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1                   **Assessment of the PCDD/F fate from MSWI residues used**  
2                   **in road construction in France**

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30 **Abstract**

31 MSWI fly ash is susceptible to contain high amount of dioxins (PCDD) and furans  
32 (PCDF). However, the use of MSWI residues for road construction started in France  
33 at period when the mixture of MSWI Bottom Ash with MSWI fly ash was used. From  
34 four old road sites, MSWI residues, road soils, reference soils and geo-textiles were  
35 sampled and their PCDD/F contents were analyzed. MSWI residues show a great  
36 heterogeneity but also high amounts of PCDD/F between 14 and 2960 ng I-TEQ.kg<sup>-1</sup>  
37 DM. Road soils show less heterogeneity and contents between 0.57 et 7.23 ng I-  
38 TEQ.kg<sup>-1</sup> DM lower than ordinary soils. Moreover, the specific analysis of the 17 toxic  
39 PCDD/F congeners (notably the 2,3,7,8-TetraCDD) indicates the very low  
40 noxiousness of road soils. The study also allows to assert the relation between the  
41 MSWI residue particle size and the PCDD/F content.

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43 **Keywords:** incineration, ash, road, dioxin, furan, particle

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## 53 **1 Introduction**

54 In many areas across the world where the high demand of construction materials  
55 compared to the availability of natural materials, as well as the lack of available  
56 space for waste disposal, are a problem, the use of by-products and wastes for road  
57 construction has been seen for a long time as an appropriate solution to reduce the  
58 amount of disposed materials and to provide at the same time alternative materials  
59 for construction. A typical case of these alternative materials is that of the Municipal  
60 Solid Waste Incinerator (MSWI) residue which is produced from the household  
61 wastes combustion and used for road and car-park construction.

62 In France, the use of MSWI residue in road construction is supervised since the 90's  
63 through an order (1991) and a memorandum (1994) both from the ministry of  
64 Environment. The environmental assessment of MSWI bottom ash is based on the  
65 measurement of its unburned fraction and the leaching potential of some heavy  
66 metals, arsenic, sulfate and total organic carbon. Yet, MSWI residues may contain  
67 persistent organic pollutants (POP) such as polychlorinated dibenzo-dioxins (PCDD)  
68 and polychlorinated dibenzo-furans (PCDF). PCDD/F molecules are poorly water  
69 soluble and leaching tests are known for not being relevant toward them,  
70 nonetheless, the affinity of PCDD/F molecules for particles is also known, and such  
71 affinity may be higher toward the finest particles. As a consequence, one wonders if  
72 under the effect of rainwater infiltration into the road body, the washing of the MSWI  
73 residue layer may induce the transfer, downward, of PCDD/F molecules bound to the  
74 finest particles of the material. In such a case, on road sites, compared to some  
75 reference soils, an increase of the PCDD/F content in the soil underlying the road  
76 (called the road soil), may be observed.

77 In order to answer to this question, PCDD/F contents of MSWI residues sampled into  
78 old road structures, were analyzed (including an assessment of their noxiousness).  
79 The relation between the dimension of MSWI residue particles and the PCDD/F  
80 content was studied. Then MSWI residue PCDD/F contents were compared to those  
81 measured in the road soil and in neighbouring soils (local references).

82 As before the enforcement of the 1991 order – thus PCDD/F compounds - MSWI  
83 residues were susceptible to contain higher amounts of fly ash, the present study  
84 was focused on pre-1991 constructions. At the same time, this allows to assess the  
85 medium-term state of road soils.

## 86 **2 Context of the study**

### 87 **2.1 Production of PCDD/F during household waste incineration**

88 As a result of incomplete combustion, incineration of household waste produces  
89 several organic compounds such as chlorinated species (polychlorinated biphenyls  
90 (PCB), polychlorinated dibenzodioxins (PCDDs), and polychlorinated dibenzofurans  
91 (PCDFs)). Two temperature ranges are responsible for the production of persistent  
92 organic pollutant (POP). The first one (200 to 400°C) which results from a catalysed  
93 reaction taking places on the ash particles present in combustion systems. The  
94 second one (500 to 800°C) is the result of a rearrangement of chlorinated precursors  
95 such as chlorophenols and chlorobenzenes in the gas phase (Stanmore, 2004).

96 Dioxin air emissions from incinerators have decreased in the last decade due to  
97 improvements in the pollution control technology and to the regulation  
98 implementation and enforcement. Two orders of 20 September, one for hazardous  
99 waste and another one for non hazardous waste, both limit the level of PCDD/F  
100 emission to  $0.1 \text{ ng.m}^{-3}$ .

## 101 **2.2 Use of MSWI residues for road construction in France**

102 The use of MSWI residue started in France during the 1950's in the area of Paris and  
103 spread all over the country during the 1980' – 1990's, a period during which many  
104 incinerators were built (AGHTM, 1994).

105 As for some other alternative materials (coal fly ash, blast furnace slag...), the use of  
106 MSWI residue was codified by the ministry for public works and transports, allowing  
107 its assimilation to one of the various kinds of natural materials considered for the  
108 classical road structure design (MELT, 1997; SETRA and LCPC, 2000). The analogy  
109 is based on geo-technical responses of the MSWI residue sample to a set of usual  
110 standard mechanical tests (resistance to fragmentation and wear, sand equivalent,  
111 surface cleanliness, compactibility...).

112 Until the 1990's the environmental question about the use of MSWI residue was not  
113 seen as a major concern. In 1991, an order required from the 1<sup>st</sup> of December 1992,  
114 the separating of MSWI residue into bottom ash (the fraction of the incineration  
115 residue which is collected from the incinerator grate) and fly ash (the fraction made of  
116 fine particles carried away by the flux of combustion gas which is later captured by  
117 dust collectors). While the production of MSWI bottom ash is around 250 kg per ton  
118 of incinerated residue, the production of fly ash is 20 kg per ton (AGHTM, 1994;  
119 Autret et al., 2007). Due to its high pollutant potential (notably high content in  
120 chlorides, arsenic, lead, zinc, mercury, cadmium and organic compounds), MSWI fly  
121 ash was classified as hazardous waste and has to be directed toward specific  
122 landfills for hazardous waste. Usually, the MSWI bottom ash fraction is classified as  
123 non-hazardous waste and is authorized in non-hazardous waste landfill, or also  
124 potentially authorized for road construction under specific conditions. Indeed, in  
125 1994, a memorandum from the Ministry in charge of the Environment (French

126 Environment Ministry, 1994) provided recommendations for the use of MSWI bottom  
127 ash in road construction (embankment, capping layers, subgrades....). The use of  
128 MSWI bottom ash depends on its unburned fraction and on its leaching potential  
129 controlled through a standard batch leaching test (NF X 31-210, 1992). The 1994  
130 memorandum sets maximum limit values related to the leachate: its global soluble  
131 fraction (total dissolved solids), plus specific limit values for seven chemical  
132 parameters: arsenic, cadmium, chromium VI, lead, mercury, sulfate and total organic  
133 carbon.

### 134 **2.3 Knowledge about the PCDD/F fate in the road environment**

135 The 1994 memorandum did not set any particular recommendation regarding dioxins  
136 and furans. Since the 1990's, MSWI residue (and more specifically MSWI bottom  
137 ash) has been extensively studied in France and worldwide from the environmental  
138 point of view. This was essentially carried out with relation to its heavy metal leaching  
139 potential and poorly with relation to its organic pollutants, notably regarding PCDD/F  
140 content and release risk (Chandler et al., 1997, Bartet et al., 2001). Consequently, as  
141 opposite to heavy metals for which laboratory, lysimeter and some field studies have  
142 provided leaching data (Silvestre and Rampignon, 1995; Adam et al., 1996;  
143 Drouadaine et al., 1997; Paris et al., 1997; Drouadaine and Badreddine, 2003), very  
144 little knowledge exists today regarding the fate of PCDD/F, notably possible transfer  
145 of PCDD/F to the open environment from the use of MSWI residues in road  
146 infrastructures.

