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10.1016/j.atmosenv.2013.07.011

# Assessment of polyaromatic hydrocarbon emissions from laser printers

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## Abstract

The potential for polyaromatic hydrocarbon (PAH) emissions from laser printers has been examined using a simulated printing process and a detailed chemical analysis of printer toner. We have analysed the PAH content of both carbon black (a toner constituent) and toner before and after heating and have found measurable evaporation and subsequent condensation of PAHs. Based on our analysis we have estimated a maximum possible PAH emission rate of 82.1  $\mu\text{g}/\text{minute}$  of printing for a 10% page coverage. Our VOC emission results agree well with those of other authors. The concentrations of individual PAHs in the emissions were relatively low, however non-trivial, especially long term.

*Keywords:*

PAHs, VOCs, toner, ultrafine particles, printing

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## 1. Introduction

1 Laser printing devices are common in workplaces, libraries and in homes.  
2 There has recently been concern over the health effects of such printers;  
3 specifically the generation of ultrafine particulate matter during the printing  
4 process. This has in turn prompted a resurgence in inkjet technology. A  
5 number of studies have measured the particle concentrations produced by  
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7 laser printers (He et al., 2007; Schripp et al., 2008; Wensing et al., 2008;  
8 Morawska et al., 2009; Koivisto et al., 2010; Wang et al., 2011; Tang et al.,  
9 2012b), while others have assessed the risk of such exposures (Hänninen  
10 et al., 2010). A comprehensive study by He et al. (2007) found that a large  
11 proportion of commercial laser printers generated ultrafine particles and that  
12 around half of those that did, did so at high concentrations.

13 This potentially represents a health risk as there is growing evidence to  
14 suggest that the surface area of carbon nanoparticles (like those generated  
15 by heating toner in the printing process) is the most toxicologically relevant  
16 factor (Stoeger et al., 2006). Though at this stage there is little epidemiolog-  
17 ical evidence linking printer emissions to health problems (Hänninen et al.,  
18 2010).

19 However, work with human lung cell cultures has found that both printer  
20 toner and printer emissions have a genotoxic effect (Gminski et al., 2011;  
21 Tang et al., 2012a; Könzöl et al., 2013). The exact component(s) of printer  
22 toner which cause this effect are, however unclear as there are many volatile  
23 organic compounds (VOCs) and polyaromatic hydrocarbons (PAHs) present  
24 in printer toner. The presence of such compounds is an artifact of the pro-  
25 duction of carbon black (a key component in toner) via combustion in sub-  
26 stoichiometric air. Additionally, the particles emitted during the printing  
27 process contain inorganics, such as iron, silicon and bromine (Barthel et al.,  
28 2011).

29 Depending on the temperature reached during the printing process, these  
30 VOCs and PAHs may be released. He et al. (2010) studied the effect of fuser  
31 roller temperature in laser printers and found that it was the most significant  
32 factor in terms of the number of particles generated.

33 Given that laser printers are almost exclusively used indoors, there will  
34 be a risk of exposure to printer emissions and as such consideration must be  
35 given to printer emissions when monitoring indoor air quality. Kagi et al.  
36 (2007) considered the implications of both chemical and ultrafine particles  
37 for indoor air quality. While some studies have measured and identified  
38 VOC emissions from office equipment (such as printers and photocopiers)  
39 (Lee et al., 2001; Lee and Hsu, 2007), as well as considering health impacts  
40 (Lee et al., 2006; Wolkoff and Nielsen, 2001), to the best of our knowledge no  
41 study has identified the compounds present in emissions from laser printers.

42 The presence and release of PAHs in and from toner is important as a large  
43 number of PAHs are classified as carcinogens or probable carcinogens (Straif  
44 et al., 2005). This work examines the release of PAHs from toners using

45 a simulated printing process, to identify compounds that may be released  
46 during the printing process, as well as the PAHs that are present in toner.

