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Transfer and uptake of polychlorinated dibenzo-p-dioxins and furans (PCDD/Fs) and polychlorinated biphenyls (PCBs) into meat and organs of indoor and outdoor reared pigs.

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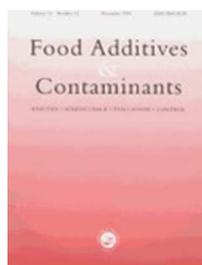
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Methods/Techniques:	Chromatography - GC/MS, Risk assessment, Health significance
Additives/Contaminants:	Dioxins, Dioxins - TEQs, Environmental contaminants
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Abstract:	<p>This study was designed to investigate how and to what extent PCDD/Fs and PCBs are transmitted from exposure sources to porcine muscle and other tissues derived from pigs. The experimental approach involved two longitudinal studies in which indoor and outdoor pigs were reared to market readiness using typical animal husbandry practices; closely matched samples of soil, feed, bedding, meat etc., were collected and analysed for PCDD/Fs and PCBs. The total PCDD/F + PCB WHO-TEQs in pig liver were much higher than in meat and kidney samples from the same animals and exceeded the current relevant EU maximum limits (6 ng PCDD/F-TEQ/kg fat). Liver samples were also characterised by much lower PCB contributions to the total TEQ than for the corresponding meat and kidney samples, and by a predominance of many of the hepta- and octa-substituted PCDD/Fs. At ages approaching market readiness, TEQ values in meat samples from outdoor pigs tended to be slightly higher than those from comparable ages in the indoor programme, possibly due to additional intake from soil. Biotransfer factors (BTFs) were derived for each of the 39 PCDD/F and PCB congeners measured. Interpretation of the findings focused particularly on trends in four selected congeners, namely 2,3,7,8-TCDD, 2,3,4,7,8-PeCDF, PCB 153 and PCB 169. Increases in the BTF for PCB 169 in the pig rearing programmes were noticed when the diet changed from being dominated by sow's milk to feed. Much higher</p>

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	transfer factors for many of the more heavily chlorinated PCDD/Fs (e.g. 2,3,4,7,8-PeCDF) were found in liver compared with meat or kidney samples from the same animals. Soil consistently accounted for at least 30% of input for many hexa- or higher chlorinated PCDD/Fs, while rarely representing more than 10% of the total intake.

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Transfer and uptake of polychlorinated dibenzo-*p*-dioxins and furans (PCDD/Fs) and polychlorinated biphenyls (PCBs) into meat and organs of indoor and outdoor reared pigs

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Abstract

This study was designed to investigate how and to what extent PCDD/Fs and PCBs are transmitted from exposure sources to porcine muscle and other tissues derived from pigs. The experimental approach involved two longitudinal studies in which indoor and outdoor pigs were reared to market readiness using typical animal husbandry practices; closely matched samples of soil, feed, bedding, meat etc., were collected and analysed for PCDD/Fs and PCBs. The total PCDD/F + PCB WHO-TEQs in pig liver were much higher than in meat and kidney samples from the same animals and exceeded the current relevant EU maximum limits (6 ng PCDD/F-TEQ/kg fat). Liver samples were also characterised by much lower PCB contributions to the total TEQ than for the corresponding meat and kidney samples, and by a predominance of many of the hepta- and octa-substituted PCDD/Fs. At ages approaching market readiness, TEQ values in meat samples from outdoor pigs tended to be slightly higher than those from comparable ages in the indoor programme, possibly due to additional intake from soil. Biotransfer factors (BTFs) were derived for each of the 39 PCDD/F and PCB congeners measured. Interpretation of the findings focused particularly on trends in four selected congeners, namely 2,3,7,8-TCDD, 2,3,4,7,8-PeCDF, PCB 153 and PCB 169. Increases in the BTF for PCB 169 in the pig rearing programmes were noticed when the diet changed from being dominated by sow's milk to feed. Much higher transfer factors for many of the more heavily chlorinated

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3 PCDD/Fs (e.g. 2,3,4,7,8-PeCDF) were found in liver compared with meat or
4 kidney samples from the same animals. Soil consistently accounted for at
5 least 30% of input for many hexa- or higher chlorinated PCDD/Fs, while rarely
6 representing more than 10% of the total intake.
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10 **Keywords:** *biotransfer factors, bioconcentration factors, indoor and outdoor*
11 *pigs.*
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13 14 15 **Introduction**

16 Polychlorinated dibenzo-*p*-dioxins and furans (PCDD/Fs or 'dioxins') and
17 polychlorinated biphenyls (PCBs) are ubiquitous environmental contaminants.
18 They are highly lipophilic and human exposure is primarily through the
19 consumption of foods rich in animal and marine fats and oils. The
20 transmission of dioxins and PCBs from pasture, soils and feed into cow's milk
21 and beef has been the focus of a number of studies (Thomas et al, 1999;
22 Bluthgen et al, 1995; Schuler et al, 1997; McLachlan, 1993; Slob et al, 1995;
23 Stevens and Gerbec, 1998; Chang et al, 1989; Goldman et al, 1989) and
24 attempts have been made to model their transfer through the food chain
25 (Douben et al, 1997; McLachlan, 1997; Harrad and Smith, 1997). By
26 comparison few data are available on the transmission of dioxins and PCBs
27 into other animal produce, although there have been some laboratory studies
28 on the bioavailability of PCDD/Fs from highly contaminated soil by pigs
29 (Wittsiepe et al, 2004 & 2007). The first paper in this series (Fernandes et al,
30 2011) described the general approach that we have used to investigate the
31 movement of dioxins and PCBs through the food chain; this paper focuses on
32 indoor and outdoor reared pigs reared under normal farm conditions.
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47 Congener specific studies involving farm animals and various wildlife species
48 have shown that the bioavailability of dioxins and PCBs from environmental
49 and dietary sources is congener dependent and generally reduces with
50 increased chlorination. Uptake rates appear both congener and tissue
51 dependent and duration of exposure plays a role in the distribution of
52 contaminants between tissues. Congener profiles and concentrations in
53 tissues have been shown to reflect feeding habits, and the metabolic
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3 characteristics of particular species. Comparisons of PCBs congener profiles
4 in various biota have suggested that the more toxic dioxin-like congeners may
5 preferentially accumulate. TEQ profiles also appear to vary considerably from
6 species to species (Fernandes et al, 2011).
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11 This study aimed to (i) obtain full range of bio transfer factors (BTFs) for the
12 congeners measured in pigs, (ii) to obtain full TEQ values for meat and food
13 from pigs reared using standard but controlled animal husbandry practices
14 and to correlate the results with surveillance data (iii) to evaluate potentially
15 significant sources of dietary exposure to these contaminants and (iv) to
16 provide a more comprehensive basis on which to validate and optimise
17 predictive environmental pathway and exposure models in this area.
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24 25 26 **Materials and methods**

27 ***Rearing and Sampling***

28 Selected animals were reared to market readiness using typical commercial
29 animal husbandry practices. During this period, closely matched sets of soil,
30 feed, grass, sows' milk and meat from the pigs that were reared (including
31 offal) were collected and analysed for dioxins and PCBs.
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38 Summaries of the outdoor and indoor rearing and sampling schedules are
39 shown in Figures 1 and 2, and details of the type, supply periods and feed
40 consumption patterns for the sow and the growing pigs are given in Figures 3
41 and 4 for the outdoor sow and growing pigs respectively and Figures 5 and 6
42 for the indoor sow and growing pigs respectively.
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48 **Outdoor pigs**

49 ***Rearing schedule***

50 The pigs were reared outdoors at Easton College, Norfolk, England, as part of
51 the normal commercial activities of the farm. The sows used were a
52 Landrace/Duroc/Large White hybrid (LR 25%/DR 25%/LW 50%). The boar
53 was a Large White and thus the offspring were also hybrids (LR 12.5%, DR
54 12.5% and LW 75%). Conception was by artificial insemination and the
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3 detailed rearing schedule is shown in Figure 1. The typical time required from
4 conception to market readiness is 8-9 months; with three main stages, namely
5 gestation (four months), lactation (one month), and rearing and finishing
6 (three-four months).
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11 Although only one sow and her offspring were used for the project, a second
12 pregnant sow was also identified as a back-up. Both pregnant sows were
13 kept on the same field during the period of gestation. Following the birth of
14 the piglets, the two sows and their offspring were transferred to separate
15 outdoor enclosures (arcs) and both sets of piglets were closely observed for
16 signs of distress or ill-health.
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23 The sow selected for the study gave birth to ten piglets (five female), after a
24 gestation period of 115 days. On the basis of health and strength, eight of the
25 newly born animals were selected for the rearing programme and given
26 identification tags.
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31 The young piglets were weaned from the sow after 25 days. They were
32 weighed on that day and again at 7 weeks old; the mean weights of the young
33 pigs at weaning and at 7 weeks were 7.2 kg and 19.2 kg respectively. To avoid
34 possible stress to the growing pigs no further weighings were carried out.
35 Immediately following weaning, the sow and two of the piglets (aged 25 days)
36 were slaughtered. The remaining eight piglets were transferred to an outdoor
37 'growing' pen. Two of these were slaughtered aged 81 days, and a further four
38 were slaughtered aged 142 days, having reached desired market weight of 95 -
39 100 kg.
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48 The sow and her young were housed in a traditional corrugated metal arch
49 following birth. After weaning, the pigs were kept in an outdoor enclosure
50 fenced constructed from galvanised metal sheets. No incidents of ill health were
51 observed during the programme. Details of routine veterinary inputs are
52 provided in Table 1.
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58 *Samples collected*
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5 The sampling schedule for outdoor pigs is detailed in Figure 1. During lactation,
6 milk letdown to the piglets occurs every 60 – 90 minutes and lasts for 15-20
7 seconds only. This short letdown period combined with the fact that modern
8 breeds of pigs tend to be highly stressed animals and their power and potential
9 aggressiveness, made the collection of milk from an unrestrained pig difficult
10 and it was not done. Furthermore, obtaining milk from *outdoor* sows is
11 recognised to be considerably more difficult to obtain than from *indoor*
12 equivalents as the outdoor sows find restraint far more stressful.
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19 *Feed intake*

20 Given the requirement to adopt husbandry techniques typical of the pig industry
21 it was not feasible to measure the precise daily feed intake by the sow and each
22 offspring, and reliable estimates were used instead.
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28 *Feed- outdoor sow*

29 Prime rolls were provided up to the time of insemination, and lactating nuts
30 were provided for the first three weeks of gestation, followed by prime rolls
31 again for a further twelve weeks (Figure 1). For the nine days prior to the birth
32 of the piglets, lactating nuts were again provided to ensure that sufficient milk
33 would be available. Overall, prime rolls were provided for 84 days (72%) of
34 the gestation period of 116 days. Daily feed intake during this time remained
35 fairly constant, ranging from 1.8 – 2.7 kg.d⁻¹ (mean 2.6 kg.d⁻¹).
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43 Following the birth of the piglets, the feed provided to the sow reverted back
44 to prime rolls and feed intake increased from 2.3 kg.d⁻¹ to 9.5 kg.d⁻¹ after 17
45 days. Intake remained constant until weaning one week later and mean feed
46 intake by the sow over this period was 4.4 kg.d⁻¹. Between the date of
47 insemination and slaughter, the sow consumed 332 kg of prime rolls and 69
48 kg of lactating nuts. Total feed intake was 401 kg, equivalent to an average of
49 2.9 kg.d⁻¹ over the 139 day period.
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Feed- outdoor young pigs

Eight young pigs from the litter produced by a single sow were monitored; two were slaughtered at 25 days old, a further two at 81 days and the remaining four at 142 days (standard market weight). In order to raise young pigs to market readiness in an outdoor environment, we followed normal practice and used three different types of feed. Startercare Easiween was provided to facilitate the transition from mother's milk to solid food and was given for a relatively short period either side of weaning. In contrast, Startercare Maxecreep represents the major source of feed during the overall rearing period, being provided for a total of 94 days. Daily consumption of this feed rose steadily from 0.2 kg.d⁻¹ to 2.1 kg.d⁻¹ after four months later. The final feed (Sovereign pellets) was provided for 13 days immediately prior to slaughter, at which point daily consumption levels had reached 2.4 kg.d⁻¹.