147 In the French context, this issue is essentially related to the effect of pre-1991 MSWI  
148 residues, as at that time bottom and fly ashes were not separated. Considering on  
149 the one hand the long term potential effect of PCDD/F, and on the other hand the  
150 infiltration of rainfall through road surface (van Ganse, 1978) and the permeability of

151 the MSWI residue layers (i.e.  $10^{-5}$  to  $10^{-4}$  m.s<sup>-1</sup>) (François et al., 2003), understanding  
152 the fate of PCDD/F hold into old MSWI residues used in road structures has become  
153 a necessity. Indeed, due to its relatively poor mechanical properties, MSWI residue  
154 has primarily been used by road engineers mainly in the deeper layers of the road  
155 structure (SETRA and LCPC, 2000), where mechanical constraints are the lowest,  
156 immediately above the underlying natural soil. The latter (called road soil), due to its  
157 direct contact with the MSWI layer and to its ability to retain pollutants represents a  
158 major target to be considered in the context of alternative material use in road  
159 construction (Jullien and François, 2006).

### 160 **3 Materials**

#### 161 **3.1 Road site identification**

162 In order to take advantage of the longest possible period of contact between the  
163 MSWI residue layer and the road soil, road sites for study were chosen as old as  
164 possible. However, due to of the lack of written records for the oldest roads, it was  
165 only possible to go back in time as early as 20 years ago, thanks to the memory of  
166 the people who took part to the construction. For more recent sites (around 10 years  
167 old), more data was available.

168 The road body is a multi-layer structure. The pavement layers (surface course, base  
169 course, sub-base) are built on the pavement foundation, consisting of the natural  
170 ground after earthworks (scrapped and compacted) called the subgrade, generally  
171 topped with a capping layer in the French design technique (SETRA and LCPC,  
172 2000). Figure 1a presents the different road layers of a complete structure. In  
173 practice, depending on the physical stress expected on the road body during its use



174 (load due to traffic, climatic agents) and on the properties of the road materials, the  
175 number of layers in the structure and their thickness can vary.

176 When the natural soil on which the road structure is built contains too many fine  
177 particles, this may induce a transfer of fine particles from the road soil to the upper  
178 layer. This phenomenon can induce an increase of the upper layer sensitivity to  
179 moisture variation, detrimental to its bearing capacity. This risk is usually avoided  
180 using a geo-textile; such a geo-textile was found in two of the investigated sites.

181 Four sites (noted A, B, C and D) were investigated from various regions in France.  
182 Sites A and B were built in the second half of the 1970's, while sites C and D were  
183 built between 1991 and 1994. Their structure is described in Figure 1b. In both site,  
184 MSWI residues were used as 0-31.5 mm unbound graded aggregates.

185 Site A is the private road of a MSW incinerator plant, which essentially bears a heavy  
186 lorry traffic. The structure corresponds to a flexible pavement in which the MSWI  
187 residue was used in a thick sub-base layer (70 cm). The road soil is sandy. Built in  
188 1978, site A was sampled at the age of 20.

189 Site B is an urban pavement which only undergoes light vehicle traffic. The structure  
190 is that of a flexible pavement in which the MSWI residue was used in the sub-base  
191 layer (25 cm). The underlying soil is silty. Built in 1976, Site B was sampled at the  
192 age of 22.

193 Site C is another urban pavement which undergoes light traffic. The structure  
194 corresponds to a semi-rigid pavement in which the MSWI residue was used in a quite  
195 thick sub-base layer (40 cm), topped with a bound layer made of blast furnace slag  
196 and coal fly ash. Due to the silt nature of the road soil, a geo-textile was laid by the

197 road constructor below the MSWI residue layer in order to prevent fine particles lifting  
198 towards the sub-base layer. Built in 1992, site C was sampled at the age of 9.

199 Site D is a public car park platform. The uncovered structure (a simple 1 cm-thick  
200 gravelling) is unusual for traditional car parks but is sometime chosen for  
201 occasionally used ones. The MSWI ash is used in the base layer (30 cm). Due to the  
202 silty nature of the road soil, a geo-textile was also laid by the road constructor below  
203 the MSWI residue layer in order to prevent fine particles lifting towards the base  
204 layer. Built in 1994, site D was sampled at the age of 9.

## 205 **3.2 Material sampling**

### 206 **3.2.1 Sampling**

207 On each site, the sampling operation starts by digging a trench in the pavement,  
208 down to the top of the MSWI residue layer. For safety reasons, on circulated roads,  
209 the trench is dug on the road edge side. No such consideration had to be taken into  
210 account regarding the car park. In all case, beforehand, information is collected  
211 regarding the location of buried networks (water, gas, electricity...).

212 Usually, the thickness of the MSWI residue layer is not known exactly; on one site it  
213 can vary by few centimeters from one point to another, which makes preferable,  
214 when possible, to dig more than one trench. A core sampler is used to collect at once  
215 the MSWI residue layer and the road soil. Then, the real thickness of the MSWI  
216 residue layer at the sampling point is measured on the core sample. The thickness of  
217 the sampled underlying soil is also measured. The core sample can then be cut in  
218 different sub-layers in order to assess the contaminant content at different depths.  
219 The upper sub-sample of the road soil, just below the MSWI residue layer, is always  
220 rather thin (usually 5 cm thick). Samples for analysis are collected in the middle of

221 the core section. This is a precaution avoiding peripheral contamination from the  
222 upper levels to the lower ones, as while the core sampler is pushed in, particles can  
223 move along its internal wall.

224 When the road site makes it easy to obtain a reference situation of the soil away from  
225 the MSWI residue road layer influence, reference samples are collected with the core  
226 sampler for analysis and comparison with the road soil. Providing data on the  
227 surrounding situation regarding PCDD/F influence on the site, the so-call reference  
228 soil makes it possible to have a view of the net impact on the road soil. For all  
229 materials, before analysis, all samples were stored in plastic bags and drums,  
230 hermetically closed.

### 231 **3.2.2 Samples**

232 Table 1 provides an overview of the set of samples that were analyzed, together with  
233 their codification, the numbering is for the trench (1, 2 or 3). Soil samples were  
234 collected at different depths in order to detect any vertical content variation. Depth of  
235 sampling was conditioned by the soil own-thickness.

236 For sites A, B and C it was possible to identify a reference soil, but not for site D. In  
237 site A, four  $A_R$  samples were collected for PCDD/F content analysis (0-20 cm, 20-40  
238 cm, 40-60 cm and 80-95 cm). In sites B, two samples were collected: 0-20 cm and  
239 60-80 for  $B_R$ . In site C, the reference soil ( $C_R$ ) was not sampled as deep as the two  
240 others: 0-5 cm and 5-15 cm.

241 Regarding MSWI residues, in site A, two trenches were dug into the road structure.  
242 Only one sample was collected in the first trench ( $A_{M1}$ ) because at that point the  
243 MSWI residue layer was thin (12 cm). In the second trench ( $A_{M2}$ ), the layer thickness  
244 was greater (65 cm) and four samples were collected in the MSWI residue ( $A_{M2/14-29}$ ;

245  $A_{M2/35-45}$ ;  $A_{M2/45-65}$  and  $A_{M2/65-85}$ ). In site B, one trench was dug, providing one sample  
246 ( $B_{M1}$ ) of MSWI residue (35-60 cm). Similarly for site C ( $C_{M1}$ ), only one sample was  
247 collected (50-88 cm). Lastly, in site D three trenches were dug providing each one a  
248 sample ( $D_{M1}$ ,  $D_{M2}$  and  $D_{M3}$ ) with the same geometrical characteristics (10-30 cm).