## 47 **2. Methods**

48 Our “simulate” printing (or toner heating) methods emulate the evaporation-  
49 condensation processes which are likely to occur on the fuser-roller of a laser  
50 printer. We neglect the additional forces (mechanical and electrostatic) which  
51 exist in a printer. We also do not have a sorbent substance (paper) present.  
52 The heating rates in our system were necessarily slower than in a real printer,  
53 and the toner mass higher per unit area. However, we believe our system  
54 accurately replicates the evaporation of PAHs and SVOCs from toner, if not  
55 the fate once released. Our two methods (TGA and large scale) produced  
56 almost identical mass losses of toner, despite different heating rates, which  
57 supports this conclusion. Most studies of printer emissions (Morawska et al.,  
58 2009; He et al., 2007; Wang et al., 2011) have found a spike in particulate  
59 emissions at the commencement of the printing process, which rapidly dimin-  
60 ishes after approximately 30 s. This suggests that SVOCs and PAHs may  
61 possibly deposit on the fuser roller (or other printer components), and be  
62 re-released at the start of the printing process.

63 Given that the release of ultrafine particles during a single printing oper-  
64 ation is relatively low, and that PAHs only make up a small fraction of the  
65 toner constituents, identifying individual components in the emissions would  
66 be difficult. Therefore, this work has utilised a simulated printing process  
67 whereby a sample (either toner (Black MP C5503, RICOH, USA), or carbon  
68 black (Printex U, Degussa, Germany) (Bredin et al., 2011)) is heated rapidly,  
69 using a Thermogravimetric Analyser (TGA, NETZSCH Tarus TG209 F3).  
70 This allows any mass loss from the toner due to heating to be measured.

71 A series of measurements were made using the TGA, with samples (10-30  
72 mg) of either toner or carbon black, with one of three different temperature  
73 profiles. All measurements were preceded by a 45 minute purge of the sample  
74 chamber with either air or nitrogen at 38°. The first set of measurements  
75 was conducted by heating at 50°C/min to a temperature of 250°C. The TGA  
76 was then held isothermal for 5 minutes before the temperature was returned  
77 to 38°C as quickly as possible. The purpose of this rapid cooling is to give  
78 as close an approximation to the printing process as possible.

79 The second set of measurements the TGA was held isothermal at 250°C  
80 for 1 hour, before being allowed to return to the ambient temperature.

81 The final set of measurements considered mass loss at different maximum  
82 temperatures. In these measurements, the toner was heated to temperatures  
83 of 150, 200, 250 and 300°C and then allowed to return to ambient temperature  
84 as quickly as possible.

85 In order to allow the results of the simulated printing process to be re-  
86 lated to actual printing, we evaluated the toner consumption for a printer, by  
87 printing 100 identical pages and determining the mass loss of toner from the  
88 cartridge. For this work we used a FujiXerox DocuCentre IV C 3375, multi-  
89 function printer. These measured values, combined with measured emissions  
90 in other work were then used to calculate emission rates.

91 Additional experiments were also conducted using larger size toner sam-  
92 ples (1 g) in a glass vessel. This set up involved drawing emissions from  
93 heated toner through a filter. The set-up is shown in Figure 1.