Indoor pigs

Rearing schedule

The sows and boar used were of an identical breed to those used for the outdoor pig programme. Although we used only one sow and her offspring, two other pregnant sows on the farm were also identified as back up. All three sows were kept under the same conditions and were given the same feed during the period of gestation. One sow was artificially inseminated and subsequently gave birth to ten young piglets (8 male and 2 female) after a gestation period of 115 days. Two of the piglets were slaughtered on the day of birth, the remaining piglets were weaned from their mother aged 27 days. After weaning, the mother and two further piglets were slaughtered. Two more piglets were slaughtered aged 90 days and the remaining four were slaughtered aged 179 days at market weight (around 95-100kg). The young pigs were weighed at birth and at weekly intervals during the suckling period and agreed with the expected growth pattern. Details of routine veterinary inputs to the sow and the growing pigs are shown in Table 1. No instances of ill health were recorded during the programme.

The sow and offspring were housed in buildings that have been used to rear pigs for the last 20 years or so. The walls were rendered concrete and the

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3 floors were concrete overlaid with bitumen blocks to provide improved thermal
4 insulation. Interior partitions were made of untreated plywood and the sows
5 farrowed in metal pens which are pressure washed with a viral disinfectant
6 (Virkon) between each batch of pigs. An overview of the key features of the
7 rearing programme is given in Figure 2.
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11 12 13 *Samples collected*

14 In view of the difficulties in obtaining milk samples for the outdoor pigs, it was
15 decided to use a combination of stresnil and oxytocin from the outset in order
16 to facilitate milk release. This enabled the first of the planned samples to be
17 successfully collected soon after the mother gave birth, but despite repeated
18 attempts it was not possible to obtain later samples. Milk from one of the
19 back-up animals sow was however obtained on the same date as that from
20 the project sow, and a further, smaller sample was obtained from this second
21 sow 12 days later.
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28 29 30 *Feed – indoor sow*

31 Only one type of feed (Challenger nuts) was given to this sow throughout the
32 programme, in contrast to the regime used for the outdoor sow. Both
33 represent common farm practice. Daily feed intake was approximately 2.5
34 kg.d⁻¹ during gestation and was reduced to around 1.4 kg.d⁻¹ around the time
35 the piglets were born. After the birth of the piglets, daily feed consumption
36 increased reaching a maximum of 5.4 kg.d⁻¹. This level was maintained until
37 the young pigs were weaned and the sow slaughtered 20 days later. Mean
38 daily feed intake for the sow during the period from the birth to slaughter was
39 4.5 kg.d⁻¹, similar to that for the outdoor sow (4.4 kg.d⁻¹, see above). From
40 insemination to the date of slaughter, the sow consumed around 409 kg feed,
41 an average daily intake of 2.9 kg.d⁻¹, which compares with 401 kg and 2.9
42 kg.d⁻¹ respectively for the outdoor sow.
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51 52 53 *Feed – indoor young pigs*

54 The indoor programme involved the rearing and monitoring of ten young pigs
55 that constituted the litter of a single sow. Of the ten animals, two were
56 slaughtered on the day of birth, two straight after weaning (aged 27 days) and
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3 a further two at 90 days old. The remaining four were slaughtered aged 179
4 days having reached the desired market weight. They were reared to market
5 readiness using two main types of feed, namely Startercare Maxecreep and
6 Sovereign pellets. The indoor-reared piglets were weaned onto solid food
7 using Startercare Maxecreep rather than the Easewean feed used in the
8 outdoor programme, but both reflect common farming practice.
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14 A summary of the type, periods and daily intake of feed is given in Figure 6,
15 which also shows that a third feed (OP Pellets) were provided in the last week
16 of the programme. This feed is similar to Sovereign pellets, but sourced from
17 a different manufacturer. The feeds were provided for 73, 84 and 5 days
18 respectively. By the time the animals had reached market weight, daily and
19 total feed intake had reached 2.4 kg.d⁻¹ and 192 kg respectively.
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26 For the animals slaughtered prior to reaching market weight, the patterns of
27 feed intake were different; details of the four groups of animals (slaughtered at
28 birth, 27, 90 and 179 days respectively) are shown in Table 2.
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32 33 **Analytical**

34 The analytical methodology used was based on that reported previously
35 (Fernandes et al, 2004). Briefly, the sample was freeze-dried and ground,
36 and thoroughly homogenised. An aliquot was fortified with known amounts of
37 surrogate (¹³C₁₂-labelled) analogues of target analytes and was exhaustively
38 extracted using mixed organic solvents. The extract was purified by acid
39 hydrolysis followed by adsorption chromatography. *Ortho*-PCBs, non-*ortho*-
40 PCBs and PCDD/Fs were segregated into three separate fractions. Each
41 fraction was concentrated and further cleaned up before the inclusion of
42 additional ¹³C₁₂-labelled internal sensitivity standards. Final determination
43 was by high resolution gas chromatography with either low resolution mass
44 spectrometric detection (*ortho*-PCBs) or high resolution mass spectrometric
45 detection (non-*ortho*-PCBs and PCDD/Fs). All 17 PCDD/Fs and PCBs
46 assigned a WHO-TEF, the ICES 7 PCBs and some additional PCBs were
47 measured (as listed in the results tables such as the first column in Table 4).
48 All analytical data were assessed for compliance with the analytical quality
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3 assurance criteria prescribed in EU legislation for control of these
4 contaminants in food (European Commission, 2002), and the demands of ISO
5 17025 accreditation. Further validation and quality assessments were made
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7 by participation in interlaboratory comparison exercises including those run by
8 the Folkehelse Institute for Public Health in Norway (eg. National Institute of
9 Public Health, 2005).
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13 14 **Results and discussion**

15 ***PCB and PCDD/F concentrations in pigs***

16 A summary of several key results is given in Table 3 (a) for the indoor and 3 (b)
17 for the outdoor pigs. Where more than one animal was available, samples were
18 taken from one of them at random. The TEQs for the meat samples generally
19 decline with the age of the pig and are lower than those in the feed. This
20 contradicts the hypothesis that indoor pigs accumulate PCDD/Fs and PCBs in
21 their meat through ingestion of feed, at least while they are still growing. Two
22 samples of sows' milk were obtained immediately after the birth of piglets, and
23 the TEQs for these were below those calculated for all of the feed and most of
24 the meat samples. A relatively high TEQ was found for pigs' liver,
25 approximately ten times greater than the corresponding values for meat and
26 kidney samples from the same animal. The liver result was also distinctive in
27 the relatively low PCB contribution to the total TEQ and raised levels for many of
28 the hepta- and octa-substituted PCDD/Fs.
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41 At ages approaching market readiness, the TEQ values for outdoor reared pigs
42 tended to be slightly higher than those from samples at comparable ages in the
43 indoor programme. This may be due to additional PCDD/F and PCB intake
44 from soil, but note that the soil samples analysed were well within the range
45 expected of rural background levels.
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50 ***Sources and uptake routes***

51 The transfer of PCBs and PCDD/Fs into pigs may occur by either: ingestion of
52 feed, soil, soil organisms, vegetation or water (in the case of young pigs,
53 sow's milk may be an important uptake route); inhalation; dermal uptake
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3 from soils; or from contact with farm buildings, bedding etc. (Fernandes et al,
4 2011)
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8 On the basis of studies of other farm-reared animals (McLachlan 1993); the
9 ingestion of feed would be expected to constitute the dominant route. But there
10 is a tendency for pigs reared outdoors to wallow in shallow mud baths and to
11 have a generally high degree of contact with the soil, which raises the possibility
12 that the uptake of PCDD/Fs and PCBs through the skin could also be an
13 important factor for these animals. The relative significance of the various
14 routes by which PCDD/Fs and PCBs can be taken up into pig tissues is likely to
15 be influenced by a wide range of ancillary factors which include breed, sex,
16 rearing conditions, type of feed and feed intake, state of health, age, and stage
17 of breeding season.
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26 A small number of controlled exposure studies have examined the levels of
27 contamination in pig tissues following ingestion of specially formulated diets
28 containing varying concentrations of PCDD/Fs and PCBs. Borchard et al (1976)
29 investigated the uptake of PCBs by rearing pigs following ingestion of feed to
30 which Aroclor 1254 had been added. The transfer of PCDD/Fs from spiked milk
31 to arterial blood in pigs was studied by Rychen et al (2002). Other investigations
32 focused on the concentrations of contaminants in pigs reared on sewage sludge
33 amended soils known to be contaminated with Aroclors (Hansen et al 1981) or
34 following exposure to contaminated feed (Bernard et al 2002). Such studies are
35 useful for our understanding of pathways and uptakes of PCDD/Fs and PCBs in
36 pigs but contaminants may behave differently at high concentrations compared
37 with conventional diets and animal husbandry techniques.
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48 Although many studies have reported data on the levels of PCDD/Fs and PCBs
49 in samples of pork meat destined for human consumption (e.g. Ryan et al 1985;
50 Beck et al 1989; Furst et al 1990; Liem and Theelen 1997; Lorber et al 1997), no
51 simultaneous analyses were made of the contaminant concentrations in feed
52 and there are no systematic investigations into the levels and sources of
53 PCDD/Fs and PCBs in pigs reared on conventional diets.
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3 PCDD/F and PCBs may also be ingested through the incidental consumption of
4 soil during foraging due to the characteristic rooting and foraging behaviour of
5 outdoors reared pigs (Fries et al 1982). This is supported by the work of Jacobs
6 et al (1981) which demonstrated that pigs confined to soil containing
7 polybrominated biphenyls (PBBs) accumulated higher levels in their fat than
8 cattle confined to fields with similar soil concentrations. Wittsiepe et al, (2004 &
9 2007) have shown that the bioavailability of PCDD/Fs from highly contaminated
10 soil ingested by Goettingen minipigs is relatively low compared with
11 bioavailability from spiked feed.
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20 The rate of soil ingestion may be related to factors such as the nature of the
21 pasture, time of year, weather conditions and the level and type of feed
22 provided. One study of seasonal variations (Healy 1967) showed that soil
23 ingestion rates by animals reared on grazing pastures were greatest in winter.
24 A later study by Healey and Drew (1970), which explored how soil intake
25 varied with feeding regime, demonstrated that animals allowed to graze on
26 root crops such as swedes during the winter months ingested considerably
27 more soil than those grazed on pastureland. Mean soil ingestion rates
28 measured over an eleven-week period for animals on swedes and those on
29 pasture were 84 g.d^{-1} and 30 g.d^{-1} respectively. The same study also showed
30 that soil ingestion by pigs varied considerably between individual animals and
31 increased substantially during wet conditions.
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41 Age and sex of animals can also influence soil uptake rates as demonstrated in
42 a study by Lorber et al (1997) in which it was found that boars accumulated
43 higher levels of PCDD/Fs and PCBs than sows reared under the same
44 conditions, and that concentrations in older boars were generally greater than in
45 younger animals. Although soil ingestion is likely to be relatively small
46 compared with total feed, the known persistence of PCDD/Fs and PCBs in the
47 surface layers means that soils can make a significant contribution to overall
48 contaminant intakes, and could easily be a significant problem if contaminated
49 slurry or other material has recently been spread on the land (Hansen et al
50 1981). Dioxins have been recognised as a potential contaminant following
51 uncontrolled burning in the vicinity of farmland following the pyres used to
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3 dispose of animal carcasses during a Foot and Mouth disease outbreak in the
4 United Kingdom (Rose et al, 2005).
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8 Piglets are born with a body burden of PCDD/Fs and PCBs as a result of in
9 utero transfer of contaminants. Further sources can include transfer of
10 PCDD/Fs and PCBs directly into young pigs via sow's milk for suckling pigs.
11 Young pigs are weaned from their mother at four weeks old and rely on
12 commercial feed thereafter, and so samples taken from around four weeks and
13 earlier are likely to reflect input from the mothers' milk whereas later the feed will
14 have increasing influence.
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21 Opportunities for comparisons between animal species and tissue type are
22 limited by the lack of data. One study in the Netherlands (Liem and Theelen
23 1997) involved the collection of chicken, horse, mutton, goat and pork
24 samples (animal fat and liver) from slaughterhouses during 1990. The results
25 indicated that the total concentrations of PCDD/Fs and PCBs in pork fat
26 samples were considerably lower than those in beef and chicken. By
27 contrast, levels in pork liver samples were substantially higher than those in
28 beef and chicken livers, but well below those typical of goat and horse.
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36 In a similar Belgian survey (Focant et al 2002), a range of lamb, beef, pork,
37 chicken and horse meat samples were collected from slaughterhouses or retail
38 outlets in 2000 and 2001. Total concentrations of PCDD/Fs plus PCBs in pork
39 were found to be substantially lower than in any of the other types of meat. Few
40 data are available on the relative levels of PCDD/Fs and PCBs in different pig
41 tissues. On the basis of studies in other farm animals such as cattle (Thomas et
42 al 1999), it might be expected that the levels of these contaminants in pig's liver
43 would be higher than in a corresponding meat sample from the same animal.
44 The study by Liem and Theelen (1997), which reported mean concentrations of
45 17 and 0.6 (ng WHO-TEQ/kg fat) in liver and meat tissues from the same
46 animal, not only confirms this expectation but also suggests that liver may be a
47 particular target organ for PCDD/Fs and PCBs in the pig, in common with
48 findings for sheep (Fernandes et al, 2010; Rose et al, 2010). The investigation
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3 of PCDD/Fs by Goettingen minipigs also demonstrated accumulation
4 predominantly in the liver (Wittsiepe et al, 2004).
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8 The study of PCDD/F concentrations in retail foodstuffs from the Netherlands
9 (Liem and Theelen 1997) demonstrated that the congener patterns in pig liver
10 samples were significantly different from those in meat samples from the same
11 animal. As shown by Bernard (2002), the higher chlorinated congeners
12 (especially the hepta- and octa-substituted) were found to predominate in pig
13 liver samples. The shift in PCDD/F congener patterns between liver and meat
14 samples was quite marked. By way of comparison, a similar shift in PCDD/F
15 patterns was also found in sheep (Rose et al, 2010) and goats but, interestingly,
16 no such differences were found in chickens (Fernandes et al, 2010). Overall,
17 the results of these studies suggest that the uptake and transfer of PCBs and
18 PCDD/Fs in pigs may be different to those in other farm animals.
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28 *Comparisons with previous data*