249 Regarding road soils, in site A, three samples were collected in the sandy road soil of  
250 trench T1 ( $A_{S1}$ ) (32-37 cm, 37-42 cm and 42-52 cm). Three road soil samples were  
251 also collected at trench T2 ( $A_{S2}$ ) (29-35 cm, 85-90 cm and 95-105 cm). Sample  $A_{S2/29-}$   
252  $35$  taken from trench T2 is a thin sand layer which accidentally slid on the MSWI  
253 residue during the road work; it was not removed and has remained inserted in the  
254 MSWI residue layer since then. In site B ( $B_{S1}$ ), two samples were collected in the silty  
255 road soil ( $B_{S1/60-70}$  and  $B_{S1/70-80}$ ). In site C, a single road soil sample (silty) was  
256 collected ( $C_{S1/88-93}$ ). In site D, three silty road soil samples were collected in trench T1  
257 ( $D_{S1/30-35}$ ;  $D_{S1/35-45}$  and  $D_{S1/93-103}$ ); two in trench T2 ( $D_{S2/30-35}$  and  $D_{S2/35-45}$ ); and a single  
258 sample in trench T3 ( $D_{S3/30-35}$ ).

259 In sites C and D, during construction geo-textiles were laid between the MSWI  
260 residue layer and the road soil. One sample of geo-textile was collected in the trench  
261 of site C ( $C_{G1}$ ) and two geo-textile samples were collected at site D, one from trench  
262 T1 ( $D_{G1}$ ), the second from trench T2 ( $D_{G2}$ ).

## 263 **4 Methods**

### 264 **4.1 Grading of materials**

265 The total sample, dried at 105°C, is sieved at 2 mm. The fraction below 2 mm is  
266 sieved in a dried phase in a stainless steel sieve to separate the fractions below 1  
267 mm and 0.5 mm. The particle size distribution of the fraction below 0.5 mm is  
268 achieved using the laser diffraction technique (Mastersizer, Malvern Instrument).

269 **4.2 PCDD/F analysis**

270 Determination of dry matter content was achieved by drying subsamples at 105°C  
271 following the standard EN ISO 11465.

272 The samples were beforehand dried at room temperature. The dried samples were  
273 treated and digested with chlorhydric acid. Materials (MSWI residues and soil  
274 samples) were prepared using an accredited method, based on the standard  
275 EN 1948-2 and EN 1948-3, which consists in extracting the analyzed components  
276 with mixture of toluene and acetone. This step is followed with several stages of  
277 clean-up by chromatography on columns filled with absorbents using solvents or  
278 various elution strength. After filtration, the dioxin measurement requires a solid/liquid  
279 extraction followed with a cleaning up step. The purified extracts are reduced to a  
280 minimum volume and then mixed in a solvent compatible with the final analysis by  
281 gas chromatography.

282 The total eluate was prepared following the same methodology as the one used for  
283 MSWI residues.

284 Analyses of PCDD/F were carried out by means of a High Resolution Mass  
285 Spectrometry coupled with a High Resolution Gas Chromatography (HRMS/HRGC)  
286 VG/AutoSpec.

287 The analysis consisted in measuring 17 toxic congeners (7 congeners for PCDD and  
288 10 congeners for PCDF). The seven dioxin congeners are 2,3,7,8-TetraCDD;  
289 1,2,3,7,8-PentaCDD; 1,2,3,4,7,8-HexaCDD; 1,2,3,6,7,8-HexaCDD; 1,2,3,7,8,9-  
290 HexaCDD; 1,2,3,4,6,7,8-HeptaCDD and OctaCDD. The ten furan congeners are  
291 2,3,7,8-TetraCDF; 1,2,3,7,8-/1,2,3,4,8-PentaCDF; 2,3,4,7,8-PentaCDF, 1,2,3,4,7,8-  
292 /1,2,3,4,7,9-HexaCDF; 1,2,3,6,7,8-HexaCDF; 1,2,3,7,8,9-HexaCDF; 1,2,3,4,6,7,8-

293 HeptaCDF; 1,2,3,4,7,8,9-HeptaCDF and OctaCDF. Interferences with the other 193  
294 non toxic congeners and some other components such as Polychlorobiphenyls  
295 (PCBs), Polychloroterphenyls (PCTs), or Polychloronaphtalens (PCNs) are  
296 eliminated. The determination of congeners was realized by the isotopic dilution  
297 method using isotope as interne markers for congeners identification and  
298 quantification.

299 The concentration of one PCDD or PCDF congener can be converted into an  
300 International Toxic Equivalent Quantity (I-TEQ), with a Detection Limit (DL) of 1.22  
301 nanogram I-TEQ.kg<sup>-1</sup> of dry material (noted DM) and an accuracy of 4.7% on the  
302 Toxic Equivalent value. The model used for determining the I-TEQ is NATO (1998).

### 303 **4.3 Leaching**

304 Regarding the geo-textiles found on two sites, before chemical analyses, the  
305 recovery of particles was realized by means of leaching, intended to wash the geo-  
306 textile. The operation was renewed until the complete extraction.

307 Regarding MSWI residues, as PCDD/F are not water soluble compounds (Sakai et  
308 al., 2000a), the purpose of the test was not to assess their solubility but their possible  
309 residual release associated to very fine particle extraction (namely below 0.45 µm in  
310 the condition of the test due to the filter size) under the effect of water flushing. The  
311 leaching test was performed for MSWI residues from sites B and D following the EN  
312 12457-2 standard protocol (2002). Determination of the dry matter content was made  
313 after drying of test portion at 105°C, according to the international standard ISO  
314 11465 (1994). The liquid/solid separation is performed by means of filtration on a  
315 0.45 µm membrane filter using a pressure filtration device. The eluate obtained after  
316 filtration was analyzed to determine PCDD/F compounds' nature and quantity.

317

## 318 **5 Results**

319 Results concerning old MSWI residues are first presented. Then are those of geo-  
320 textiles, road soils and reference soils. All material samples are defined in relation to  
321 their depth from the surface (expressed in centimeters) and all PCDD/F contents are  
322 expressed in nanogram of I-TEQ per kilogram of dry matter (noted  $\text{ng I-TEQ.kg}^{-1}$   
323 DM).

324 The PCDD/F congener with the greatest toxic potential, and for which the greatest  
325 amount of toxicological data is available, is 2,3,7,8-TetraCDD (Mac Kay, 2002). Its  
326 content in all material samples is provided (in  $\text{ng.kg}^{-1}$  DM).

327 Additionally, in order to assess the distribution of the different PCDD/F compounds in  
328 the different materials the sum of the seven PCDD congeners and that of the ten  
329 PCDF congeners was calculated (in  $\text{ng.kg}^{-1}$  DM).

### 330 **5.1 MSWI residues' characteristics**

#### 331 **5.1.1 PCDD/F contents in MSWI residues**

332 Results are presented in Table 2. In site A, the only one showing values below 100  
333  $\text{ng I-TEQ.kg}^{-1}$  DM, the PCDD/F content for the MSWI residue in trench T1 ( $A_{M1}$ ) is  
334  $14.0 \text{ ng I-TEQ.kg}^{-1}$  DM. In trench T2 ( $A_{M2}$ ), it increases from the upper sample to the  
335 third one (from  $35.7$  to  $227 \text{ ng I-TEQ.kg}^{-1}$  DM) and decreases in the lower sample  
336 ( $63.2 \text{ ng I-TEQ.kg}^{-1}$  DM).