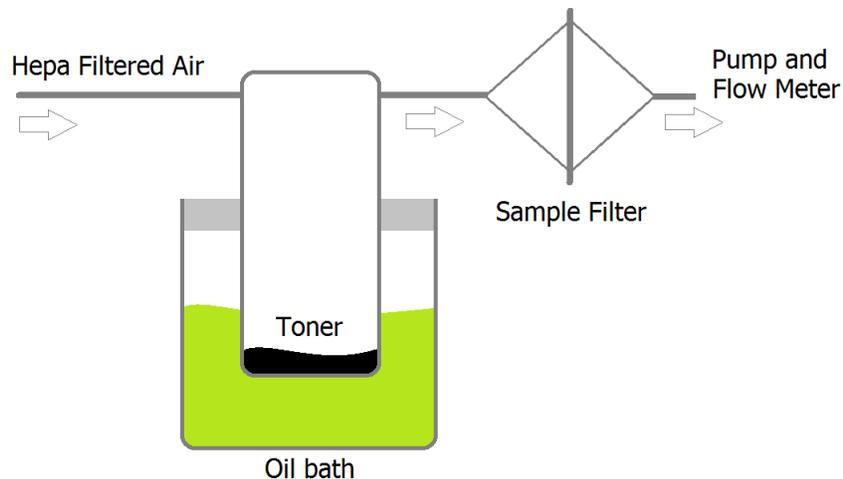


Figure 1: A schematic of the experimental set up for the large scale experiments

94 In order to maintain an evenly distributed and stable temperature a sand  
95 and avocado oil bath was used to heat the glass vessel containing the sample  
96 (Figure 1). The emissions from the heated toner were passed through a glass  
97 fibre filter. The oil bath was pre-heated to 230 -250°C, then the glass vessel  
98 place inside to simulate rapid heat-up during printing. After 10 minutes  
99 the sample vessel was removed from the oil bath and the pump left running  
100 for a further five minutes, so that any additional emissions could be drawn

101 through the filter. The filters were weighed before and after the tests so that  
102 the collected mass of emissions could be obtained.

103 Each of the filters used was initially heated to either 550°C or 250°C and  
104 then cooled in a dessicator before use. At the conclusion of sample collection  
105 the filters were removed and returned to the dessicator before being weighed.  
106 After weighing the filter was heated to 100°C before being returned to the  
107 dessicator and re-weighed. This process was repeated for temperatures of  
108 150°C and 250°C.

109 In order to approximate the amount of carbon black in the toner, an ele-  
110 mental analysis of both toner and Printex U was performed using a Thermo  
111 Finnigan EA 1112 Series Flash Elemental Analyser.

### 112 *2.1. PAH analysis*

113 Samples of carbon black and toner were analysed for PAH content. Ad-  
114 ditional samples of carbon black were heated to 250°C and 300°C and then  
115 analysed to measure any loss of PAHs through evaporation, as may occur  
116 during the printing process.

117 Identification of the PAHs was carried out by extraction using organic  
118 solvent, followed by pre-concentration and analysis by gas chromatography  
119 mass spectrometry (GC/MS). Control and laboratory blank samples were  
120 analysed concurrently with the toner samples.

121 Samples were spiked with a known amount of surrogate standard (Chem-  
122 Service Product CSS8250-1JM) and placed in the ASE for further extraction  
123 with 4:1 mixture of hexane and ethylacetate. The sample extracts were com-  
124 bined and concentrated down, a known amount of internal standard (Chem-  
125 Service Product PP-HC8JM) was added prior to the sample being made up  
126 to volume with equal volumes of ethylacetate and hexane. Sub-samples of  
127 the extract were analysed by GC/MS.

128 For the duration of this study an Agilent 6890 Gas Chromatograph (GC)  
129 coupled to a 5973 Mass Spectrometer (MS) operating in the selected ion  
130 monitoring (SIM) mode was used to carry out the analyses. The GC was  
131 fitted with a HP-5MS capillary column (60 m x 0.25 mm x 0.25  $\mu$ m). The  
132 injector was operated in the pulsed splitless mode and was held at 300°C  
133 with a target pulse pressure of 50 psi. After the run had been initiated the  
134 oven was held at 50°C for 2 minutes, the column was then heated to 240°C  
135 at 12°C/min and then to 310°C at 3°C/min, the column was then held at  
136 this temperature for 16.5 minutes. The GC eluate was introduced into the  
137 MS via a transfer line maintained at 300°C. The MS operated with a start

138 delay of 10 minutes and positive electron ionization (EI) of 70 eV. To improve  
139 sensitivity the system was set to monitor five groups of ions ranging from 82  
140 to 172 atomic mass units (amu) with a dwell time of 40 milliseconds (ms)  
141 in Group 1, to 138 to 300 amu with a 40 ms dwell time in Group 5. The  
142 GC/MS system was calibrated using five calibration standards, plus a zero  
143 point.