29 Meat

30 A comparison of the mean total TEQ concentrations in pig meat from the
31 present study with previous survey data is given in Table 3 (c). The total TEQ
32 data for the seven studies listed in the table show a concentration range of 0.08
33 – 4.2 ng TEQ.kg⁻¹.fat with a mean value of 1.1 ng TEQ.kg⁻¹.fat. The studies
34 reporting the lowest concentrations (0.08 and 0.19 ng TEQ.kg⁻¹.fat respectively)
35 both treated congener concentrations below the limit of detection as equal to
36 zero.
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45 An examination of the total TEQ concentrations from the present study
46 presented in Table 3 (c) suggests that they are consistent with previously
47 published data. For example, the overall mean value (0.77 ng TEQ.kg⁻¹.fat) for
48 the meat samples analysed in the current study falls within the range of mean
49 values previously reported. However, the contribution of dioxin-like PCBs to the
50 total TEQ (range 37-74%; mean 53%) appears to be greater than that from
51 previous surveys (4.4-40%; mean 21%).
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58 Liver and kidney

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3 A comparison of the total TEQ concentrations in liver and kidney samples from
4 the present study with previous survey data is given in Table 3 (d). The total
5 TEQ data for the first three studies listed show a concentration range of 8.8-
6 17.0 ng TEQ.kg⁻¹.fat with a mean value of 13.0 ng TEQ.kg⁻¹.fat. The
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8 corresponding values (range 8.9-20.6; mean 14.8 ng TEQ.kg⁻¹.fat) from the
9
10 present study agree with previously reported data. The mean contribution of
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12 PCBs to total TEQs in the present study (14%) falls at the lower end of the
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14 range (12-28%) reported from earlier surveys. The samples analysed in the
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16 earlier UK studies (MAFF 1997; FSA 2000) were of offal and hence would have
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18 included some other tissues in addition to pig's liver. The table also indicates
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20 that the total TEQ concentrations (0.88 ng TEQ.kg⁻¹.fat) in kidney samples
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22 collected during the present project are much lower than in the liver samples
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24 from the same animals.

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26 BTFs for Indoor pigs

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28 *Intakes of feed and milk*

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30 The mean daily feed intakes of the growing pigs were calculated from the feed
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32 consumption profile. For example, two of the pigs were each estimated to
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34 have consumed a total of 24.4 kg feed over a 28 day period, equivalent to a
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36 mean daily intake of 0.87 kg.d⁻¹. Two of the pigs were only provided with feed
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38 during the last ten days of their lives. Total consumption for this period
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40 amounted to 1.0 kg which, averaged over the lifetime of the animals (27
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42 days), gave a mean daily intake for the period of 0.04 kg.d⁻¹. In order to
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44 compare with growing pigs, the daily consumption of feed by the sow was
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46 also calculated for the 28 day period immediately prior to the slaughter of the
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48 animal using the consumption profile for growing pigs, and was calculated to
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50 be 4.40 kg.d⁻¹.

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52 Milk production by a sow depends upon factors including the weight of the
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54 animal, breeding history, size of litter and stage of lactation (Agricultural
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56 Research Council 1967; BSAS 2003). For a sow of comparable weight to
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58 those used here (200 kg), daily milk production typically commences at
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60 around three litres per day when the offspring are born, rising to eight litres
per day after a week. Milk production tends to peak at around 9.5 litres per

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3 day after 21 days (BSAS, 2003; Dunning 2003; Whittemore 2003). Litter size
4 may also influence the volume of milk produced by a sow, and the most
5 common litter size for the breed of animals used in the project was ten
6 animals. In the case of the indoor rearing programme, the sow was only
7 providing milk for eight piglets because two were slaughtered at birth.
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13 To estimate levels of milk production by pigs we used the relationship
14 between total weight gain of a litter and milk yield of the sow i.e.
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18 Milk yield per day = 4 x total weight gain by litter per day (BSAS 2003)
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21 During the suckling period the growing animals were weighed at regular
22 intervals. Using these data, the mean weight gain per animal over the 27
23 days was found to be 5.5 kg, which was equivalent to a total weight gain by
24 the litter (8 animals) of 44 kg. The mean daily milk production by the sow was
25 calculated at 6.52 litres per day; each of the eight piglets was therefore
26 consuming an average of 0.82 litres per day over the 27 day suckling period.
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31 32 33 *Intake flux and BTFs*

34 Intake details were combined with data on concentrations of PCDD/F and
35 PCB congeners to calculate BTFs for selected samples using a standard
36 method (Fernandes et al, 2011). To obtain the numerator for each BTF the
37 congener concentration in the meat sample was calculated on a fat weight
38 basis (Table 4).
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44 Piglets at birth showed a body burden as a result of in utero transfer.
45 Although this was similar in magnitude to other samples on a concentration
46 basis, given the low weight at birth, the impact of this overall contribution
47 became less important as the animals gained weight, and since it was broadly
48 equivalent for all animals, it was not factored into subsequent calculations.
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54 Sets of congener specific input fluxes for each possible PCDD/F and PCB
55 source were derived by multiplying the whole weight concentrations by the
56 corresponding daily intakes. The third to fifth columns in Table 4 show these
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calculations for feed, while the sixth to eighth do the same for milk (assuming a litre weighs one kilogram). For example, 2,3,7,8-TCDD in feed:

$$0.025 \text{ ng.kg}^{-1} \times 0.04 \text{ kg.d}^{-1} = 0.001 \text{ ng.d}^{-1}$$

The final step in obtaining BTFs was to divide each congener level in meat by the sum of the corresponding input fluxes for feed and milk. For 2,3,7,8-TCDD the calculation was:

$$\frac{0.05}{0.001 + 0.005} = \frac{0.05}{0.006} = 8.31$$

The right hand column of Table 4 lists the BTFs for all 39 PCDD/F and PCB congeners and shows values ranging from 3.27 to 1806. The range of BTF values in Table 4 implies differences in ease with which congeners are transferred and accumulated in the meat sample. Care must be taken where some samples contained concentrations around or below the limit of determination for the analysis since this may give an artificial impression of robustness for the BTF.

A similar process was conducted for eight indoor pig meat, liver or kidney samples. The relative contribution of different sources (e.g. milk or feed) to the total input flux was calculated. For instance, for a sample of meat from one of the young piglets, the percentages for congener 2,3,7,8-TCDD were:

$$\begin{array}{l} \text{Feed } 0.0010032 / 0.00601832 = 16.67\% \\ \text{Milk } 0.00501512 / 0.00601832 = 83.33\% \end{array}$$

Similar calculations were also carried out on totals across all 39 congeners. For the above sample, feed totalled 23.89 ng.d⁻¹ and milk 192.30 ng.d⁻¹, so the relative contribution from feed was 11.05%.