337 In site B ( $B_{M1}$ ), the PCDD/F content for the MSWI residue is  $721 \text{ ng I-TEQ.kg}^{-1}$  DM,  
338 three time higher than the maximum value measured in site A.

339 In site C ( $C_{M1}$ ), the PCDD/F content is similar to the maximum value found in site A  
340 (235 ng I-TEQ.kg<sup>-1</sup> DM).

341 The three trenches of site D ( $D_{M1}$ ,  $D_{M2}$  and  $D_{M3}$ ) show, by far, the highest PCDD/F  
342 contents. These contents are respectively 1960, 2160 and 1640 ng I-TEQ.kg<sup>-1</sup> DM.

### 343 **5.1.2 Relation between PCDD/F amount and particle size**

344 A sample with a high PCDD/F content ( $D_{M1}$ ), was chosen in order to assess the  
345 possible relation between the particle size distribution of MSWI residues and their  
346 PCDD/F load. PCDD/F contents related to fractions < 0.1 mm; 0.1-0.5 mm; 0.5-1  
347 mm; 1-2 mm; 2-10 mm; 10-31.5 mm of the material are presented in Figure 2.

348 The PCDD/F contents of fractions between 2 and 31.5 mm are similar, comprised  
349 between 733 ng I-TEQ.kg<sup>-1</sup> and 888 ng I-TEQ.kg<sup>-1</sup>. The finest fractions and  
350 particularly the one below 0.1 mm is 7 times higher, reaching 6590 ng I-TEQ.kg<sup>-1</sup>.

### 351 **5.1.3 Leaching of MSWI residues**

352 The leaching test was carried out in order to detect the proportion of PCDD/F  
353 particles inferior to 0.45 µm. For both sites (B and D), leaching results (Table 3) show  
354 that leachates contain a small amount of PCDD/F: 2.19 pg I-TEQ.l<sup>-1</sup> for sample  
355  $B_{M1/35-60}$ ; and 4.4.1 pg I-TEQ.l<sup>-1</sup> for sample  $D_{M1/10-30}$ . Brought to the mass of dry  
356 material involved in the leaching test, such releases are respectively equal to 0.019  
357 ng I-TEQ. kg<sup>-1</sup> DM for the first sample, and 0.041 ng I-TEQ. kg<sup>-1</sup> DM for the second.

### 358 **5.2 Geo-textiles' load of PCDD/F**

359 The load of PCDD/F on the geo-textile from site C ( $C_{G1}$ ) is 175 ng I-TEQ.kg<sup>-1</sup> DM  
360 (Table 4). Site D geo-textile samples show far higher values : 754 ng I-TEQ.kg<sup>-1</sup> DM  
361 in trench T1 ( $D_{G1}$ ), and 1600 ng I-TEQ.kg<sup>-1</sup> DM in trench T2 ( $D_{G2}$ ). The latter value is  
362 close to the content of the MSWI residue layer above.



### 363 **5.3 PCDD/F contents in road soils**

364 For site B ( $B_{S1}$ ), it varies from 7.23 to 0.57 ng I-TEQ.kg<sup>-1</sup> DM from the upper to the  
365 lower sample. In site C ( $C_{S1/88-93}$ ), the single sample value is 2.87 ng I-TEQ.kg<sup>-1</sup> DM.  
366 In site D, from the top to the bottom of the investigated thickness in trench T1 ( $D_{S1}$ ),  
367 the three values are respectively 0.86, 0.79 and 1.99 ng I-TEQ.kg<sup>-1</sup> DM. In trench T2  
368 ( $D_{S2}$ ), the values are of the same order (2.22 and 0.64 ng I-TEQ.kg<sup>-1</sup> DM). Lastly,  
369 trench T3 sample (D ( $D_{S3}$ )) PCDD/F content is 2.04 ng I-TEQ.kg<sup>-1</sup> DM (Table 5).

370 Site A presents a contrasted situation regarding its two trenches. In trench T2 ( $A_{S2}$ ),  
371 the PCDD/F contents of the three samples are in the range of the previous cases B,  
372 C and D, with values evolving from 2.98 to 2.24 and 1.31 ng I-TEQ.kg<sup>-1</sup> DM, from the  
373 upper to the lower sample. On the other hand, in trench T1 ( $A_{S1}$ ), whereas the two  
374 first samples present low values (1.35 and 0.74 ng I-TEQ.kg<sup>-1</sup> DM), the deeper  
375 sample shows a content of 24.8 ng I-TEQ.kg<sup>-1</sup> DM, which is relatively high in  
376 comparison with the content of the MSWI residue layer located just above (i.e. 14.0  
377 ng I-TEQ.kg<sup>-1</sup> DM). As a consequence, this values ( $A_{S1/42-52}$ ) is very uncertain and will  
378 not be considered in the interpretation.

### 379 **5.4 PCDD/F contents in reference soils**

380 Results are presented in the Table 6. In site A ( $A_R$ ), the PCDD/F content of the  
381 reference soil decreases from 9.4 to 0.30 ng I-TEQ.kg<sup>-1</sup> DM, from the surface to the  
382 deeper sample. The top sample value can be related to the atmospheric  
383 contamination in the vicinity of the incineration plant, from the chimney, at a time (the  
384 1970's) when fume de-pollution by means of old dust separators was not as efficient  
385 as the nowadays air pollution control systems (Chandler et al., 1997)

386 In site B ( $B_R$ ), contents are homogeneous and low (1.05 and 0.79 ng I-TEQ.kg<sup>-1</sup> DM).  
387 Contrary to site A, it seems that no particular source of pollution has an effect on the  
388 vertical profile of content.

389 Site C ( $C_R$ ) shows intermediate values between the two previous ones i.e. 5.40 and  
390 6.49 ng I-TEQ.kg<sup>-1</sup> DM for the upper and the lower samples respectively. Site C is not  
391 located in the vicinity of a particular source of PCDD/F, but it is however located in a  
392 large urban area with several potential sources.

### 393 **5.5. Distribution of PCDD/F congeners in the road structure**

394 Results related to the distribution of the different PCDD/F congeners (Tetra, Penta,  
395 Hexa, Hepta and Octa) in the MSWI residues, on geo-textiles samples, and in the  
396 road soils, for all sites, are illustrated by the example of site A trench T2 (Figure 3)  
397 and site C (Figure 4).

398 For site A, regarding the MSWI residue ( $A_{M2/14-29}$ ;  $A_{M2/35-45}$ ;  $A_{M2/45-65}$ ;  $A_{M2/65-85}$ ) they  
399 show the predominance of OctaCDD, and the secondary importance of HeptaCDD  
400 and HeptaCDF. For site C, they show the predominance of OctaCDD and OctaCDF  
401 in the MSWI residue and the secondary importance of HeptaCDD. The geo-textile of  
402 site C also show the predominance of OctaCDD and the secondary importance of  
403 HeptaCDD.

404 For MSWI residues, the distribution between dioxin and furan congeners is provided  
405 in Table 2. The proportion of dioxin congeners is of 50% for  $C_{M1}$  but it is higher for  
406 other samples: 73% for  $B_{M1}$ ; 74 to 79% for  $D_M$  and 57 to 97% for  $A_M$ .

407 The distribution between dioxin and furan congeners is provided in Table 4 for geo-  
408 textiles. In the geo-textile from site D, the proportion of dioxin congeners (74-75%) is

409 equivalent to that of the above MSWI residue. For site C, it is higher (69%) to that of  
410 the MSWI residue.