### 144 3. Results and Discussion

145 In order for laser printers to produce emissions (from the toner) there  
146 must be a mass loss of toner during the printing process. Figure 2 shows  
147 the mass loss of samples of toner, during the simulated printing process  
148 at different temperatures. It is clear that significant mass loss (and hence  
149 release of emissions) occurs at temperatures higher than 250°C. There is also  
150 minimal mass loss at 150°C, indicating minimal water and VOC content in  
151 the toner. The significantly higher mass loss at 300°C, is possibly due to  
152 thermal decomposition of the binder (a styrene based polymer).

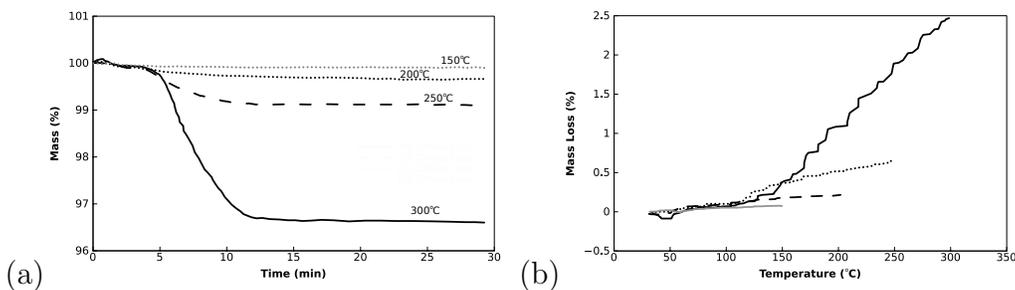


Figure 2: Mass loss of printer toner during a simulated printing process at different temperatures, (a) shows the change in the original mass of toner during the simulated printing process and, (b) shows the cumulative mass loss during heating.

153 This is in contrast to Printex U, which begins to lose mass at lower  
154 temperatures. This can be seen clearly in Figure 3 where results for both  
155 Printex U and toner are shown. All samples were heated to 250°C. The  
156 temperature profile is shown so that the mass loss can be seen in relation to  
157 temperature. All samples lost a significant proportion of their total mass loss  
158 during heating. The higher mass loss of Printex U samples at the beginning  
159 of the measurement, was attributed to the presence of moisture in the sample  
160 (despite dessication prior to analysis, which suggests a high surface area).

161 In comparing the results, it should be noted that carbon black is a com-  
 162 ponent of toner and therefore would be expected to show a higher mass loss  
 163 than the toner itself, where it has effectively been diluted with binder. It is  
 164 useful in this study, to consider Printex U as it contains a higher proportion  
 165 of PAHs and therefore they should be more readily measured.

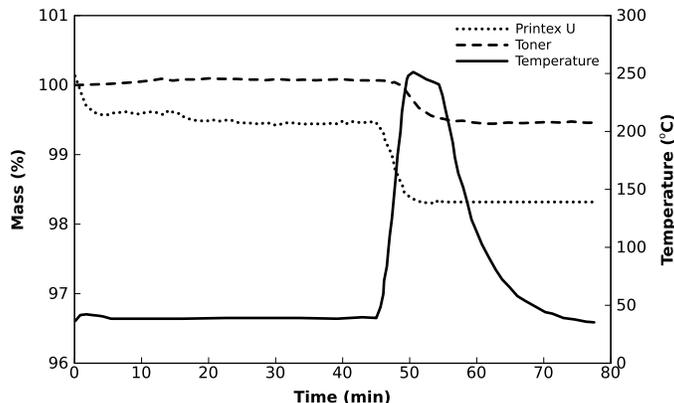


Figure 3: Mass loss of toner and Printex U samples during the simulated printing process, for 4 different maximum temperatures.

166 Given that printer toner contains carbon black in combination with binder  
 167 and other components, the VOC and PAH analysis was carried out on the  
 168 Printex U, as this is essentially the carbon black component of toner in  
 169 isolation. The results of the VOC analysis are given in Table 1, where  $c$  is  
 170 the concentration of the compound in the carbon black (w/w).

