62	4,52	4,67	5	5
Enhet	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g
#77 TeCB*	13	71	110	130	8,9	17	440	140	18	120	320	4,7	1200	4,2	3,3	4,7	2,3	3,2
#81 TeCB*	1,6	9,5	16	13	1,6	1,8	68	14	1,4	5,8	42	-0,6	260	0,31	ND(0,44)	ND(0,43)	0,42	ND(0,4)
#126 PeCB*	3,3	38	32	74	4	2,2	260	20	3,5	13	280	1,4	400	0,64	0,67	0,59	0,78	0,88
#169 HxCB*	1,3	11	3,1	10	0,85	ND(0,79)	63	1,4	ND(0,43)	ND(0,42)	28	-0,4	50	0,72	ND(0,44)	ND(0,43)	ND(0,4)	ND(0,4)
#105 PeCB**	19	40	43	330	13	18	250	40	10	8700	880	10	420	6,9	6,9	14	7,3	6,1
#114 PeCB**	0,91	3,1	4,7	19	2	0,88	18	1,7	0,94	350	45	0,56	35	0,62	0,38	0,61	0,51	0,43
#118 PeCB**	72	88	110	1300	43	61	510	160	29	21000	3500	31	630	29	25	55	23	21
#123 PeCB**	0,6	2,3	2,5	11	1,3	0,79	16	3,9	0,63	230	65	0,45	39	0,62	0,3	0,52	0,42	0,29
#156 HxCB **	10	42	39	1300	22	5,7	240	30	3,7	1500	1900	3,3	200	2,7	1,8	4,5	2,2	1,8
#157 HxCB**	1,1	9,6	6	140	3,6	0,67	83	5,8	0,97	260	350	0,43	74	0,52	0,49	0,56	0,47	0,34
#167 HxCB**	4,8	17	18	530	9,9	2,5	99	14	1,9	520	1100	0,91	89	1,5	0,92	1,9	1,3	0,85
#189 HpCB**	0,9	13	7,9	290	7,1	0,51	110	25	0,57	22	350	0,4	58	0,97	0,22	2	0,42	0,25

Instrument: * Waters Autospec Ultima MS instrument (accept sample A5 ash), ** Agilent QQQ MSD

Results Indicator PCBs																		
Provbeteckning	AC5	G11	S1	G3	G10	AC11	S6	S9	AC7	AC3	AC9	G1	S8	AC5 ash	S9 ash	AC9 ash	Lab blank	Lab blank
UmU provmärkning	3966:1	3966:2	3966:3	3966:4	3966:5	3966:6	3966:7	3966:8	3966:9	3966:10	3966:11	3966:12	3966:13	3966:14	3966:15	3966:16	3966:B1	3966:B2
Provtyp	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Sot	Aska	Aska	Aska	Blank	Blank
Mängd analyserat prov (g)	2,54	5,01	4,91	4,1	5,04	2,53	4,76	4,36	4,68	4,79	4,92	4,97	4,84	4,62	4,52	4,67	5	5
Enhet	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g	pg/g
#28 TrCB	350	210	300	150	270	190	1500	830	160	1400	6700	200	460	150	150	290	110	120
#52 TeCB	110	80	120	400	43	260	520	280	64	15000	3000	57	480	44	46	100	36	40
#101 PeCB	140	130	260	2300	82	180	850	290	56	26000	6900	54	490	60	40	130	38	40
#118 PeCB	72	88	110	1300	43	61	510	160	29	21000	3500	31	630	29	25	55	23	21
#138 HxCB	130	240	370	7100	130	63	1300	300	35	14000	15000	32	890	38	22	65	35	24
#153 HxCB	190	230	430	6300	120	93	1300	330	38	11000	16000	39	870	52	25	92	37	26
#180 HpCB	74	200	230	9400	150	31	1200	240	21	1600	14000	22	740	18	12	24	22	14
Sum I-PCBs	1066	1178	1820	26950	838	878	7180	2430	403	90000	65100	435	4560	391	320	756	301	285

Instrument: Agilent QQQ MSD