411 The distribution between dioxin and furan congeners is provided in Table 5 for road  
412 soils. For road soils, the proportion of dioxin congeners for all sites, ranges from 54 to  
413 89%. For sites A, B and D it is comparable to the distribution observed for the MSWI  
414 residue. For site C, it is higher.

415 The distribution between dioxin and furan congeners is provided in Table 6 for  
416 reference soils. It is comparable to that of the respective road soils, 85% for B<sub>R</sub>; 72%  
417 for C<sub>R</sub>; 69 to 90 for A<sub>R</sub>.

418 The toxicity of PCDD/F varies substantially depending on the different congeners. It  
419 is generally agreed that only 17 out of the 210 dioxin and furans congeners are toxic.  
420 The examination of is 2,3,7,8-TetraCDD content in the different samples of MSWI  
421 residue samples, geo-textiles, road soils and reference soils, reveals that its amount  
422 in road soils is very low.

423 For road soils (Table 5), contents range from less than 0.04 ng.kg<sup>-1</sup> (samples A<sub>S2/85-90</sub>  
424 and D<sub>S2/35-45</sub>) to 2.35 ng.kg<sup>-1</sup> (sample A<sub>S1/42-52</sub>), not very different from those of  
425 reference soils (Table 6), ranging from less than 0.01 ng.kg<sup>-1</sup> (samples B<sub>R/0-20</sub> and  
426 C<sub>R/0-5</sub>) to less than 0.9 ng.kg<sup>-1</sup> (sample A<sub>R/0-20</sub>).

427 As a matter of comparison, for MSWI residues (Table 2), the 2,3,7,8-TetraCDD  
428 content is below 1.5 ng.kg<sup>-1</sup> for site A, and ≤ 50 ng.kg<sup>-1</sup> for sites B, C and samples  
429 D<sub>M1</sub> and D<sub>M3</sub>. Sample D<sub>M2</sub> content is 190 ng.kg<sup>-1</sup>. For geo-textiles (Table 4), contents  
430 are from 6.8 to 57.5 ng.kg<sup>-1</sup>.

## 431 **6 Discussion**

### 432 **6.1 Characterization of MSWI residues**

### 433 **6.1.1 PCDD/F contents**

434 A great heterogeneity of MSWI residue PCDD/F contents, i.e. a factor 154 from 14.0  
435 ( $A_{M1}$ ) to 2160 ng I-TEQ.kg<sup>-1</sup> DM ( $D_{M2}$ ) is observed between sites. A great  
436 heterogeneity can also be observed in a site such as A (a factor 16 between 14.0  
437 and 227 ng I-TEQ.kg<sup>-1</sup> DM).

438 The lowest recorded value (14.0 ng I-TEQ.kg<sup>-1</sup> DM for  $A_{M1-12-24}$ ) is in the middle of the  
439 range of values reported by Damien (1997) for bottom ash produced by recent  
440 incinerators in France in the 1990's (4.0 to 20.6 ng I-TEQ.kg<sup>-1</sup> DM). All other contents  
441 are two times to 100 times above the maximum value recorded by Damien. Such  
442 results are also well above the contents reported by Badreddine and Drouadaine  
443 (2006) on MSWI bottom ash from recent incineration and treatment facilities (i.e.  
444 around 10 ng I-TEQ.kg<sup>-1</sup> DM) (Figure 5). Highest values ( $M_D$ ) are even above the  
445 highest value (i.e. 1500 10 ng I-TEQ.kg<sup>-1</sup> DM) reported by Sakai et al. (2000b) for  
446 Japan. A comparison showing difference between MSWI residue from the old and  
447 from recent site was proposed in figure 5.

### 448 **6.1.2 Importance of the fine fraction**

449 The analyses of size distribution of MSWI residues have shown an important  
450 proportion of the fine fraction.

451 The possible relation between the particle size and the PCDD/F content was  
452 postulated in an earlier study (Badreddine et al., 2003). The good relation between  
453 the PCDD/F content and the particle size demonstrates that the fine fraction is  
454 enriched with PCDD/F compounds. The sub-sample with the finest fraction (< 0.1  
455 mm) shows by far a higher PCDD/F content (6590 ng I-TEQ.kg<sup>-1</sup>), 7 times above the  
456 other particle fractions. As the fraction below 0.1 mm represents less than 10% of the

457 all graded aggregate (MSWI residue), this means that at least 659 ng I-TEQ.kg<sup>-1</sup> (i.e.  
458 33%) of the 1960 ng I-TEQ.kg<sup>-1</sup> of the whole material (sample D<sub>M1/30-60</sub>), are included  
459 in the finest fraction.

460 These results confirm the assumption of the relation between the high value of the  
461 PCDD/F and the presence of fly ash mixed with bottom ash before 1991 in France.  
462 Indeed, the PCDD/F levels in fly ash are generally much higher than in bottom ash  
463 (Mac Kay, 2002). Chang and Chung (1998) reported values between 41 ng.g<sup>-1</sup> and  
464 703 ng.g<sup>-1</sup> DM for MSWI fly ash).

465 Considering on one hand the range figures provided by Damien (1997) for MSWI  
466 bottom ash (39 to 648 ng I-TEQ.kg<sup>-1</sup>) and for MSWI fly ash (765 to 4815 ng I-TEQ.kg<sup>-1</sup>)  
467 <sup>1</sup>), and on the other hand the ratio of production between bottom ash (250 kg.ton<sup>-1</sup>)  
468 and fly ash (20 kg.ton<sup>-1</sup>) from incineration, one reaches the range of 67 to 814 ng I-  
469 TEQ.kg<sup>-1</sup> for a theoretical mixture of bottom and fly ash. PCDD/F contents observed  
470 for MSWI residues from site A trench T2 (A<sub>M2</sub>), from site B (B<sub>M1</sub>) and site C (C<sub>M1</sub>) are  
471 in this range. The sample from site A trench T1 is below, but those from site D are  
472 two times above the highest value of the theoretical range.

### 473 **6.1.3 Mobility of PCDD/F**

474 Very low PCDD/F releases were assert (0.0219 and 0.0441 ng I-TEQ.kg<sup>-1</sup>).  
475 Compared to the total content of PCDD/F compounds in the respective MSWI  
476 residue samples (i.e. 721 ng I-TEQ.kg<sup>-1</sup> DM for B<sub>M1/35-60</sub> and 1960 ng I-TEQ.kg<sup>-1</sup> DM  
477 D<sub>M1/10-30</sub>), the released fractions are respectively 0.003 and 0.002% of the total  
478 PCDD/F amount.

479 The low value recorded can be linked to the low solubility of the PCDD/F and the  
480 presence of the PCDD/F in the particles superior to 0.45 μm (Badreddine et al.,

481 2003). Depending on congeners, solubility values are comprised between  $0.74 \cdot 10^{-7}$   
482 and  $3.75 \cdot 10^{-3}$  for PCDD (Inserm, 2000) and between  $4.19 \cdot 10^{-4}$  and  $1.16 \cdot 10^{-6}$  for  
483 PCDF (OMS, 1997).