171 The VOCs shown in Table 1 only make up 0.015 % of the mass of Printex  
 172 U, and so are likely present in toner in very low (difficult to measure) con-  
 173 centrations.

174 The results of the PAH analysis are shown in Table 2. Multiple samples  
 175 were analysed, with the resultant mean concentration,  $c_m$ , and standard  
 176 deviation (SD) given. Samples of Printex U were analysed as supplied as well  
 177 as after heating to 250°C and 300°C. None of the PAHs present in Printex U,  
 178 as supplied, were detectable in the samples heated to 300°C, and so no data is  
 179 shown in Table 2. Only compounds detected are listed, quantities indicated  
 180 by  $<$  were below the detection limit. The standard deviations for some of  
 181 the heated samples are not listed as only one of the three samples gave a  
 182 quantity over the detection limit. In these cases the concentration given is  
 183 for the single measurement not a mean concentration. The large standard

Table 1: VOC content of Printex U

Compound	$c$ (mg/kg)
Benzene	30
Styrene	4.4
Toluene	95
Xylene, m- & p-	12
Xylene, o-	0.7
1,2,4-trimethylbenzene	0.6
Ethylbenzene	0.9
Chloroform	2.8
Tetrachloro-ethylene	1.4
Dichloromethane	2.5

184 deviations for some compounds are attributed to samples being taken from  
 185 different batches of Printex U. Some individual Printex U samples showed  
 186 overall PAH levels up to 5x that of a typical diesel engine soot (also analysed  
 187 by the authors), which is concerning.

Table 2: PAH content of Printex U

Compound	As Supplied		After Heating to 250°C	
	$c_m$ (mg/kg)	SD $\pm$	$c_m$ (mg/kg)	SD $\pm$
Naphthalene	70.1	46.0	5	-
Acenaphthylene	83.4	58.4	<	-
Acenaphthene	12	-	<	-
Phenanthrene	402.8	143.4	48.5	31.8
Anthracene	47.6	12.4	<	-
Fluoranthene	173.3	73.2	86.5	33.2
Pyrene	109.4	50.1	56	22.6
Benz(a)anthracene	37.5	-	<	-
Chrysene	30.2	-	<	-
Benzo(b)fluoranthene	11	1.4	8.5	2.1
Benzo(k)fluoranthene	16.8	2.9	7	-
Benzo(e)pyrene	5.7	0.6	<	-
Benzo(a)pyrene	9.5	5.7	<	-
Indeno(1,2,3-cd)pyrene	5	0	<	-

188 It is evident from Table 2 that PAHs will be released when Printex U and

189 hence toner is heated, as is the case in laser printers. The Printex U samples  
190 contained between 0.08 and 0.13 % PAH by mass.

191 Table 3 shows the results of the PAH analysis for printer toner, again  
192 only compounds present in quantities above the detection limit are shown.

Table 3: PAH content of toner

Compound	$c_m$ (mg/kg)	SD
Phenanthrene	5.1	1.7
Anthracene	5.8	1.7
Fluoranthene	5.9	0.4
Pyrene	2.7	1.7
Benz(a)anthracene	9.1	-
Chrysene	7.1	-
Benzo(k)fluoranthene	3.5	1.0
Benzo(a)pyrene	5	1.4

193 Based on the results of the elemental analysis, and assuming a styrene  
194 binder (or binder with comparable hydrogen to carbon ratio) the amount of  
195 carbon black in the toner was found to be approximately 4.7 %. Considering  
196 the significant amount of dilution of carbon black in toner, it is not surprising  
197 that fewer PAHs were detectable in the toner samples. These are mostly the  
198 compounds present in the highest concentrations in Printex U.

199 In order to relate these results back to ‘real world’ printing we consider  
200 the rate of printing and toner consumption for a typical office printer. For our  
201 given printer (see Section 2) the results of toner consumption tests are shown  
202 in Table 4, where toner usage per page is shown in relation to a percentage  
203 of page coverage. Alternatively, we can also express toner consumption in  
204 relation to a unit printed area (100% coverage), which in this case is 6.19  
205  $\mu\text{g}/\text{cm}^2$ .