The complete set of congener BTFs for the eight indoor pig samples is given in Table 5. BTFs for four selected congeners chosen to reflect a breadth of

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3 chemical properties are highlighted for discussion in more detail and to show
4 changes over time. They are shown in Table 6 and are discussed in more
5 detail below. The table also includes average BTFs for all 39 congeners to
6 set the values for the four congeners in a wider context, and the BTFs for all
7 39 congeners have been ranked (1 = highest, 39 = lowest). These ranks
8 were used for evaluating relative differences in the uptake of congeners
9 between foodstuffs and over time.
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16 Table 6 shows that the meat BTFs decline in magnitude during the rearing
17 programme. This trend reflects the tendency for concentrations of PCDD/F
18 and PCB levels to show a small decrease in meat with age, while intakes and
19 consequently input fluxes increase. Tables 4 and 5 indicate that, across all 39
20 congeners, the total input flux at 27 days was dominated by sow's milk, whilst
21 for all later samples the only source was feed. The only consistent effect
22 associated with this change was for PCB 169, where the meat BTFs became
23 higher (relative to other congeners) once feed was the sole source. There
24 were also signs of similar increases for some of the higher chlorinated
25 PCDD/Fs (e.g. 1,2,3,4,6,7,8-HpCDF) and reductions for ortho PCBs.
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35 Of the four selected congeners, PCB 153 generally had the highest BTF into
36 indoor pig meat and 2,3,7,8-TCDD the lowest. The ranking of the four
37 congeners for the kidney sample was similar to that for meat from animals of
38 the same age. For liver PCB 153 was less prominent and 2,3,4,7,8-PeCDF
39 was more prominent. The BTFs in Table 5 indicate a general tendency for
40 more chlorinated PCDD/Fs to have higher transfer factors in liver.
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46 Outdoor pigs

47 *Intakes of feed, soil and milk*

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49 The pigs were reared on fields largely devoid of vegetation, making it likely that
50 the animals ingested soil whilst foraging for food. For most of the animals, the
51 period selected represents the 28 days prior to slaughter and the collection of
52 the relevant tissue sample(s). For two of the pigs, the period was taken as the
53 full duration of the lives of the animals i.e. 25 days.
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3 Mean daily feed intakes were calculated from the feed consumption profile as
4 described above for indoor pigs. The mean daily feed intakes for the two pigs
5 slaughtered at 81 days was 0.90 kg.d^{-1} and for the two slaughtered at 142
6 days it was 2.12 kg.d^{-1} . In the case of the pigs slaughtered at 25 days, these
7 animals were only provided with feed for the last 5 days of their lives. Total
8 consumption during this period was 1.0 kg which gave a mean daily intake of
9 0.04 kg.d^{-1} when averaged over the 25 day period.
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17 To allow comparisons with growing pigs, the daily feed consumption by the
18 sow was calculated over the 28 day period immediately prior to the slaughter
19 of the animal. Feed intake was derived from the consumption profile, and was
20 calculated as 4.08 kg.d^{-1} .
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26 Several authors have attempted to estimate the amounts of soil ingested by
27 pigs whilst foraging for food (see earlier). One method involves the use of an
28 indicator such as titanium that is present in soil but is not taken up by plants.
29 The concentration of the indicator in the faeces of the animal can then be
30 used to estimate the rate of soil intake. Another approach is to calculate soil
31 intakes as a % of feed intake (Fries et al 1982; Fries 1996). For example,
32 Fries et al (1982) reported a soil intake ranging from 1.2 – 5.7% of dry mass
33 feed intake. On the basis of the percentages reported, together with the
34 relatively dry conditions during the rearing period, a daily soil intake of 3.5% of
35 feed intake was used as an estimate for the present study, which gave values
36 of 1.40, 31.5, and 74.2 g.d^{-1} for the pigs slaughtered at 25, 41 and 142 days
37 respectively and 143 g.d^{-1} for the sow.
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47 The titanium method of measuring soil intakes was also used to provide
48 useful supporting data to the calculations based on feed intake. Samples of
49 faeces were therefore collected from the young pigs and analysed. Freshly-
50 voided faeces collected directly from the animal at various stages of the
51 rearing process are ideally required if reliable results are to be achieved by
52 this method (Fries et al 1982), but these were not possible to collect
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3 A third potential source of dietary PCB and PCDD/F intake into growing pigs
4 is sow's milk. The mean daily volume of milk (8.3 litres d⁻¹) produced by the
5 sow over the period 2-27 September was estimated from the profile of milk
6 production based on the data that were collected. As the litter consisted of 10
7 animals, the mean daily consumption by each of the piglets was 0.83 litre d⁻¹
8 over the 25 day period. The young pigs slaughtered aged 81 and 142 days
9 respectively, received no sow's milk during the corresponding consumption
10 periods.
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18 *Intake flux and BTFs*

19 Intake details were combined with data on concentrations of PCDD/F and
20 PCB congeners to calculate BTFs for nine samples from the outdoor pig
21 rearing programme. No sample of sow's milk was available for the outdoor
22 pigs, so the value obtained from the indoor programme was substituted.
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28 The BTFs were calculated using the same method as explained for indoor
29 pigs and a complete set of the congener BTFs for the nine samples is given in
30 Table 7. Summary results for the four selected congeners are presented in
31 Table 8. This table shows a number of trends similar to those found for indoor
32 pigs, including a tendency for the meat BTFs to decline in magnitude during
33 the rearing programme and the very different results for liver compared to
34 other samples. The BTFs again indicate a general trend for more chlorinated
35 PCDD/Fs to have much higher transfer factors in liver. Of course, as the
36 animal grows there is a dilution effect of the contaminants that needs to be
37 considered when drawing overall conclusions.
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46 For all 39 congeners, the total input flux at 25 days was dominated by sows'
47 milk, whilst in the later samples feed typically accounted for 88-93% and soil
48 the remainder. As with the indoor pigs, the change from milk to feed is
49 associated with a higher ranking in the meat BTFs for PCB 169, but it is
50 difficult to attribute any obvious effect from the soil intake in outdoor pigs.
51 Given the small proportion of total input from soil this is not surprising, but in
52 market-ready animals soil typically accounted for around 50% of the input flux
53 for several of the more chlorinated PCDD/Fs. This point highlights the
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3 contrasting PCDD/F and PCB profiles of commercial feed and soil, but overall
4 the results indicated considerable consistency in the patterns of transfer and
5 uptake between the two pig rearing programmes. There are also some
6 differences e.g. for outdoor pigs BTFs decrease with age for all congeners
7 (Table 7) whereas for indoor pigs several congeners show an increase with
8 age (Table 5). For outdoor pigs, BTFs for TCDD and 2,3,4,7- PeCDF
9 increase whilst for indoor pigs a dip at day 90 was observed. Overall, BTFs
10 for outdoor pigs were much higher.

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12 Full details including congener specific results for all samples analysed are
13 available in the contractors report (Foxall et al, 2004).

22 **Conclusions**

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24 The analytical data obtained from the indoor and outdoor pig rearing
25 programmes were generally in agreement with the results of previous studies
26 and appear consistent with the PCDD/F and PCB levels to be expected from
27 animals raised in rural background locations. The contribution of PCBs to the
28 total TEQ values found also agrees with data previously reported. A slight
29 decrease with age in total TEQ values in meat was evident in the indoor and
30 outdoor pig rearing programme reported here, similar to that seen for lowland
31 and highland sheep and for broiler chicken rearing programmes (Fernandes
32 et al, 2011). Total TEQs in meat were found to be generally lower than those
33 recorded in commercial feeds and there is consequently no evidence for a
34 general trend in which pigs accumulate higher levels of PCDD/Fs and PCBs
35 in meat through the ingestion of feed.

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37 The total TEQs in pig liver were much higher than in meat and kidney
38 samples from the same animals. Despite the animals being reared in rural
39 background conditions, the PCDD/F TEQ values of all four liver samples
40 exceeded the current EU maximum limits (6 ng PCDD/F-TEQ/kg fat) for liver
41 and liver products. Liver samples were also characterised by much lower
42 PCB contributions to the total TEQ than for the corresponding meat and
43 kidney samples, and by a predominance of many of the hepta- and octa-
44 substituted PCDD/Fs.

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5 At ages approaching market readiness, TEQ values in meat samples from
6 outdoor pigs tended to be slightly higher than those from comparable ages in
7 the indoor programme, suggesting that outdoor pigs accumulate these
8 contaminants at a faster rate. It is possible that these differences might be
9 attributable to additional exposure to PCB and PCDD/Fs from soil. It is also
10 likely that the outdoor pigs had a higher body burden at birth since the outdoor
11 sows had a higher contaminant concentration, although the impact of this
12 would have been lost as the animals gained weight unless there was on-going
13 exposure to higher concentrations.
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21 Transfers of PCDD/Fs and PCBs from dietary sources to foodstuffs such as
22 meat, liver and kidney were investigated through the calculation of biotransfer
23 factors (BTFs). These coefficients were derived for each of 39 PCDD/F or
24 PCB congeners. Interpretation of the findings focused particularly on trends
25 in four selected congeners, namely 2,3,7,8-TCDD, 2,3,4,7,8-PeCDF, PCB 153
26 and PCB 169.
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33 Particular dietary constituents also varied in their importance as contributors to
34 the input flux of individual congeners. One example is that soil consistently
35 accounted for at least 30% of input for many hexa- or more chlorinated
36 PCDD/Fs, while rarely representing more than 10% of the total intake during a
37 consumption period.
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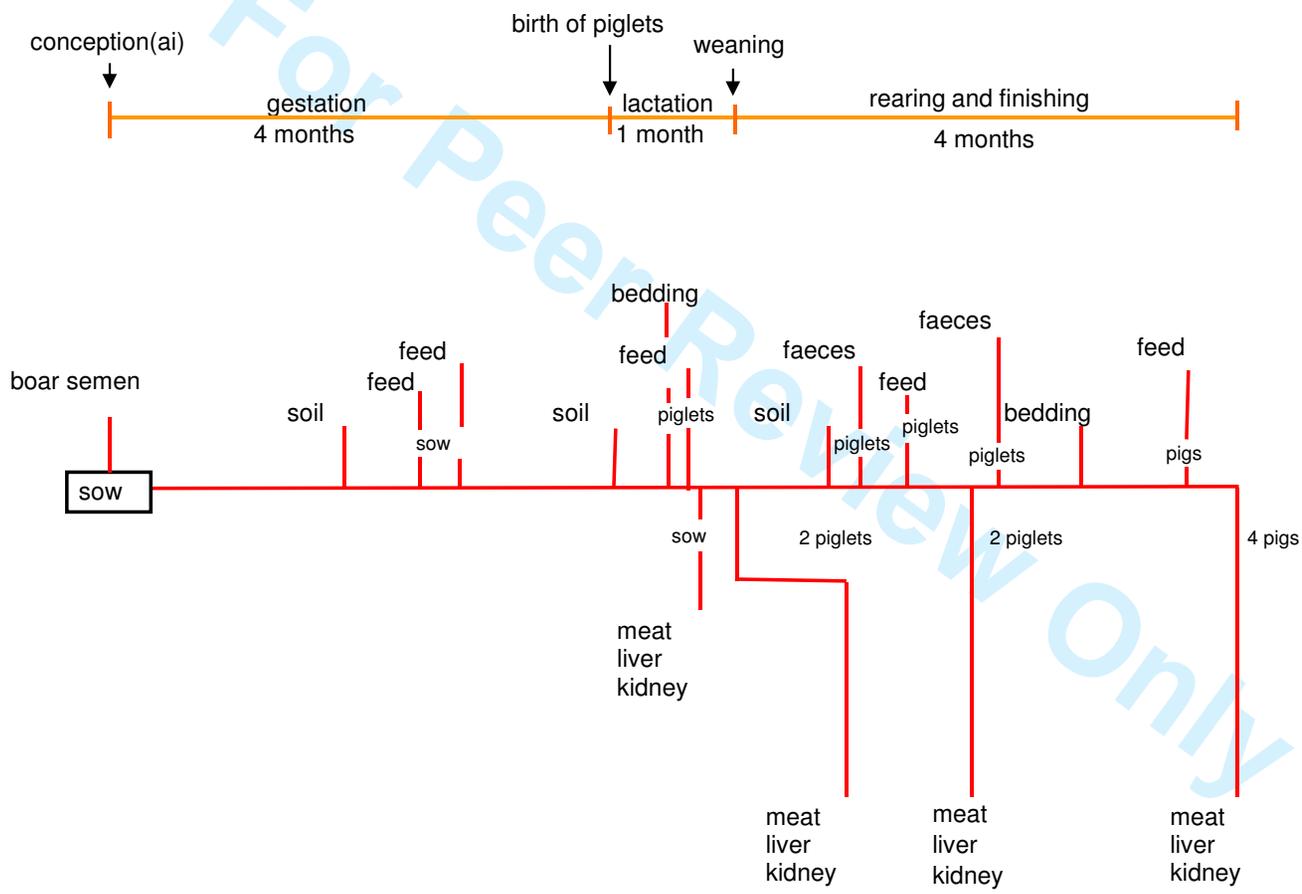
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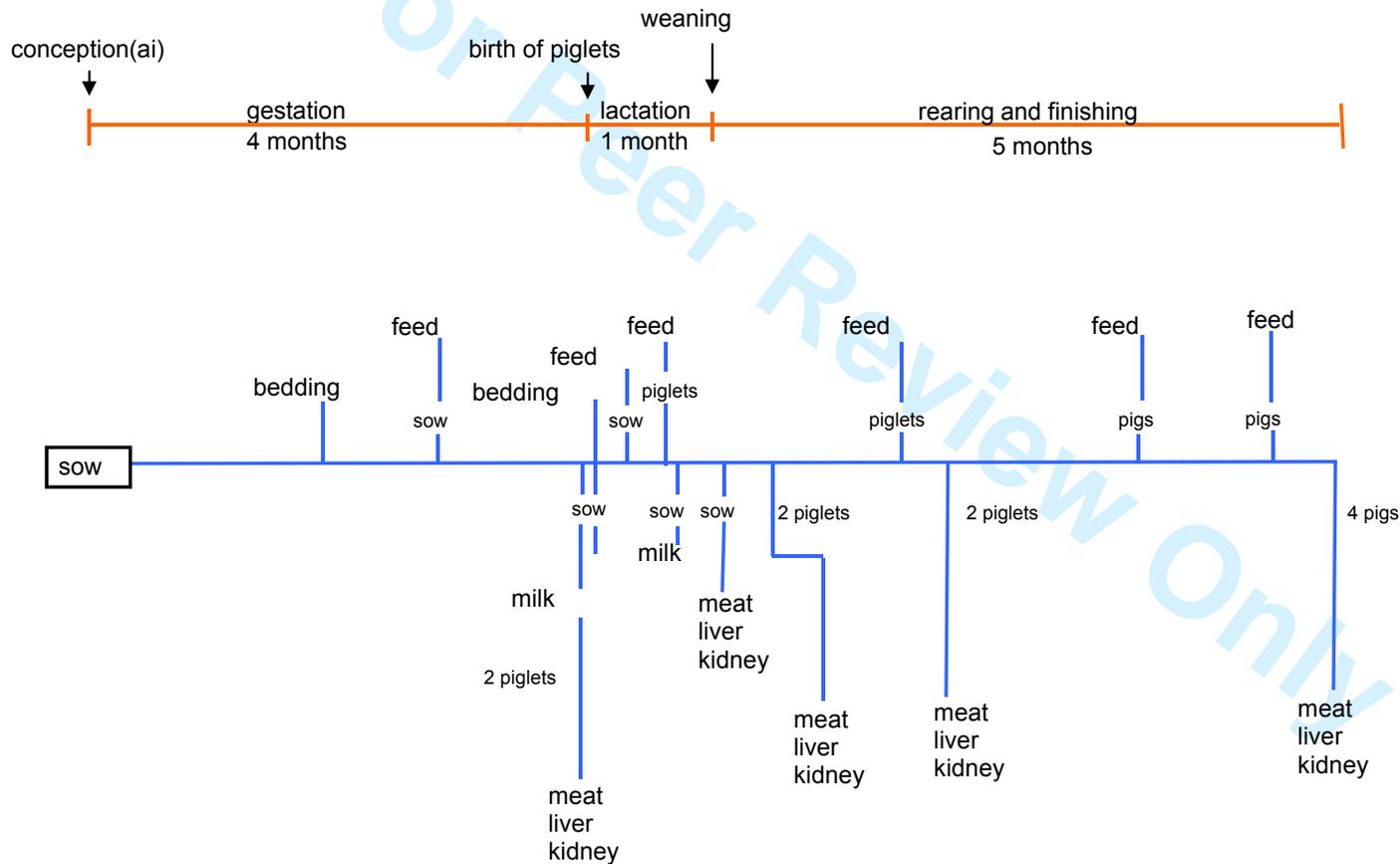
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Figure 1: Outdoor pig programme - rearing and sampling schedules