## 484 6.2 Assessment of PCDD/Ffate

### 485 6.2.1 PCDD/F contents of road soil

486 The heterogeneity among all road soil PCDD/F contents, i.e. a factor 9 between  $0.74$   
487 ( $A_{S1}$ ) and  $7.23 \text{ ng I-TEQ.kg}^{-1} \text{ DM}$  ( $B_{S1}$ ) is far lower than among MSWI residues. Such  
488 values are low in comparison to those reported by Nominé (1999) for soils of urban  
489 areas in the absence of neighbouring sources of pollution (from  $<1$  to more than  $30$   
490  $\text{ng.kg}^{-1} \text{ I-TEQ.kg}^{-1} \text{ DM}$ ), for soils nearby MSW incineration plants (more than  $1000$   
491  $\text{ng.kg}^{-1} \text{ I-TEQ.kg}^{-1} \text{ DM}$ ), and even to those of soils of pasture in Europe (from  $<1$  to  $43$   
492  $\text{ng.kg}^{-1} \text{ I-TEQ.kg}^{-1} \text{ DM}$ ).

### 493 6.2.2 Comparison to reference soils' contents

494 In order to assess the state of road soils, comparison can be made with their  
495 respective reference soils. Depending on the context (more or less potential sources  
496 of pollution in the area), the difference between them is negative (site B), negligible  
497 (site A), or even positive (site C where pollution sources affect the reference soil).

498 Indeed, regarding Site B, the ratio between the average contents in road soil ( $3.9 \text{ ng}$   
499  $\text{I-TEQ.kg}^{-1} \text{ DM}$ ) and the reference soil ( $0.92 \text{ ng I-TEQ.kg}^{-1} \text{ DM}$ ) is around 4.

500 Regarding Site A, depending on the consideration of sample  $A_{R/0-20}$  or not in the  
501 comparison, one can consider that the PCDD/F content in the road soil is lower (9  
502 times) or slightly higher ( $1.04 \text{ ng I-TEQ.kg}^{-1} \text{ DM}$  in average for road soil vs  $0.44 \text{ ng I-}$   
503  $\text{TEQ.kg}^{-1} \text{ DM}$  in average for reference soil) in trench T1. Considering trench T2, the

504 conclusion is the same, i.e. respectively 4 times lower, or slightly higher (2.17 ng I-  
505 TEQ.kg<sup>-1</sup> DM in average for road soil vs 0.44 ng I-TEQ.kg<sup>-1</sup> DM).

506 In the case of Site C, the content in the road soil sample ( $C_{S1/88-93}$ ) is 2 times lower  
507 than in the reference soil (5.94 ng I-TEQ.kg<sup>-1</sup> DM in average). Located in a large  
508 urban area, references soil of Site C can have been affected for years by several  
509 sources, which can lead to a situation similar as for Site A.

### 510 **6.2.3 Comparison to MSWI residues' contents**

511 Some vertical profiles of PCDD/F contents in road soils (sites A and B) show  
512 decreasing values from the upper sample, downward, indication of a possible contact  
513 effect of the MSWI residue layer. Contents in the road soil are however low and the  
514 transition with the MSWI residue layer with high contents, is very well marked.

515 For sites A and B, where the influence of the geo-textile is not susceptible to  
516 interfere, the ratio between the road soil upper sample content and the MSWI residue  
517 layer content can serve as an indicator. Regarding Site A trench T1, this ratio (1.35  
518 vs 14.0 ng I-TEQ.kg<sup>-1</sup> DM) is 9.6%, and for trench T2 (2.98 vs 101 ng I-TEQ.kg<sup>-1</sup> DM  
519 in average) it is 2.9% (the MSWI residue content is 101 ng I-TEQ.kg<sup>-1</sup> DM in  
520 average). Regarding Site B, the ratio (7.23 vs 721 ng I-TEQ.kg<sup>-1</sup> DM) is only 1.0%.

521 For sites with geo-textiles, such ratios are 1.2% for site C (2.87 vs 235 ng I-TEQ.kg<sup>-1</sup>  
522 DM), or lower for site D, i.e. 0.04% for trench T1 (0.86 vs 1960 ng I-TEQ.kg<sup>-1</sup> DM)  
523 and 0.1% for trench T2 (2.22 vs 2160 ng I-TEQ.kg<sup>-1</sup> DM).

### 524 **6.3. Role of geo-textiles**

525 The PCDD/F load of geo-textiles compared to the content of the MSWI residue  
526 located just above is equal to 74% of the latter in the case of site C ( $C_{G1}/C_{M1}$ ). For

527 site D, such ratios are equal to 86% in the case of trench T1 ( $D_{G1}/D_{M1}$ ) but only 35%  
528 in the case of trench T2 ( $D_{G2}/D_{M2}$ ).

529 In order to assess the role of geo-textiles toward the possible PCDD/F transfer, their  
530 load can also be compared to the content of the road soil upper sample. In the case  
531 of site C, Such ratio is 61 ( $C_{G1}/C_{S1}$ ), and it is higher in the case of site D, 1860 for  
532 trench T1 ( $D_{G1}/D_{S1}$ ), and 339 for trench T2 ( $D_{G2}/D_{S2}$ ).

533 The role of the geo-textile inserted between the MSWI residue layer and the road soil  
534 should be clarified : may be it acts as a filter toward the transfer of fine particles  
535 downward. But may be the porosity of the road soil in itself is low enough to act as a  
536 filter, which would explain the slightly higher PCDD/F contents in some road soil  
537 upper samples.

## 538 **7 Conclusion**

539 This study shows that some MSWI residues used for road construction before the  
540 enforcement of the 1991 order can contain very high amount of PCDD/F compared to  
541 the MSWI bottom ash produced and used afterward. The heterogeneity between  
542 MSWI residues can be great from one road site to another but also on a single site.  
543 The important contribution of the fraction below 0.1 mm to the MSWI residue total  
544 contents of PCDD/F was asserted. Crossed with leaching test results, this indicates  
545 that the fraction between 0.45 and 100  $\mu\text{m}$  should be investigated in more detail in  
546 order to specify the most loaded particle sizes.

547 As a whole, road soils PCDD/F contents are below the contents recorded for ordinary  
548 urban or rural soils, and consequently, no significant difference is observed with local



549 reference soils. This indicate the absence of transfer of MSWI residue to the road  
550 soil.

551 In addition, thanks to the very low proportion of the 2,3,7,8-TetraCDD congener, the  
552 noxiousness of road soils is reduced. In the presence of geo-textile or not, the  
553 PCDD/F content reduction between the MSWI residue and the road soil is great. The  
554 role of the geo-textile inserted between the MSWI residue layer and the road soil  
555 should be clarified.

556 Considering the improvements brought by the enforcement of the 1991 order  
557 regarding the fate of MSWI fly ash and those brought by the more recent air pollution  
558 control systems, the diagnosis achieved thanks to this study provides a rather  
559 positive and reassuring insight concerning the effect of today produced and used  
560 MSWI bottom ash in road construction.