206 Using the manufacturers listed printing rate of 35 pages/minute and as-  
207 suming a 10% coverage per page, the PAH emissions in relation to printing  
208 time are estimated at 82.1  $\mu\text{g}$  PAH/minute. It should be noted that this  
209 would be an overestimate as this assumes that all PAHs are emitted to air.  
210 In reality, it is likely that given the proximity of the paper to the fuser roller,  
211 some (or most) of the PAHs emitted will be absorbed by the paper. The  
212 other consideration is that the heating of the toner by the fuser roller will  
213 likely be more rapid than in the simulated printing process we have used,  
214 which may lead to reduced emissions. The estimate provided here should be

Table 4: Toner consumption during printing

% page coverage	toner used (mg/page)	PAH* ( $\mu\text{g}/\text{page}$ )
5	19.19	1.17
10	38.39	2.35
15	57.58	3.52

\* Estimated value, based on carbon black composition. The majority of PAH emitted would remain in the printed area or be absorbed into the paper.

215 treated as a ‘worst case scenario’ and indicates that we need at least to be  
 216 aware of PAH emissions from printers, or PAH levels absorbed into printed  
 217 paper.

218 The results of our work may also be compared to results in the literature  
 219 of measured printer emissions. Wang et al. (2011) measured the emissions  
 220 of VOCs during printing, calculating total VOC emissions of 2.14 mg, over  
 221 a 1000 page print cycle, giving 2.14  $\mu\text{g}/\text{page}$ . Based on our VOC analysis  
 222 of carbon black, we estimate VOC emissions of 2.7  $\mu\text{g}/\text{page}$ . The difference  
 223 between the two values is likely due to a difference in compositions in the  
 224 VOC components of the toner used by Wang et al. (2011) and carbon black.  
 225 With that considered, the two results agree well.

226 To further confirm the release of compounds from toner, large scale tests  
 227 were conducted. These tests heated the toner and collected any particulate  
 228 produced in a filter. Toner mass losses during these tests were equivalent to  
 229 those given in Figure 2(a). An increase in mass in the filter was observed  
 230 indicating the presence of such substances in toner emissions. After initial  
 231 weighing, the filters were heated, then weighed. It was found that all collected  
 232 emissions could be evaporated from the filter at or before 250°C. The results  
 233 are shown in Figure 4.

234 It can be seen in Figure 4 that all mass collected by the filter is driven off  
 235 at 250°C. On this basis, and given the known presence of PAHs and VOCs  
 236 it is assumed that all collected emissions are either, water, SVOCs or PAHs.  
 237 Given that over 80% of the mass collected on the filter is still present after  
 238 heating to 100°C, it is assumed that the majority of the emissions are VOCs  
 239 and PAHs. Additionally, based on the results of the VOC analysis, where  
 240 the only (detected) compound with a boiling point above 150°C was 1,2,4-  
 241 trimehtylbenzene, we propose that the majority of the collected emissions  
 242 are PAHs. We do note however, that during the printing process, long chain

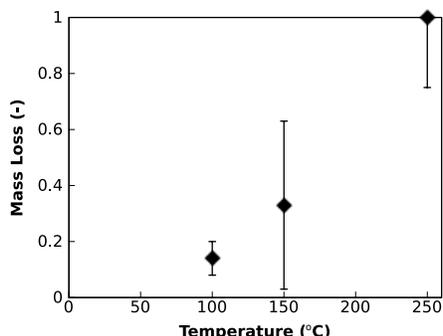


Figure 4: Cumulative mass loss from the filters, each data point represents a mean value, with error bars indicating  $\pm 1$  SD

243 alkanes and siloxanes have been detected by other authors (Barthel et al.,  
 244 2011; Morawska et al., 2009). These however, are considered to be too volatile  
 245 (and in too low concentrations) to form persistent particles (Morawska et al.,  
 246 2009) and so were not specifically tested for. Furthermore, the carbon and/or  
 247 toner contains no silicon and therefore siloxanes must have another source  
 248 (such as printer components - therefore presumably more of an issue with  
 249 newer printers). This leads to the interesting question of source (and gener-  
 250 ation mechanism) apportionment of printer emissions, which is however  
 251 beyond the scope of this work.