Notes
¹ Conception by artificial insemination
² Sow gave birth to 5 male and 5 female offspring

Figure 2: Indoor pig programme - rearing and sampling schedules



Notes

- 1 Conception by artificial insemination
- 2 Sow gave birth to 8 male and 2 female offspring

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Figure 3 : Outdoor pig programme - daily feed intake (kgd⁻¹) by sow

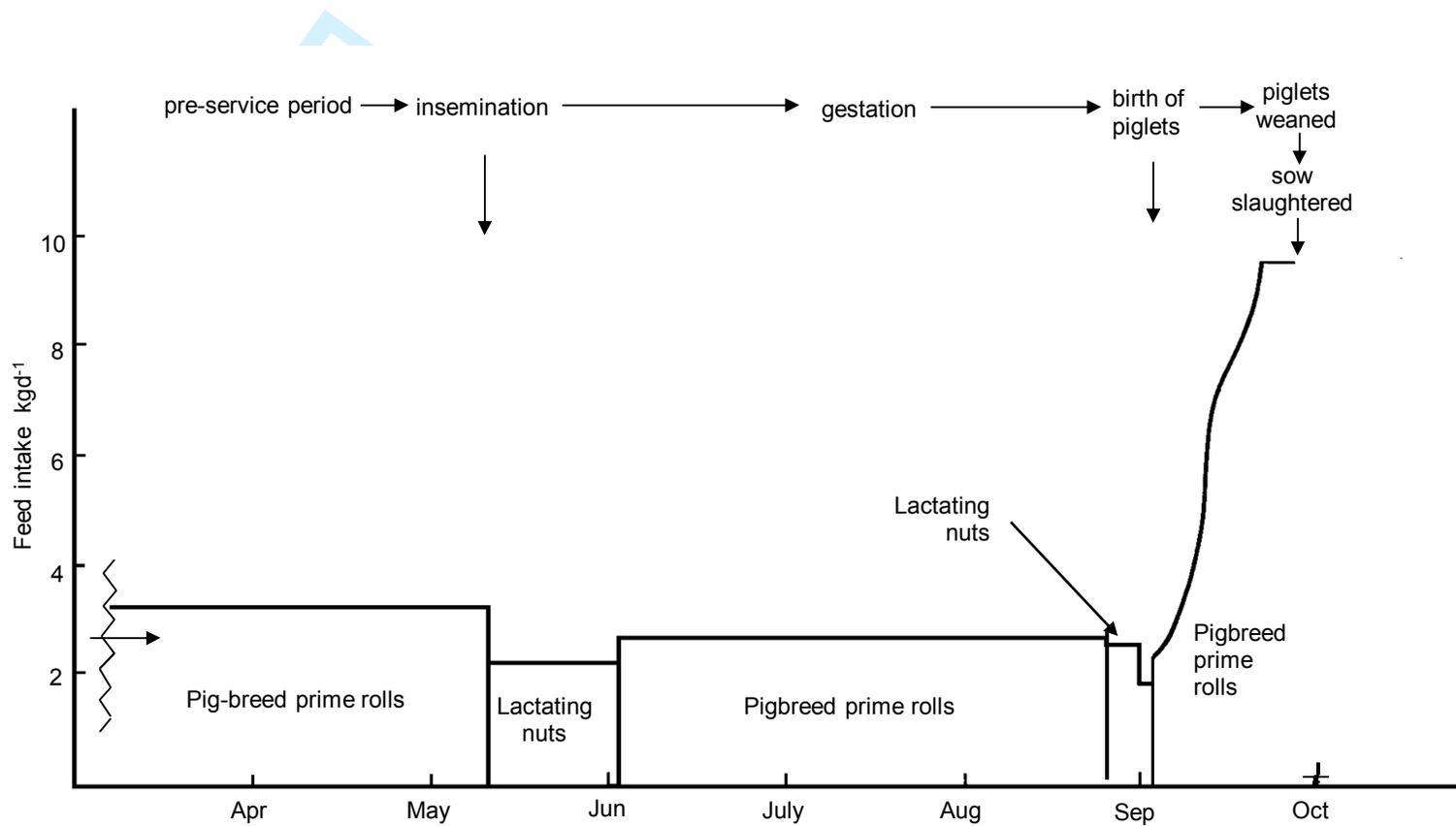
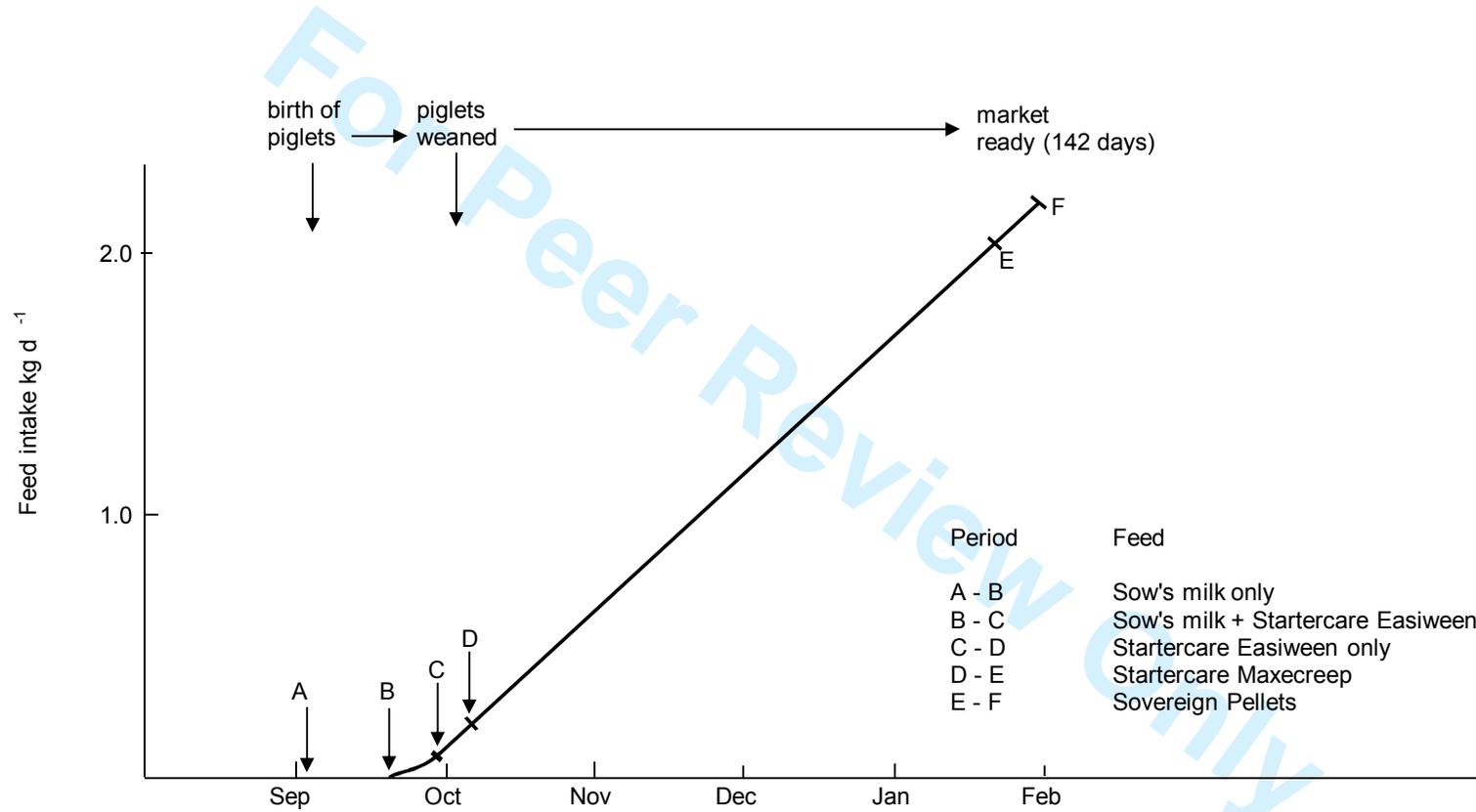
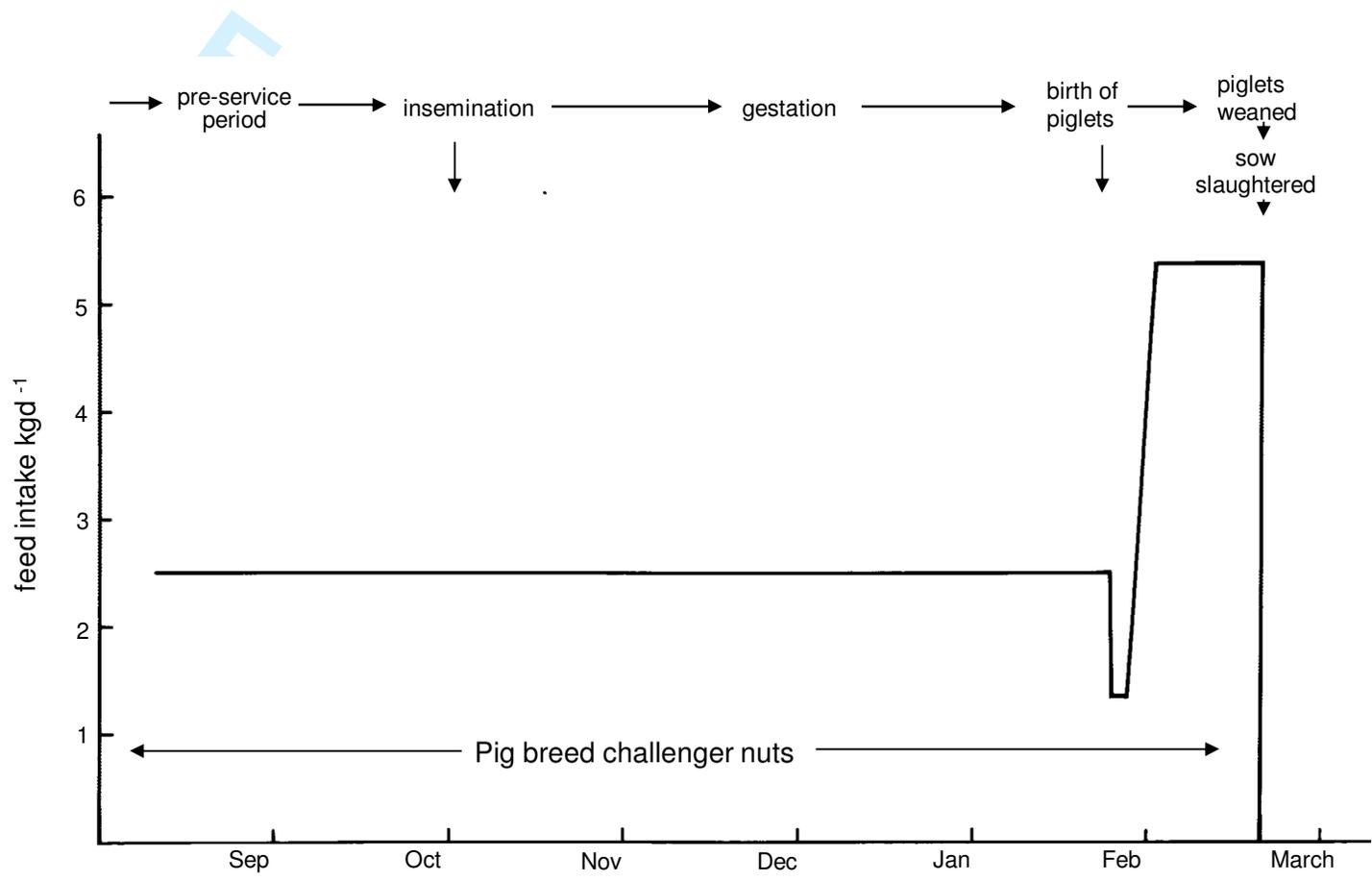