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642

643 **List of Figures:**

644 Figure 1a: The typical road structure in France

645 Figure 1b: Road structures of both sites

646 Figure 2: Relation between particle size and PCDD/F content

647 Figure 3: PCDD/F congeners distribution in materials from site A (trench T2)

648 Figure 4: PCDD/F congeners distribution in materials from site C

649 Figure 5 : PCDD/F content variation with age of MSWI residue production

650

651 **List of Tables**

652 Table 1 : Overview of the set of samples

653 Table 2 : PCDD/F contents of MSWI residues

654 Table 3 : PCDD/F contents from eluates

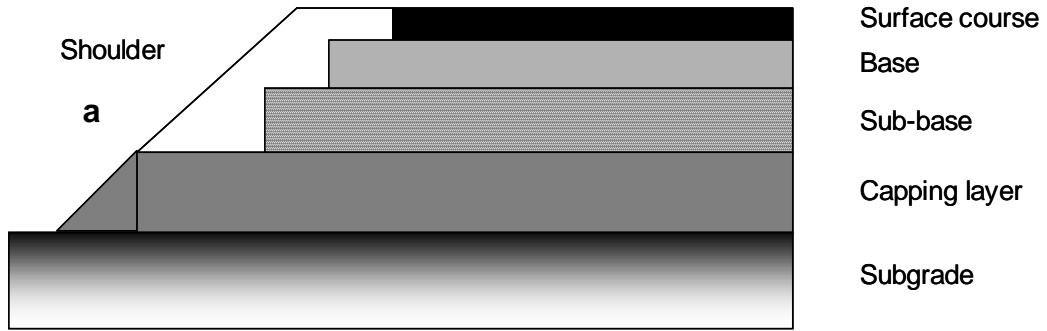
655 Table 4 : PCDD/F loads of geo-textiles

656 Table 5 : PCDD/F contents of road soils

657 Table 6 : PCDD/F contents of reference soils

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**b**

Site	A	B	C	D
Surface course	4 cm bituminous concrete	4 cm bituminous concrete	4 cm bituminous concrete	4 cm bituminous concrete
Base	10 cm	22 cm	42 cm	30 cm MSWI residue above geo-textile
Sub-base	70 cm MWSI residue	25 cm MWSI residue	40 cm MSWI residue above geo-textile	-
Road soil	Sand	Silt-clay	Silt	Silt

Figure 1 : (a) : The typical road structure in France (MELT, 1997)  
(b) : roads structures of both sites

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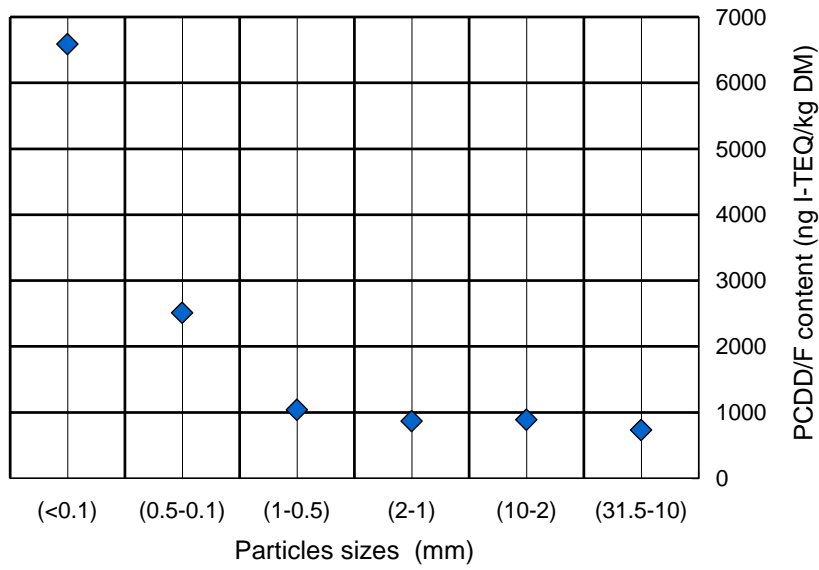


Figure 2 : relation between particle size and PCDD/F content

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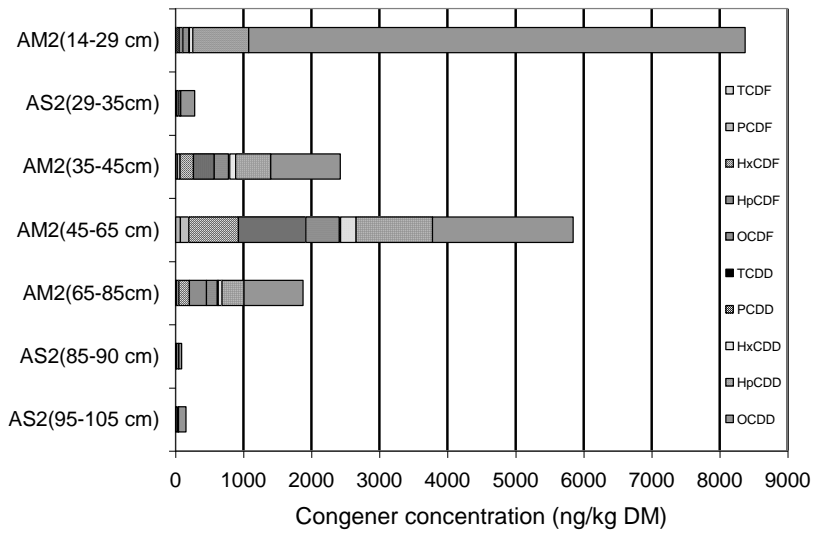


Figure 3 : PCDD/F congeners distribution in materials from site A (trench T2)

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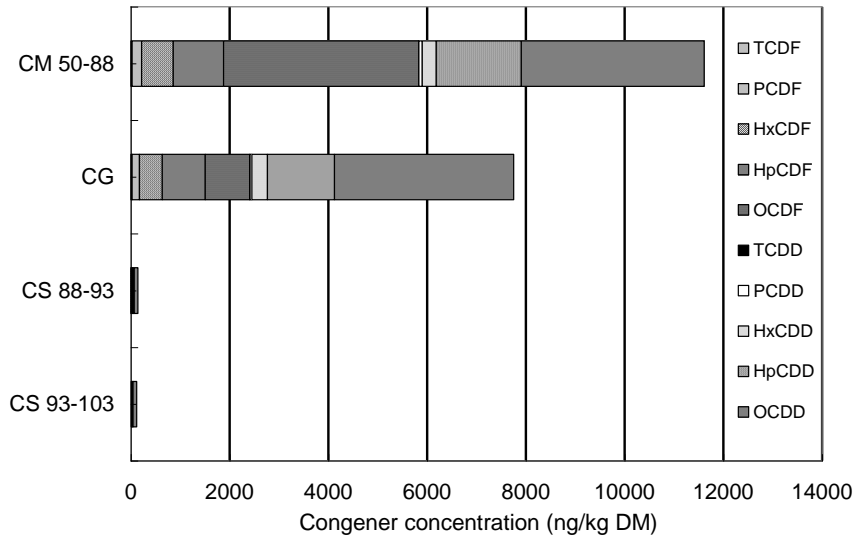