252 We have only considered the evaporation-condensation mechanism of  
 253 aerosol formation, neglecting additional mechanical forces. Other forces (me-  
 254 chanical, electrostatic) and processes exist, which may serve to either gener-  
 255 ate additional particles, or collect those generated from heating and fusing  
 256 toner.

#### 257 4. Conclusion

258 This work identified 14 different PAHs in toner and its constituents. A  
 259 number of these were released during a simulated printing process and are  
 260 therefore likely to be released during normal laser printing operations. We  
 261 have estimated maximum possible PAH emissions at  $82.1 \mu\text{g}/\text{minute}$  for 10%  
 262 page coverage at 35 pages/minute. Due to differences between the actual  
 263 printing process and our simulated printing process actual emissions are ex-  
 264 pected to be lower than this estimate. As manufacturers are beginning to  
 265 use lower printing temperatures the amount of PAHs released will likely be

266 decreased. Nevertheless it may be advisable for carbon black manufacturers  
267 to attempt to reduce PAH levels on their products. and more consideration  
268 given to PAHs.

## 269 **Acknowledgements**

270 The authors would like to acknowledge Thomas Jeffreys (AERC) for as-  
271 sistance with the TGA measurements, the ChemCentre WA, for assistance  
272 with the PAH analysis and Dr Thomas Rodemann of the Central Science  
273 Laboratory at the University of Tasmania for the elemental analysis.

## 274 **References**

- 275 Barthel, M., Pedan, V., Hahn, O., Rothhardt, M., Bresch, H., Jann, O.,  
276 Seeger, S., 2011. Xrf-analysis of fine and ultrafine particles emitted from  
277 laser printing devices. *Environmental Science & Technology* 45, 7819–7825.
- 278 Bredin, A., Larcher, A. V., Mullins, B. J., 2011. Thermogravimetric analy-  
279 sis of carbon black and engine soot - towards a more robust oil analysis  
280 method. *Tribology International* 44, 1642–1650.
- 281 Gminski, R., Decker, K., Heinz, C., Seidel, A., Könzöl, M., Goldenberg,  
282 E., Grobéty, B., Ebner, W., Gieré, R., Mersch-Sundermann, V., 2011.  
283 Genotoxic effects of three selected black toner powders and their dimethyl  
284 sulfoxide extracts in cultured human epithelial a549 lung cells in vitro.  
285 *Environmental and Molecular Mutagenesis* 52, 296–309.
- 286 Hänninen, O., Brüske-Hohfeld, I., Loh, M., Stoeger, T., Kreyling, W.,  
287 Schmid, O., Peters, A., 2010. Occupational and consumer risk estimates  
288 for nanoparticles emitted by laser printers. *Journal of Nanoparticle Re-  
289 search* 12, 91–99.
- 290 He, C., Morawska, L., Taplin, L., 2007. Particle emission characteristics of  
291 office printers. *Environmental Science & Technology* 41, 6039–6045.
- 292 He, C., Morawska, L., Wang, H., Jayaratne, R., McGarry, P., Johnson, G. R.,  
293 Bostrom, T., Gonthier, J., Authemayou, S., Ayoko, G., 2010. Quantifica-  
294 tion of the relationship between fuser roller temperature and laser printer  
295 emissions. *Journal of Aerosol Science* 41, 523–530.