Figure 4: Outdoor pig programme - daily feed intake (kg d^{-1} per animal) by growing pigs



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Figure 5 : Indoor pig programme - daily feed intake (kgd⁻¹) by sow



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Figure 6: Indoor pig programme - daily feed intake (kgd⁻¹ per animal) by growing pigs

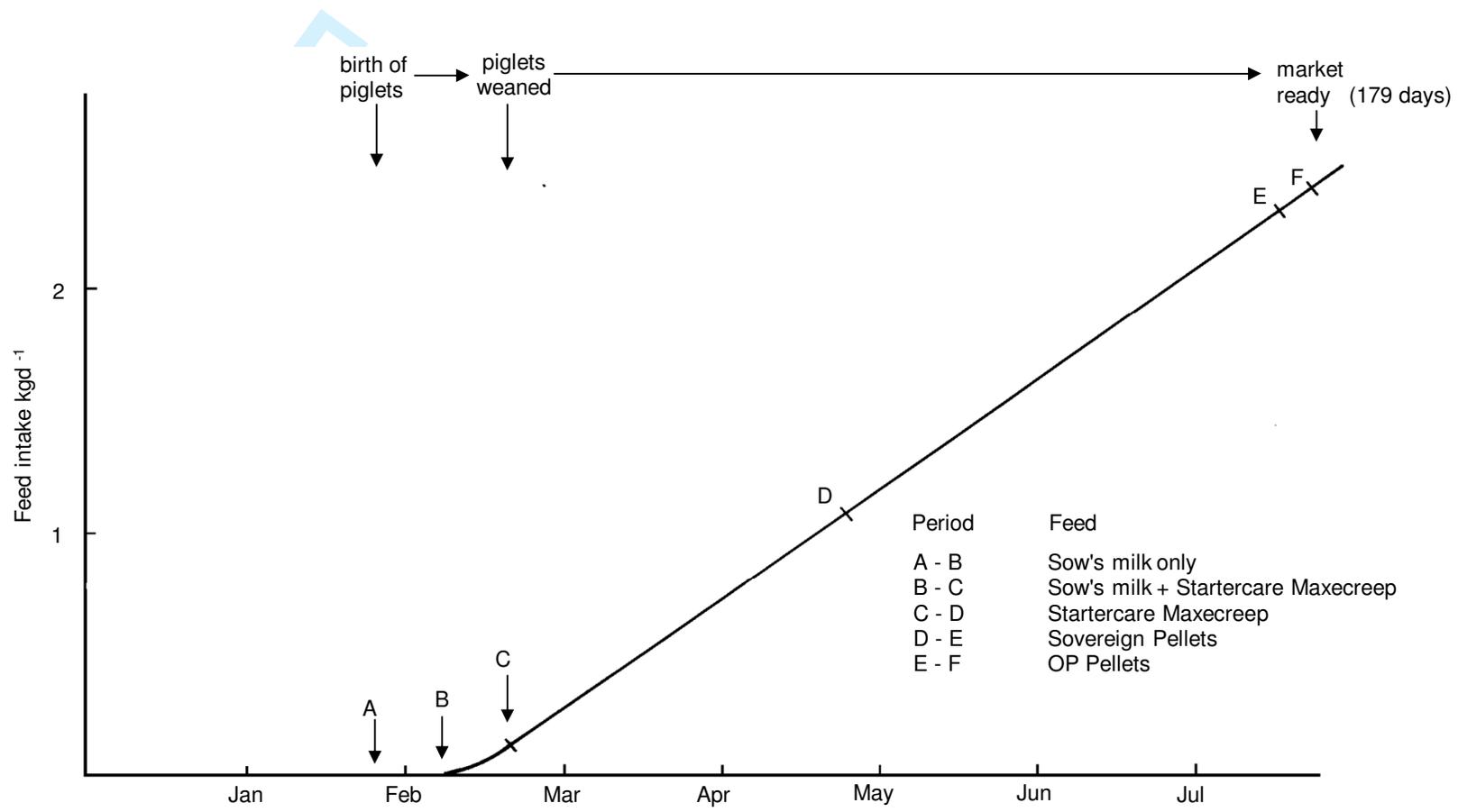


Table 1: – details of routine veterinary inputs to sows

Input	Dose	Notes
Sow (outdoor)		
Heptavac	5ml	Vaccination against Clostridia and tetanus
Heptavac	5ml	
Sow (indoor)		
Illiren	3ml	Used to induce farrowing
Suraxyn Parvo	2ml	Prevent Parvo virus infection
Colisorb	2ml	Prevent erysipelas in sows and piglets. Protect piglets against neonatal E.coli
Heptavac	2ml	Vaccination against clostridia and tetanus in piglets.
Licel / Mange wash	5ml	External treatment just before farrowing against greasy skin syndrome.
Piglets (indoor)		
Iron solution	20ml	Prevention of anaemia
Dapmadox LA	20ml	Protect against infection of joints following abrasion injuries.

Note: In contrast to the young pigs reared indoors, the outdoor reared piglets received no veterinary inputs.