Figure 4 : PCDD/F congeners distribution in materials from site C

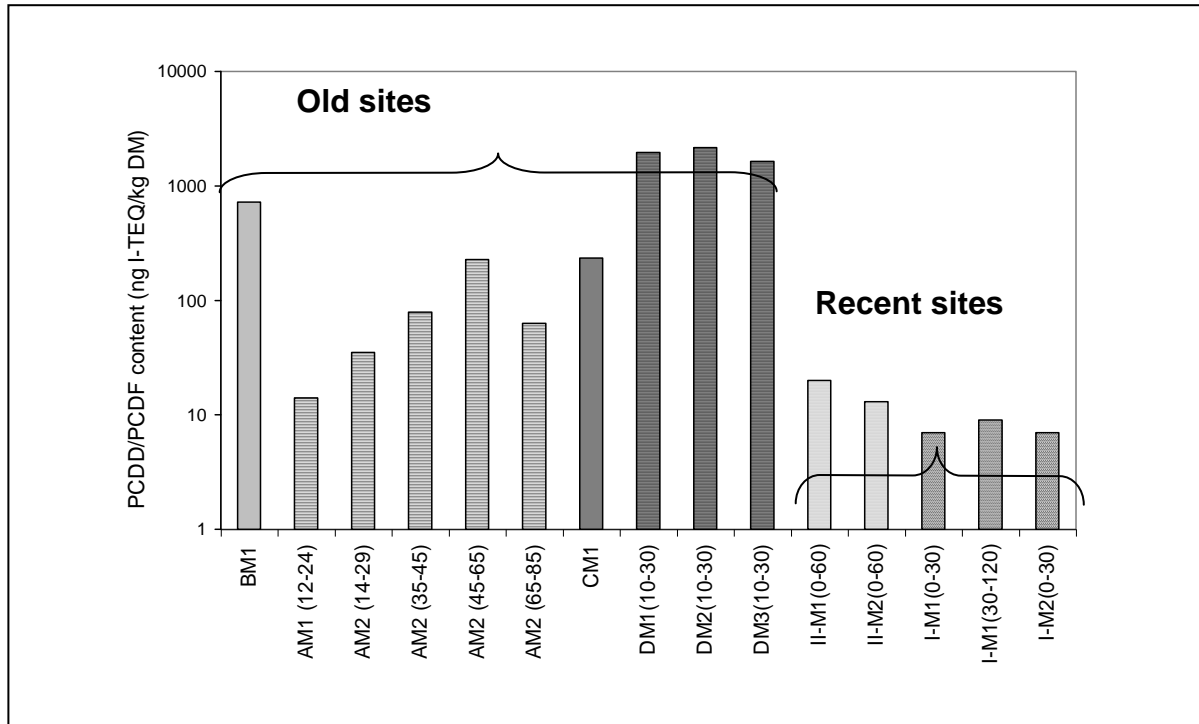


Figure 5 : PCDD/F content variation with age of MSWI residue production



783 Table 1 : Overview of the set of samples

Site	A	B	C	D
Material (M)	A <sub>M1</sub> , A <sub>M2</sub>	B <sub>M1</sub>	C <sub>M1</sub>	D <sub>M1</sub> , D <sub>M2</sub> , D <sub>M3</sub>
Geo-textile (G)	-	-	C <sub>G1</sub>	D <sub>G1</sub> , D <sub>G2</sub>
Road soil (S)	A <sub>S1</sub> , A <sub>S2</sub>	B <sub>S1</sub>	C <sub>S1</sub>	D <sub>S1</sub> , D <sub>S2</sub> , D <sub>S3</sub>
Reference soil (R)	A <sub>R</sub>	B <sub>R</sub>	C <sub>R</sub>	-

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Table 2 : PCDD/F contents of MSWI residues

Site	A				
Sample	A <sub>M1/12-24</sub>	A <sub>M2/14-19</sub>	A <sub>M2/35-45</sub>	A <sub>M2/45-65</sub>	A <sub>M2/65-85</sub>
ITE (ng I-TEQ.kg <sup>-1</sup> DM)	14.0	35.7	78.7	227	63.2
2,3,7,8-TetraCDD (ng.kg <sup>-1</sup> )	0.79	1.46	< 0.33	< 2.15	< 0.15
7 Dioxin congeners (ng.kg <sup>-1</sup> )	691	8176	1643	3436	1257
10 Furan congeners (ng.kg <sup>-1</sup> )	94	211	830	2576	670
Dioxin (%)	88	97	66	57	65
Site	B	C	D		
Sample	B <sub>M1/35-60</sub>	C <sub>M1/50-88</sub>	D <sub>M1/10-30</sub>	D <sub>M2/10-30</sub>	D <sub>M3/10-30</sub>
ITE (ng I-TEQ.kg <sup>-1</sup> DM)	721	235	1960	2160	1640
2,3,7,8-TetraCDD (ng.kg <sup>-1</sup> )	21.6	9.16	49.6	190	51.2
7 Dioxin congeners (ng.kg <sup>-1</sup> )	25152	5864	95852	81009	91743
10 Furan congeners (ng.kg <sup>-1</sup> )	9121	5825	31853	21904	31822
Dioxin (%)	73	50	75	79	74

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Table 3 : PCDD/F contents from eluates

Site	B	D
Sample	B <sub>M1/35-60</sub>	D <sub>M1/10-30</sub>
ITE (pg I-TEQ.l <sup>-1</sup> )	2.19	4.41

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794 Table 4 : PCDD/F loads of geo-textiles

Site	C		D	
Sample	C <sub>G1</sub>	D <sub>G1</sub>	D <sub>G2</sub>	
ITE (ng I-TEQ.kg <sup>-1</sup> DM)	175	1600	754	
2,3,7,8-TetraCDD (ng.kg <sup>-1</sup> )	6.84	34.9	57.5	
7 Dioxin congeners (ng.kg <sup>-1</sup> )	5346	74545	28437	
10 Furan congeners (ng.kg <sup>-1</sup> )	2407	26384	9317	
Dioxin (%)	69	74	75	

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Table 5 : PCDD/F contents of road soils

Site	A						B	
Sample	A <sub>S1/32-37</sub>	A <sub>S1/37-42</sub>	A <sub>S1/42-52</sub>	A <sub>S2/29-35</sub>	A <sub>S2/85-90</sub>	A <sub>S2/95-105</sub>	B <sub>S1/60-70</sub>	B <sub>S1/70-80</sub>
ITE (ng I-TEQ.kg <sup>-1</sup> DM)	1.35	0.74	24.8	2.98	2.24	1.31	7.23	0.57
2,3,7,8-TetraCDD (ng.kg <sup>-1</sup> )	0.11	0.1	2.53	0.24	< 0.04	< 0.32	0.46	< 0.07
7 Dioxin congeners (ng.kg <sup>-1</sup> )	46.2	63.2	410.8	238.3	44.5	115.6	280.7	52.3
10 Furan congeners (ng.kg <sup>-1</sup> )	10.9	7.8	354.3	45.1	28.9	20.0	111.2	11.2
Dioxin (%)	81	89	54	84	61	85	72	82
Site	C		D					
Sample	C <sub>S1/88-93</sub>	D <sub>S1/30-35</sub>	D <sub>S1/35-45</sub>	D <sub>S1/93-103</sub>	D <sub>S2/30-35</sub>	D <sub>S2/35-45</sub>	D <sub>S3/30-35</sub>	
ITE (ng I-TEQ.kg <sup>-1</sup> DM)	2.87	0.86	0.79	1.99	2.22	0.64	2.04	
2,3,7,8-TetraCDD (ng.kg <sup>-1</sup> )	< 0.10	< 0.05	< 0.05	< 0.11	0.21	< 0.04	0.19	
7 Dioxin congeners (ng.kg <sup>-1</sup> )	99.1	52.2	18.1	90.4	70.4	12.4	95.9	
10 Furan congeners (ng.kg <sup>-1</sup> )	43.3	7.9	9.5	24.3	22.7	4.6	28.8	
Dioxin (%)	70	87	66	79	76	73	77	

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802 Table 6 : PCDD/F contents of reference soils

Site	A				B		C	
Sample	A <sub>R/0-20</sub>	A <sub>R/20-40</sub>	A <sub>R/40-60</sub>	A <sub>R/80-95</sub>	B <sub>R/0-20</sub>	B <sub>R/60-80</sub>	C <sub>R/0-5</sub>	C <sub>R/5-15</sub>
ITE (ng I-TEQ.kg <sup>-1</sup> DM)	9.4	0.67	0.36	0.30	1.05	0.79	5.40	6.49
2,3,7,8-TetraCDD (ng.kg <sup>-1</sup> )	< 0.9	0.05	< 0.02	< 0.03	< 0.01	< 0.19	< 0.01	< 0.18
7 Dioxin congeners (ng.kg <sup>-1</sup> )	216.8	58.5	41.9	50.0	109.3	35.2	240.0	200.0
10 Furan congeners (ng.kg <sup>-1</sup> )	98.7	7.3	7.1	5.8	17.5	6.6	82.3	86.0
Dioxin (%)	69	89	86	90	86	84	74	70

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