- 296 Kagi, N., Fujii, S., Horiba, Y., Namiki, N., Yoshio, O., Emi, H., Tamura,  
297 H., Kim, Y., 2007. Indoor air quality for chemical and ultrafine particle  
298 contaminants from printers. *Building and Environment* 42, 1949–1954.
- 299 Koivisto, A. J., Hussein, T., Niemelä, R., Tuomi, T., Hämeri, K., 2010.  
300 Impact of particle emissions of new laser printers on a modeled office room.  
301 *Atmospheric Environment* 44, 2140–2146.
- 302 Könzöl, M., Weiß, A., Gminski, R., Merfort, I., Mersch-Sundermann, V.,  
303 2013. Oxidative stress and inflammatory response to printer toner particles  
304 in human epithelial a549 lung cells. *Toxicology Letters* 216, 171–180.
- 305 Lee, C.-W., Dai, Y.-T., Chien, C.-H., Hsu, D.-J., 2006. Characterisitcs and  
306 health impacts of volatile organic compounds in photocopy centers. *Envi-  
307 ronmental Research* 100, 139–149.
- 308 Lee, C.-W., Hsu, 2007. Measurements of fine and ultrafine particles formation  
309 in photocopy centers in taiwan. *Atmospheric Environment* 41, 6598–6609.
- 310 Lee, S. C., Lam, S., Fai, H. K., 2001. Characterization of vocs, ozone, and  
311 pm<sub>10</sub> emissions from office equipment in an environmental chamber. *Build-  
312 ing and Environment* 36, 837–842.
- 313 Morawska, L., He, C., Johnson, G. R., Jayaratne, R., Salthammer, T., Wang,  
314 H., Uhde, E., Bostrom, T., Modini, R., Ayoko, G., McGarry, P., Wens-  
315 ing, M., 2009. An investigation into the characterisitcs and formation  
316 mechanisms of particles originating from the operation of laser printers.  
317 *Environmental Science & Technology* 43, 1015–1022.
- 318 Schripp, T., Wensing, M., Uhde, E., Salthammer, T., He, C., Morawska, L.,  
319 2008. Evaluation of ultrafine particle emissions from laser printers using  
320 emission test chambers. *Environmental Science & Technology* 42, 4338–  
321 4343.
- 322 Stoeger, T., Reinhard, C., Tekenaka, S., Schroepfel, A., Karg, E., Ritter, B.,  
323 Heyder, J., Schulz, H., 2006. Instillation of six different ultrafine carbon  
324 particles indicates a surface are threshold dose for acute lung inflammation  
325 in mice. *Environmental Health Perspectives* 114, 328–333.

- 326 Straif, K., Baan, R., Grosse, Y., Secretan, B., El Ghissassi, F., Coglianò, V.,  
327 2005. Carcinogenicity of polycyclic aromatic hydrocarbons. *The Lancet*  
328 *Oncology* 6, 931–932.
- 329 Tang, T., Gminski, R., Könzcöl, M., Modest, C., Armbruster, B., Mersch-  
330 Sundermann, V., 2012a. Investigations on cytotoxic and genotoxic effects  
331 of laser printer emissions in human epithelial a549 lung cells using an  
332 air/liquid exposure system. *Environmental and Molecular Mutagenesis* 53,  
333 125–135.
- 334 Tang, T., Hurraß, J., Gminski, R., Mersch-Sundermann, V., 2012b. Fine and  
335 ultrafine particles emitted from laser printers as indoor air contaminants  
336 in german offices. *Environmental Science and Pollution Research* 19, 3840–  
337 3849.
- 338 Wang, Z.-M., Wagner, J., Wall, S., 2011. Characterization of laser printer  
339 nanoparticle and voc emissions, formation mechanisms , and strategies to  
340 reduce airborne exposure. *Aerosol Science and Technology* 25, 1060–1068.
- 341 Wensing, M., Schripp, T., Uhde, E., Salthammer, T., 2008. Ultra-fine parti-  
342 cles release from hardcopy devices: Sources, real-room measurements and  
343 efficiency of filter accessories. *Science of the Total Environment* 407, 418–  
344 427.
- 345 Wolkoff, P., Nielsen, G. D., 2001. Organic compounds in indoor air - their  
346 relevance for perceived indoor air quality? *Atmospheric Environment* 35,  
347 4407–4417.