Table 7: Biotransfer Factors (BTFs) for Outdoor Pigs

Sample Type	Meat	Meat	Meat	Meat	Meat	Meat	Liver	Kidney	Meat
Age (Days)	25	25	81	81	142	142	142	142	Adult
Input Flux (ng/day)	243	243	376	376	1373	1373	1373	1373	1913
Fat Content (%)	6.80	6.07	3.87	3.29	4.31	4.76	3.32	8.11	2.66
day/kg fat									
2,3,7,8-TCDD	34.28	37.54	2.58	10.75	2.46	0.88	2.63	2.28	1.32
1,2,3,7,8-PeCDD	40.07	46.75	4.25	8.50	1.71	0.49	13.81	1.59	0.92
1,2,3,4,7,8-HxCDD	41.71	39.11	5.84	8.23	4.19	1.20	73.64	1.80	1.55
1,2,3,6,7,8-HxCDD	19.81	19.81	5.73	6.26	4.33	1.06	46.02	1.69	1.53
1,2,3,7,8,9-HxCDD	54.89	63.12	1.75	7.50	1.82	0.54	18.75	1.71	0.73
1,2,3,4,6,7,8-HpCDD	16.02	12.69	3.07	2.39	2.67	0.85	107.87	1.17	0.74
OCDD	6.15	5.80	1.38	1.15	1.40	0.61	100.03	0.77	0.57
2,3,7,8-TCDF	12.77	15.09	1.26	5.95	1.14	0.38	1.77	1.07	0.52
1,2,3,7,8-PeCDF	35.58	40.33	2.05	6.93	1.98	0.69	2.08	1.39	0.63
2,3,4,7,8-PeCDF	52.34	41.51	5.80	7.97	3.55	0.95	154.05	1.47	1.56
1,2,3,4,7,8-HxCDF	47.80	42.71	7.71	5.38	4.24	1.47	158.16	2.12	1.74
1,2,3,6,7,8-HxCDF	34.68	28.65	5.15	5.72	3.60	0.93	152.80	1.54	1.13
1,2,3,7,8,9-HxCDF	54.04	58.55	3.19	5.84	1.21	1.01	11.95	1.21	0.93
2,3,4,6,7,8-HxCDF	28.03	22.78	3.73	5.60	2.10	0.54	140.73	1.01	0.76
1,2,3,4,6,7,8-HpCDF	12.52	11.02	3.49	1.97	3.10	0.91	175.54	1.13	1.33
1,2,3,4,7,8,9-HpCDF	36.96	42.65	2.23	10.78	2.42	0.76	91.51	2.27	0.41
OCDF	27.17	30.73	0.66	2.36	0.59	0.25	27.56	0.33	0.19
PCB77	82.01	136.45	2.58	11.54	1.24	2.40	1.34	1.61	2.54
PCB81	60.06	95.44	2.89	9.59	1.78	2.40	3.57	1.17	2.58
PCB126	28.38	42.57	7.42	19.58	2.75	2.87	23.95	2.57	1.52
PCB169	19.96	24.14	21.95	17.10	7.40	3.49	13.94	1.35	6.88
PCB18	23.44	23.44	6.74	8.58	3.84	1.83	2.74	2.01	0.93
PCB28	63.18	48.82	5.82	7.41	8.23	2.40	2.57	1.89	2.42
PCB31	26.75	25.26	6.74	8.58	3.84	1.83	2.74	1.83	1.19
PCB52	30.61	32.88	8.87	8.44	3.32	2.04	4.21	1.79	1.49
PCB99	31.67	32.76	28.19	20.84	8.47	3.36	6.87	3.36	4.90
PCB101	77.93	105.70	14.11	10.58	2.75	1.17	1.83	1.33	5.13
PCB105	21.52	30.12	6.74	8.58	3.84	1.83	2.74	1.83	1.74
PCB114	23.93	23.93	6.74	8.58	3.84	1.83	2.74	1.83	1.34
PCB118	35.24	52.44	17.89	13.41	3.68	1.84	2.65	2.07	4.12
PCB123	23.93	36.70	6.74	8.58	3.84	1.83	2.74	3.84	2.41
PCB128	22.81	31.94	8.58	8.58	3.84	1.83	2.74	1.83	1.61
PCB138	50.18	110.43	28.51	20.67	5.68	3.36	6.84	3.42	15.40
PCB153	67.81	165.36	29.18	23.01	5.55	3.60	5.26	3.43	24.24
PCB156	23.93	23.93	6.74	8.58	3.84	1.83	2.74	1.83	1.34
PCB157	23.93	23.93	6.74	8.58	3.84	1.83	2.74	1.83	1.34
PCB167	23.93	33.50	6.74	8.58	3.84	1.83	2.74	1.83	1.61
PCB180	52.32	197.03	21.83	18.29	5.72	3.03	4.38	2.86	21.99
PCB189	23.93	23.93	6.74	8.58	3.84	1.83	2.74	1.83	1.34

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Table 8: Biotransfer factors (BTFs) for selected PCDD/F and PCB congeners in the outdoor pig rearing programme

Sample Type Day of Sample Collection ¹	Meat 25		Meat 81		Meat 142		Liver 142		Kidney 142		Sow Meat Adult	
Congener	BTF ²	Rank ³	BTF ²	Rank ³								
2,3,7,8-TCDD	35.91	17	6.67	23	1.67	30	2.63	34	2.28	7	1.32	26
2,3,4,7,8-PeCDF	46.93	10	6.89	22	2.25	24	154.05	3	1.47	28	1.56	16
PCB 169	22.05	34	19.52	5	5.44	2	13.94	14	1.35	30	6.88	4
PCB 153	116.58	2	26.10	1	4.57	4	5.26	19	3.43	2	24.24	1
Average for 39 PCDD/F or PCB Congeners	41.95		8.82		2.58		35.48		1.84		3.20	

Notes

¹Day of sample collection during the rearing programme (i.e. 0 = day of birth for piglets).

²BTF is concentration in foodstuff (ngkg⁻¹ fat) / daily contaminant input flux (ngd⁻¹ whole weight).

³Rank of BTF out of that for all 39 PCDD/F or PCB congeners (1 = highest BTF). The ranking is based on BTFs calculated using 'upper bound' values and thus could be significantly influenced by the LOD values for the various media analysed.

Table 2: nature and levels of feed consumption by growing pigs (Sept 2001 – Jan 2002)

Outdoor pig programme –

Age at slaughter (days)	Type of feed consumed	Duration of consumption period(days)	Mean feed intake ¹ (kgd ⁻¹)	Total intake of each feed (kg)	Cumulative feed intake ² (kg)
25	Startercare Easiween	5	0.2	1.0	1.0
81	Startercare Easiween	13	0.2	2.6	42.0
	Startercare Maxecreep	48	0.8	39.4	
142	Startercare Easiween	13	0.2	2.6	151
	Startercare Maxecreep	94	1.3	118	
	Sovereign Pellets	13	2.3	29.9	

Indoor pig programme –

0.0	-	-	-	-	-
27	Startercare Maxecreep	10	0.1	1.0	1.0
90	Startercare Maxecreep	73	0.5	36.5	36.5
179	Startercare Maxecreep	73	0.5	36.5	192
	Sovereign Pellets	84	1.7	143	
	OP Pellets	5	2.4	12.0	

Notes

¹ Value quoted is mean daily intake over consumption period indicated

² Figures are calculated for period from birth to day of slaughter

Table 3: (a) Summary of PCDD/F and PCB concentrations (upper bound TEQs) for samples in the indoor pig rearing programme

Sample Type	Day of Sample Collection ¹	Total TEQ ²	PCB Contribution to Total TEQ (%)	Congeners Below LOD ³	
Indoor Bedding*		0.24	54.17	13	[*Whole weight]
Sow Milk	0	0.53	47.17	18	
Sow Milk	0	0.64	45.31	18	
Sow Feed		3.67	45.78	25	
Rearing Feed		5.20	45.00	33	
Rearing Feed		3.38	46.15	30	
Meat	0	2.01	60.20	21	
Meat	27	1.00	79.00	10	
Meat	90	0.68	39.71	18	
Meat	90	0.92	39.13	18	
Meat	179	0.56	48.21	18	
Meat	179	0.72	43.06	21	
Liver	179	8.90	18.43	14	
Kidney	179	0.89	57.30	28	
Sow Meat	Adult	0.50	74.00	9	

Notes

*Composite of several samples.

¹Day of sample collection during the rearing programme (i.e. 0 = day of birth for piglets).

²TEQs are on a ng TEQ/kg fat basis for all samples except bedding (whole weight).

³Number of congeners below LOD out of the 39 PCDD/F and PCB congeners analysed.

Table 3: (b) Summary of PCDD/F and PCB concentrations (upper bound TEQs) for samples in the outdoor pig rearing programme

Sample Type	Day of Sample Collection ¹	Total TEQ ²	PCB Contribution to Total TEQ (%)	Congeners Below LOD ³	
Soil*		1.74	10.92	13	[*Whole weight]
Soil*		1.94	13.92	12	[*Whole weight]
Sow Feed		1.55	39.35	23	
Sow Feed		3.08	41.56	22	
Rearing Feed		3.54	57.34	15	
Rearing Feed		1.77	40.11	25	
Rearing Feed		4.41	50.79	19	
Meat	25	1.24	37.90	17	
Meat	25	1.35	42.96	14	
Meat	81	0.83	44.58	15	
Meat	81	1.48	40.54	22	
Meat	142	1.37	43.80	17	
Meat	142	0.62	62.90	16	
Liver	142	20.65	8.96	20	
Kidney	142	0.87	43.68	12	
Sow Meat	Adult	0.93	36.56	13	

Notes

*Composite of several samples.

¹Day of sample collection during the rearing programme (i.e. 0 = day of birth for piglets).

²TEQs are on a ng TEQ/kg fat basis for all samples except soil (whole weight).

³Number of congeners below LOD out of the 39 PCDD/F and PCB congeners analysed.

Table 3: (c) Comparison of mean PCDD/F and PCB concentrations (ng TEQ/kg fat) in pig meat with literature values (background sources only)

PCDD/F TEQ	PCB TEQ non-ortho + ortho	Total TEQ ¹	% PCB TEQ contribution to total TEQ	Origin of samples	Number of samples	Sampling date	Reference
0.43	0.16	0.59	27	Netherlands	2	1990	Liem and Theelen (1997) ²
1.3	0.06	1.4	4.4	USA	56	1995	Lorber et al (1997) ³
2.5	1.7	4.2	40	USA	1	1995	Schechter et al (2001) ⁴
0.85	0.09	0.94	9.6	Spain	10	1999	Abad et al (2002) ⁵
0.051	0.024	0.08	32	Finland	6	1998-2000	Kiviranta et al (2001) ⁶
0.43	0.14	0.57	25	Spain	5	2000	Eljarrat et al (2002) ⁷
0.17	0.02	0.19	11	Belgium	34	2000-2001	Focant et al (2002) ⁸
Present study ⁹							
0.59	0.34	0.93	37	UK	1	2001	Outdoor sow
0.13	0.37	0.50	74	UK	1	2002	Indoor sow
0.50	0.50	1.0	53	UK	2	2002	Market-ready outdoor pig
0.35	0.29	0.64	46	UK	2	2002	Market-ready indoor pig

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Notes

¹Total concentrations of dioxins and PCBs may not equal the sum of individual dioxins and PCBs due to rounding.

²Nationally representative composite samples of pork fat from animals collected from slaughterhouses across the country. Values <LOD=LOD.

³Sub-cutaneous belly fat samples from market-ready animals randomly selected from slaughterhouses across the country. Values <LOD=1/2LOD.

⁴Pooled sample from various supermarkets. Values <LOD=1/2LOD.

⁵Retail samples collected from four provinces of Catalonia. Values <LOD=LOD.

⁶Tenderloin samples from slaughterhouses. Values <LOD=0.

⁷Retail samples collected from four provinces of Catalonia. Values <LOD=LOD.

⁸Samples collected from slaughterhouses or purchased in local supermarkets. Values <LOD=0.

⁹For present study, <LOD=LOD. Samples were analysed individually.

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Table 3: (d) Comparison of mean PCDD/F and PCB concentrations (upper bound, ng TEQ/kg fat) in pig liver and kidney with literature values (background sources only)

PCDD/F TEQ	PCB TEQ non-ortho + ortho	Total TEQ ¹	% PCB TEQ contribution to total TEQ	Origin of samples	Number of samples	Sampling date	Reference
LIVER							
15.0	2.0	17.0	12	Netherlands	2	1990	Liem and Theelen (1997) ²
10.3	2.9	13.2	22	UK	1	1992	MAFF (1997) ³
6.3	2.5	8.8	28	UK	1	1997	FSA (2000) ⁴
Present study							
18.8	1.8	20.6	9.0	UK	1	2002	Market-ready outdoor pig
7.3	1.6	8.9	18	UK	1	2002	Market-ready indoor pig
KIDNEY – present study							
0.49	0.38	0.87	44	UK	1	2002	Market-ready outdoor pig
0.38	0.51	0.89	57	UK	1	2002	Market-ready indoor pig

Notes

¹Total concentrations of dioxins and PCBs may not equal the sum of the individual dioxins and PCBs due to rounding.

²Nationally representative composite samples of liver from animals collected from slaughterhouses across the country. Values <LOD=LOD.

³Material analysed was composite of retail offal samples from 24 locations across the UK collected as part of the 1992 Total Diet Study. Figures quoted are derived from values given in FSIS No. 105, re-expressed as WHO-TEQs. Values <LOD=LOD.

⁴Material analysed was composite of retail offal samples from 24 locations across the UK collected as part of the 1997 Total Diet Study. Values <LOD=LOD.

Table 4: Example of BTF calculation for indoor pig meat sample

PCDD/F and PCB Congeners	Meat ng/kg fat	Feed ng/kg whole	Daily Intake kg d ⁻¹	Input Flux ng d ⁻¹	Milk ng/kg whole	Daily Intake litres d ⁻¹	Input Flux ng d ⁻¹	Sum Input Flux ng d ⁻¹	BTF
2,3,7,8-TCDD	0.05	0.02508	0.04	0.0010032	0.006116	0.82	0.00501512	0.00601832	8.31
1,2,3,7,8-PeCDD	0.05	0.03531	0.04	0.0014124	0.003892	0.82	0.00319144	0.00460384	10.86
1,2,3,4,7,8-HxCDD	0.06	0.01980	0.04	0.0007920	0.007228	0.82	0.00592696	0.00671896	8.93
1,2,3,6,7,8-HxCDD	0.11	0.02376	0.04	0.0009504	0.015568	0.82	0.01276576	0.01371616	8.02
1,2,3,7,8,9-HxCDD	0.05	0.02112	0.04	0.0008448	0.002224	0.82	0.00182368	0.00266848	18.74
1,2,3,4,6,7,8-HpCDD	0.82	0.13398	0.04	0.0053592	0.121208	0.82	0.09939056	0.10474976	7.83
OCDD	2.91	1.47807	0.04	0.0591228	1.013032	0.82	0.83068624	0.88980904	3.27
2,3,7,8-TCDF	0.13	0.01716	0.04	0.0006864	0.003336	0.82	0.00273552	0.00342192	37.99
1,2,3,7,8-PeCDF	0.05	0.01452	0.04	0.0005808	0.002780	0.82	0.00227960	0.0028604	17.48
2,3,4,7,8-PeCDF	0.06	0.02772	0.04	0.0011088	0.003892	0.82	0.00319144	0.00430024	13.95
1,2,3,4,7,8-HxCDF	0.11	0.02112	0.04	0.0008448	0.009452	0.82	0.00775064	0.00859544	12.80
1,2,3,6,7,8-HxCDF	0.05	0.02772	0.04	0.0011088	0.006116	0.82	0.00501512	0.00612392	8.16
1,2,3,7,8,9-HxCDF	0.05	0.01848	0.04	0.0007392	0.001668	0.82	0.00136776	0.00210696	23.73
2,3,4,6,7,8-HxCDF	0.05	0.02244	0.04	0.0008976	0.004448	0.82	0.00364736	0.00454496	11.00
1,2,3,4,6,7,8-HpCDF	0.44	0.04587	0.04	0.0018348	0.112312	0.82	0.09209584	0.09393064	4.68
1,2,3,4,7,8,9-HpCDF	0.04	0.01716	0.04	0.0006864	0.002780	0.82	0.00227960	0.002966	13.49
OCDF	0.13	0.09042	0.04	0.0036168	0.018348	0.82	0.01504536	0.01866216	6.97
PCB 77	21.05	1.03422	0.04	0.0413688	0.138444	0.82	0.11352408	0.15489288	135.90
PCB 81	1	0.06369	0.04	0.0025476	0.010564	0.82	0.00866248	0.01121008	89.21
PCB 126	1.99	0.13926	0.04	0.0055704	0.027244	0.82	0.02234008	0.02791048	71.30
PCB 169	0.66	0.02376	0.04	0.0009504	0.043368	0.82	0.03556176	0.03651216	18.08
PCB 18	100	33	0.04	1.32	6.672	0.82	5.47104	6.79104	14.73
PCB 28	190	33	0.04	1.32	6.672	0.82	5.47104	6.79104	27.98
PCB 31	120	33	0.04	1.32	6.672	0.82	5.47104	6.79104	17.67
PCB 52	230	33	0.04	1.32	6.672	0.82	5.47104	6.79104	33.87
PCB 99	540	33	0.04	1.32	18.348	0.82	15.04536	16.36536	33.00
PCB 101	1170	33	0.04	1.32	7.228	0.82	5.92696	7.24696	161.45
PCB 105	160	33	0.04	1.32	6.672	0.82	5.47104	6.79104	23.56
PCB 114	100	33	0.04	1.32	6.672	0.82	5.47104	6.79104	14.73
PCB 118	520	33	0.04	1.32	8.896	0.82	7.29472	8.61472	60.36
PCB 123	400	33	0.04	1.32	6.672	0.82	5.47104	6.79104	58.90
PCB 128	230	33	0.04	1.32	6.672	0.82	5.47104	6.79104	33.87
PCB 138	9540	33	0.04	1.32	46.148	0.82	37.84136	39.16136	243.61
PCB 153	14730	33	0.04	1.32	53.932	0.82	44.22424	45.54424	323.42
PCB 156	170	33	0.04	1.32	6.672	0.82	5.47104	6.79104	25.03
PCB 157	650	33	0.04	1.32	6.672	0.82	5.47104	6.79104	95.71
PCB 167	100	33	0.04	1.32	6.672	0.82	5.47104	6.79104	14.73
PCB 180	29560	33	0.04	1.32	18.348	0.82	15.04536	16.36536	1806.25
PCB 189	100	33	0.04	1.32	6.672	0.82	5.47104	6.79104	14.73

Table 5: Biotransfer Factors (BTFs) for Indoor Pigs

Sample Type	Meat*	Meat	Meat	Meat	Meat	Liver	Kidney	Meat
Age (Days)	27	90	90	179	179	179	179	Adult
Input Flux (ng/day)	216	520	520	1327	1327	1327	1327	3138
Fat Content (%)	4.15	2.79	2.02	4.32	3.86	2.77	4.90	10.20
day/kg fat								
2,3,7,8-TCDD	8.31	5.50	6.42	0.90	1.62	1.98	1.62	0.18
1,2,3,7,8-PeCDD	10.86	3.58	5.53	0.63	1.64	4.04	1.26	0.25
1,2,3,4,7,8-HxCDD	8.93	5.81	9.87	3.20	2.74	44.57	2.06	0.68
1,2,3,6,7,8-HxCDD	8.02	10.16	15.48	4.61	4.61	60.34	3.27	0.85
1,2,3,7,8,9-HxCDD	18.74	2.72	3.27	1.08	1.73	20.60	2.17	0.32
1,2,3,4,6,7,8-HpCDD	7.83	20.59	18.10	14.31	13.67	639.51	12.24	0.67
OCDD	3.27	11.42	7.48	7.04	5.95	345.66	6.20	0.41
2,3,7,8-TCDF	37.99	5.36	6.70	0.99	0.80	3.18	1.99	0.55
1,2,3,7,8-PeCDF	17.48	3.17	3.96	0.94	1.57	2.19	1.88	0.31
2,3,4,7,8-PeCDF	13.95	2.90	8.71	1.14	1.63	50.90	1.63	0.33
1,2,3,4,7,8-HxCDF	12.80	9.25	10.34	3.04	2.60	76.54	2.82	0.74
1,2,3,6,7,8-HxCDF	8.16	1.66	4.56	1.30	1.63	69.60	1.30	0.33
1,2,3,7,8,9-HxCDF	23.73	0.62	0.62	0.97	1.69	2.42	2.17	0.24
2,3,4,6,7,8-HxCDF	11.00	3.07	4.10	1.01	1.61	107.71	2.01	0.30
1,2,3,4,6,7,8-HpCDF	4.68	113.01	44.35	38.92	23.20	2008.40	19.84	0.92
1,2,3,4,7,8,9-HpCDF	13.49	4.02	4.02	1.06	1.59	127.10	2.11	0.26
OCDF	6.97	5.59	4.83	2.87	2.87	304.49	2.34	0.20
PCB77	135.90	1.89	3.60	0.68	0.97	2.07	1.21	0.90
PCB81	89.21	18.59	22.56	0.96	1.08	3.75	1.59	0.94
PCB126	71.30	5.61	9.90	1.44	1.67	26.35	2.93	0.87
PCB169	18.08	22.74	53.21	3.23	4.73	12.44	3.23	3.88
PCB18	14.73	3.48	4.18	1.36	1.64	3.41	2.73	4.70
PCB28	27.98	4.53	6.62	1.36	1.64	4.77	2.73	0.61
PCB31	17.67	3.48	4.18	1.36	1.64	3.41	2.73	0.34
PCB52	33.87	3.83	4.18	1.50	1.64	5.59	2.73	0.55
PCB99	33.00	12.54	8.71	2.32	2.18	4.23	2.73	2.11
PCB101	161.45	5.57	5.57	1.77	1.64	4.23	2.73	1.51
PCB105	23.56	3.48	4.18	1.36	1.64	3.41	2.73	0.48
PCB114	14.73	3.48	4.18	1.36	1.64	3.41	2.73	0.34
PCB118	60.36	5.22	4.18	2.05	2.05	3.41	2.73	1.43
PCB123	58.90	3.48	4.18	1.36	1.64	3.41	2.73	0.82
PCB128	33.87	3.48	4.18	1.36	1.64	3.41	2.73	0.75
PCB138	243.61	29.26	16.02	5.73	5.86	13.91	5.05	11.84
PCB153	323.42	32.04	18.11	6.14	6.00	11.87	5.18	16.27
PCB156	25.03	3.48	4.18	1.36	1.64	3.41	2.73	0.41
PCB157	95.71	3.48	4.18	1.36	1.64	3.41	2.73	2.66
PCB167	14.73	3.48	4.18	1.36	1.64	3.41	2.73	0.34
PCB180	1806.25	10.45	5.57	2.45	2.32	3.82	2.73	55.80
PCB189	14.73	3.48	4.18	1.36	1.64	3.41	2.73	0.34
* = composite sample								

Table 6: Biotransfer factors (BTFs) for selected PCDD/F and PCB congeners in the indoor pig rearing programme

Sample Type Day of Sample Collection ¹	Meat 27		Meat 90		Meat 179		Liver 179		Kidney 179		Sow Meat Adult*	
Congener	BTF ²	Rank ³	BTF ²	Rank ³								
2,3,7,8-TCDD	8.31	33	5.96	15	1.26	34	1.98	39	1.62	35	0.18	39
2,3,4,7,8-PeCDF	13.95	27	5.81	16	1.38	30	50.90	10	1.63	34	0.33	30
PCB 169	18.08	20	37.98	2	3.98	7	12.44	15	3.23	7	3.88	5
PCB 153	323.42	2	25.08	3	6.07	4	11.87	16	5.18	4	16.27	2
Average for 39 PCDD/F Or PCB Congeners	90.62		9.67		3.16		102.56		3.33		2.96	

Notes

*Composite of meat from two animals.

¹Day of sample collection during the rearing programme (i.e. 0 = day of birth for piglets).

²BTF is concentration in foodstuff (ngkg⁻¹ fat) / daily contaminant input flux (ngd⁻¹ whole weight).

³Rank of BTF out of that for all 39 PCDD/F or PCB congeners (1 = highest BTF). The ranking is based on BTFs calculated using 'upper bound' values and thus could be significantly influenced by the LOD values for the various media analysed.